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Fuselage Burnthrough from Large Exterior Fuel Fires

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Final Report

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16. Abstract

The burnthrough resistance of aircraft fuselages to external fuel fires was investigated in this test series. Three tests were conducted in a wheels-up mode and three in the wheels-down configuration. A comprehensive data base was developed documenting fire entry paths, burnthrough time, and cabin environmental conditions. The overall resistance of the two test intact aircraft fuselages to fire penetration was documented.

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EXECUTIVE SUMMARY

This report represents the observations, test data, and conclusions obtained during the course of six full-scale fuselage burnthrough tests. These tests were conducted by FAA Technical Center personnel at the Laurinburg-Maxton Airport, Maxton, North Carolina. Charlotte Aircraft Corporation provided contractual support in test article preparation. A comprehensive data base was developed which represented the flammability resistance of an intact fuselage when exposed to an exterior fuel fire. Three tests were conducted with the fuselage on the ground simulating a wheels-up condition, and three tests were conducted with the wheels down.

Two aircraft fuselages were obtained for use as test articles. A DC-8 was utilized for the wheels-up configuration and a Convair 880 was tested wheels-down. Each fuselage was partitioned into three compartments with steel sheeting and thermal insulation. This restricted the exterior fuel fire and any interior fire to the test section.

Instrumentation was provided in each compartment to measure temperature, heat flux, and smoke density. The data gathered from the instrumentation, in addition to interior and exterior video and motion picture coverage, were used to determine the location and fire path of any burnthrough. In addition, each compartment was fitted with a deluge type water sprinkler system to extinguish any internal fires.

Each compartment in the DC-8 was subjected to an external fuel fire located on the starboard side adjacent to the fuselage. The Convair 880 compartments were exposed to external fuel fires centered under the fuselage. The duration of each test was determined by observing fire penetration utilizing real-time internal video, then, extinguishing the fire when a burnthrough was noted. The external fire was extinguished by airport fire service personnel and the internal fire by the deluge sprinkler system. Six tests were conducted, each burning one third of the test article.

TEST RESULTS.

1. The aluminum skin provides protection from a fully developed fuel fire for 30 to 60 seconds.

2. The fiber glass, acoustical insulation is an effective thermal barrier.

3. Flame penetration into the cheek area provides a fire path into the cabin through the floor air return grills.

4. The aircraft with its gear extended is more vulnerable to burnthrough from a pool fire than an aircraft resting on its belly.

5. Areas, such as the empennage crawlthrough, that are not acoustically insulated are more vulnerable to burnthrough than other parts of the insulated fuselage.

INTRODUCTION

PURPOSE.

The purpose of this project was to study the burnthrough characteristics of commercial passenger-carrying transport aircraft when subjected to a large external fuel fire. Specifically, areas of likely flame penetration and resultant flame paths within the fuselage were to be identified as well as a time frame for each event.

BACKGROUND.

The majority of previous full-scale fire tests conducted by the FAA utilized a fuselage with a fire pan at the cabin floor level adjacent to an opening in the hull. This configuration was representative of a severe but survivable fire condition in which interior materials' flammability could be compared. Exposing the interior of the fuselage to the direct intense thermal radiation of the fuel fire allowed the evaluation of the combustibility of combinations of materials in a realistic scenario.

This type of full-scale testing resulted in new FAA standards for low heat release interior panels and seat cushion fire-blocking layers. Another crash scenario is one where an intact fuselage is exposed to an external ground level fuel fire. In this case the fire penetrates into the cabin by means of a fuselage hull burnthrough. Four examples of this type accident are those at Los Angeles, 1978; Malaga, 1982; Calgary, 1984; and Manchester, 1985. The aircraft resistance to burnthrough in each accident and the resultant survivability varied as follows:

- Los Angeles, 1978: A Douglas DC-10 was exposed to a large pool fire for 2 1/2 minutes before the fire was extinguished by crash fire rescue teams. The fuel fire did not penetrate and ignite the cabin materials; although, there was some evidence of fire damage at the panel seams and along the seat back cushions. In this case, the fuselage exhibited significant burnthrough resistance.

- Malaga, 1982: A Douglas DC-10 aborted takeoff and overran the runway striking the right wing on an obstruction. The wing was severed from the aircraft rupturing the fuel tanks and exposing the intact fuselage to a large exterior fuel fire. The fuselage resisted burnthrough for a relatively long period of time allowing 344 of the 394 people on board to escape.

- Calgary, 1984, and Manchester, 1985: Both accidents were very similar in configuration. In each case, the aircraft was a Boeing 737, the accident was caused by an engine failure, and the aircraft was completely gutted by fire. The similarity ends however when survivability is considered. In Calgary, all of the occupants escaped the aircraft whereas in Manchester fifty-five people lost their lives due to the fire. At Manchester, it was reported that the fuel fire penetrated the cabin in less than 60 seconds.

Fire can penetrate into an intact fuselage and into the passenger cabin in a number of different ways. Likely areas of penetration include the sidewall (above the floor), windows, cheek areas (below the floor), cabin floor, and baseboard air return grills. There is no direct evidence from past accidents or test data from previous experiments to indicate which area is most vulnerable to fire penetration or which provides the most likely path for flame travel once a penetration occurs. Previous tests examined the burnthrough resistance of individual fuselage elements such as the aluminum skin, windows, sidewall panels, thermal, acoustical insulation, and cargo compartment liners. This work was primarily materials testing aimed at improving burnthrough resistance of specific assemblies. There is no record of full-scale tests in the past to examine the resistance of the complete fuselage with the goal of identifying fire penetration paths as well as burnthrough times.

APPROACH.

Two aircraft were used as test articles. The first, a 1961 Douglas DC-8, was tested with the landing gear up. The second, a Convair 880 constructed in 1958, was tested with the landing gear down. The tests were conducted at the Laurinburg-Maxton Airport, Maxton, North Carolina, with the assistance of Charlotte Aircraft Corporation.

Each aircraft was partitioned into three compartments to allow separate tests to be run without endangering the entire aircraft (figure 1). The seats, partitions, galleys, and forward lavatories were removed to allow unobstructed observation of potential flame penetration. The original ceiling, sidewall, and floor remained intact. Each compartment was fully instrumented with temperature and heat flux measuring devices and complete photographic, motion picture, and video coverage was provided for each test.

Six tests were conducted, three on each aircraft. The test conditions included varying wind conditions, fuel fire exposure times, and sizes of fuel fires.

TEST PROCEDURE

Each aircraft was divided into three compartments by installing steel barriers above and below the floor. The barriers contained any developing fire within the test compartment. External baffles were installed to protect the aluminum skin of the adjacent compartments from the external fuel fire.

Temperature and heat flux measuring devices were installed to record the thermal conditions within the aircraft and of the external fuel fire. Figure 2 shows a typical instrumentation installation at a window location. Thermo Electric Type K Chromal/Alumel thermocouples (PN K116U-304-0-24-OX) were used exclusively. A thermocouple was embedded in the pressure pane and one in the fail-safe pane. A third thermocouple was installed through both panes and extended two inches beyond the pressure pane to measure the external fire temperature. A calorimeter, Thermogage model 1000-1 (used throughout in ranges up to 30 BTU/FT^2-sec) was installed 12 inches from the dust pane. This configuration allowed for the measurement of the temperature profile through the window as well as the heat flux transmitted through the window into the cabin. Figure 3 shows a similar instrumentation setup that was used to measure the temperature profile through the exterior skin, the insulation, the interior panel, and into the cabin. In addition, a calorimeter was installed flush with the exterior skin just below the window level to measure the heat flux of the exterior fire.

Thermocouple trees were installed in the cabin to measure the air temperature profile from the floor to the ceiling. In addition a smoke meter was provided to measure the cabin visibility. The percent of light transmission was measured using a Hugen Weston Photronic Cell smoke meter, model # 856-9901011-YR and a Magna-light pen light as the light source. The smoke meter operated through an exposed beam length of 4 inches.

Thermocouples were placed in areas of possible burnthrough such as, but not limited to, the cheek area, under the cabin floor, air return grills, cabin overhead, and in the cargo compartment to document flame penetration.

Motion picture and video cameras were installed in the cabin and in the cargo compartments to record flame penetration. Video coverage of the external fuel fire was also provided.

All data were recorded using an IBM compatible computer and an Omega Data Acquisition System.

A deluge type water sprinkler system was installed to extinguish internal fires above and below the cabin floor.

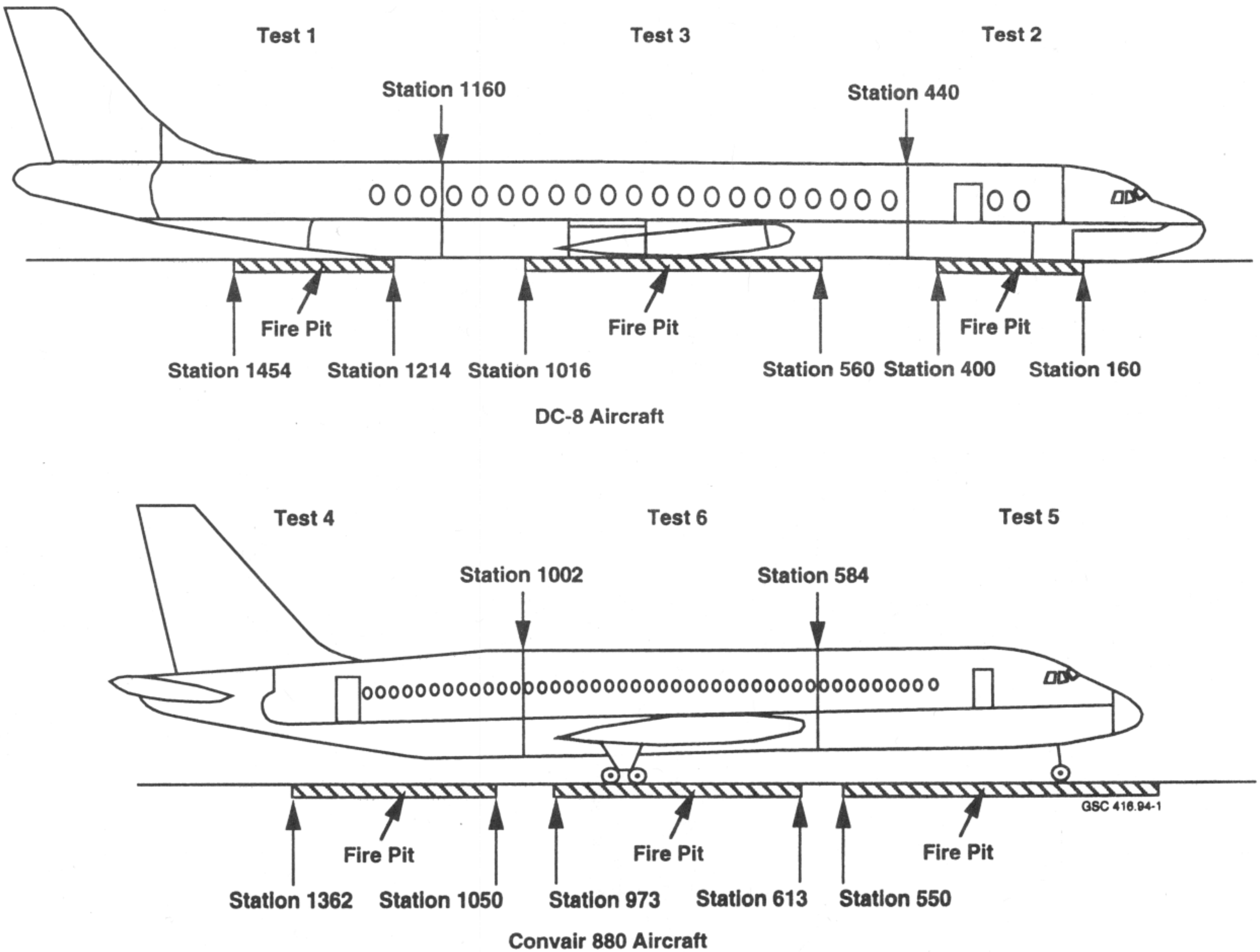

FIGURE 1. DC-8 AND CONVAIR 880 TEST SECTIONS

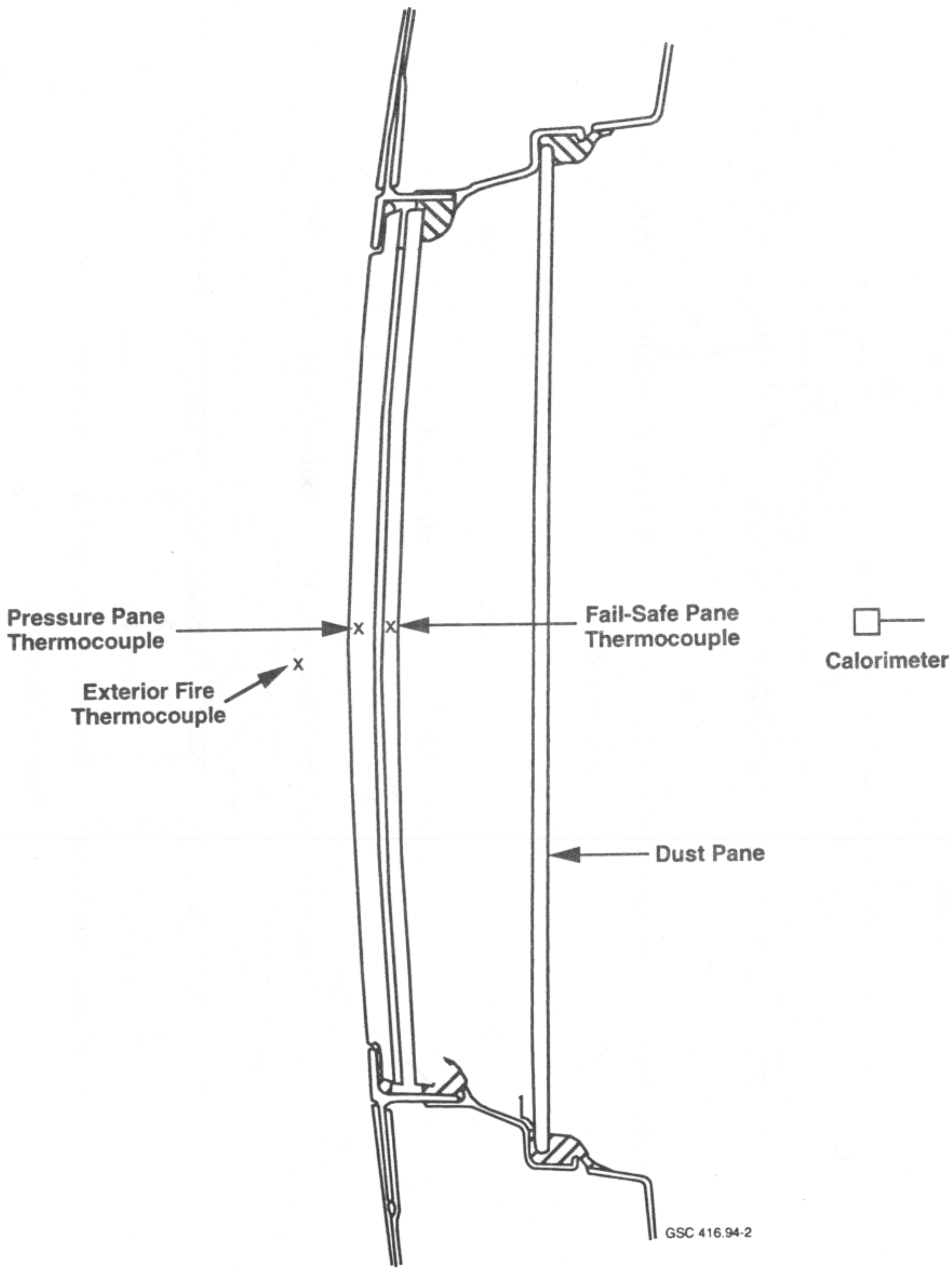

FIGURE 2. TYPICAL WINDOW INSTRUMENT

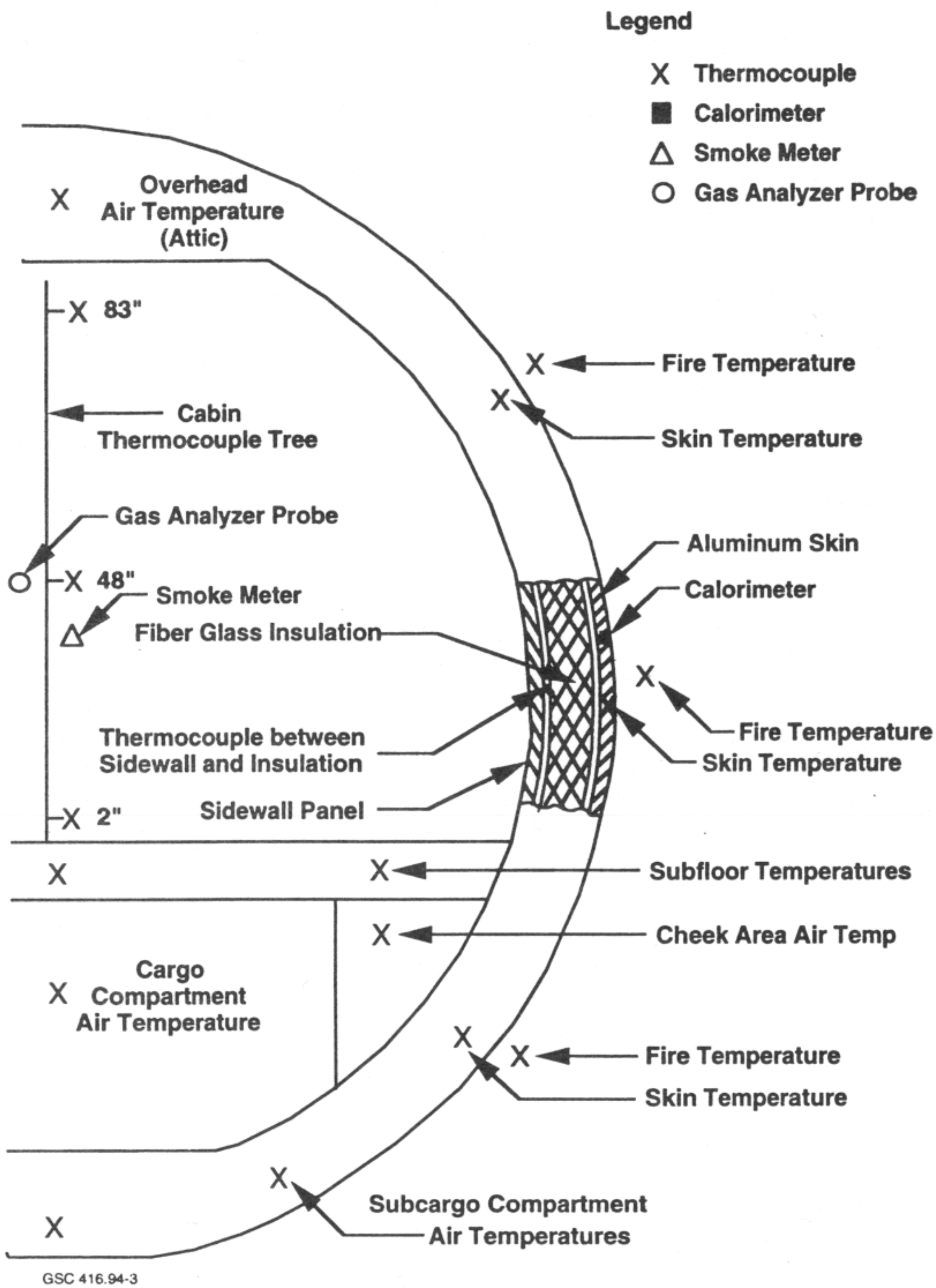

FIGURE 3. TYPICAL FUSELAGE AND CABIN INSTRUMENTATION

The size of the fuel pit was varied to provide maximum exposure of the test compartment to the fuel fire. Sufficient fuel was provided to insure 6 to 8 minutes of fully developed pan fire.

Real-time video cameras were used to determine the moment of fire penetration into the cabin. Once the cabin had been breached by fire, the test was terminated by extinguishing the external fire and activating the water deluge sprinkler system. The external fire was extinguished by crash fire rescue teams utilizing Aqueous Film Forming Foam (AFFF). The internal deluge sprinkler system utilized up to two thousand gallons of plain water.

Each test section was inspected to determine the location and the mode of flame penetration into the aircraft compartment. The section was photo documented before and after the test.

A summary of test parameters is presented in table 1.

TABLE 1. SUMMARY OF TESTS

Test	Date	Mode	Section	Wind	Duration* (Minutes)
DC-8					
1	5-11-88	wheels up	Aft	Calm	2:37
2	7-20-88	wheels up	Nose	3 kns	3:13
3	9-27-88	wheels up	Center	Calm	6:42
CV-880					
4	2-16-89	wheels down	Aft	3-7 kns	6:00
5	5-24-89	wheels down	Nose	3-6 kns	4:50
6	7-12-89	wheels down	Center	Calm	4:01

* Water sprinklers turned on; pool fire extinguishment started.

DC-8 TESTS

DC-8 FUSELAGE PARTITIONING.

The DC-8 was partitioned into three compartments by constructing two partitions within the fuselage (figure 1). These partitions were constructed of sheet steel and extended from the floor to the outer skin both below and above the floor. Each partition included a doorway to allow entry into the compartment.

COMPARTMENT 1. The first partition was constructed at station 440. It created a compartment that included the following:

. Cockpit

. Radio rack

- First-class cabin
- Forward lavatory
- Forward galley
- Forward right door
- Forward half of the forward cargo compartment
- Air conditioning equipment bay
- Forward cargo compartment hatch
- Main cabin air supply duct that runs from the air conditioning bay through the radio rack to the overhead air duct
- Two starboard side windows
- Fuselage skin materials:
  - Station 0 to station 310: Cockpit, belly to top of fuselage - 0.050 inch 7075 sheet aluminum.
  - Station 310 to station 440:
    - Belly to cargo compartment floor - 0.050 inch 7075 sheet aluminum.
    - Cargo compartment floor to cabin floor - 0.050 inch 7075 sheet aluminum, except around cargo compartment door which was 0.063 inch 7075 sheet aluminum.
  - Cabin floor to cabin ceiling - 0.063 inch 7075 sheet aluminum.
  - Top of fuselage - 0.050 inch 7075 sheet aluminum.

COMPARTMENT 2. The second partition was constructed at station 1160 which created a compartment approximately 50 feet long extending aft from the first partition. This compartment contained the following:

- Fifty feet of the main cabin
- Section of ceiling that contains the life raft compartments
- Overwing exits
- Aft half of the forward cargo compartment
- Aft cargo compartment hatch
- Cable bay
- Center wing tank
- Wing boxes
- Eighteen starboard side windows
- Landing gear bays and doors
- Forward half of the aft cargo compartment
- Forward cargo compartment hatch
- Fuselage skin materials:
  - Belly to cabin floor:
    - Station 440-610 - 0.050 inch 7075 sheet aluminum
    - Station 610-680 - 0.063 inch 7075 sheet aluminum
    - Station 902-1050 - 0.220 and 0.090 inch 7075 sheet aluminum
    - Station 1050-1150 - 0.080 inch 7075 sheet aluminum
  - Cabin floor to cabin ceiling:
    - Station 440-680 - 0.071 inch 7075 sheet aluminum
    - Station 680-902 - 0.125 inch 7075 sheet aluminum
    - Station 902-1150 - 0.090 inch 7075 sheet aluminum

. Station 902-1150 - 0.090 inch 7075 sheet aluminum

. Top of fuselage:

. Station 440-680 - 0.050 inch 7075 sheet aluminum
. Station 680-781 - 0.090 inch 7075 sheet aluminum
. Station 781-1040 - 0.080 inch 7075 sheet aluminum
. Station 1040-1150 - 0.090 inch 7075 sheet aluminum

COMPARTMENT 3. The third compartment extended aft of the second partition located at station 1160 to the aft pressure bulkhead. This compartment was approximately twenty-seven feet long and included the following:

. Aft section of the main cabin
. Aft galley
. Right rear door
. Aft lavatories
. Aft section of the aft cargo compartment
. Aft cargo compartment hatch
. Aft crawl through including the outflow valves
. Three right side windows
. Fuselage skin materials:

. Belly to cabin floor - 0.063 inch 7075 sheet aluminum
. Cabin floor to cabin ceiling - 0.090 inch 7075 sheet aluminum
. Top of fuselage - 0.090 inch 7075 sheet aluminum

COMPONENTS COMMON TO ALL COMPARTMENTS.

. Main overhead air supply duct

. Passenger gasper air supply ducts

. Cabin air pressurization outlet grills

. Cabin air return grills (floor level)

. Cabin interior panels constructed of a wood/paper sandwich material

. Cargo compartment liners are woven fiber glass on the floor and sidewall and uni-directional fiber glass on the ceiling.

. Cabin floor carpeting

TEST 1 - AFT SECTION.

The starboard side of the aft section of the DC-8 was exposed to a 20- by 20-foot pool fire containing 125 gallons of Jet A fuel primed with five gallons of aviation gasoline. All elapsed times were measured using the pool fire ignition point as the zero mark. The fire took approximately 50 seconds to cover the entire pool. By the 68-second mark, small flames had penetrated the door seals of the aft service door and smoke and momentary flames (1/10-sec duration) emerged from the floor grills in the vicinity of the door. By the 94-second mark, smoke began pouring from the grills all along the starboard side. At 156 seconds into the test, the onboard sprinkler system was activated and the pool fire was simultaneously extinguished by the standby firemen, terminating the test.

FLAME IMPINGEMENT. This test was conducted under near zero wind conditions. The pool fire, once fully developed, rose vertically into the air. This exposed the fuselage to a stable flame ranging from station 1200 to station 1450 and extending well above the aircraft (figure 4).

The schematics and graphs for this test are found in appendix A. The fuselage was instrumented in two vertical groups at station 1402 and station 1286 (figure A-1). Each vertical grouping provided flame and skin temperatures and heat flux measurements.

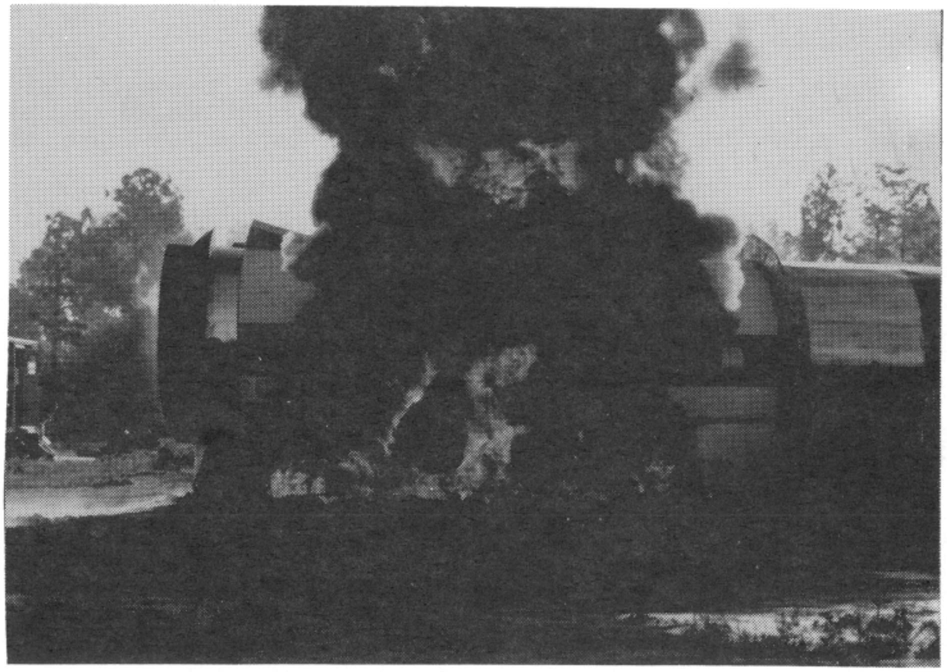

FIGURE 4. TEST 1 DC-8 FLAME EXPOSURE

The indicated fire temperature, measured at the fuselage, ranged from 1600 to 1800 °F. The skin temperatures lagged behind the fire temperatures due to the high heat absorption capability of the aluminum (figures A-2 through A-6).

The forward calorimeter registered a peak value of 3.9 BTU/FT^2-second. The aft calorimeter registered a peak value of 9.0 BTU/FT^2-second (figure A-7).

EXTERIOR FIRE DAMAGE.

Skin Penetration. The aluminum skin melted away in an area below the floor and centered about the aft service door (figure A-8). The damage extended approximately 6 feet forward and 5 feet aft of the door. The skin was buckled approximately 30 inches on all sides of the melted area. The titanium doubler strips were undamaged. The skin above the door was melted in a triangular shape extending 12 inches on either side of the doorway and 30 inches above the door.

Fiber Glass Insulation. The insulation exposed by the melted skin was charred and extended downward 30 inches from the floor level but was mostly intact. The insulation had fallen away in the cheek area, approximately 3 feet forward of the aft service door, exposing the cargo compartment liner to the fire. The cargo liner was cracked and scorched in this area. Where the insulation remained in place there was no fire damage to the interior of the aircraft.

Aft Service Door. The exterior skin of the door was completely burned away exposing the door operating mechanism and interior panel to the fire. The door window's exterior pressure pane was opaque and bulged toward the fire but remained intact. The interior fail-safe pane was clear and undamaged.

INTERIOR FIRE DAMAGE.

Cargo Compartment. The cargo liner was cracked and burned in the cheek area corresponding to the melted exterior skin. The area around the crack was soot covered and a soot trail extended above the crack onto the ceiling. The remainder of the cargo compartment was clean and undamaged. The area above the cargo liner under the cabin floor was heavily sooted but there was no damage to the floor or the floor supports.

Cabin Interior.

Sidewall Panels. There was no damage to the cabin side of the sidewall panels. The panels have fiber glass insulation bonded to the exterior surface. This insulation showed some charring but only where the bagged insulation was physically dislodged.

Ceiling. There was a hidden fire located in the overhead above the cabin ceiling that continued to burn for 10 to 12 minutes after the pool fire was extinguished. This fire was extinguished with Halon 1211. The cabin side of the ceiling panel was soot covered but undamaged. The back side of the ceiling panels that form the overhead were burned down to the honeycomb in most places. The most extensive damage was centered above the aft service door corresponding to a section of melted skin above the doorway.

FIRE PATHS. The smoke and fire that entered the cabin came through the air conditioning return grills located on the sidewall at the floor level. These grills are open into the cheek area on each side of the cargo compartment. This area forms a duct that channels the exhaust air to the outflow valves located in the empennage crawlthrough aft of the cargo compartment. The pool fire melted the skin in the cheek area, opening a path to the grills. The fire in the overhead did not travel up through the sidewalls or through the ventilation ducts. The skin above the door was penetrated directly by the pool fire plume (figure A-8). Here the insulation was dislodged, allowing access to the overhead.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature. The air temperature did not rise significantly during the test. The maximum temperature recorded at the ceiling was 105 °F just prior to sprinkler activation (figure A-9).

Smoke. There was no quantitative recording of smoke data for this test. Motion picture and video camera coverage provided a visual indication of smoke penetration. Smoke penetrated the cabin 68 seconds after ignition, but the cabin never became fully obscured.

TEST 2 - FORWARD SECTION.

The starboard side of the forward section of the DC-8 was exposed to a 20- by 20-foot pool fire consisting of 200 gallons of Jet A fuel primed with five gallons of aviation gasoline. The elapsed times were measured using the pool fire ignition as the zero mark. The fire took approximately 30 seconds to cover the entire pool. In the next 30 seconds smoke and fire penetrated the lower door seal of the starboard service door. Smoke also penetrated the seals on the cargo compartment door. At 71 seconds into the test, smoke began to pour from the floor grills. Fire penetrated the forward service door at 80 seconds. Fire penetrated the cargo door seals at 110 seconds. By 140 seconds, the cabin and cargo compartment became totally obscured. The test was terminated at 3 minutes 45 seconds into the test by activating the sprinkler system and extinguishing the pool fire.

FLAME IMPINGEMENT. The flame plume was blown against the fuselage and aft by a light wind that measured a steady 3 knots. This shifted the fire towards the rear of the compartment. The exterior baffles prevented the flame from damaging the center compartment. The fuselage was exposed to flame that extended from station 440 forward to station 284 at which point the flame trailed off toward the cockpit (figure 5). Instrumentation locations are shown in figure B-1. The fire temperatures measured at the windows (station 287 and 241) ranged from 1500 to 1800 °F (figures B-2 and B-3). The fire temperature measured at station 226 peaked at 1800 °F, while the fuselage skin at this location only reached 600 °F (figure B-4). The forward calorimeter located at station 228 registered a peak heat flux of 5.8 BTU/FT^2-second and the aft calorimeter registered a peak value of 16.8 BTU/FT^2-second foot (figures B-5 and B-6).

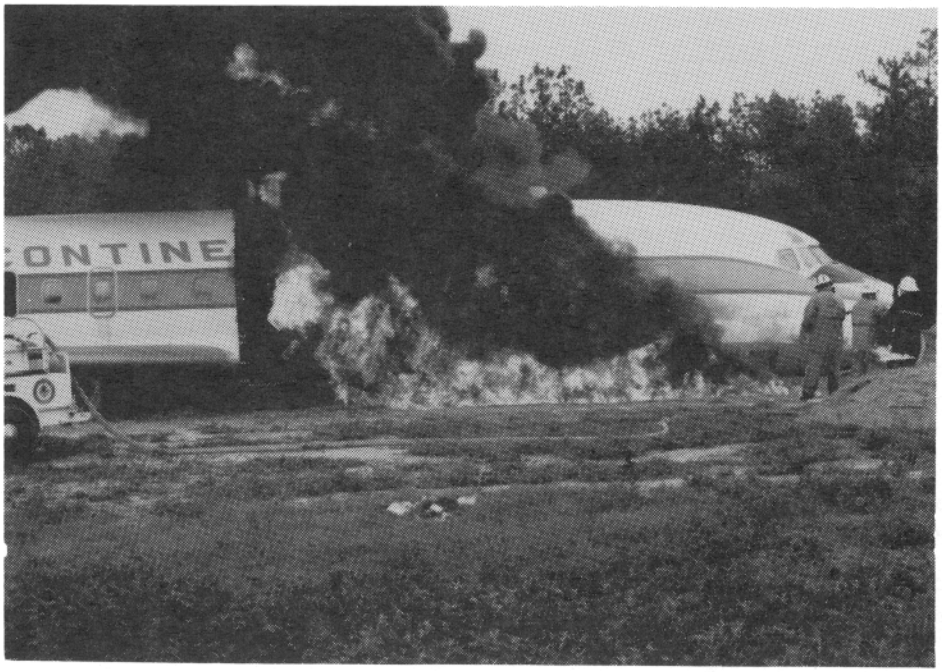

FIGURE 5. TEST 2 DC-8 FLAME EXPOSURE

EXTERIOR FIRE DAMAGE.

Skin Penetration. The aluminum skin was extensively destroyed from the fire barrier, located at the compartment partition, to approximately 16 feet forward as shown in figure B-7. The damage extended from ground level up to the center or the top of the aircraft (figure B-8). The skin on the service door was completely melted away. The cargo door skin was also melted away. Nearly all of the skin below the floor level was melted. The two windows on the starboard side were checkered but were still in their frames.

Fiber Glass Insulation. Most of the bagged insulation remained in place but was heavily charred on the fire side.

Forward Service Door. The skin on the door was completely melted away. Both the door window pressure pane and fail-safe pane were gone from their frame and much of the frame was melted. The interior door panel was 80 percent destroyed leaving a hole approximately 2 by 4 feet to the outside.

Forward Cargo Door. The skin on the cargo door was completely melted away, and the inner door panel was also completely destroyed. There is no insulation between the door skin and the inner door panel, and once the inner panel was breached, the fire had direct access to the cargo compartment.

INTERIOR FIRE DAMAGE.

Cargo Compartment. The fire breached the cargo compartment through the cargo door. The liner was blackened but not cracked where it was exposed in the cheek area. The interior of the compartment was sooted but undamaged. The area between the upper liner and the cabin floor was heavily sooted and the insulation charred but still intact. The temperature above the upper liner at station 270 reached a peak of 1100 °F (figure B-9). The cargo door was completely destroyed.

Cabin Interior.

Sidewall Panels. There was no damage to the sidewall panels forward of the starboard service door. The interior panel of the starboard service door was completely burned through as shown in figure B-10. The only insulation in the door consisted of one half-inch fiber glass bonded to the exterior side of the interior door panel. The panels aft of the door adjacent to the steel partition were heavily charred but not penetrated. The panels all along the starboard side (when removed from the aircraft) exhibited heavy charring on the fire side. In most cases the insulation protected the panels.

Ceiling. The ceiling directly above the starboard service door was heavily charred from the inside out. The service panel above the door came unhooked allowing it to swing down on its hinges. The skin above the service panel was completely burned through. There was a small fire in the overhead in the vicinity of the starboard service door. This was extinguished quickly with Halon 1211. The remainder of the cabin was clean and undamaged.

Windows. The temperatures of the pressure and fail-safe panes of the windows located at stations 241 and 287 stayed low when exposed to flame temperatures as high as 1800 °F. The pressure pane charred quickly providing an insulating layer that protected the fail-safe pane (figures B-11 and B-12). Calorimeters located inside the cabin and 18 inches from the windows registered heat flux values transmitted through the window panes of only 0.2 to 0.3 BTU/FT^2-second. (figures B-13 and B-14).

FIRE PATHS. The smoke initially penetrated the cabin through the floor grills. This was quickly followed by smoke and fire penetration through the starboard service door. Penetration into the cargo compartment was achieved through the cargo door. The extensive skin penetration allowed the fire to penetrate the cabin adjacent to the steel cabin partition. The interior panel and insulation had been removed in this area to allow installation of the partition.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature. The temperature near the ceiling exceeded 250 °F prior to sprinkler activation. The floor and 4 foot above-the-floor temperatures never exceeded 130 °F (figure B-15).

Smoke. Smoke meters were not available for quantitative measurement of smoke data for this test. Motion picture and video camera coverage provided a visual indication of smoke penetration. Smoke penetrated the cabin at 51 seconds after ignition with total visual obscuration occurring at 2 minutes 13 seconds.

TEST 3 - CENTER SECTION.

The starboard side of the center section of the DC-8 was exposed to a 12- by 40-foot pool fire containing 400 gallons of Jet A fuel primed with ten gallons of aviation gasoline. Elapsed times were measured using the pool fire ignition as the zero mark. The fire took approximately 35 seconds to cover the entire pool. The fire pit was situated to expose the underside of the wing and 5 feet forward and 5 feet aft of the wing root. The leading edge wing fuel tank was filled halfway with water to simulate a fuel load. Smoke began to pour from the floor grills at 50 seconds into the test. At 80 seconds, smoke came through the sidewall panel above the window located at station 584. Fire penetrated through the top of the window seal at station 956 at 184 seconds after ignition. Two seconds later, fire penetrated through the floor grill at station 872. At 187 seconds, fire penetrated through the sidewall panel below the window at station 866. At 5 minutes into the test the cabin was totally obscured. At 6 minutes 42 seconds the sprinkler system was activated and the pool fire was extinguished by the standby firemen, terminating the test.

FLAME IMPINGEMENT. Test 3 was conducted under near zero wind conditions. The pool fire, once fully developed, rose in two plumes around the wing's leading and trailing edges. These plumes curled inward towards each other joining near the top of the fuselage. The heaviest exposure occurred above the leading and trailing edges of the wing, stations 980-781 and 717-580. Instrumentation locations are shown in figure C-1. The flame temperatures at station 575 peaked at 1750 °F but averaged only 1200 °F during the test (figure C-2). The flame temperature at station 775 located above the wing averaged 1600 °F (figure C-3). The flame temperatures measured at the aft overwing escape hatch averaged 1400 °F and registered peaks of 1600 °F (figure C-4). The forward escape hatch was exposed to an average flame temperature of 1500 °F with peaks of 1750 °F (figure C-5). The forward calorimeter located at station 575 peaked at 20 BTU/ft^2-sec and averaged 12 BTU/ft^2-sec during the test. The aft calorimeter located at station 918 peaked at 20 BTU/ft^2-sec but only averaged 5 BTU/ft^2-sec (figure C-6).

EXTERIOR FIRE DAMAGE.

Skin Penetration. The skin aft of the wing (enclosing the wheel well) was completely melted away up to the top of the well (figures 6 and C-7). There was a small hole above the wheel well that went through the skin between the top of the wheel well and the cabin floor. Forward of the wing root the skin in the cheek area was melted through and the cargo liner was exposed. The liner was heavily charred but not penetrated. The window located directly above the trailing edge of the wing was completely consumed, allowing flame penetration into the cabin. The other windows exhibited varying degrees of damage but did not allow penetration. The skin both forward and aft of the wing above the melted sections was wrinkled and perforated. Both overwing exits were operable after the test. There was a 2- by 2-foot section above the trailing edge of the wing into the overhead section of the aircraft where the skin completely melted away.

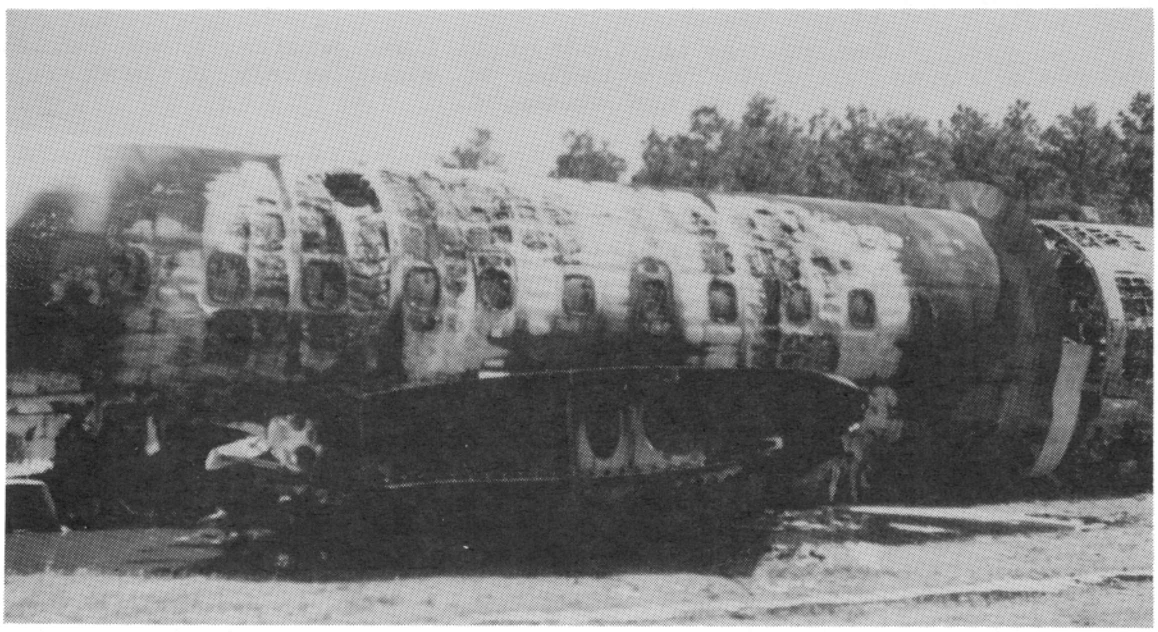

FIGURE 6. TEST 3 DC-8 CENTER SECTION FIRE DAMAGE

Wing. The trailing edge of the starboard wing was completely melted away up to the rear spar. The leading edge of the wing was burned through above the water level in the tank. The underside of the wing was blackened but undamaged while the top surface was relatively clean and undamaged. The water level in the tank was reduced to a few inches. The leading edge of the wing dropped down approximately 18 inches from its original position.

Overwing Escape Hatches. The outer window (pressure) panes on each hatch were destroyed. The inner (fail-safe) panes were heavily charred but still intact. The temperature of both the pressure and fail-safe panes remained low for most of the test (figures C-4 and C-5). Calorimeters located inside the cabin and 18 inches from the windows registered heat fluxes transmitted through the window panes of less that 0.1 BTU/ft^2-sec (figure C-8). The aluminum skin on the forward hatch was sooted and heat damaged but not melted. Fifty percent of the skin on the aft hatch was melted away.

INTERIOR FIRE DAMAGE.

Cabin Interior.

Sidewall Panels. The sidewall panel which is even with the leading edge of the wing was heavily charred and showed signs of burning. The floor grill immediately above the skin penetration forward of the wing in the cheek area was completely burned out. The panel above the floor grill had the vinyl covering burned off all the way to the ceiling. The sidewall panel even with the trailing edge of the wing also had the vinyl covering burned, but only up to 12 inches above the grill. There were soot trails above the other floor grills. The vinyl covering was also burned around the penetrated window.

Fiber Glass Insulation. Removal of the sidewall panels exposed the insulation which was heavily charred where the skin had been breached. In some cases the backsides of the sidewall panels were also charred.

Ceiling. There was a fire in the ceiling overhead centered around the skin penetration above the trailing edge of the wing. The fire was localized and extinguished at the test termination with Halon 1211. The remainder of the ceiling overhead was sooted, and the insulation was charred where the skin was penetrated. The cabin side of the ceiling was clean and undamaged. The ceiling above the floor grill flame penetration was sooted, and some of the vinyl covering was burned.

Floor. The rug near the floor grill flame penetration was burned in a semicircle around the grill in a radius of approximately 12 inches. The remainder of the floor was clean and undamaged.

FIRE PATHS. The fire penetrated the cabin in three places. The first was in the vicinity of the leading edge of the wing. Here a large section of the skin was burned away at the cheek area at the aft end of the forward cargo compartment allowing access to the floor grills. Fire penetrated through the grill and ignited the sidewall panel above the grill. The second penetration occurred through the cabin window directly above the trailing edge of the wing. The ceiling panel and the sidewall panels surrounding and above the window ignited. The third penetration occurred in the ceiling overhead. The fire was caused by a large flame penetration through the skin directly into the overhead. There was no evidence that suggested the fire traveled up through the fuselage from below the floor to the ceiling.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperatures. The cabin air temperatures did not rise above 70 °F for the duration of the test (figure C-9).

Smoke. Smoke meters were not available for quantitative measurement of smoke for this test. All data were taken visually using interior video and motion picture cameras. Smoke penetrated the cabin at 50 seconds into the test, total obscuration occurred at 5 minutes.

CONVAIR 880 TESTS

CONVAIR 880 FUSELAGE PARTITIONING.

The Convair 880 was partitioned into three compartments by constructing two partitions within the fuselage. The partitions were constructed using sheet steel and extended from the floor to the outer skin, both below and above the floor. Each partition included a doorway to allow entry into the compartment.

COMPARTMENT 1. The first partition was constructed at station 584. This created a forward compartment approximately 30 feet long and included the following:

- Cockpit
- Radio rack
- Nose wheel and wheel well
- Electronic compartment
- Most of the forward cargo compartment
- First-class cabin
- Port entry door
- Starboard service door
- Cargo compartment hatch
- Cabin windows
- Fuselage skin materials:
    - Belly up to floor level - 0.063 inch 2024-T3 clad sheet aluminum
    - Window belt level - 0.070 inch 2024-T3 clad sheet aluminum
    - Top of fuselage above window belt - 0.067 inch 2024-T3 clad sheet aluminum
    - Cockpit area (above floor) - 0.060 inch 2024-T4 clad sheet aluminum
    - Cockpit area (below floor) - 0.071 inch 2024-T4 clad sheet aluminum

COMPARTMENT 2. The second partition was constructed at station 1002. This created a middle compartment approximately 35 feet long. This compartment contained the following:

- Overwing emergency escape hatches
- Wings, landing gear, and landing gear wells
- Center fuel tank
- Air conditioning compartment
- Hydraulic compartment
- Thirty-five feet of cabin
- Fuselage skin materials:
    - Window belt area - 0.080 inch 2024-T3 aluminum tapered to 0.100 inch from stations 640 to 926
    - Top of fuselage above window belt - 0.067 inch 2024-T3 aluminum tapered to 0.098 inch from stations 640 to 926

COMPARTMENT 3. The third compartment extended from the second partition at station 1002 to the aft end of the aircraft. This included the following:

- Aft section of the main cabin
- Aft lavatories
- Port entry door
- Starboard service door
- Aft cargo compartment
- Cargo compartment hatch
- Aft crawlthrough including the outflow valve
- Empennage

- Fuselage skin materials:
  - Stations 926 to 1373 (aft pressure bulkhead):
    - Belly up to floor level - 0.063 inch 2024-T3 clad sheet aluminum
    - Window belt area - 0.095 inch 2024-T3 clad sheet aluminum
  - Top of fuselage above window belt:
    - Station 926-1182 - 0.085 inch 2024-T3 clad sheet aluminum
    - Station 1182-1373 - 0.095 inch 2024-T3 clad sheet aluminum
  - Stations 1373 aft (empennage area):
    - Belly - 0.050 inch 2024-T4 clad sheet aluminum
    - Sides - 0.071 inch 2024-T4 clad sheet aluminum
  - Top of fuselage (under vertical stabilizer) - 0.050 inch 2024-T3 clad sheet aluminum
  - Tail Cone - 0.040 inch 2024-T4 clad sheet aluminum

COMPONENTS COMMON TO ALL COMPARTMENTS.

- Overhead storage bins
- Main air supply ducts
- Cabin air return grills (floor level)
- Passenger gasper air supply ducts
- Cargo compartment liners constructed of woven fiber glass on sidewall and ceiling. The floor liner was aluminum.
- Cabin floor carpeting
- Cabin interior panels

TEST 4 - AFT SECTION.

The aft section of the Convair 880 was exposed to a 26-foot-long by 30-foot-wide pool fire containing 500 gallons of Jet A fuel and primed with ten gallons of aviation gasoline. Elapsed times were measured using the pool fire ignition as the zero mark. The pool was centered under the fuselage between stations 1050 and 1362. The fire was ignited on the upwind side and took approximately 40 seconds to cover the entire pool. At 1 minute 26 seconds, smoke penetrated the cabin floor just forward of the aft port lavatory. A small fire ball appeared at the same location 17 seconds later. Two minutes into the test the cabin became completely obscured. Smoke penetrated the aft bulkhead of the cargo compartment at 2 minutes 7 seconds. Ten seconds after the smoke appeared, flames were visibly penetrating the aft cargo bulkhead. The cargo compartment became completely obscured 3 minutes 46 seconds into the test. Six minutes after ignition the sprinkler system was activated and the pool fire was extinguished by standby firemen.

FLAME IMPINGEMENT. Test four was conducted with a 3-7 knot wind 90 degrees to the fuselage that blew from starboard to port. The fire plume from the fully developed pool fire was blown under the fuselage and rose vertically on the port side. The smoke adhered to the vertical stabilizer on the downwind (port) side due to the low pressure area formed by the tail section and the cross wind (figures 7 and 8). The starboard side experienced very little flame impingement. The port side and the belly were heavily exposed to flames from station 1400 extending forward to station 1040. Instrumentation locations are shown in figures D-1 and D-2.

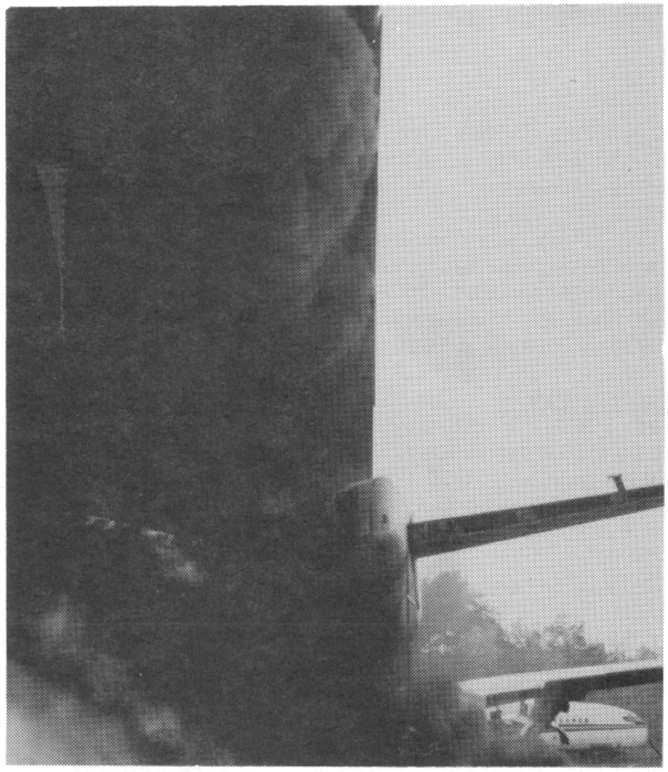

FIGURE 7. TEST 4 CV-880 PORT SIDE FLAME EXPOSURE

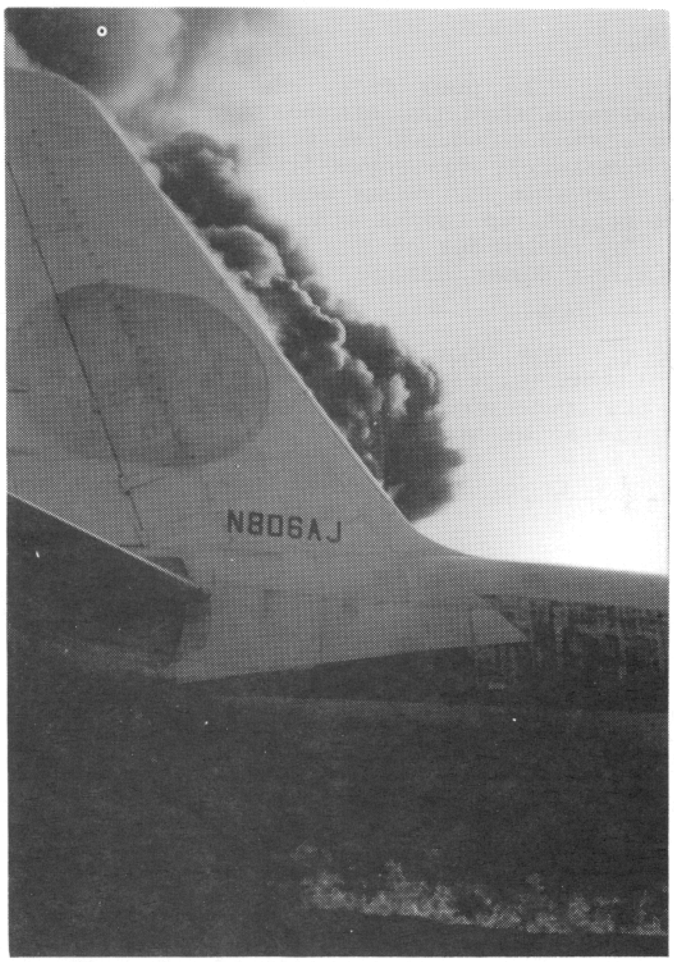

FIGURE 8. TEST 4 CV-800 STARBOARD SIDE FLAME EXPOSURE

Starboard side. The flame temperatures measured at station 1184 below the window level peaked at 325 °F and averaged approximately 250 °F (figure D-3). The flame temperatures measured at the window at station 1184 peaked at 250 °F and averaged below 200 °F (figure D-4). The flame temperatures measured at the service door (station 1270, window level) averaged approximately 210 °F (figure D-5). The flame temperatures measured at station 1177 in the cheek area peaked at 600 °F and averaged approximately 475 °F (figure D-6). The heat flux measured at station 1184 just below the window peaked at 1.0 BTU/FT^2-sec and averaged approximately 0.75 BTU/FT^2-sec (figure D-7).

Lower Fuselage (belly). The flame temperatures at station 1237 measured at the keel peaked at 1800 °F and averaged 1400 degrees (figure D-8). The flame temperatures at station 1127 measured at the cargo compartment door peaked at 850 °F and averaged approximately 600 °F (figure D-9). The temperatures measured inside the outflow valve located at station 1291 peaked at 1800 °F and average approximately 1600 °F (figure D-10).

Port Side. The flame temperatures at station 1184 measured just below the window level peaked at 1900 °F, dropped off to 1200 °F and built to a second peak of 1750 °F (figure D-11). The flame temperatures at station 1184 measured at the center of the window followed the same trend (figure D-12). The flame temperatures at station 1285 measured at the port entry door peaked at 2200 °F and averaged approximately 1200 °F (figure D-13). The flame temperatures at station 1184 measured at the cheek area peaked at 1875 °F and averaged 1500 °F (figure D-14). The heat flux at station 1184 measured just below the window level peaked at 12 BTU/FT^2-sec and averaged approximately 5 BTU/FT^2-sec (figure D-15).

EXTERIOR FIRE DAMAGE.

Skin Penetration. The pool fire, though centered under the fuselage, damaged the port side more than the starboard due to the crosswind. The wind blew at 3 to 7 knots across the fuselage from starboard to port. The underside of the aircraft was completely destroyed from station 1040 aft to station 1470 (figures 9 and 10). The skin and frame members were completely gone. The skin on the port side was melted up to the window level from station 1163 to station 1350 (figure D16). The remainder of the skin was buckled and perforated. The starboard side sustained minor damage with some slight sooting of the paint (figure D-17).

Port Entry Door. The door and the surrounding frame were intact even though the skin on either side was completely destroyed. The door skin was partially melted at the lower edge and the remainder was rippled and perforated. The door was inoperable after the test.

Starboard Service Door. This door was undamaged in the fire and was operable after the test.

Horizontal Stabilizer. The leading edge of the port stabilizer was burned off to the leading edge spar, and the resistance heating elements for the deicer system hung from the stabilizer. The underside was sooted and scorched, and the top side was heavily sooted but undamaged. The starboard stabilizer was clean and undamaged.

Vertical Stabilizer. The port side was heavily sooted and the paint was blistered, but the starboard side was clean and undamaged.

Windows. All but two of the windows on the port side were penetrated. The two remaining windows (station 1106-1125) had their pressure panes destroyed and fail-safe panes charred. The windows on the starboard side were undamaged.

INTERIOR FIRE DAMAGE.

Cargo Compartment. The cargo compartment was completely destroyed. The aft partition that separates the cargo compartment from the empennage crawlthrough area was completely gone. The ceiling of the compartment was

FIGURE 9. TEST 4 CV-880 PORT SIDE FIRE DAMAGE

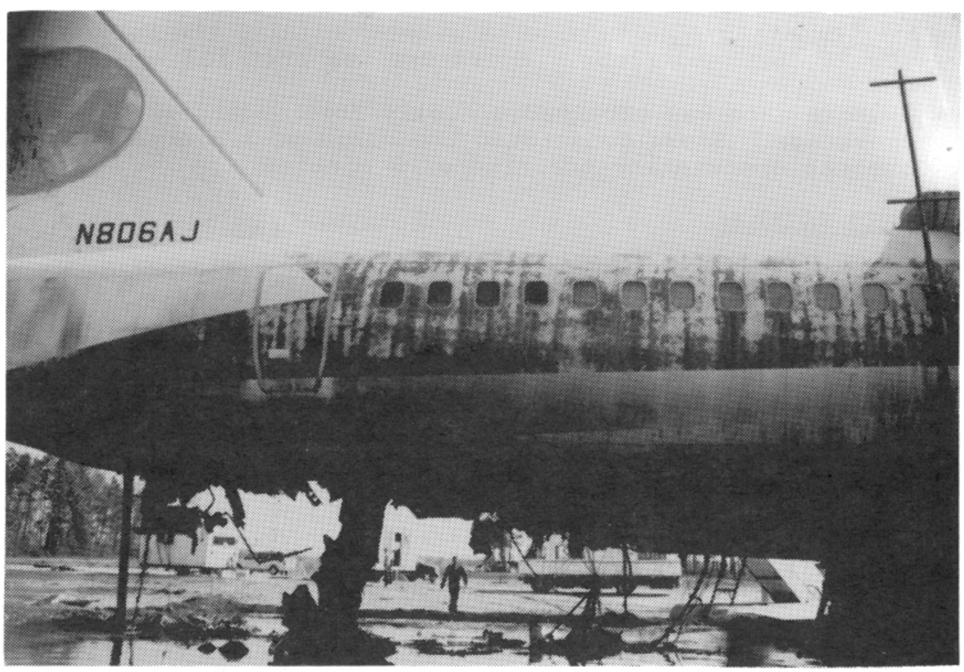

FIGURE 10. TEST 4 CV-880 STARBOARD SIDE FIRE DAMAGE

destroyed as well as 50 percent of the cabin floor above it. The forward bulkhead remained undamaged due to the protective steel partitions. The starboard cargo hatch was scorched on the inside but undamaged on the exterior. The hatch was inoperable after the test. The air temperature in the cargo compartment measured at station 1182 remained ambient for approximately 4 minutes at which time it rapidly rose to 1100 °F, dropped off to 700 °F and then peaked at 1600 °F at the conclusion of the test (figure D-18). The temperature in the cheek areas and between the floor and the top of the cargo compartment measured at station 1182 remained close to ambient for 4.5 minutes and then peaked at 1600 °F near the end of the test (figure D-19).

<u>Empennage Crawlthrough.</u> The belly and the port side of the fuselage were completely destroyed. The floor above the crawlthrough was completely burned through. The outflow valve was completely consumed by the fire.

<u>Cabin Interior.</u> The aircraft cabin was gutted by the fire. The floor on the port side and toward the rear was completely burned through. The remainder of the floor was supported only on the starboard side.

<u>Sidewall Panels.</u> The panels on the port side were completely destroyed aft of station 1106. Those forward of station 1106 were charred and burned. The sidewall panels on the starboard side were heavily sooted but unburned.

<u>Ceiling.</u> The ceiling and overhead bins were heavily charred and the bins on the port side were partially consumed by the fire. The overhead above the cabin ceiling was sooted but not burned.

<u>FIRE PATHS.</u> The initial penetration into the aircraft occurred in the empennage crawlthrough area behind the cargo compartment. This area is only partially insulated. The fire penetrated the skin and then the floor of the cabin.

Penetration into the cargo compartment was through the aft bulkhead separating the cargo compartment from the crawlthrough area. The cabin floor was initially penetrated by flames above the crawlthrough area in 1 minute 43 seconds and the cargo compartment in 2 minutes 14 seconds. The cargo compartment appeared to provide some protection to the cabin against a pool fire of this type.

<u>CABIN ENVIRONMENTAL CONDITIONS.</u>

<u>Cabin Air Temperature.</u> Six minutes after ignition, the ceiling temperature had reached 800 °F, but the floor temperature was only 115 °F (figure D-20).

<u>Smoke.</u> Smoke data was obtained visually from interior motion picture and video camera coverage. Smoke penetrated the cabin at 1 minute 26 seconds after ignition. Complete obscuration occurred at 2 minutes.

<u>TEST 5 - FORWARD SECTION.</u>

The forward section of the Convair 880 was exposed to a 45-foot-long by 30-foot-wide pool fire containing 1000 gallons of Jet A fuel primed with ten gallons of aviation gasoline. Elapsed times were measured using the pool fire ignition as the zero mark. The fuel was ignited on the upwind side and took approximately 25 seconds to cover the entire pool. The wind was blowing across the fuselage from starboard to port at 3 to 6 knots. Thirty seconds into the test, smoke began to pour into the cabin from the cockpit. At 49 seconds after ignition, smoke penetrated the port entry door seals. At 1 minute 10 seconds into the test, the cabin became obscured, and at the same time smoke began to puff through the cargo compartment door seals. By the 2 minute mark the cargo compartment was fully obscured. At 3 minutes 49 seconds after ignition, the smoke outside of the aircraft momentarily cleared to reveal that the skin on the underside of the aircraft was mostly burned away. At 4 minutes 25 seconds, the nose began to sag. At 4 minutes 28 seconds the sprinkler system was activated and the firemen began to put the pool fire out. At 4 minutes 50 seconds, the nose crashed to the ground. It took another 3 1/2 minutes to put out the interior fire.

FLAME IMPINGEMENT. Test five was conducted with a 3-6 knot wind 90 degrees to the fuselage from starboard to port. The fire plume was blown under the fuselage and rose vertically on the port side (figure 11). The most severe flame exposure was to the aircraft belly and port side, extending forward from station 584 to the nose. The starboard side received relatively little flame impingement. Instrumentation locations are shown in figures E-1 and E-2.

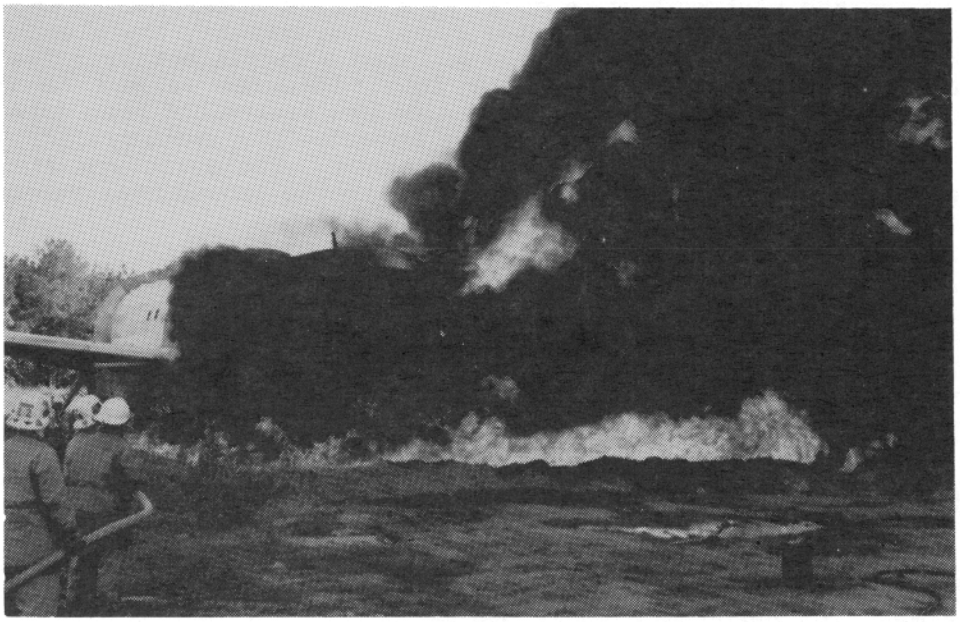

FIGURE 11. TEST 5 CV-880 FLAME EXPOSURE

Starboard Side. The flame temperatures measured at station 461 below the window level peaked at 1525 °F 45 seconds after pool ignition. The temperature dropped off rapidly as the cross wind pushed the fire under the fuselage, averaging 350 °F for the remainder of the test. Very little of this heat was radiated to the interior of the aircraft as indicated by the temperature of the interior panel which remained quite low during the test (figure E-3). The flame temperature at station 461 measured at the cheek area was considerably higher peaking at 1800 °F in 45 seconds and then dropping off to 500 °F. The flame temperature steadily rose during the remainder of the test peaking at 1200 °F (figure E-4). The flame temperatures at station 341 measured at the starboard service door peaked at 1700 °F 45 seconds after pool ignition. The flame temperature dropped off rapidly and averaged 350 °F for the remainder of the test (figure E-5). The flame temperatures at station 460 measured at the window peaked at 1350 °F within the first minute and then dropped off to an average of 300 °F for the remainder of the test (figure E-6). The heat flux at station 461 measured just below the window peaked at 8.3 BTU/ft^2-sec 45 seconds after pool ignition and then dropped off rapidly to under 2.0 BTU/FT^2-sec for the remainder of the test (figure E-7).

Port Side. The flame temperatures at station 461 measured just below the window level reached 1650 °F 45 seconds after pool ignition. The flame temperature ranged from 1250 to 2100 °F for the remainder of the test. The interior panel temperature at this location remained very low for 3.5 minutes and then started to rise, peaking at 1300 °F at 5 minutes (figure E-8). The flame temperature at station 461 measured at the window reached 1750 °F within 45 seconds and averaged approximately 1600 °F for the remainder of the test (figure E-9). The flame temperatures at station 461 measured in the cheek area peaked at 1800 °F at 45 seconds after pool ignition and averaged approximately 1500 °F for the remainder of the test (figure E-10). The flame temperature at station 341 measured at the port entry door peaked at 1750 °F within 60 seconds after pool ignition. The temperature then dropped off to 1100 °F at 2.5 minutes after ignition and then peaked again at 1700 degrees at the 3 minute mark (figure E-11). The heat flux at station 461 measured just below the window level ranged from 5 BTU/FT^2-sec to 20 BTU/FT^2-sec (figure E-12).

EXTERIOR FIRE DAMAGE.

Skin Penetration. The nose section was severely damaged by the fire. The port side was completely destroyed up to the centerline of the top of the fuselage (figures 12 and E-13). The cockpit windows were still intact; all other windows on the port side were gone. The entire underside of the aircraft was burned away. Nothing remained of the cargo compartment, the electronic bay, or the nose wheel well. The starboard side fared a little better. The belly of the aircraft was burned below the floor level (figures 13 and E-14). The remainder of the fuselage on the starboard side was sooted and heat damaged. The windows and the starboard service door were intact. The service door would not open after the test but the mechanism did operate. The structure was so badly damaged that the nose of the aircraft collapsed to the ground near the end of the test.

Port Entry Door. The skin was melted off the door.

Starboard Service Door. The skin on the door was buckled but not melted.

Landing Gear. After the test, the nose gear was retrieved from under the wreckage. The gear was intact and the tire was scorched but not burned. The gear attachment points on the aircraft were completely consumed in the fire.

Windows. All the windows on the port side were consumed in the fire. The windows on the starboard side were sooted and heat damaged but still intact.

Cargo Hatch. The skin on the cargo hatch was buckled but not penetrated. The door frame and door were all that remained below the floor level on the starboard side. The hatch was not operable.

INTERIOR FIRE DAMAGE.

Cargo Compartment. The cargo compartment was completely destroyed by the fire. The ceiling of the compartment was gone as well as the cabin floor above it. The air temperature in the cargo compartment measured at station 460 remained ambient until 3 minutes after pool ignition. The air temperature then increased rapidly reaching 1500 °F 3.75 minutes after pool ignition (figure E-15). The air temperatures at station 461 measured in the cheek areas and the space between the cargo compartment ceiling and the cabin floor remained near ambient for 3 minutes then increased rapidly to between 1500 and 1800 °F (figure E-16).

Cabin Interior. The interior of the aircraft was consumed by the fire and there was little left that was recognizable. The cockpit was gutted leaving only the seat frames.

FIRE PATHS. Initial smoke penetration came from the cockpit area. The cockpit, however, did not receive the most extensive damage. The fire may have come into the cabin through the electronics bay and up through the crew access tunnel. The electronics bay was not insulated.

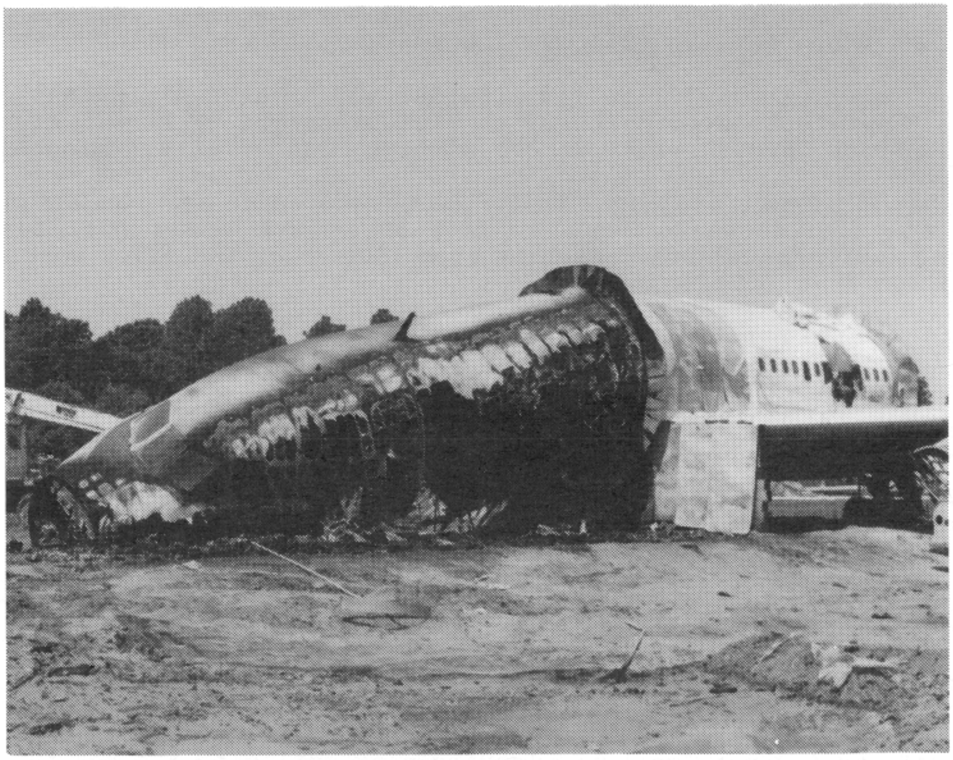

FIGURE 12. TEST 5 CV-880 PORT SIDE FIRE DAMAGE

FIGURE 13. TEST 5 CV-880 STARBOARD SIDE FIRE DAMAGE

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature. The air temperatures at station 460 measured at the center of the cabin were as follows (figure E-17):

Ceiling: 450 °F at 1.5 minutes, 975 °F at 4.5 minutes
Four-foot level: 250 °F at 3 minutes, 550 °F at 4.5 minutes
Floor level: 90 °F at 3.5 minutes, 240 °F at 4.5 minutes

Cockpit Air Temperatures. The air temperatures at station 238 measured at the pilot and copilot seats began to rise 60 seconds after pool ignition and again at the four-minute mark, reaching over 1000 °F at the pilot seat and 800 °F at the copilot seat (figure E-18).

Smoke. Smoke penetrated the cabin at 30 seconds after ignition, obscuring the video cameras at 1 minute and 10 seconds. The optical smoke meter recorded zero light transmission at four minutes (figure E-19).

TEST 6 - CENTER SECTION.

The center section of the Convair 880 was exposed to a 30- by 30-foot pool fire containing 650 gallons of Jet A fuel primed with ten gallons of aviation gasoline. The pool was centered under the fuselage. There was a near zero wind condition at the time of the test. Elapsed times were measured using the pool fire ignition as the zero mark. The fire took approximately 25 seconds to reach a fully developed state. At 40 seconds there was a small explosion under the fuselage. At 1 minute 5 seconds, smoke began to rise from the floor of the cabin at station 980. At 1 minute 35 seconds a momentary fire flash occurred at floor level, station 736. At the 1 minute 30-second mark the aluminum skin near the middle of the fuselage was burned away, and at this time the cabin became totally obscured. At the 4-minute mark the landing gear collapsed and the fuselage fell to the ground. The pool fire was extinguished at this time by the standby firemen. The water feed line to the on board sprinkler system was broken when the plane fell to the ground.

FLAME IMPINGEMENT. Test six was conducted under near zero wind conditions. The fire plumes rose in four columns, one forward and one aft of the wing roots on each side of the aircraft (figure 14). The entire aircraft belly was immersed in flame from station 584 to station 1002. The severest exposure on the port side of the fuselage extended from station 584 to station 622 and from station 945 to station 1002. The severest exposure on the starboard side of the fuselage extended from station 584 to station 622 and from station 964 to station 1002. Instrumentation locations are shown in figures F-1 and F-2.

Starboard Side. The flame temperature at station 974 measured just below the window level increased rapidly to 1900 °F then gradually rose to 2200 °F (figure F-3). The heat flux at this same location steadily increased during the test to a peak value of 22.5 BTU/FT^2-sec (figure F-4).

PORT SIDE. The flame temperatures at station 974 measured just below the window level peaked at 2050 °F 2 minutes 15 seconds after pool ignition and averaged 1700 °F for the remainder of the test (figure F-5). The flame temperatures at station 612 measured just below the window level peaked at 1650 °F 1 minute 35 seconds after pool ignition. The temperature dropped off to 1100 °F and then peaked again at 1900 °F near the end of the test (figure F-6).

EXTERIOR FIRE DAMAGE.

Skin Penetration. The port side skin that was forward of the leading edge of the wing was completely burned away up to the top of the fuselage (figures 15 and F-7). The windows in this area (station 584) were completely burned through. The windows over the wing were charred but not penetrated. The skin aft of the wing was also burned away with damage extending forward to station 884. The exposed ribs at the aft end were buckled. The windows aft of the wing had their outer pressure panes completely burned away, but the inner fail-safe panes were

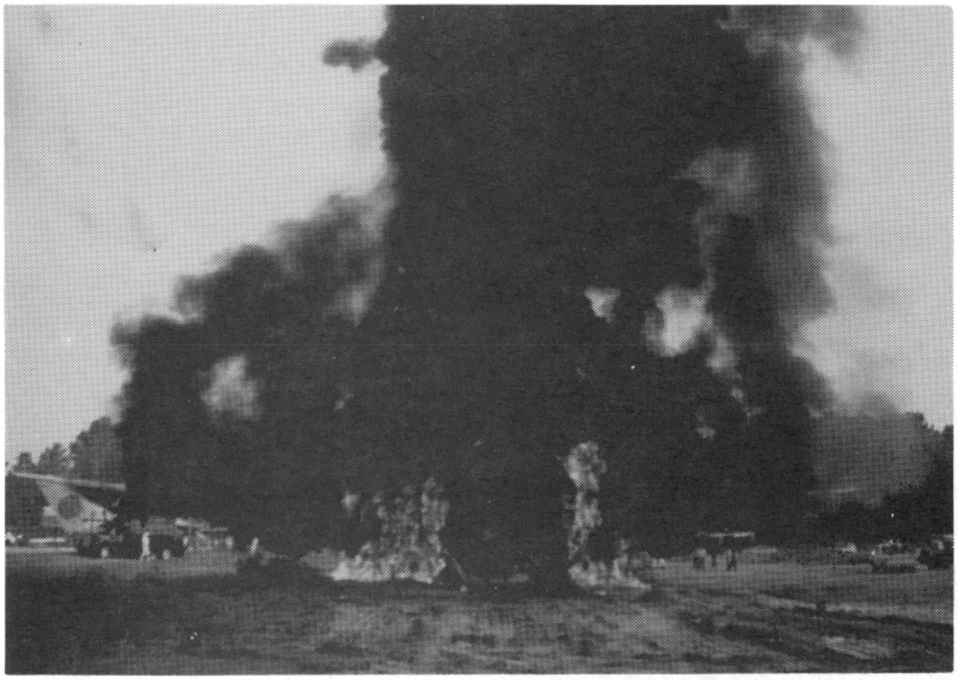

FIGURE 14. TEST 6 CV-880 FLAME EXPOSURE

FIGURE 15. CV-880 PORT SIDE FIRE DAMAGE

not penetrated. The insulation exposed by the melted skin on the fire side was charred but intact. The skin on the belly of the aircraft was heavily charred and buckled but not penetrated except forward and aft of the wing. The starboard side sustained damage similar to the port side (figures 16 and F-8). The skin aft of the wing was completely melted away exposing the insulation. The windows aft of the wing were burned through to the interior. The section forward of the wing also had the skin completely melted. The windows in this section had the pressure panes burned away with the fail-safe panes charred but not penetrated. The insulation throughout was heavily charred but intact.

FIGURE 16. TEST 6 CV-880 STARBOARD SIDE FIRE DAMAGE

Wings. The leading and trailing edges of the wings were heavily damaged by the fire. In each case the skin was melted away up to the wing spars. The upper surfaces of the wings were clean and undamaged. The lower surface was heavily charred and sooted but not penetrated except in the wheel well area. Here, the fire penetrated up into the landing gear mounting points where the structure was completely burned away. When the fuselage collapsed to the ground, the gear assembly punched through the top of the wing. It should be noted that the wing fuel tanks were filled with water to lessen the possibility of explosion. This provided a heat sink effect that protected the wings in the tank areas.

Overwing Escape Hatches. The overwing escape hatch on the starboard side was relatively undamaged. The paint was burned off and the window pane was charred. The hatch would not operate after the test. The hatch on the port side of the aircraft was also undamaged. The surface was soot covered and the window was charred. This hatch also would not open after the test. It should be noted that the hatches on the Convair 880 are located near the leading edge of the wing so they were very close to the severe fire damage that occurred in the leading edge area.

INTERIOR FIRE DAMAGE.

Cabin Interior.

Sidewall Panels. The sidewall panel located on the aft starboard section of the compartment sustained some fire damage where the window was penetrated. This was the only location that showed any signs of fire damage.

The remainder of the compartment, sidewalls and ceiling, showed some sooting and heat damage. The vinyl decorative covering used on the interior surfaces was wrinkled and stretched due to the heat.

Ceiling. The ceiling was heavily sooted and showed some charring near the compartment partitions. The overhead bins were heat damaged but intact.

Floor. The floor and rug were undamaged.

FIRE PATHS. The fire did substantial damage to the exterior of the aircraft. However, as in the DC-8 test, the wings protected the fuselage from burnthrough from underneath the aircraft. The only penetration into the cabin occurred on the aft starboard side where the windows were burned away. Here the sidewall panels were damaged. There was no ceiling overhead fire in this test. The acoustical insulation remained in place and supplied the inner sidewall panels with substantial protection from the fire.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature. The cabin air temperatures were taken at station 788 in the center of the cabin (figure F-9):

Ceiling - 200 °F at 4 minutes after pool ignition.
Four-foot level - 160 °F at 4 minutes.
Floor - 90 °F at 4 minutes.

Smoke. Smoke penetrated the cabin at 1 minute 5 seconds, obscuring the video cameras at 1 minute 30 seconds after ignition. The optical smoke meter located at station 788, 48 inches above the floor, indicated zero light transmission at 3.5 minutes after pool ignition (figure F-10).

HEAT TRANSFER THROUGH FUSELAGE SIDEWALL. The thermal resistance of each component of the fuselage sidewall was determined at station 974 on the starboard side below the window level (figure F-1). Instrumentation was installed to measure the temperatures of the exterior flame, the fuselage skin, the acoustical insulation, and the interior panel. The exterior flame temperature reached close to 2000 °F within 60 seconds after pool ignition. The fuselage skin melted at 120 seconds. The temperature behind the insulation slowly began to rise as soon as the skin melted reaching 200 °F at 3.5 minutes at which point the rate of temperature rise increased reaching 500 °F at 4.5 minutes. The interior panel temperature also began to rise slightly when the exterior skin melted but barely reached 100 °F at 3.5 minutes. At this point the interior panel temperature rose quickly to 250 °F and leveled off at the conclusion of the test (figure F-3).

The effect of additional insulation was determined at station 955 on the starboard side just below the window level and 19 inches forward of the previous profile shown in figure F-3. Additional insulation in the form of 1/4-inch Kaowool blanket was installed inside the acoustical insulation bag such that it was between the fiber glass insulation and the exterior skin. The flame temperature again reached 2000 °F at 60 seconds and the skin melted at 120 seconds. The temperature behind the Kaowool blanket began to rise as soon as the skin melted and it reached 2000 °F at 3.5 minutes. The temperature behind the fiber glass acoustical insulation rose at a slightly slower insignificant rate than that without the Kaowool. The interior panel temperature was not affected by the addition of Kaowool with the exception that the sharp rise near the end of the test was almost eliminated (figure F-11).

A similar study was conducted at station 612 on the port side just below the window level (figure F-6) and at station 955 where additional Kaowool insulation was installed (figure F-12). The results again showed no significant improvement in reducing the interior panel temperature by the addition of the 1/4-inch Kaowool.

TEMPERATURE DATA SUMMARY (ALL TESTS)

SKIN TEMPERATURES.

The skin temperatures always followed the fire temperature in profile with a 30- to 60-second delay time. Where the pool fire had a rapid buildup in temperature, the delay was in the order of 30 seconds. When the skin temperature reached approximately 900 °F, the temperature profile "plateaus" for approximately 5 to 10 seconds and then rises rapidly to coincide with the fire temperature. This plateau is the temperature at which the phase change from solid to liquid occurs, the melt point for the aluminum skin. After the skin melted, the thermocouples were exposed directly to the fire and functioned as a fire temperature measurement.

No correlation was obtainable from this data to draw any conclusions with regard to skin thickness and melting times. A major factor affecting the skin melting time is the type of structure supporting the skin. The configuration of hull formers and stringers varies considerably and provides a wide range of heat sinks transferring heat energy away from the skin.

Fuselage skin sections more likely to melt first include the cheek area, empennage crawlthrough, and the upper fuselage above the windows.

Measurement of skin melting times is difficult due to the limited amount of instrumentation available and the varying structure beneath the skin. A wide variation in hull damage can be found within a few square feet making thermocouple placement an imprecise science. Previous work by Geyer (reference 2) predicted an aluminum skin melt time of 25 seconds for 0.060-inch skin thickness and 38 seconds for 0.090-inch skin thickness. The skin melt times measured in this series of tests are consistent with those predicted by Geyer.

CABIN INTERIOR SIDEWALL TEMPERATURES.

The instrumentation generally provided a temperature profile through the fuselage from the fire to the skin through the insulation and to the cabin interior panel. The acoustical insulation proved to be an effective thermal barrier. As long as the insulation remained intact, very little of the exterior heat was transferred to the cabin panels. An example from the aft section of the Convair 880 test on the port side: the pool fire reached 1850 °F in 1 minute 45 seconds, the skin melted 1-minute 45 seconds later, the inner panel took 1-minute 45 seconds more to burn through (figure D-11). Therefore, in this case, the interior panel burned through about 3.5 minutes after the aluminum skin melted. The addition of 1/4-inch Kaowool blanket insulation to the acoustical insulation bag had no significant affect on the interior panel temperature as shown in test 6, Convair 880 center section.

CABIN AIR TEMPERATURE.

A thermocouple tree was provided for each test that measured cabin air temperatures at floor level, 4 feet above floor level, and at the ceiling level. Typically, the cabin air temperature lagged far behind the exterior fire. The cabin in each test remained below 200 °F at the 4 foot level for at least 3 1/2 minutes. As expected, the temperature at the floor level was much cooler than higher up in the cabin. In the more severe tests the temperature spread could be as much as 400 °F.

FIRE TEMPERATURES.

In the fully developed sections of the pool fire, the temperature ranged from 1600 to 2100 °F. Heat flux readings of 5 to 23 Btu/ft^2-sec were normal. A fully developed fire averaged 15 Btu/ft^2-sec.

CARGO COMPARTMENT AIR TEMPERATURES.

The cargo compartment generally remained well insulated from the exterior fire until penetration occurred. At this point the temperature rose quickly. Using the aft section of the Convair 880 again as an example, the cargo compartment air temperature remained at approximately 70 °F for 2 minutes 20 seconds after the exterior fire had reached 1800 °F. At that point the cargo compartment was penetrated with the temperature rapidly reaching 1500 °F.

WINDOWPANE TEMPERATURES.

The windowpanes, made of a stretched plexiglass, were effective flame barriers. The outer pressure panes showed a very slow temperature rise until the pane itself caught fire. Even then the temperature of the inner fail-safe pane remained very low unless the outer pane was completely consumed. An example from the aft Convair 880 test on the port side: The temperature of the outer pressure pane rose only 100 °F in 3 minutes when exposed to a fire temperature of 1800 °F. A calorimeter placed 18 inches from the window registered near zero heat flux being transmitted through the stretched plexiglass window panes due to the charring of the pressure pane.

Previous work by Geyer utilizing a DC-10 window system (reference 1) produced shorter flame penetration times than was evident during this series of tests. Typically, Geyer's tests utilized an exterior fire pan located at floor level adjacent to the fuselage. Average flame penetration times of 2.4 to 3.2 minutes were measured.

There were several differences in the test conditions and the window structure that may account for the shorter flame penetration times. The thickness of the windowpanes is dependent on the location in the fuselage. Windows installed aft of the trailing edge of the wing are dimensionally thicker to provide sound attenuation. The DC-10 window system utilized in Geyer's test consisted of a pressure pane, a fail-safe pane, and an anacoustic pane, 0.400 , 0.180 and 0.060 inches thick respectively or 0.440, 0.210,and 0.060 inches thick. These panes were held in place by a silicone rubber seal.

The windows on the Convair 880 are held in place by two silicone rubber gaskets and an outer and inner seal. The windowpanes are also constructed differently. The pressure pane and the fail-safe pane are fused together at the outer edges to form a single unit with a 1/8-inch air gap. The thicknesses of the pressure and fail-safe panes are 0.400 and 0.253 or 0.530 and 0.350 inches respectively, dependent on installation location. The thickness of the anacoustic pane is 0.187 and 0.375 inches, again dependent on location.

The typical failure mode for Geyer's test involved pyrolysis of the rubber seal and distortion and shrinking of the windowpanes allowing the panes to fall from the window frame. This provided access for the flames into the cabin. The typical failure mode for the present series of tests followed this sequence. The outer pane would first checker and craze and produce a black char. The outer pane would then catch fire and would eventually be consumed. The fail-safe pane was effectively insulated from the heat by the charring of the pressure pane and experienced little temperature rise until the pressure pane was consumed, at which time the charring process was repeated. At no time did the window unit fall from the mounting system. Typically, fragments of the pressure and fail-safe panes would still be in the gaskets even if the center of the window was penetrated. The fusing of the pressure and fail-safe panes with the 1/8-inch air gap is credited with preventing the windows from shrinking.

The DC-8 window system differed in that the pressure and fail-safe windowpanes were mechanically fastened to the window frame by through bolts. This prevented the plexiglass from shrinking and pulling away from the window frames and performed as well as the Convair 880 windows in preventing fire penetration into the cabin.

SMOKE DATA SUMMARY (ALL TESTS)

An optical smoke meter was provided for several tests located at the 4-foot level in the center of the cabin compartment. This unit utilized a 4-inch exposed beam path and provided information on cabin visibility measured in percent light transmission. Total obscuration as indicated by the onboard video cameras corresponded with approximately a 50 percent light transmission level. In most cases, once smoke began to enter the cabin, total obscuration occurred in approximately 2 to 3 minutes. Where the optical smoke meter malfunctioned or was unavailable, information on smoke obscuration was determined from interior video and motion picture cameras.

FIRE PATH SUMMARY (ALL TESTS)

GEAR RETRACTED.

The aircraft is less vulnerable in this configuration to flame penetration from an adjacent exterior fuel fire. The ground protects the lower fuselage from flame impingement. The exposed cheek area is, however, a likely area for flame penetration. Once the aluminum skin is penetrated the flames and smoke can enter the main cabin through the air conditioning return grills located on the sidewalls at the floor level. The cheek area is utilized as an air duct to channel exhaust air to the outflow valves.

The door seals are also vulnerable to early flame and smoke penetration. The heat of the fire pyrolyses the seal materials leaving a gap through which smoke and flames can enter. This is true for cabin and cargo compartment doors.

Direct penetration of the cabin through the fuselage skin can occur if acoustical insulation is dislodged. The windows provide another path for flame penetration but were not primary fire paths in these tests.

GEAR EXTENDED.

The fuselage is more vulnerable in this configuration than with the gear retracted. This is due to the larger surface area exposed to the fire. The portions of the fuselage containing the cargo compartments are less vulnerable due to the insulating quality of the compartments. The cheek areas on either side of the cargo compartments are still quite susceptible to penetration and provide a fire path through the floor grills into the cabin.

The empennage crawlthrough is generally only partially insulated and provides a path for direct fire penetration through the fuselage skin. The cabin floor above the crawlthrough area is then penetrated allowing flames and smoke into the cabin.

The nose gear wheel well, the electronics bay, and the crew access tunnel all provide likely paths for flame penetration into the cabin.

The center section of the aircraft is protected from flame penetration from underneath by the wings.

CONCLUSIONS

1. The aluminum skin can only be expected to provide protection from a fully developed pool fire for 30 to 60 seconds.

2. The windows are effective flame barriers until they are consumed by the fire which allows penetration.

3. The fiber glass, acoustical insulation is an effective thermal barrier, if not physically dislodged.

4. Flame penetration into the cheek area provides a fire path into the cabin through the floor air return grills.

5. The cabin air temperature at the floor level remains low for a minimum of 4 minutes after pool ignition.

6. Those areas such as the empennage crawlthrough that are not acoustically insulated are more vulnerable to burnthrough than other parts of the insulated fuselage.

7. The cabin sidewall is not thermally stressed as long as the acoustical insulation is intact.

8. The cargo compartment may provide a buffer zone protecting the cabin from burnthrough from underneath the aircraft.

9. The aircraft with its gear extended is more vulnerable to burnthrough from a pool fire than an aircraft resting on its belly.

10. The wings may provide a shielding effect from flames for the fuselage above the wing and the overwing emergency escape hatches.

REFERENCES

1. Geyer, G. B. and Urban, C.H., Evaluation of an Improved Flame Resistant Aircraft Window System, FAA Technical Report No. DOT/FAA/CT-83/10, May 1984.

2. Geyer, G. B., Effect of Ground Crash Fire On Aircraft Fuselage Integrity, FAA Technical Report No. NA-69-37, December 1969.

APPENDIX A

DC-8 TEST 1 AFT SECTION

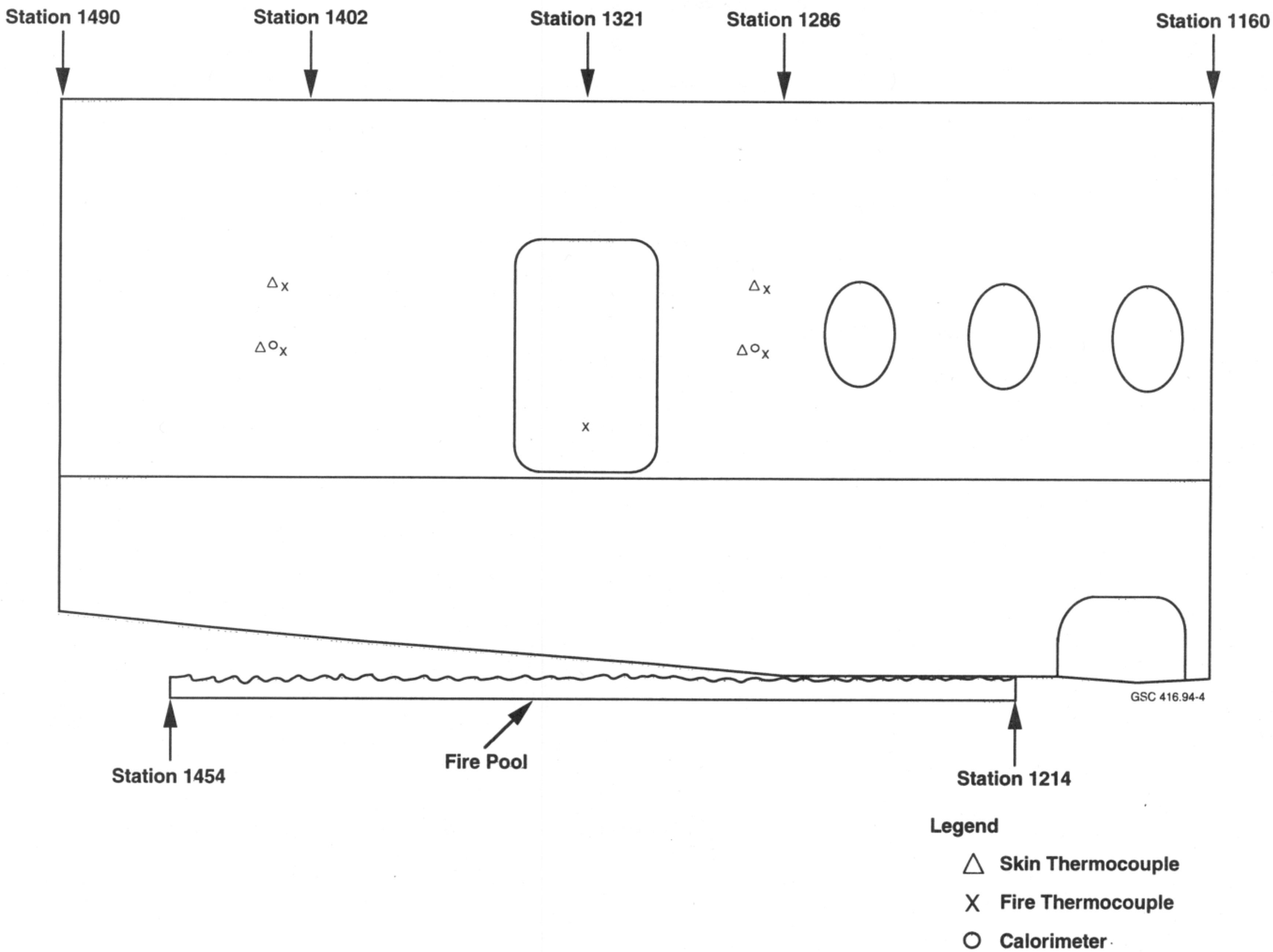

FIGURE A-1. TEST 1 DC-8 INSTRUMENTATION LOCATIONS

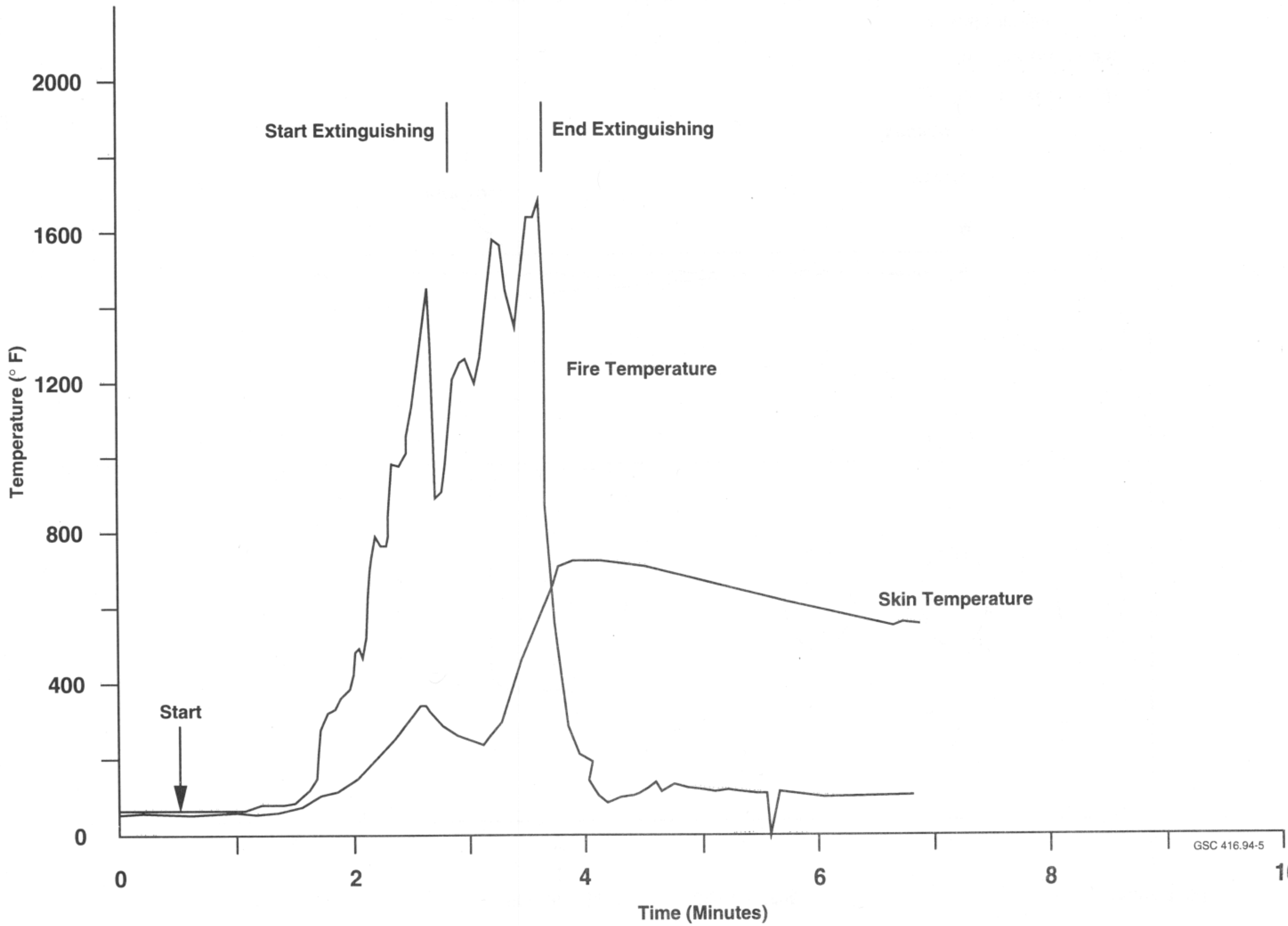

FIGURE A-2. TEST 1 FIRE AND FUSELAGE SKIN TEMPERTURES (UPPER) AT STATION 1286

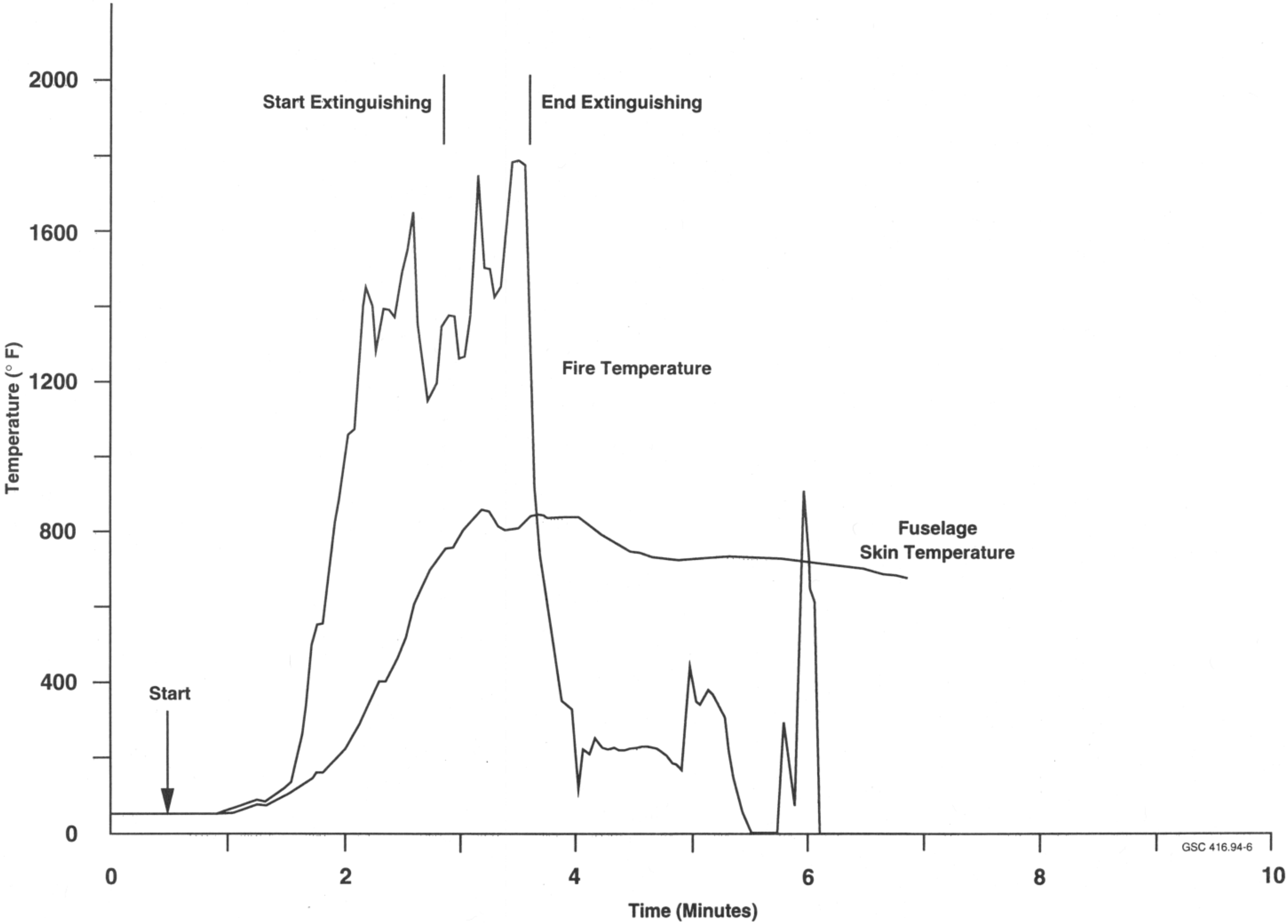

FIGURE A-3. TEST 1 FIRE AND FUSELAGE SKIN TEMPERATURES (MIDDLE) AT STATION 1286

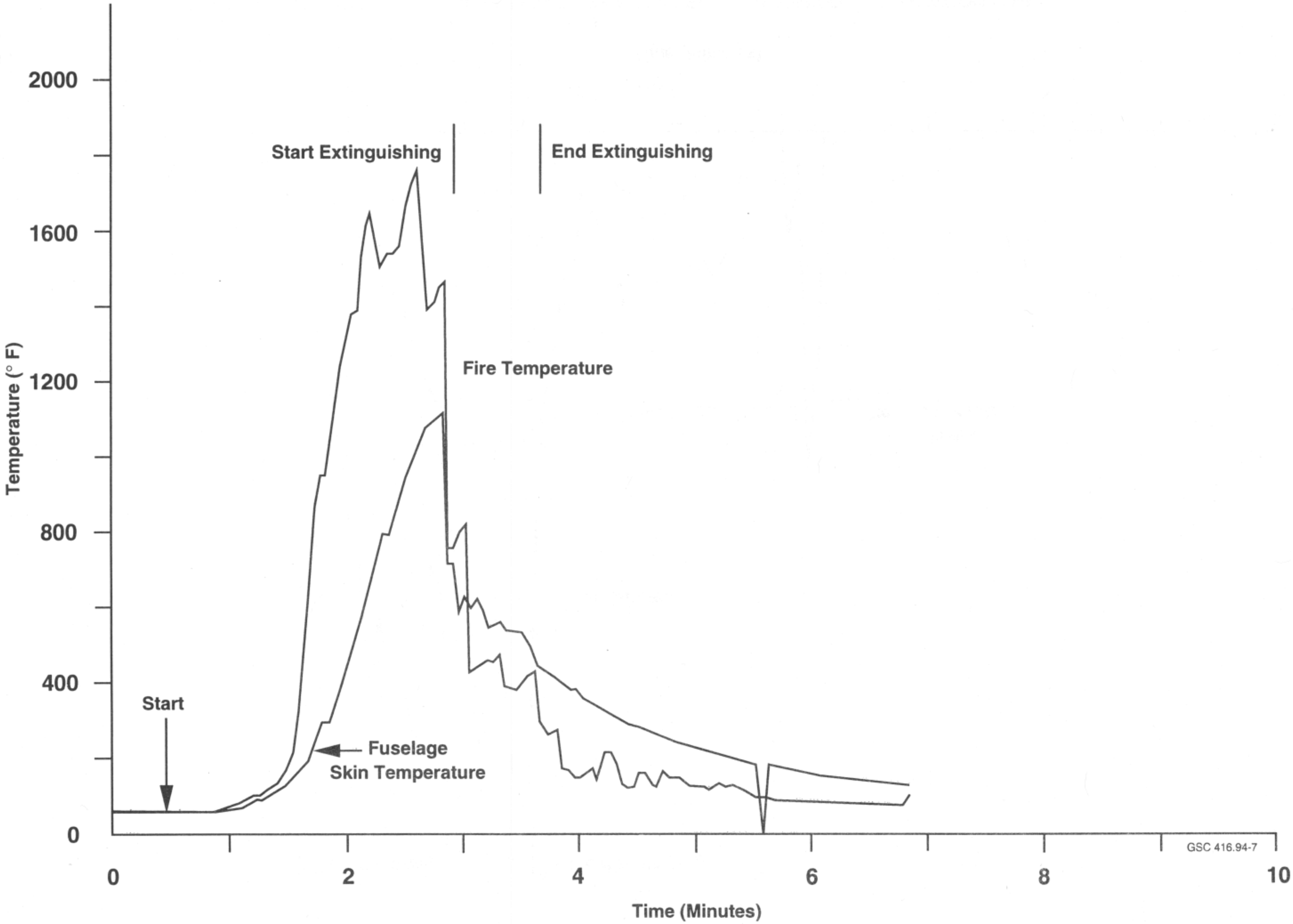

FIGURE A-4. TEST 1 FIRE AND FUSELAGE SKIN TEMPERATURES (LOWER) AT STATION 1286

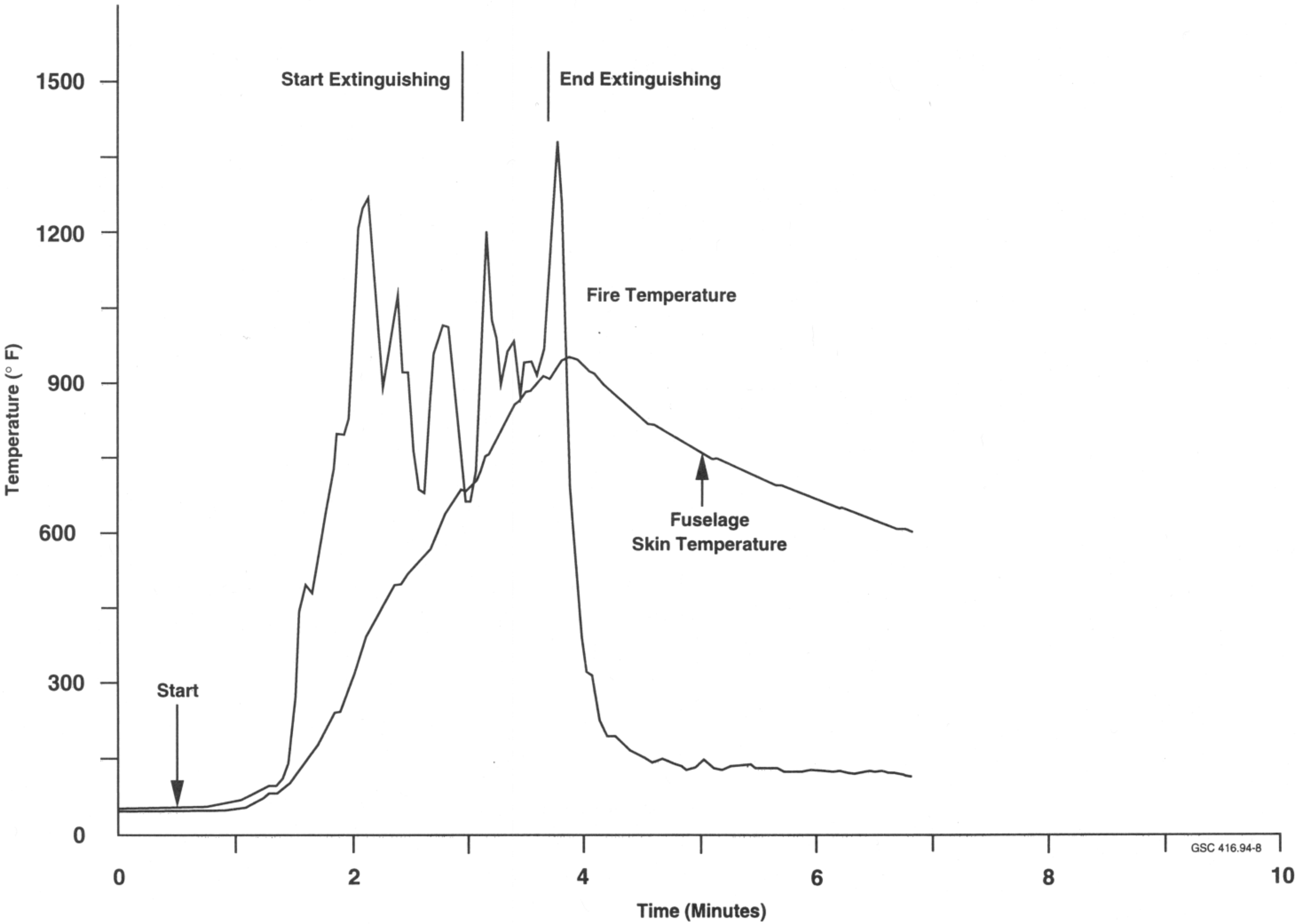

FIGURE A-5. TEST 1 FIRE AND FUSELAGE SKIN TEMPERATURES (UPPER) AT STATION 1402

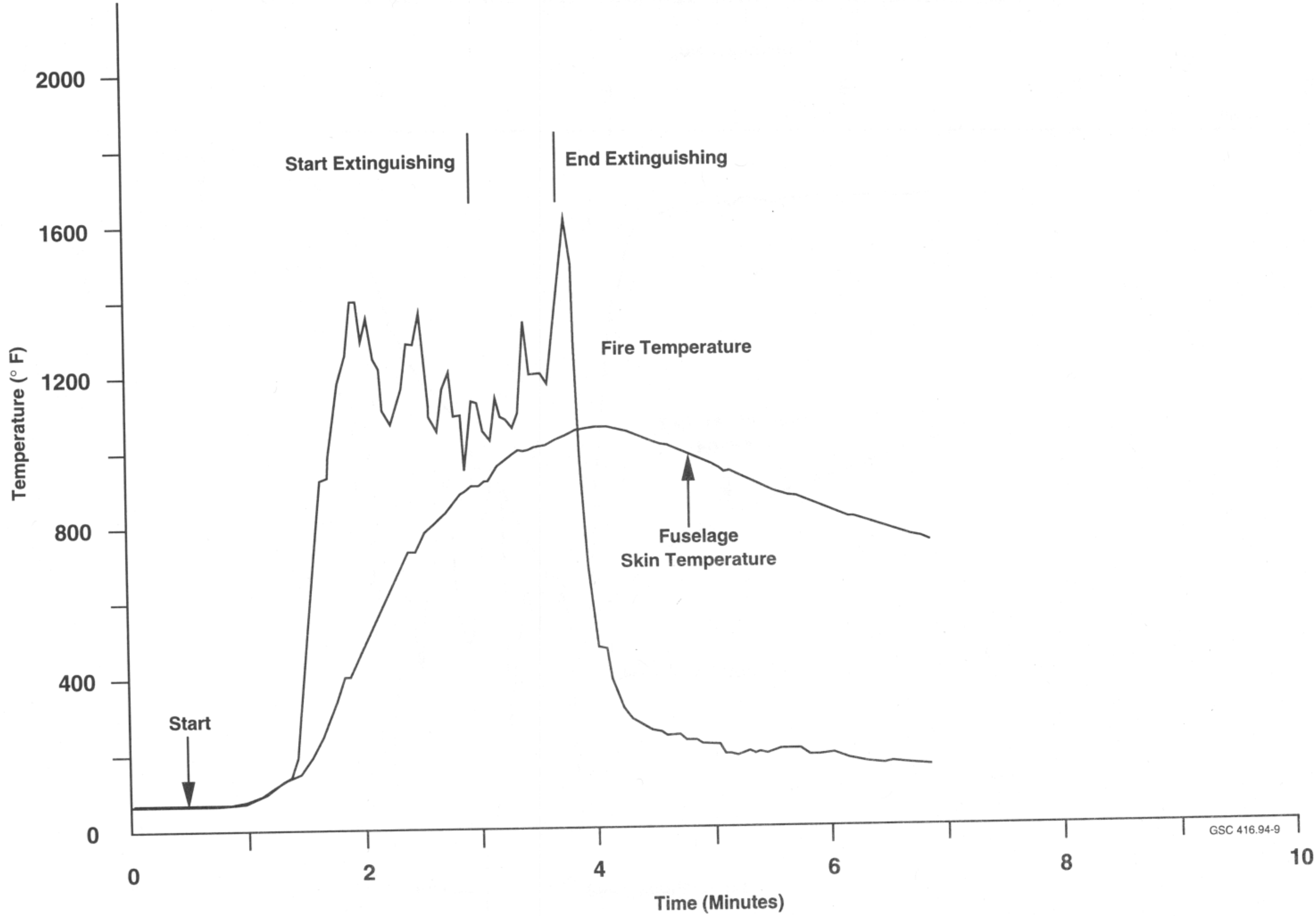

FIGURE A-6. TEST 1 FIRE AND FUSELAGE SKIN TEMPERATURES (MIDDLE) AT STATION 1402

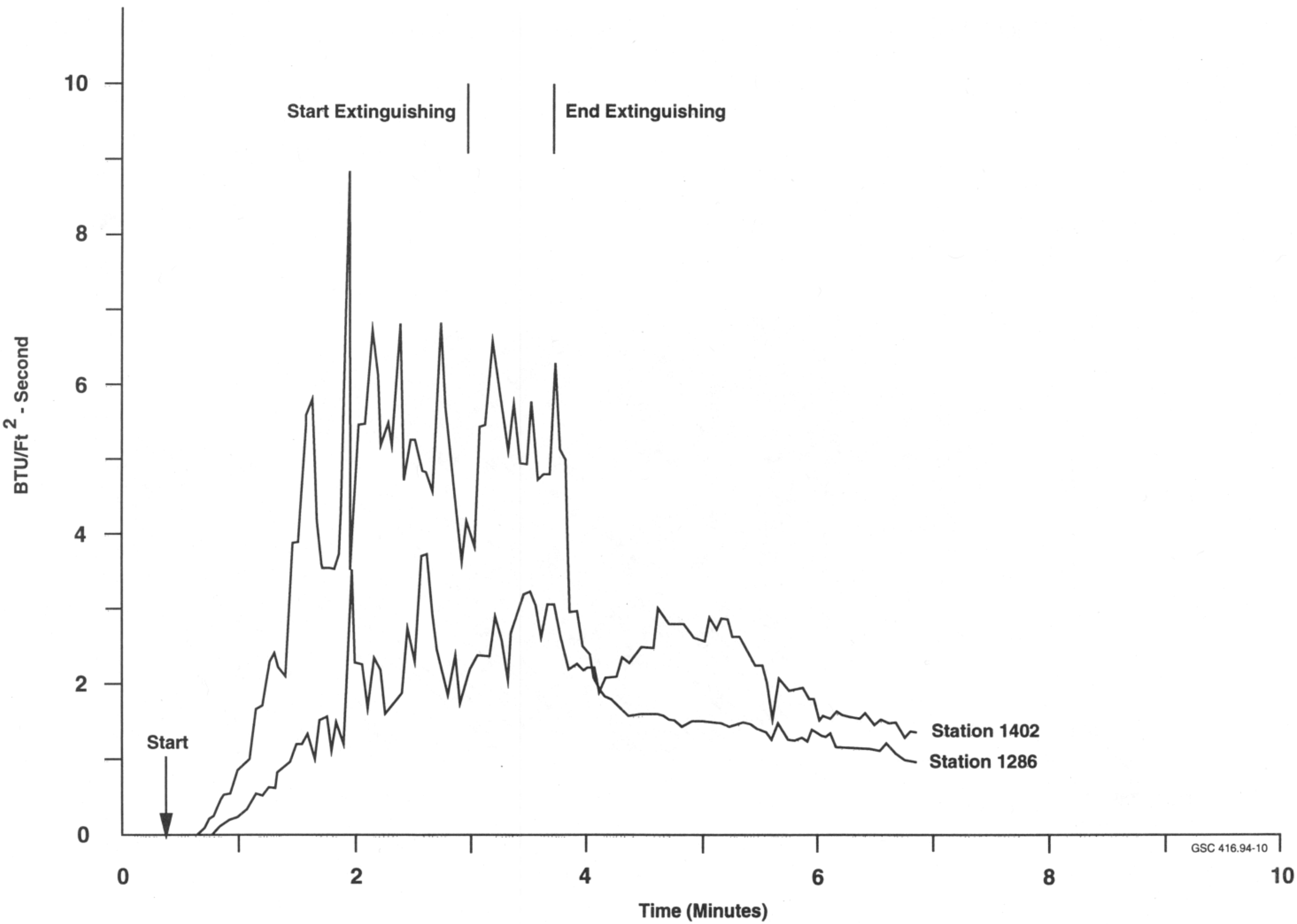

FIGURE A-7. TEST 1 EXTERIOR HEAT FLUX AT STATIONS 1402 AND 1286

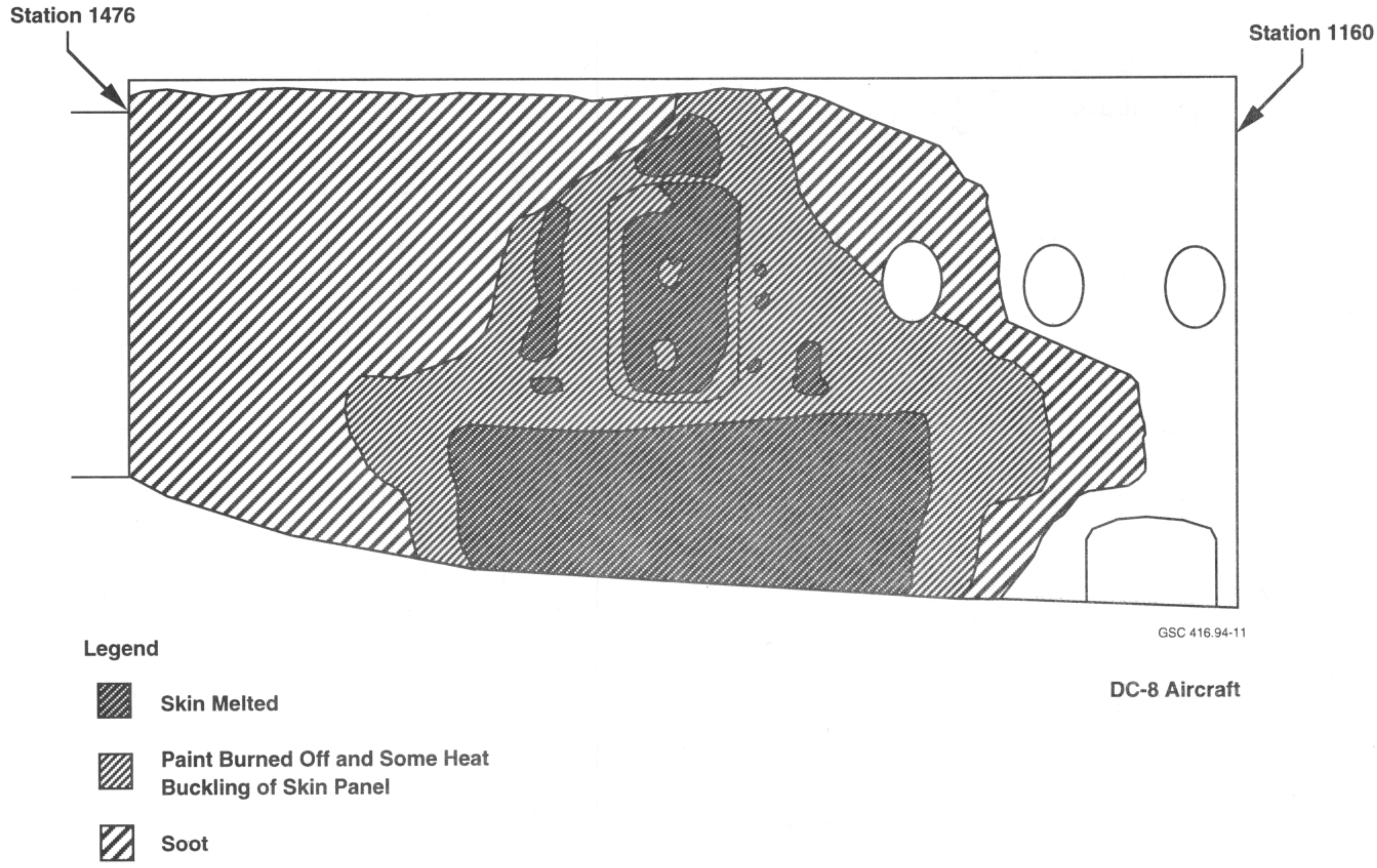

FIGURE A-8. TEST 1 EXTERIOR FIRE DAMAGE, AFT SECTION FUSELAGE STARBOARD SIDE

APPENDIX B

DC-8 TEST 2 NOSE SECTION

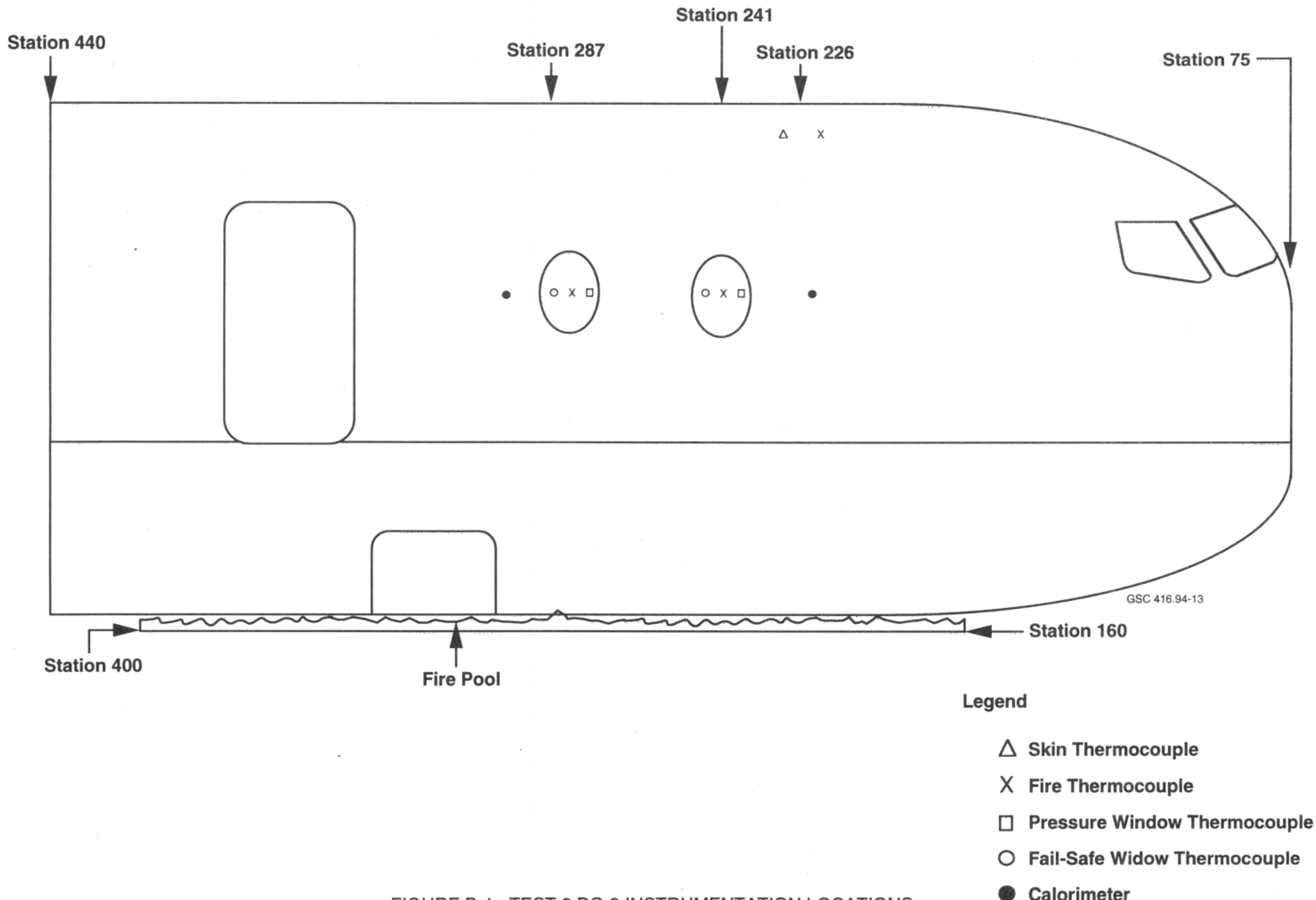

FIGURE B-1. TEST 2 DC-8 INSTRUMENTATION LOCATIONS

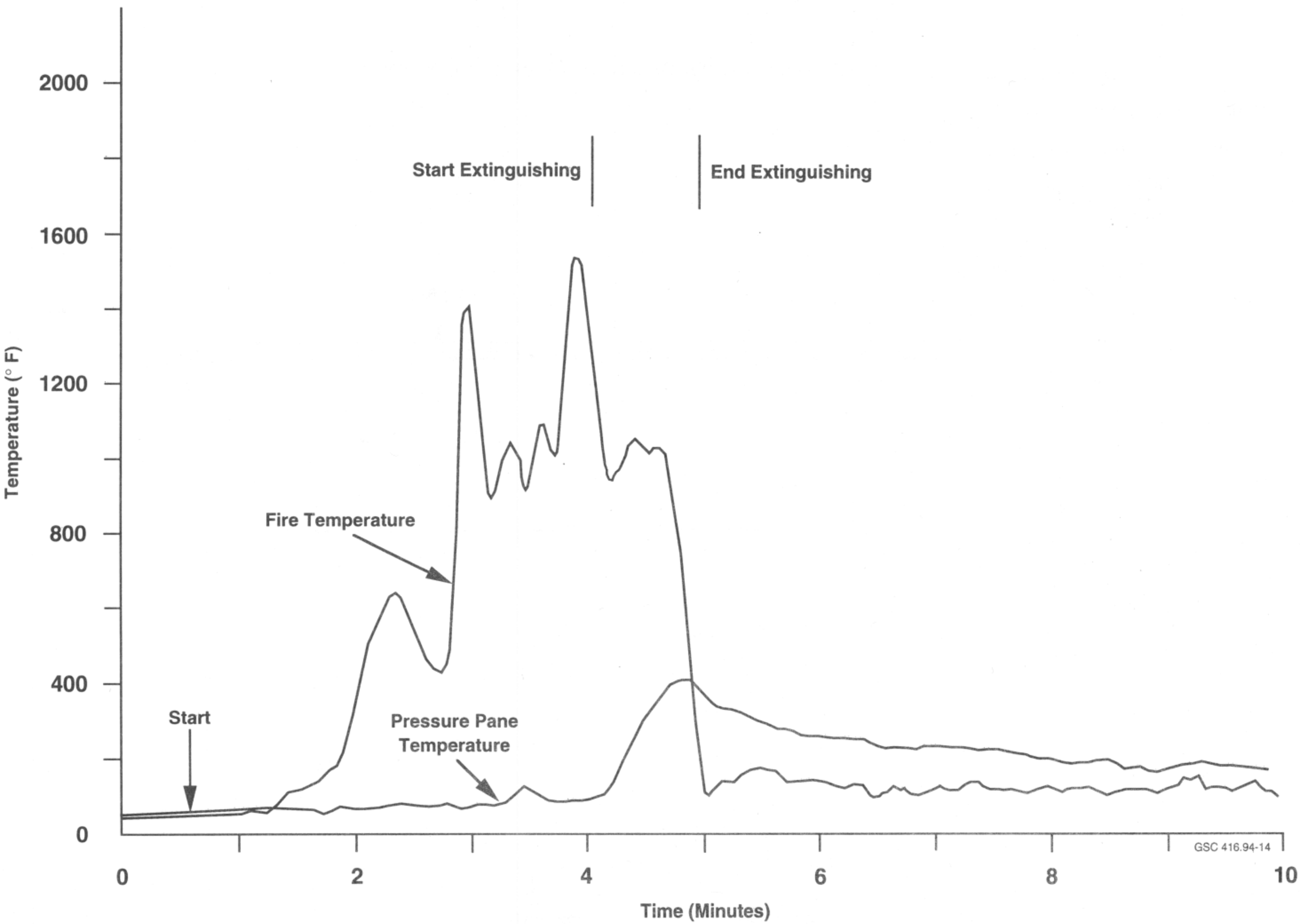

FIGURE B-2. TEST 2 WINDOW TEMPERATURES AT STATION 287

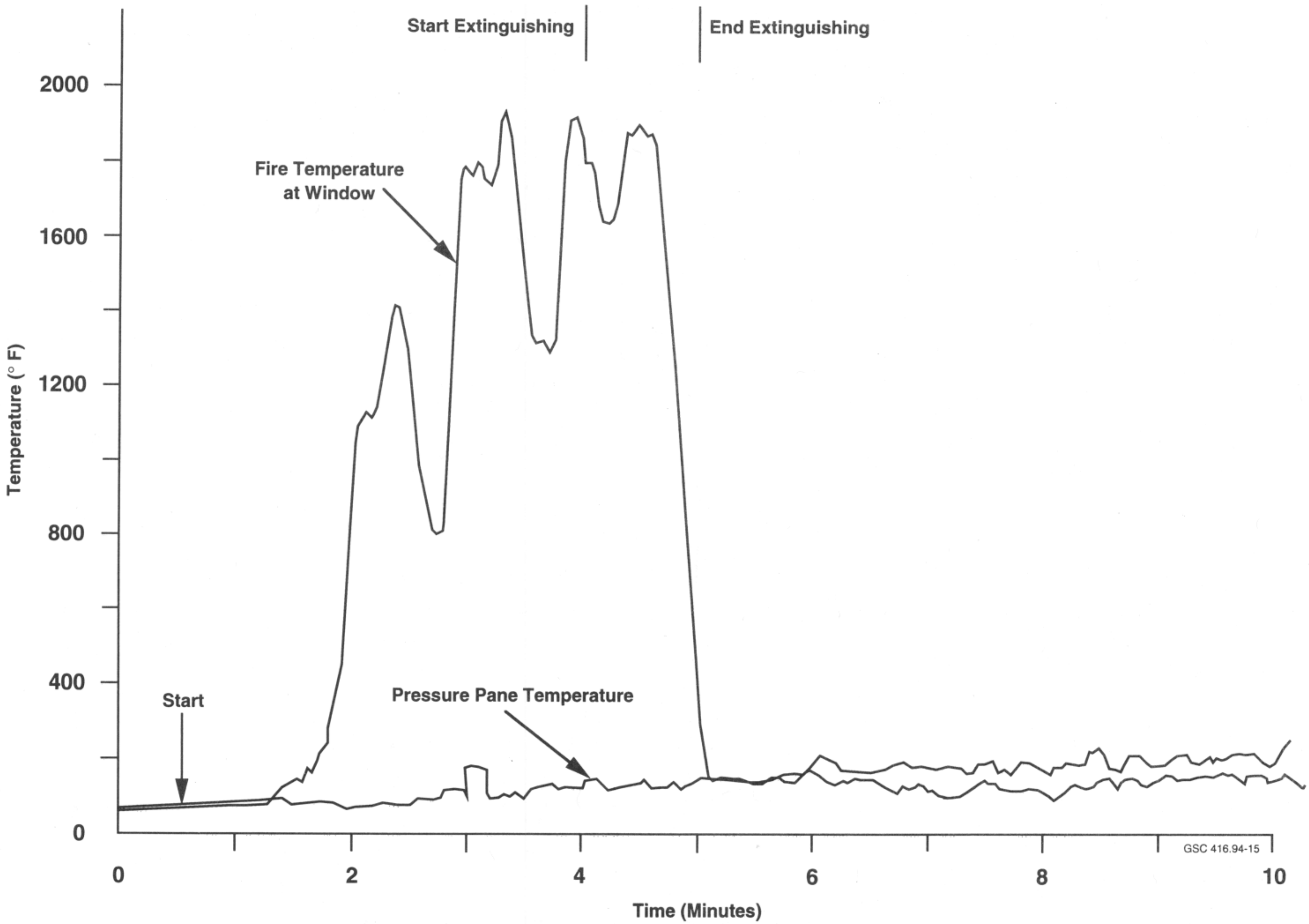

FIGURE B-3. TEST 2 WINDOW TEMPERATURES AT STATION 241

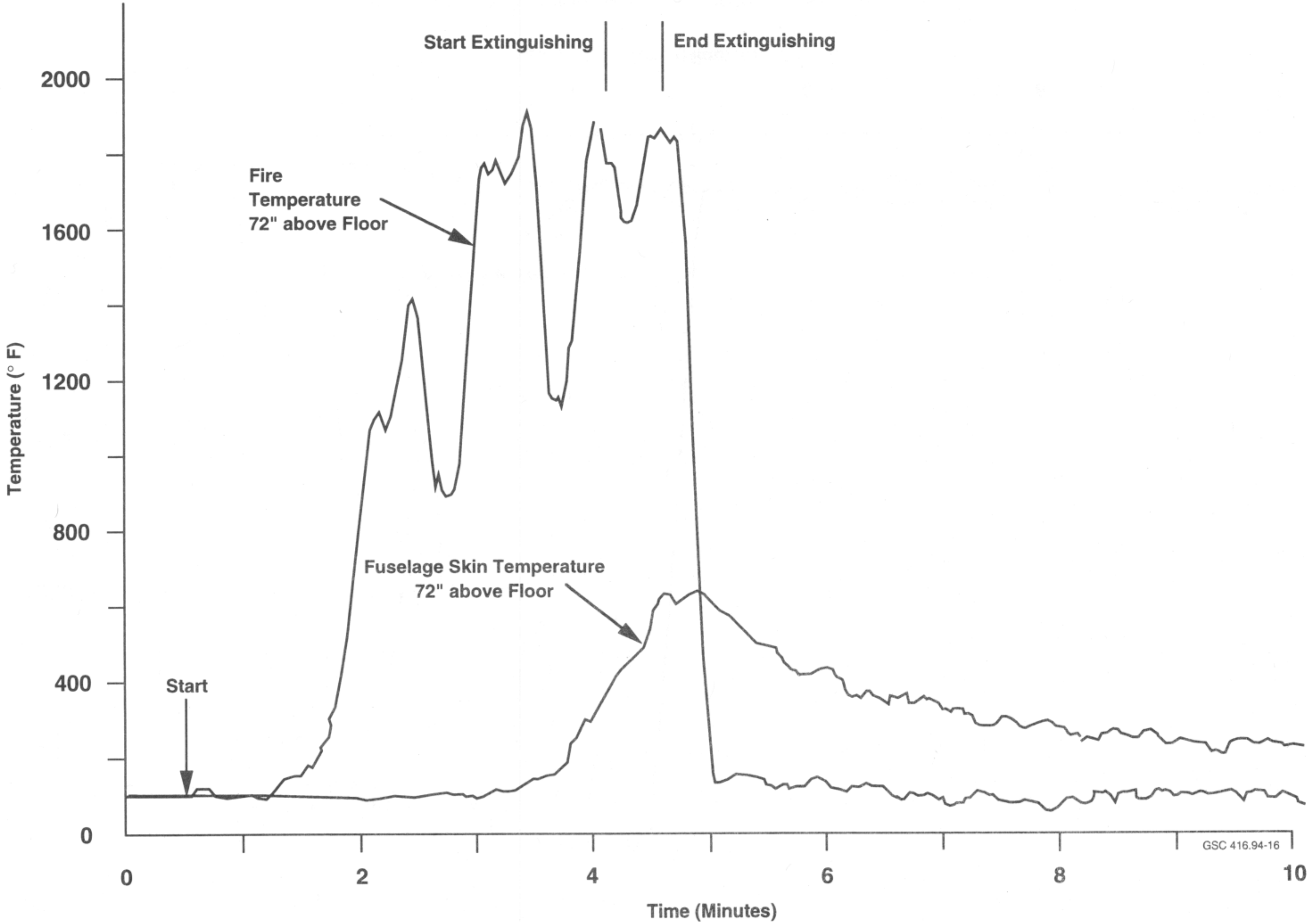

FIGURE B-4. TEST 2 FIRE AND FUSELAGE SKIN TEMPERATURES AT STATION 226

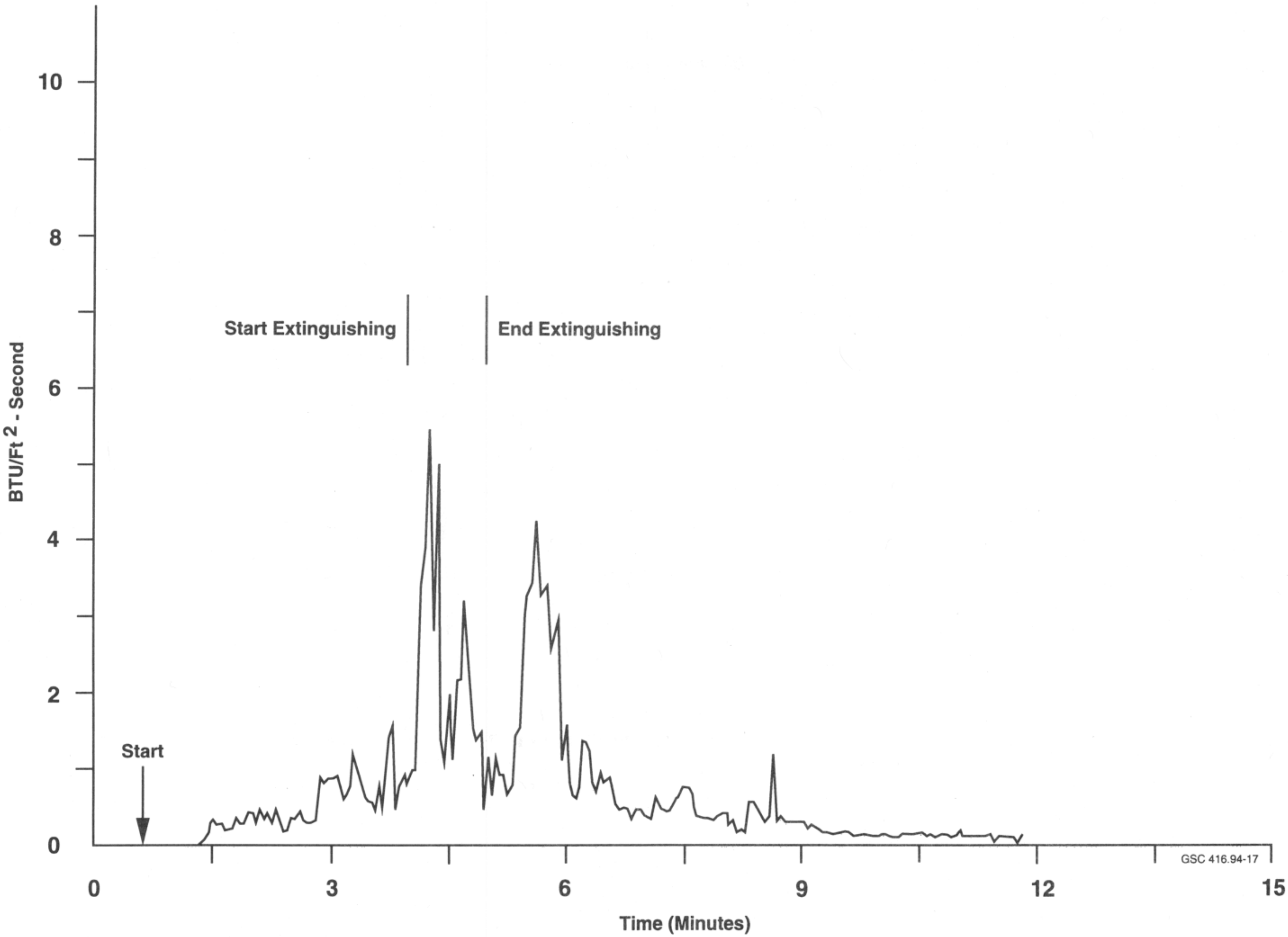

FIGURE B-5. TEST 2 EXTERNAL HEAT FLUX AT STATION 228

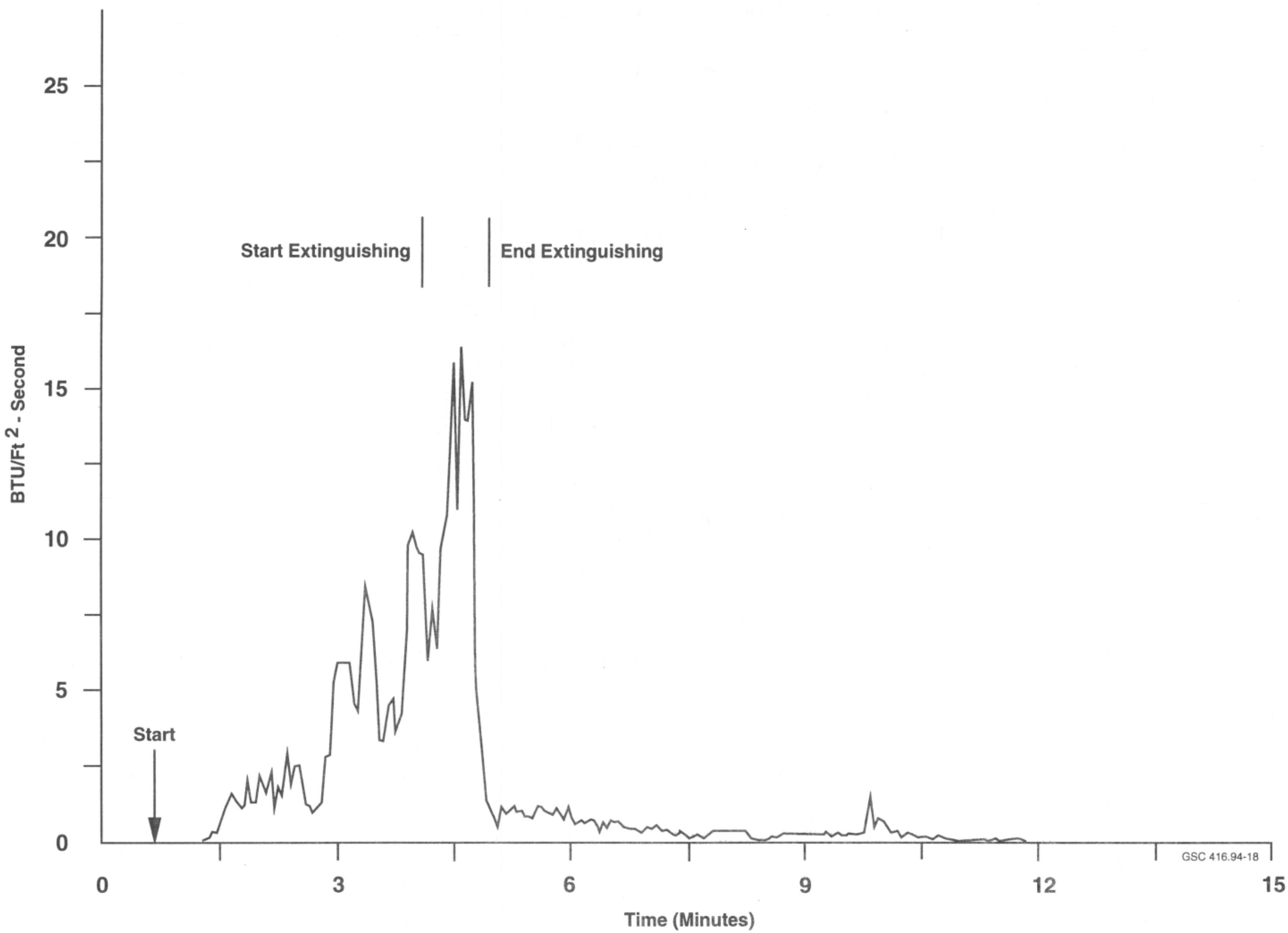

FIGURE B-6. TEST 2 EXTERNAL HEAT FLUX AT STATION 297

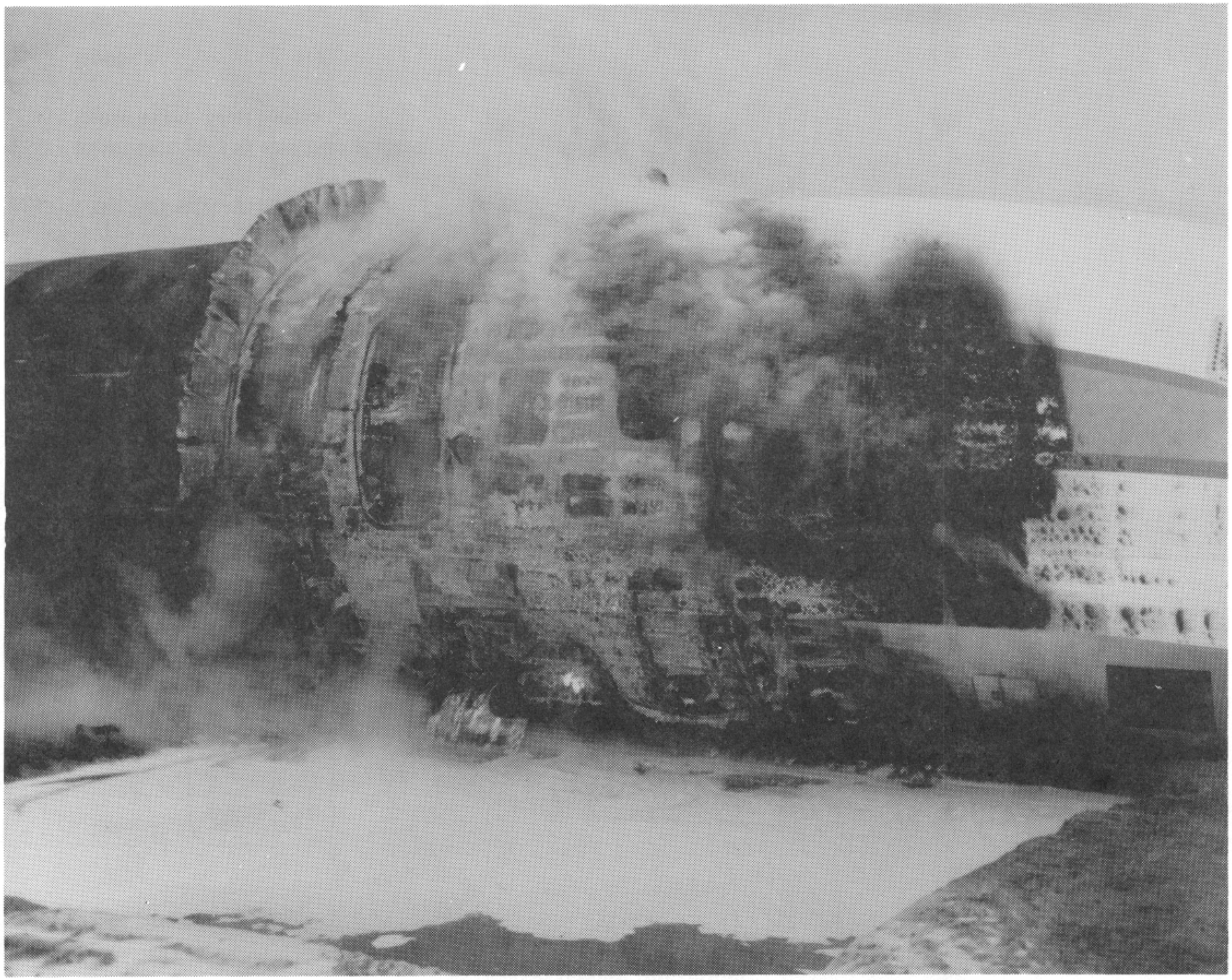

FIGURE B-7. TEST 2 EXTERNAL FIRE DAMAGE, DC-8 FORWARD SECTION

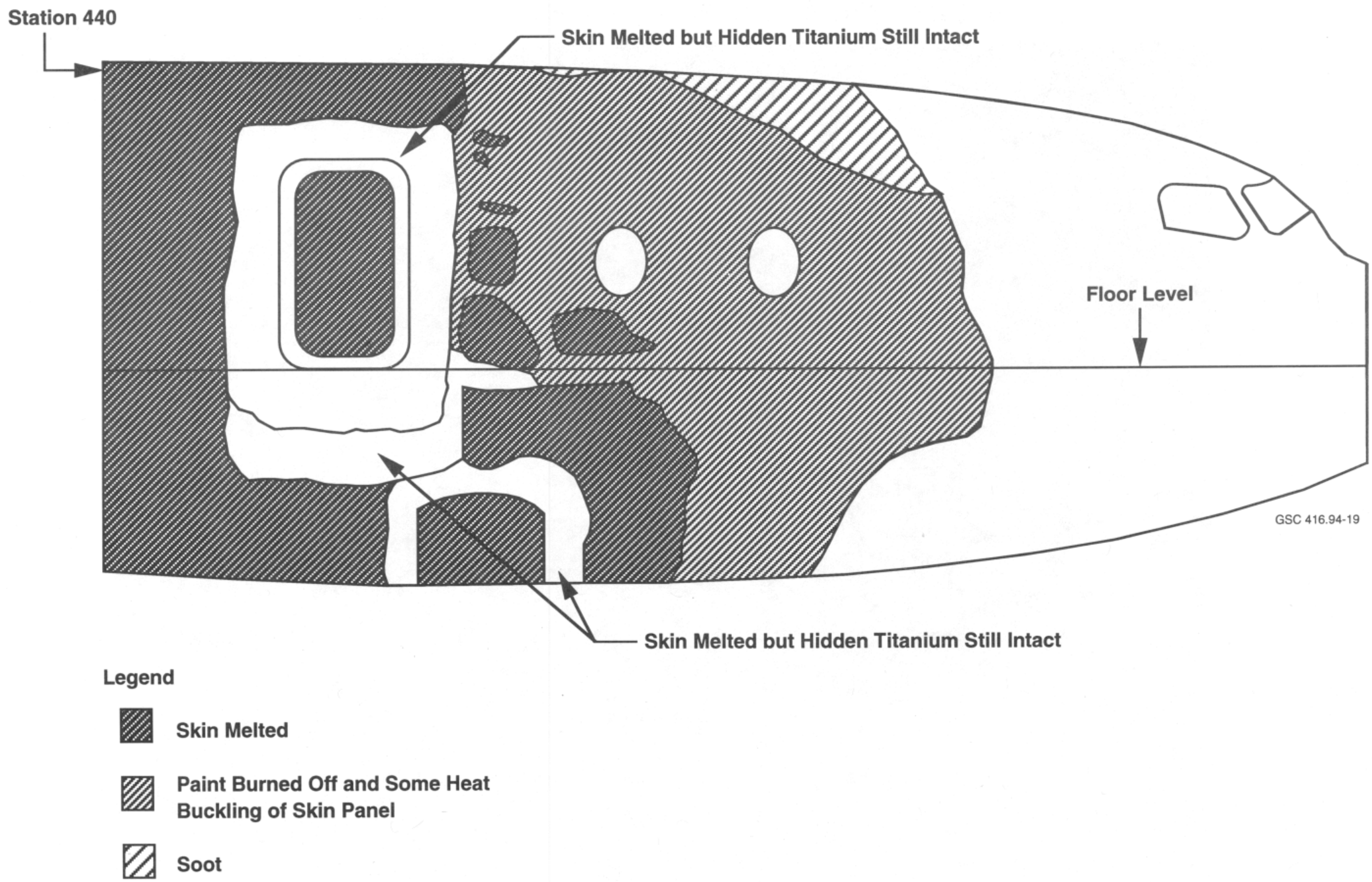

FIGURE B-8. TEST 2 EXTERIOR FIRE DAMAGE DIAGRAM, FOREWARD FUSELAGE STARBOARD SIDE

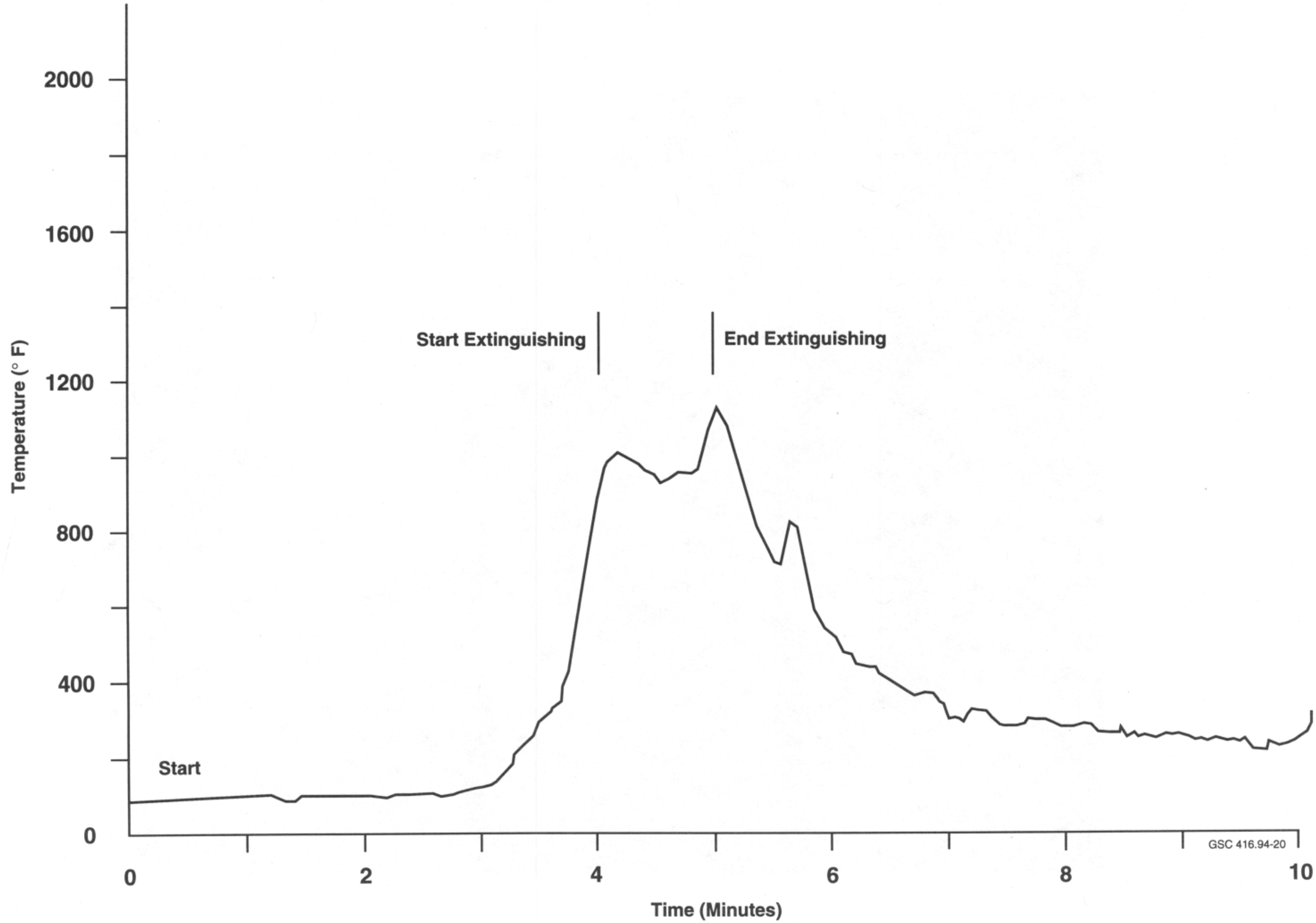

FIGURE B-9. TEST 2 AIR TEMPERATURE BETWEEN CABIN FLOOR AND THE CARGO COMPARTMENT AT STATION 270

FIGURE B-10. TEST 2 CABIN INTERIOR STARBOARD SIDE SERVICE DOOR

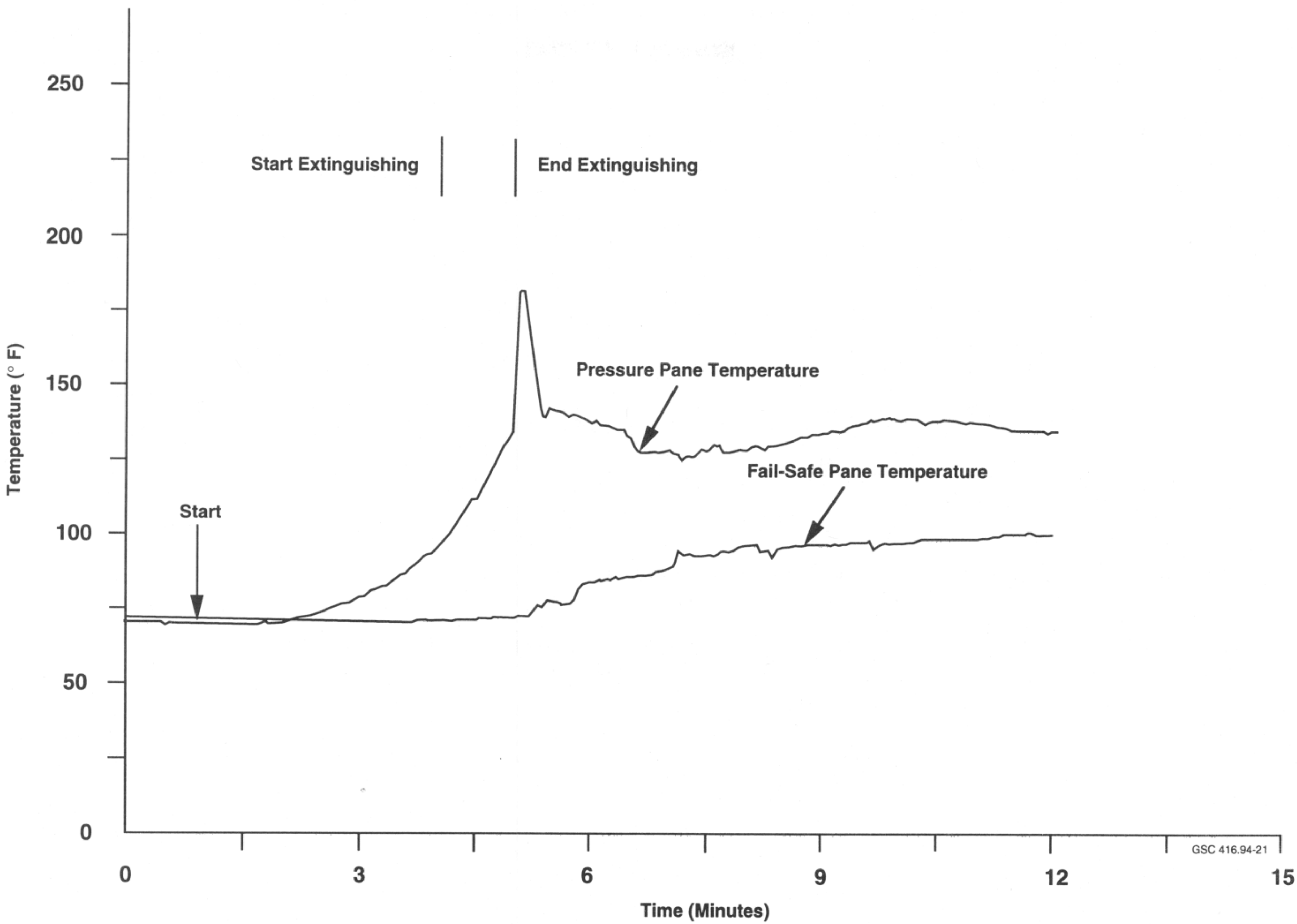

FIGURE B-11. TEST 2 WINDOWPANE TEMPERATURES AT STATION 241

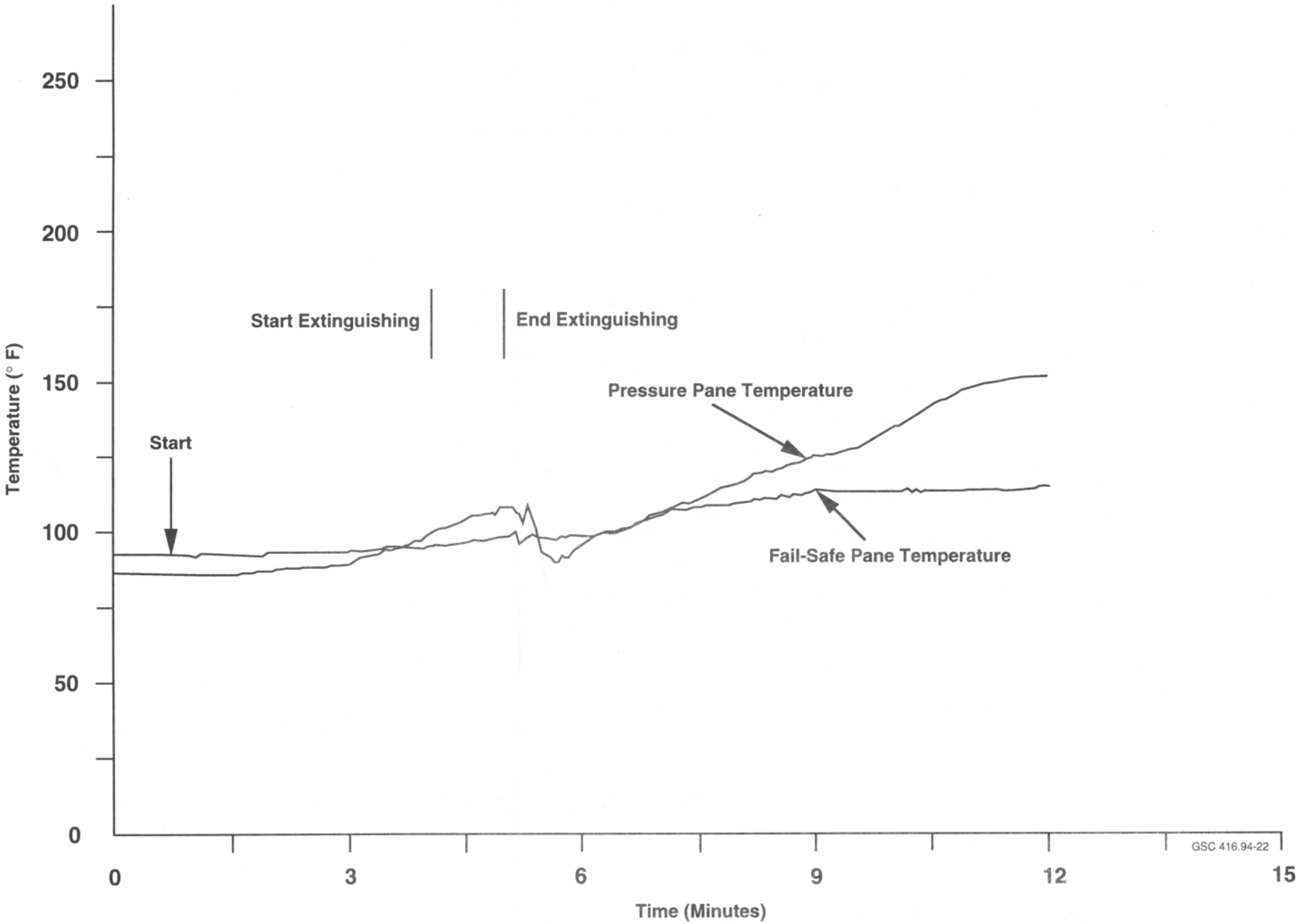

FIGURE B-12. TEST 2 WINDOWPANE TEMPERATURES AT STATION 287

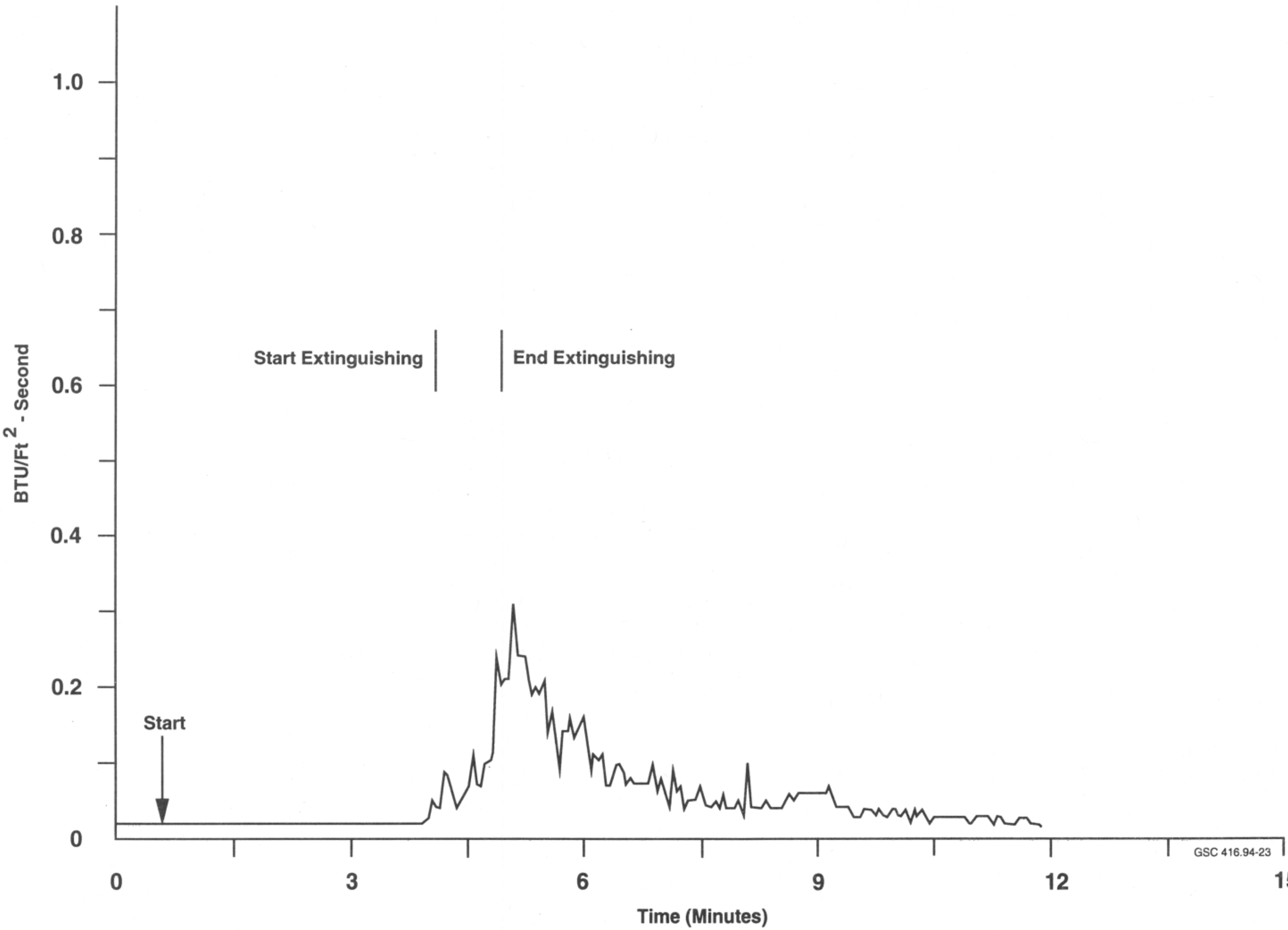

FIGURE B-13. TEST 2 HEAT FLUX TRANSMITTED THROUGH CABIN WINDOW AT STATION 241

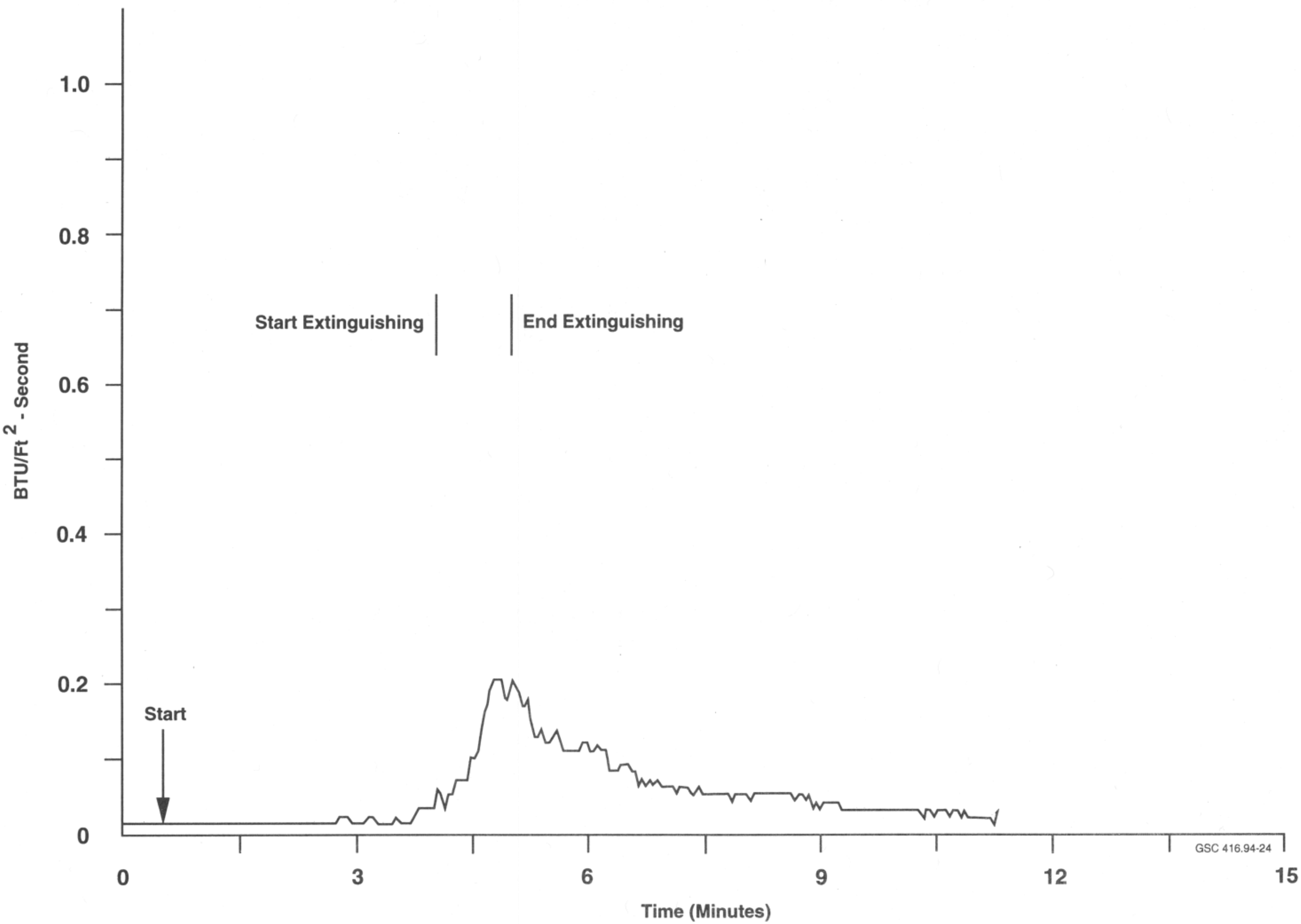

FIGURE B-14. TEST 2 HEAT FLUX TRANSMITTED THROUGH CABIN WINDOW AT STATION 287

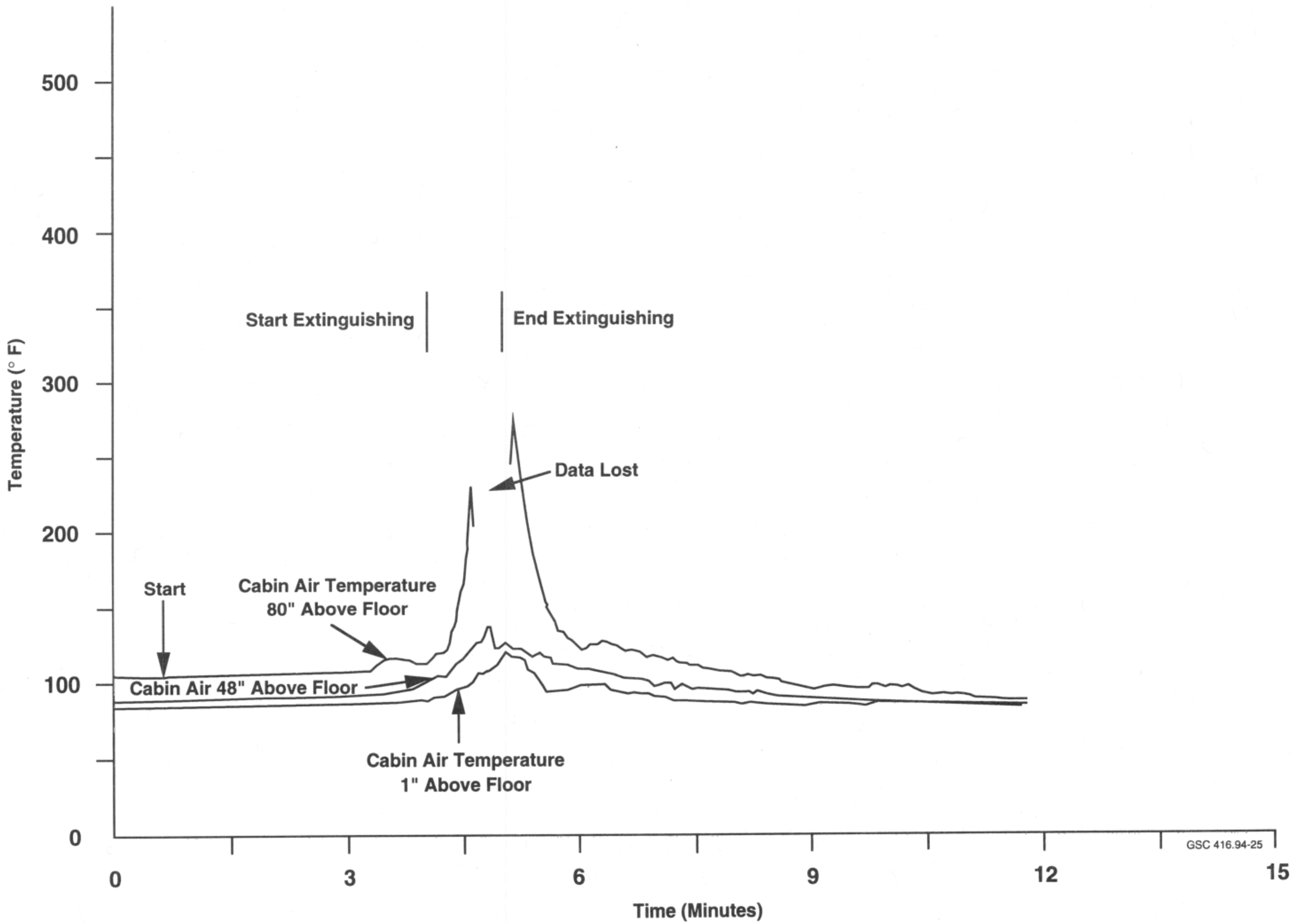

FIGURE B-15. TEST 2 CABIN AIR TEMPERATURES AT STATION 296

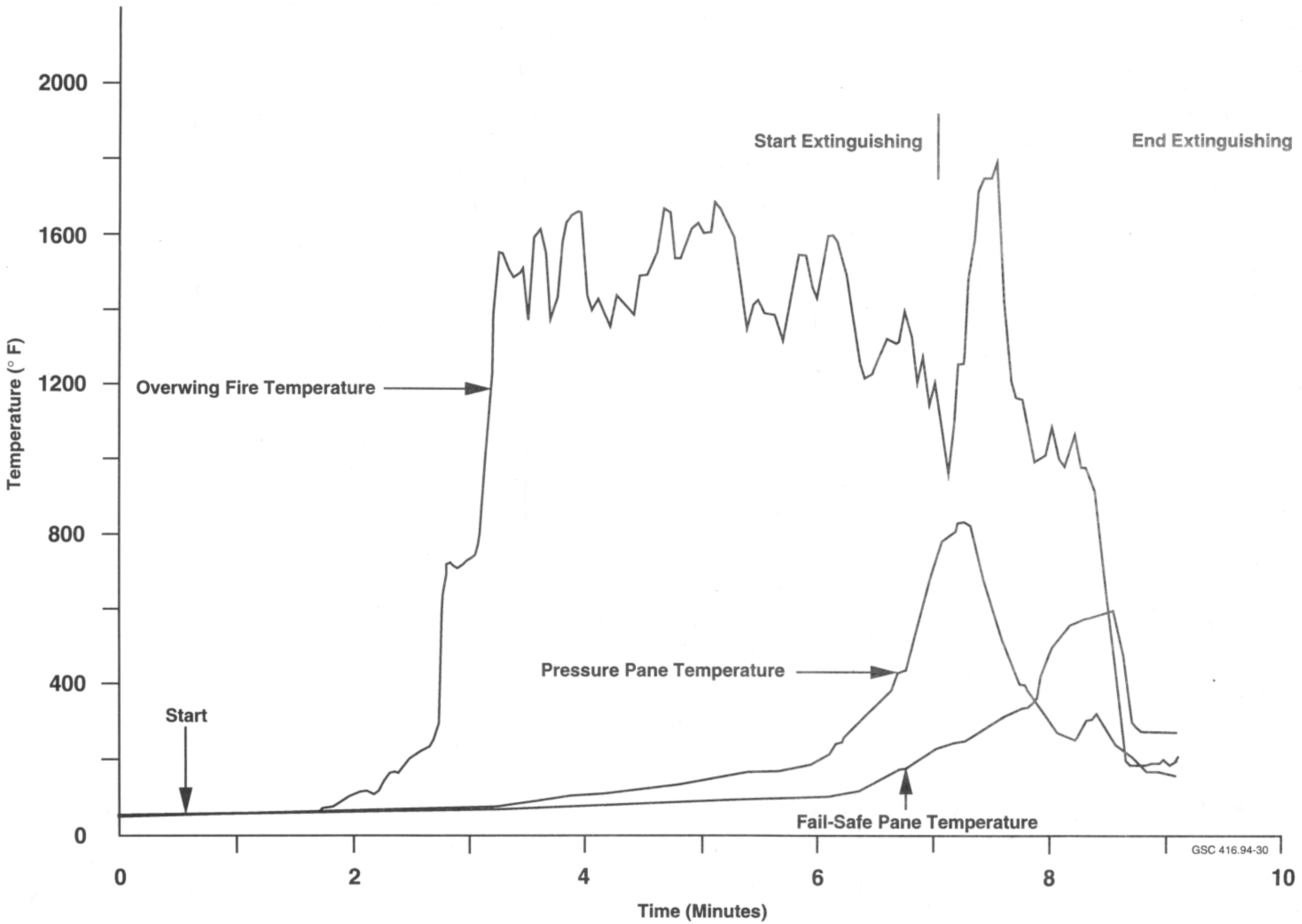

FIGURE C-5. TEST 3 EMERGENCY EXIT ESCAPE HATCH TEMPERATURES AT STATION 693

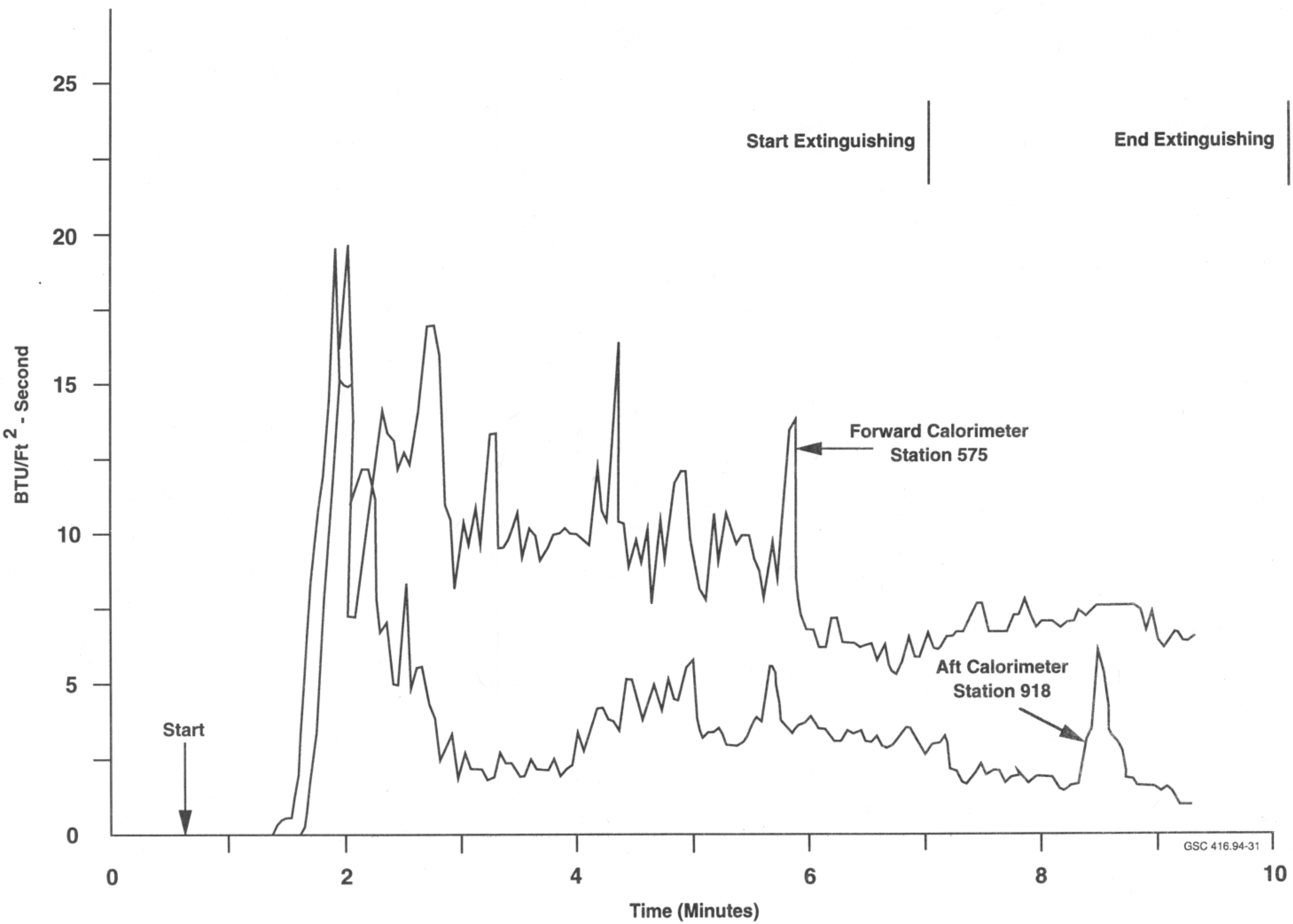

FIGURE C-6. TEST 3 EXTERNAL HEAT FLUX AT STATIONS 575 AND 918

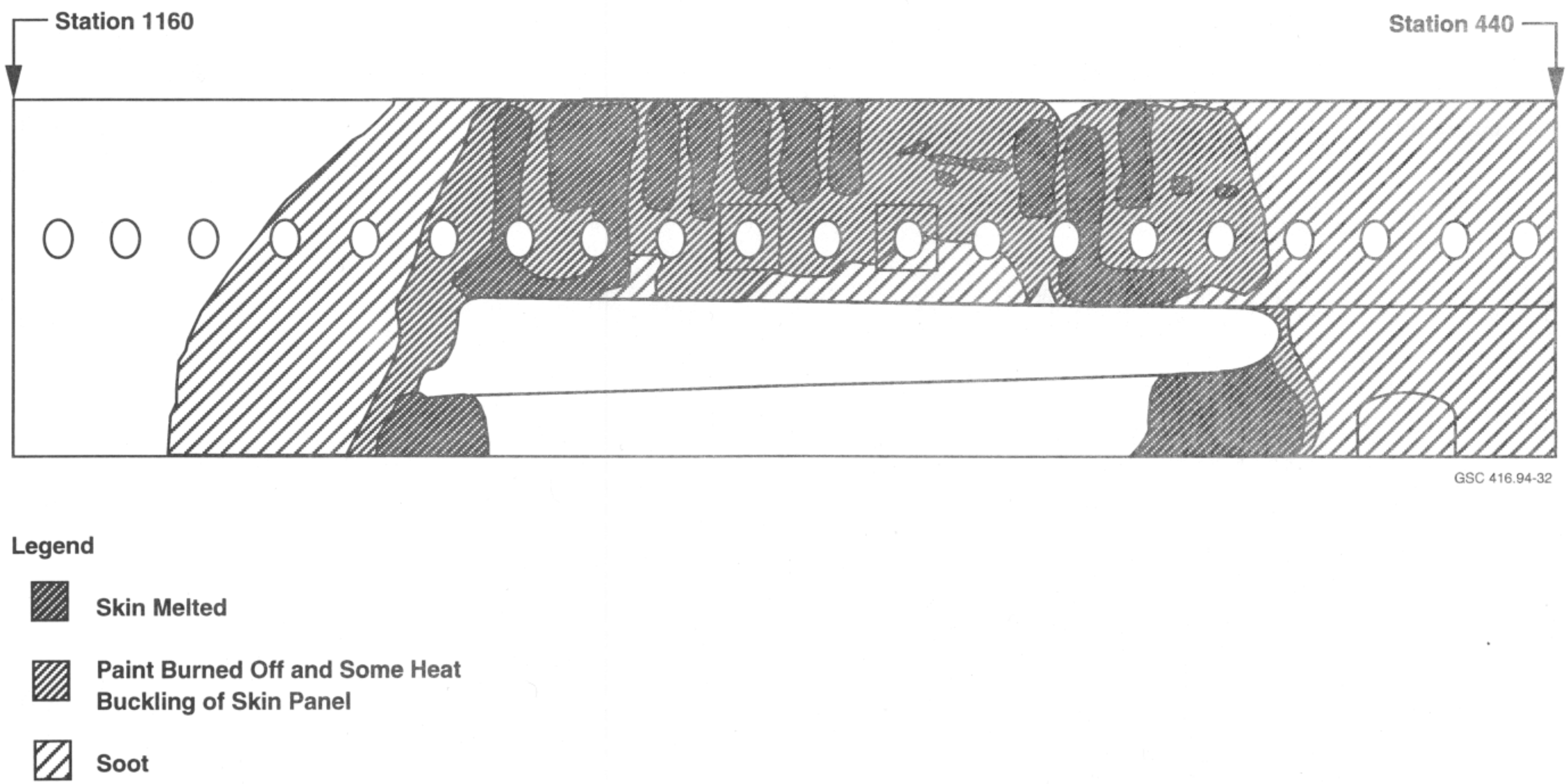

FIGURE C-7. TEST 3 EXTERIOR FIRE DAMAGE, CENTER SECTION FUSELAGE STARBOARD SIDE

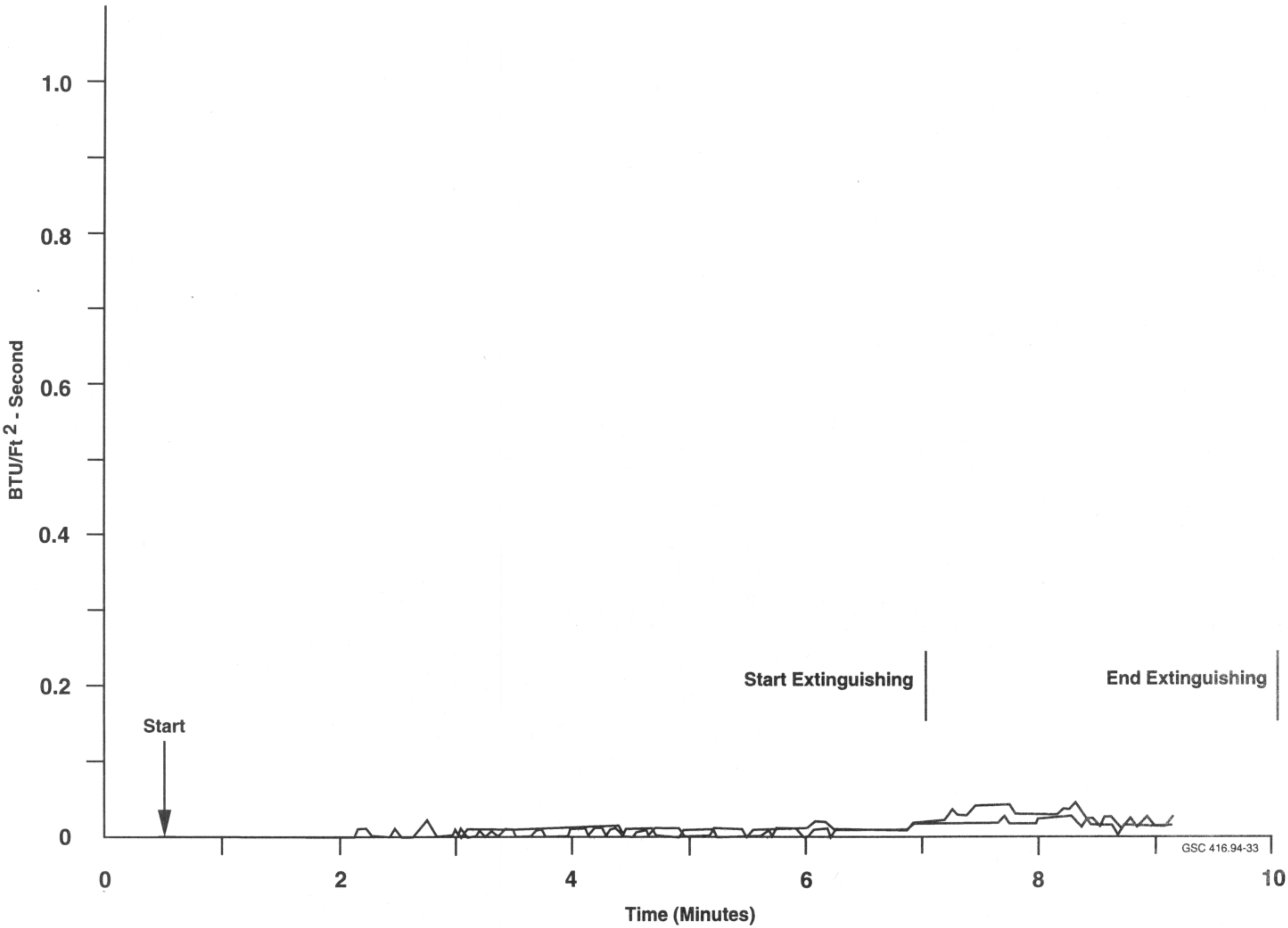

FIGURE C-8. TEST 3 HEAT FLUX TRANSMITTED THROUGH EMERGENCY EXIT WINDOWS AT STATIONS 693 AND 775

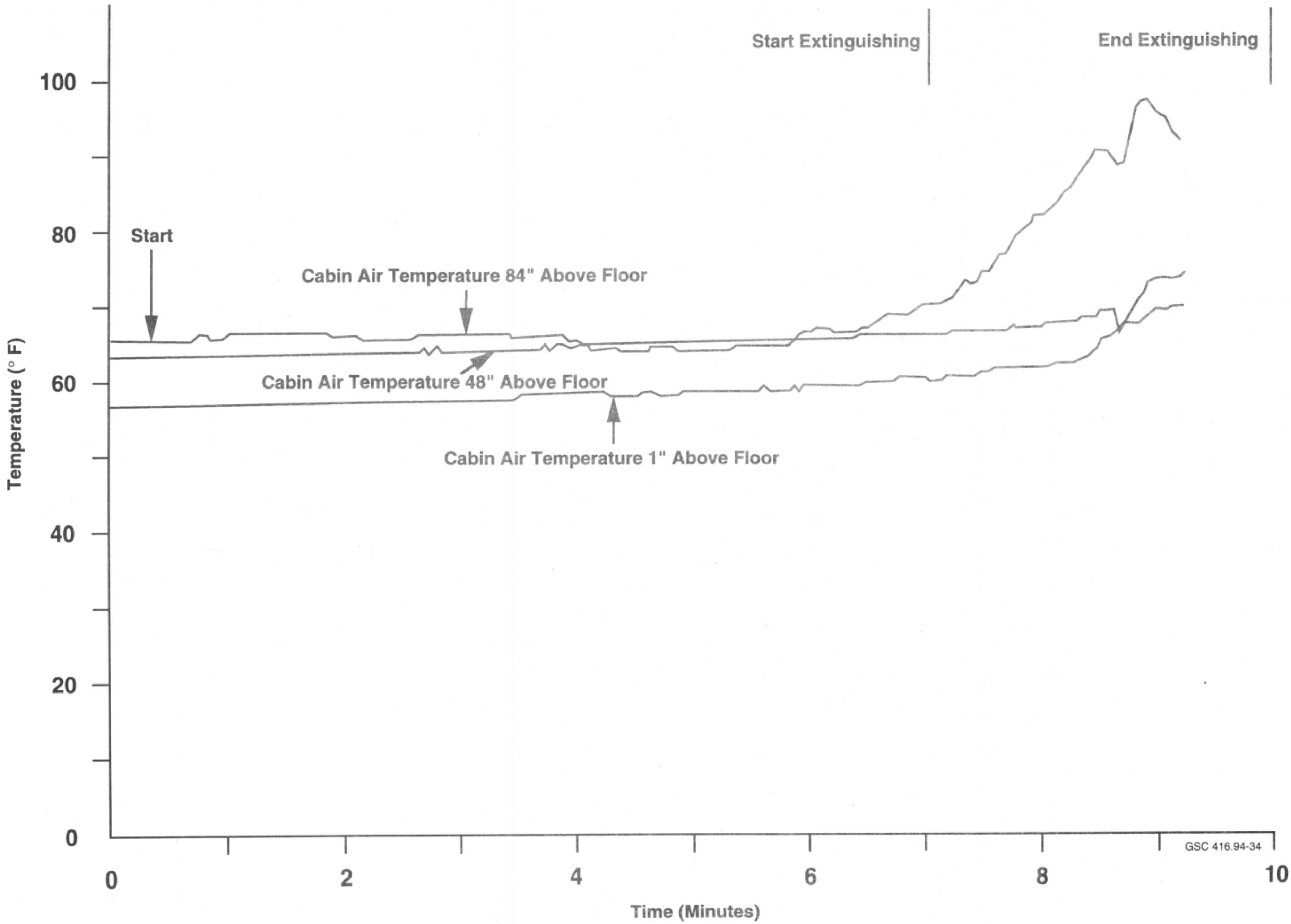

FIGURE C-9. TEST 3 CABIN AIR TEMPERATURES AT STATION 586

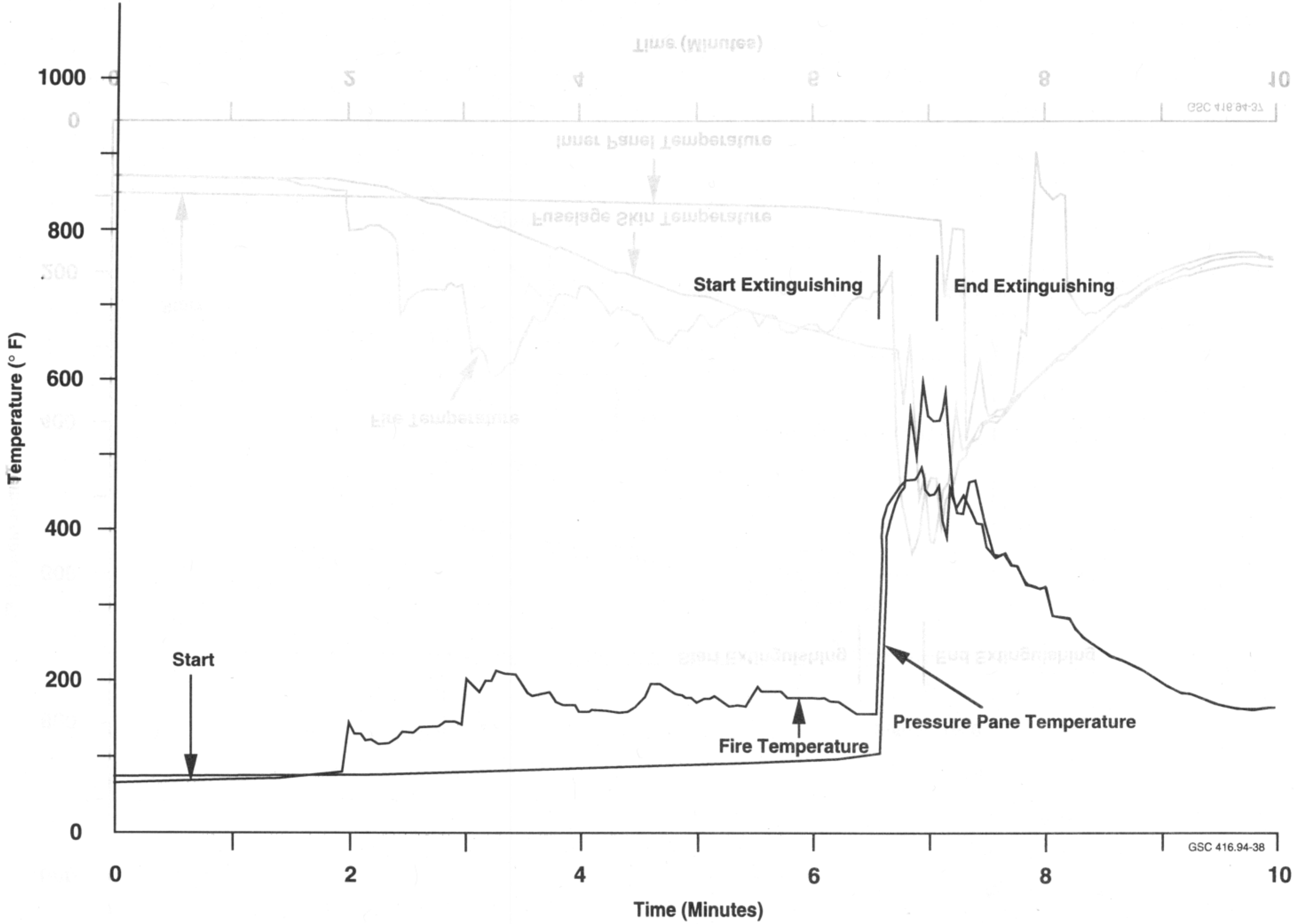

FIGURE D-4. TEST 4 EXTERNAL FIRE AND WINDOW PRESSURE PANE TEMPERATURES STARBOARD SIDE AT STATION 1184

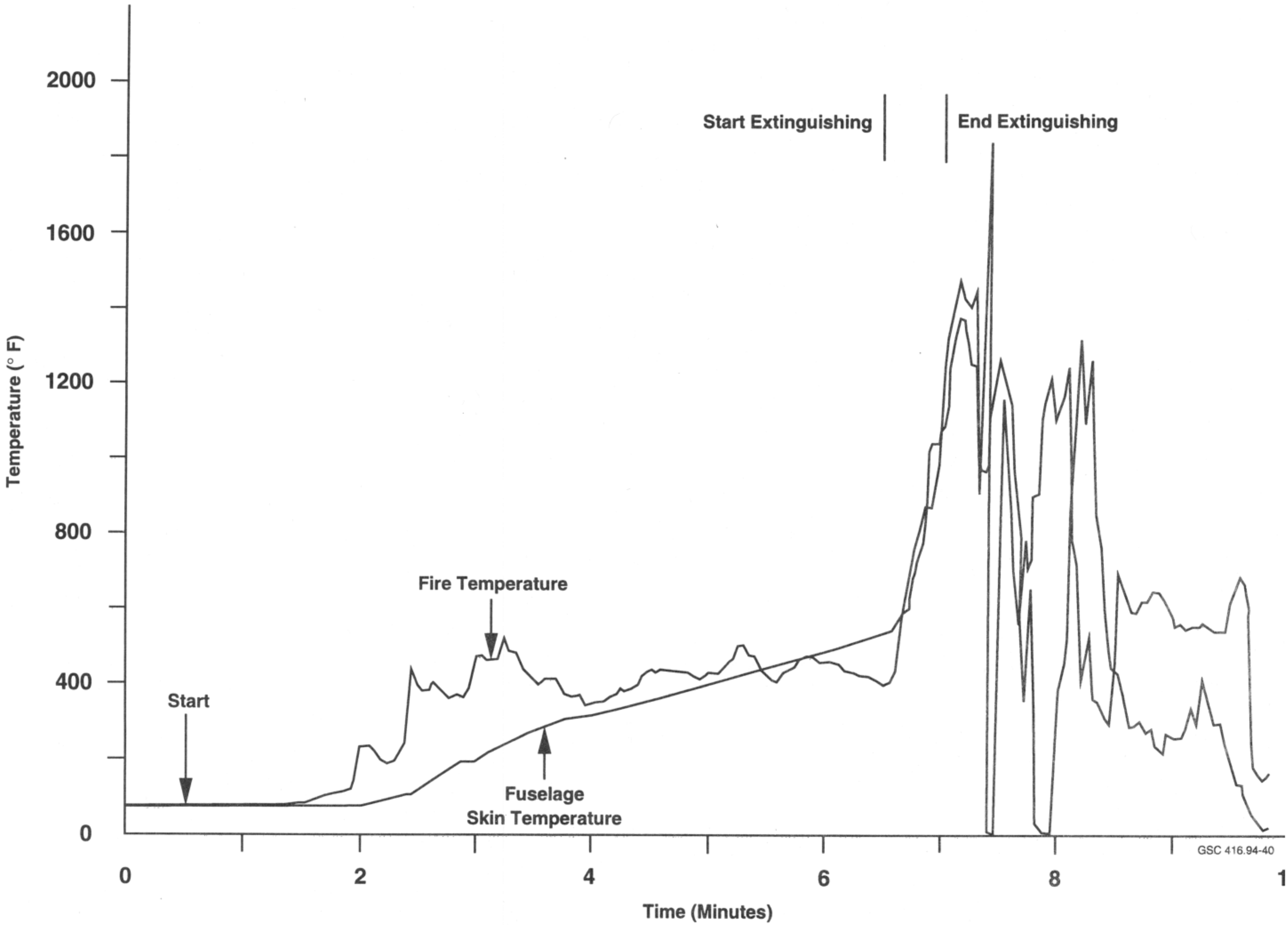

FIGURE D-6. TEST 4 FIRE AND FUSELAGE SKIN TEMPERATURES, STARBOARD SIDE (LOWER) AT STATION 1177

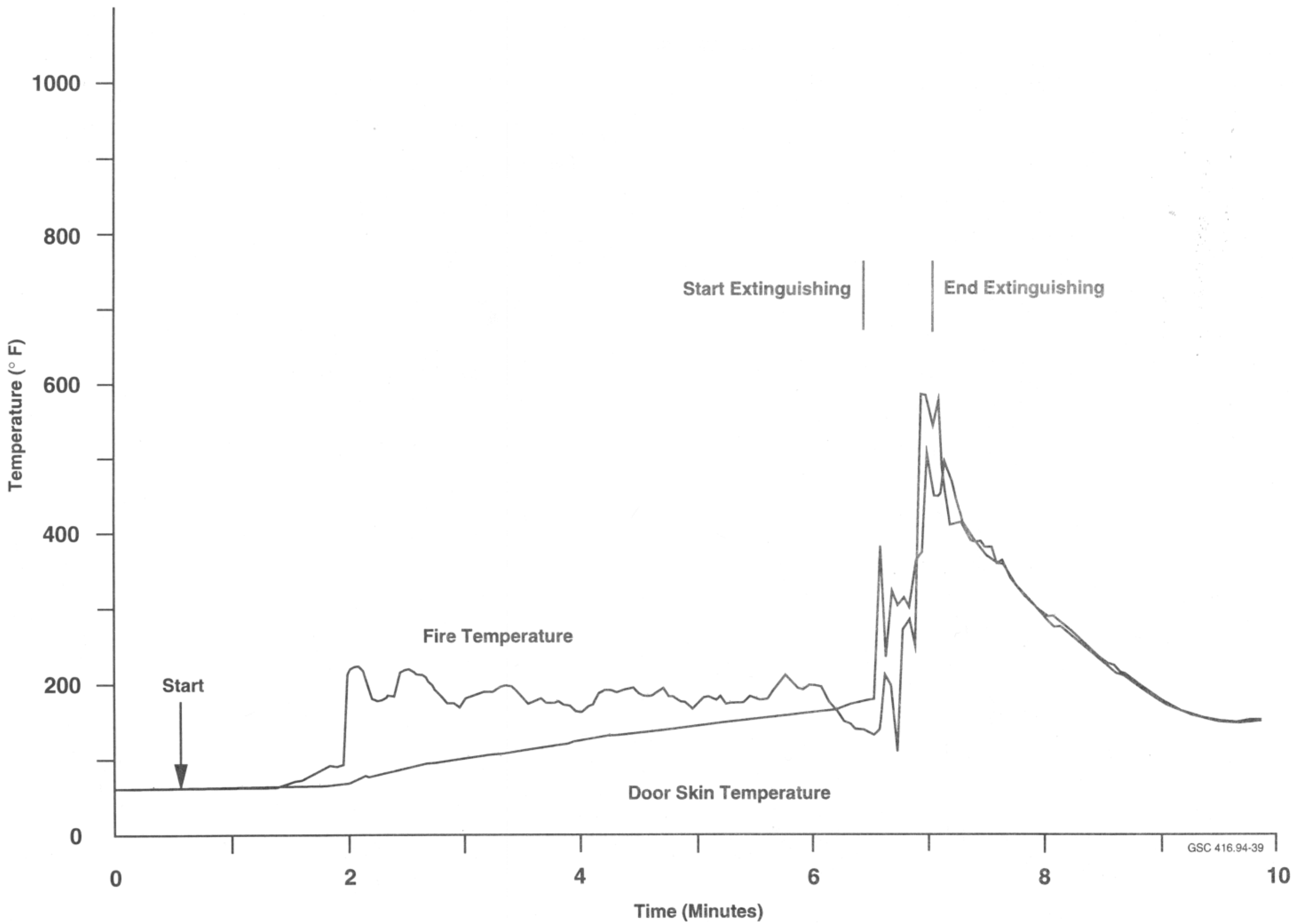

FIGURE D-5. TEST 4 EXTERNAL FIRE AND STARBOARD SERVICE DOOR SKIN TEMPERATURES AT STATION 1270

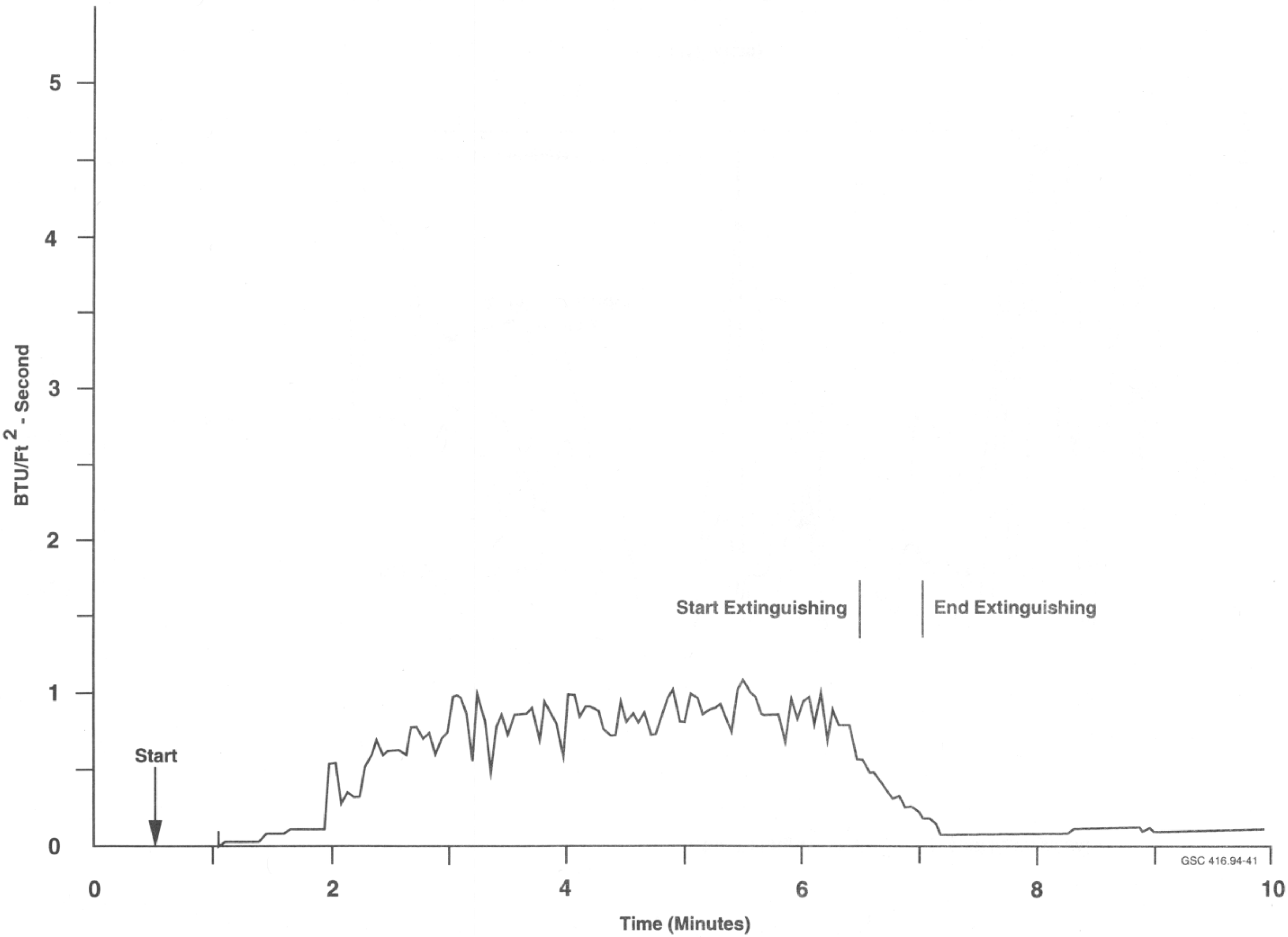

FIGURE D-7. TEST 4 EXTERNAL HEAT FLUX, STARBOARD SIDE AT STATION 1184

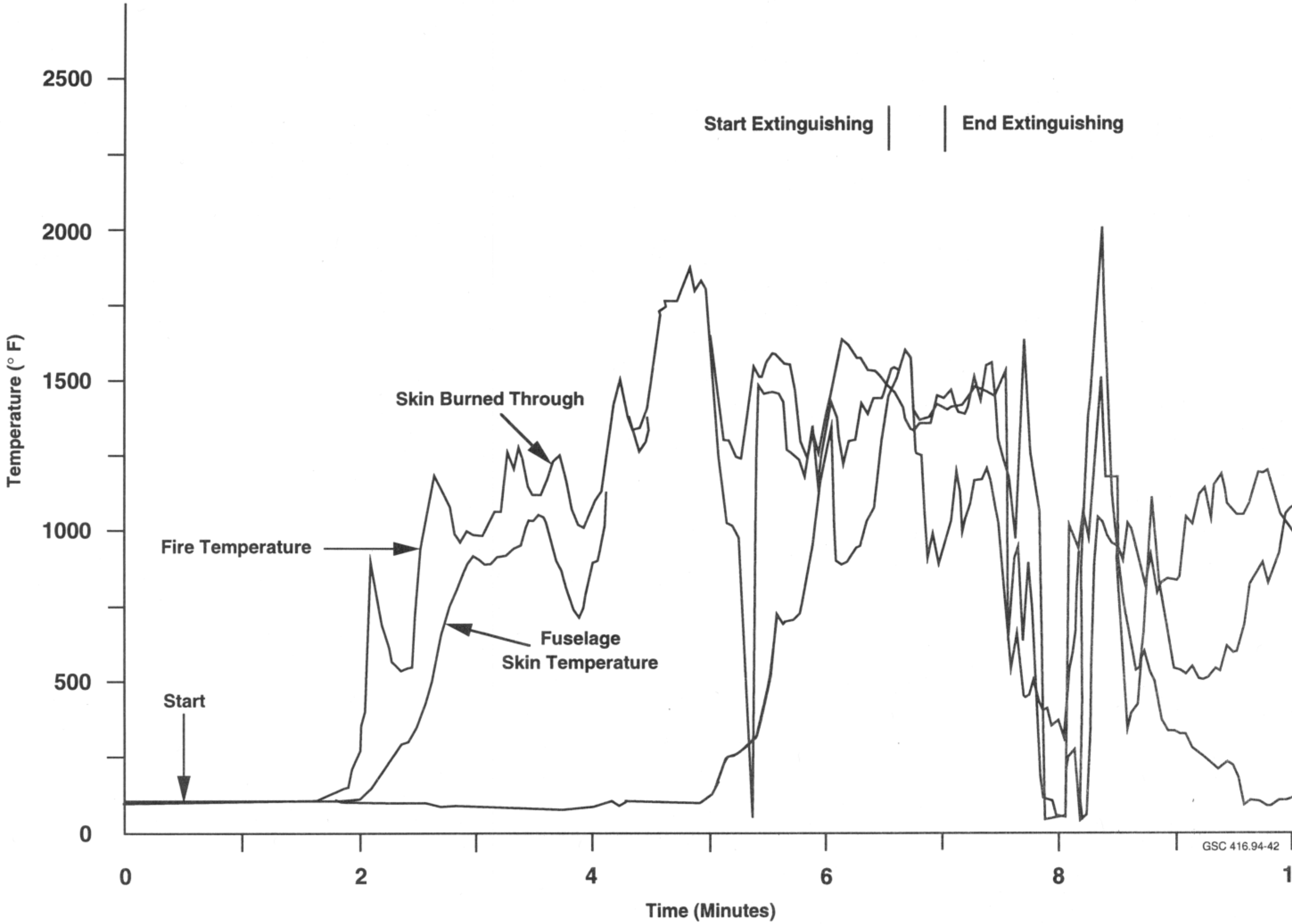

FIGURE D-8. TEST 4 FIRE AND FUSELAGE SKIN TEMPERATURES (BOTTOM) AT STATION 1237

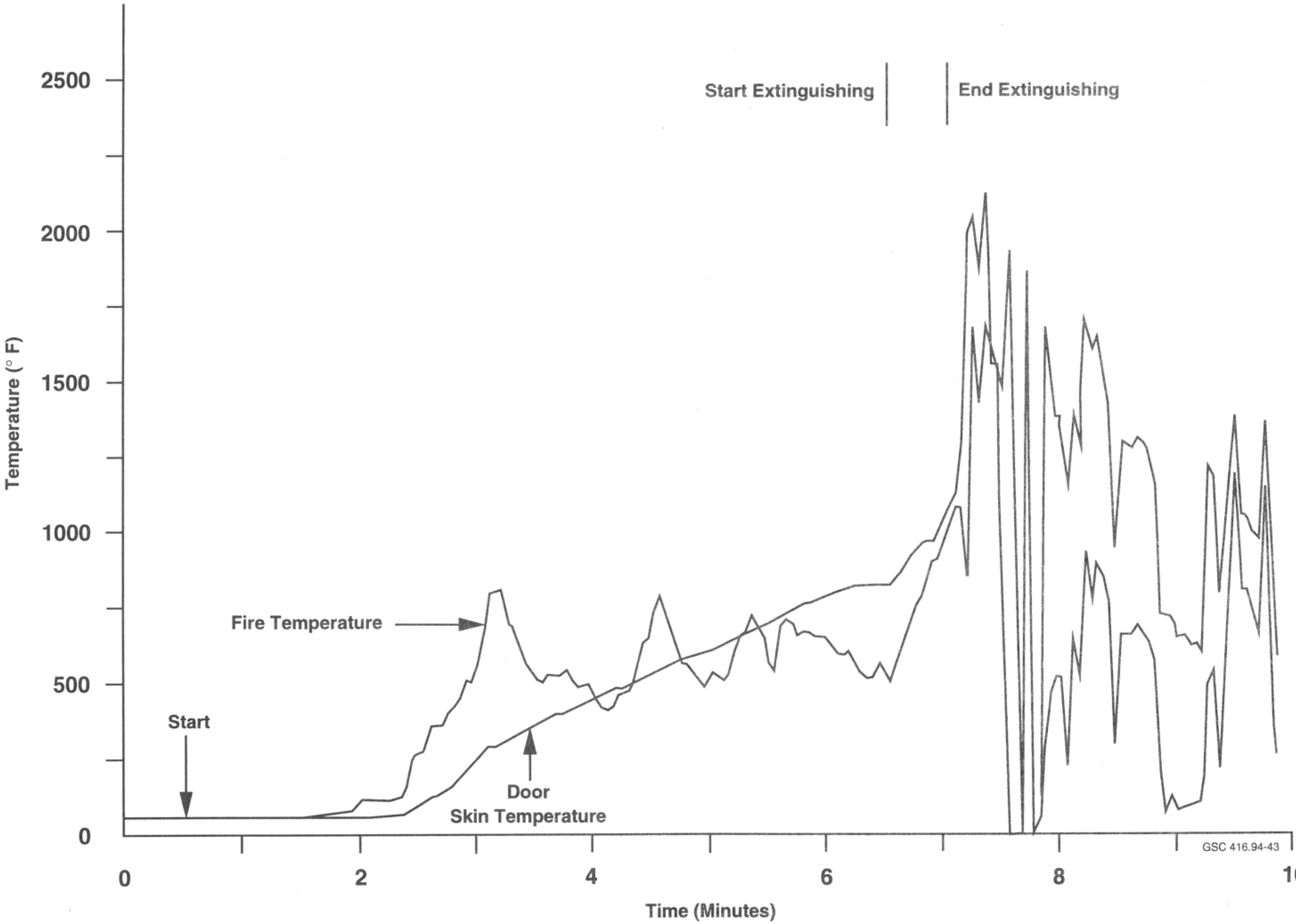

FIGURE D-9. TEST 4 EXTERNAL FIRE AND CARGO COMPARTMENT DOOR SKIN TEMPERATURES AT STATION 1127

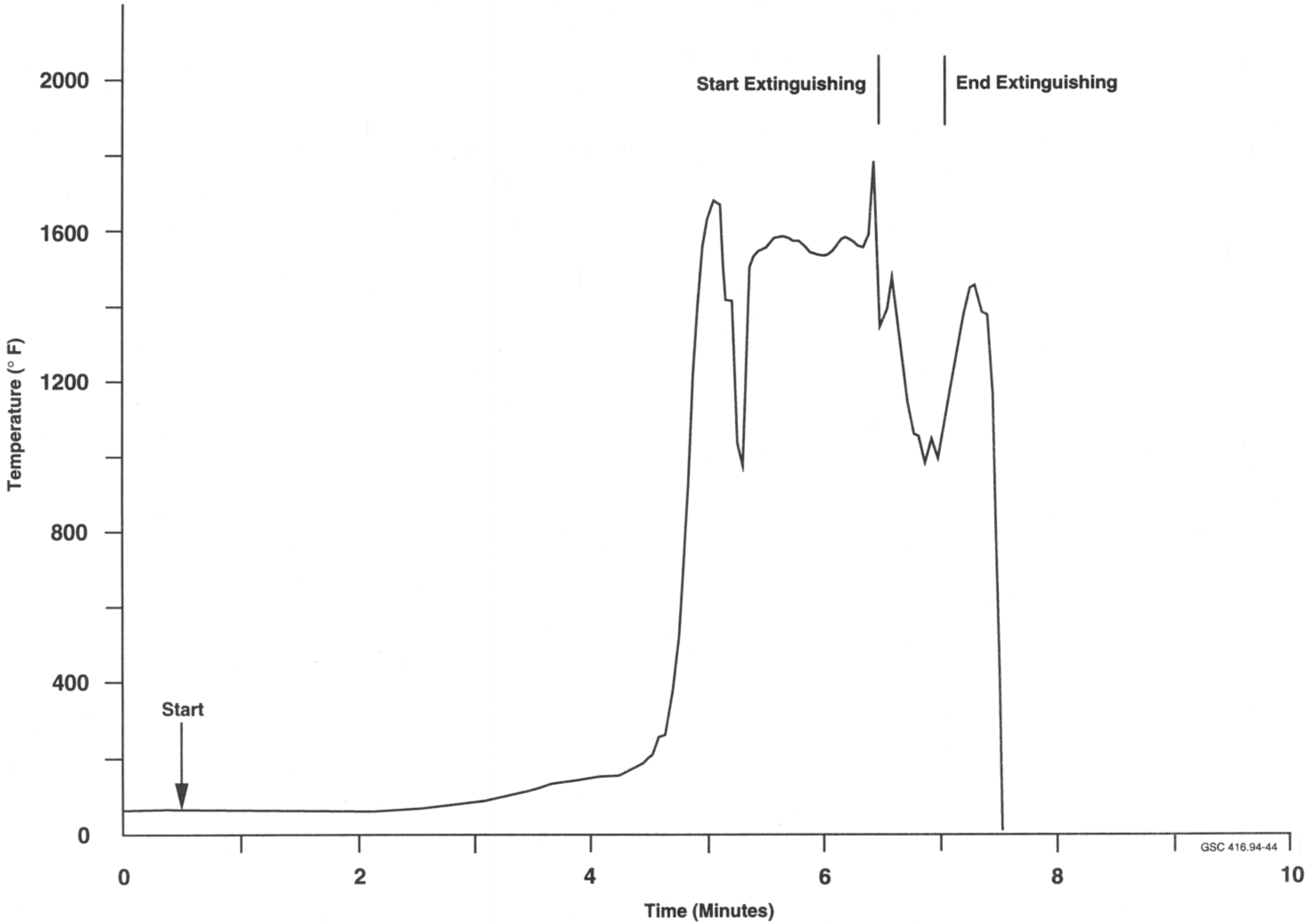

FIGURE D-10. TEST 4 OUTFLOW VALVE TEMPERATURE AT STATION 1291

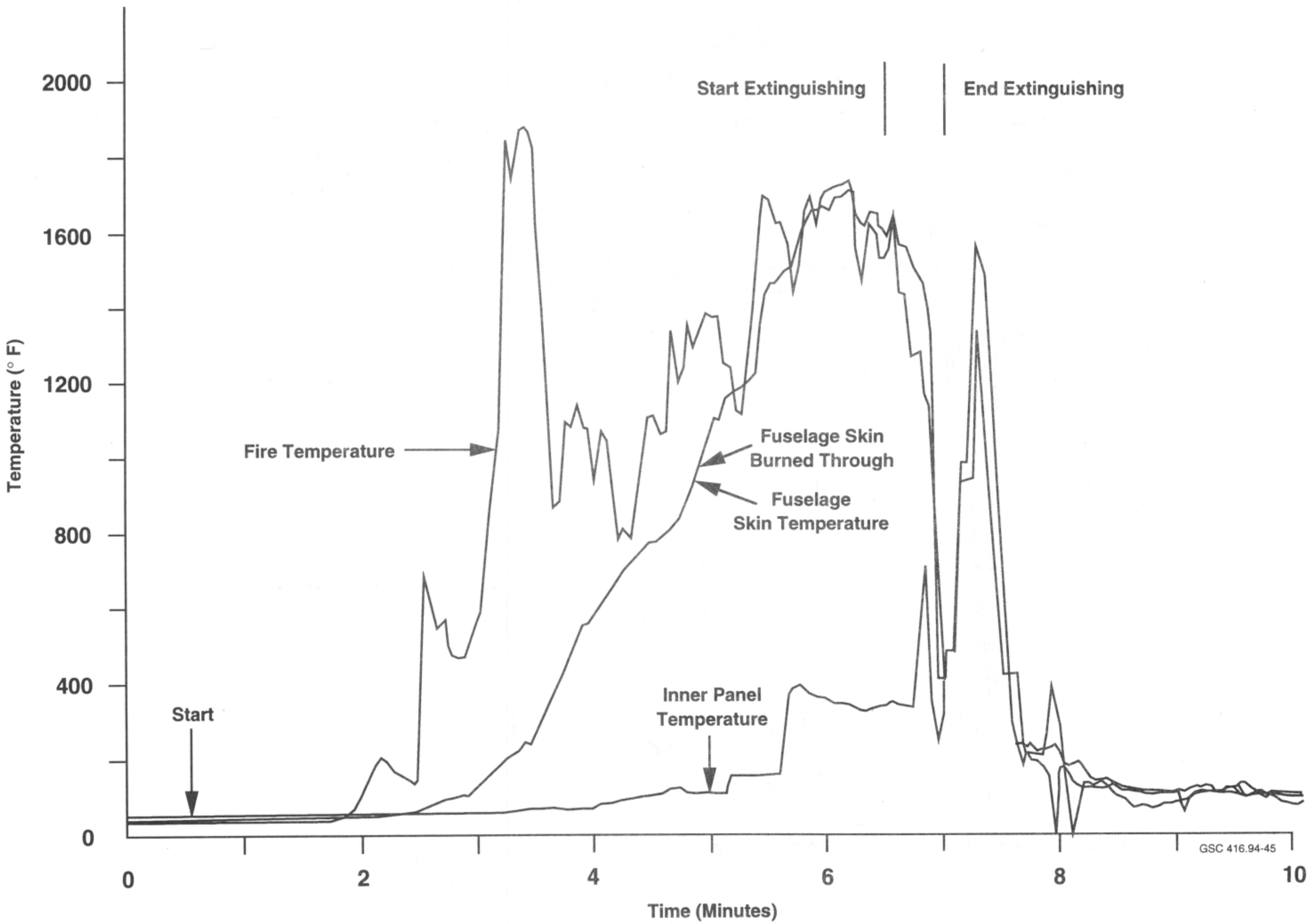

FIGURE D-11. TEST 4 FIRE, FUSELAGE SKIN, AND INTERIOR PANEL TEMPERATURES, PORT SIDE (UPPER) AT STATION 1184

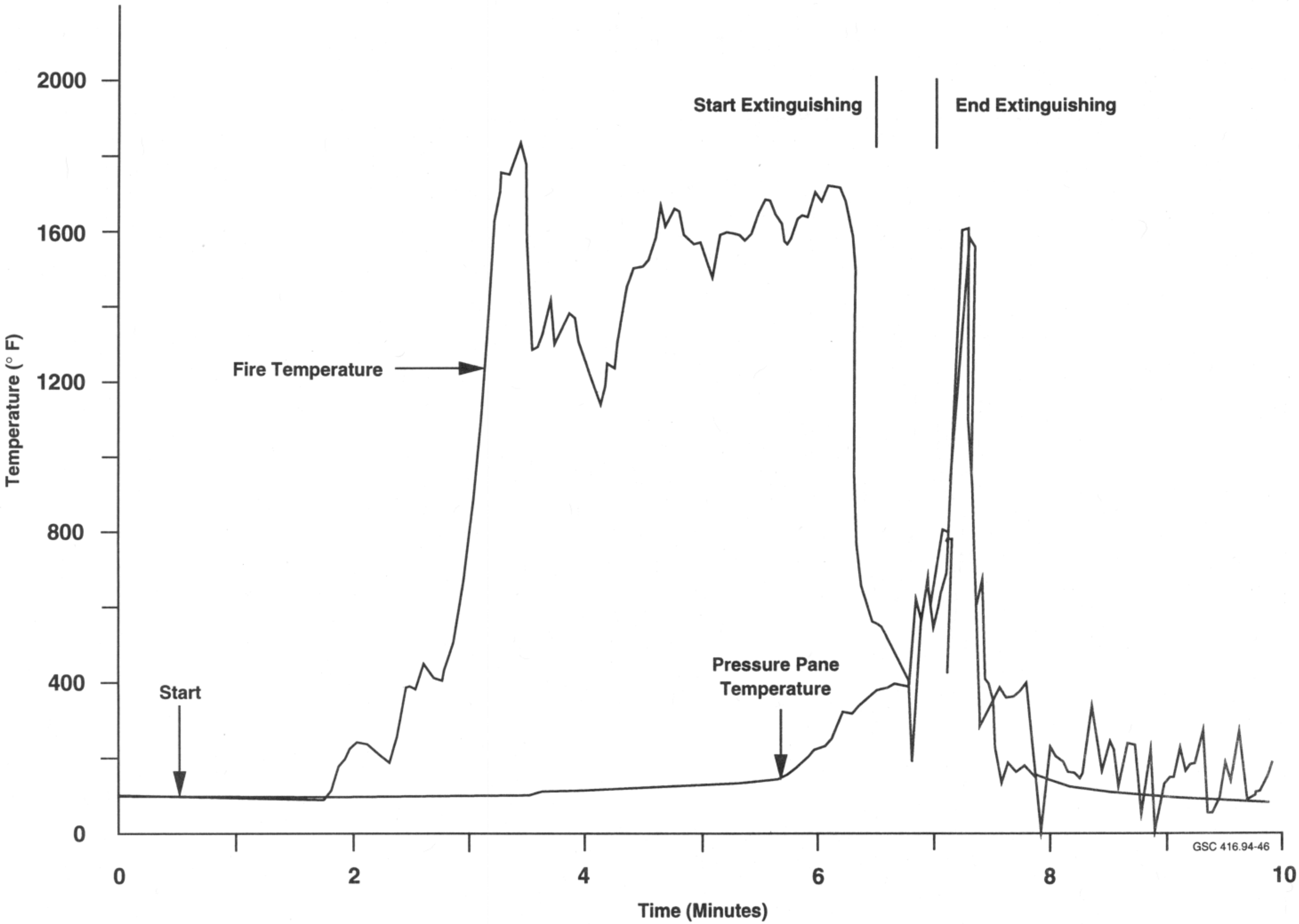

FIGURE D-12. TEST 4 EXTERNAL FIRE AND WINDOW PRESSURE PANE TEMPERATURES, PORT SIDE AT STATION 1184

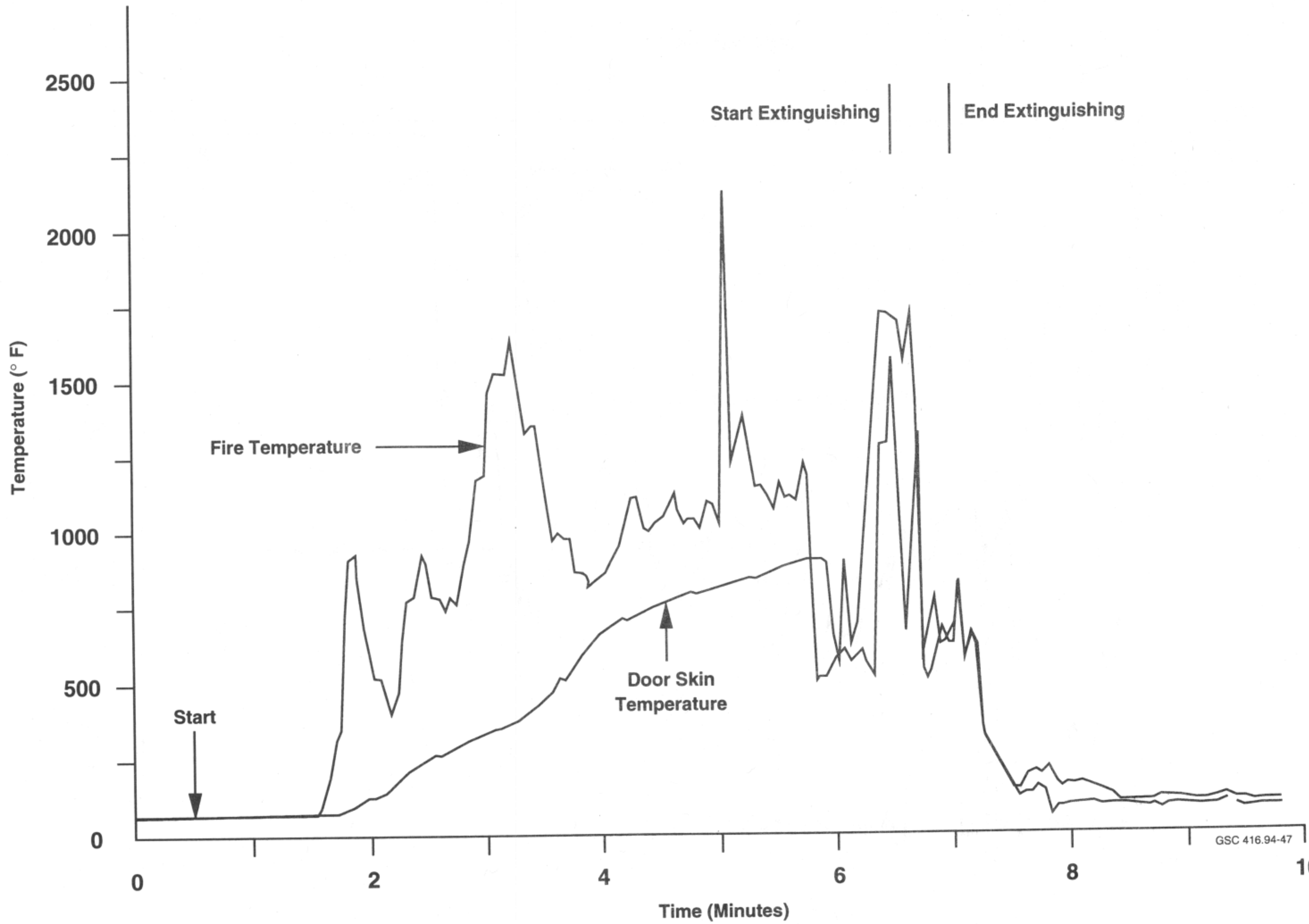

FIGURE D-13. TEST 4 EXTERNAL FIRE AND PORT SERVICE DOOR SKIN TEMPERATURES AT STATION 1285

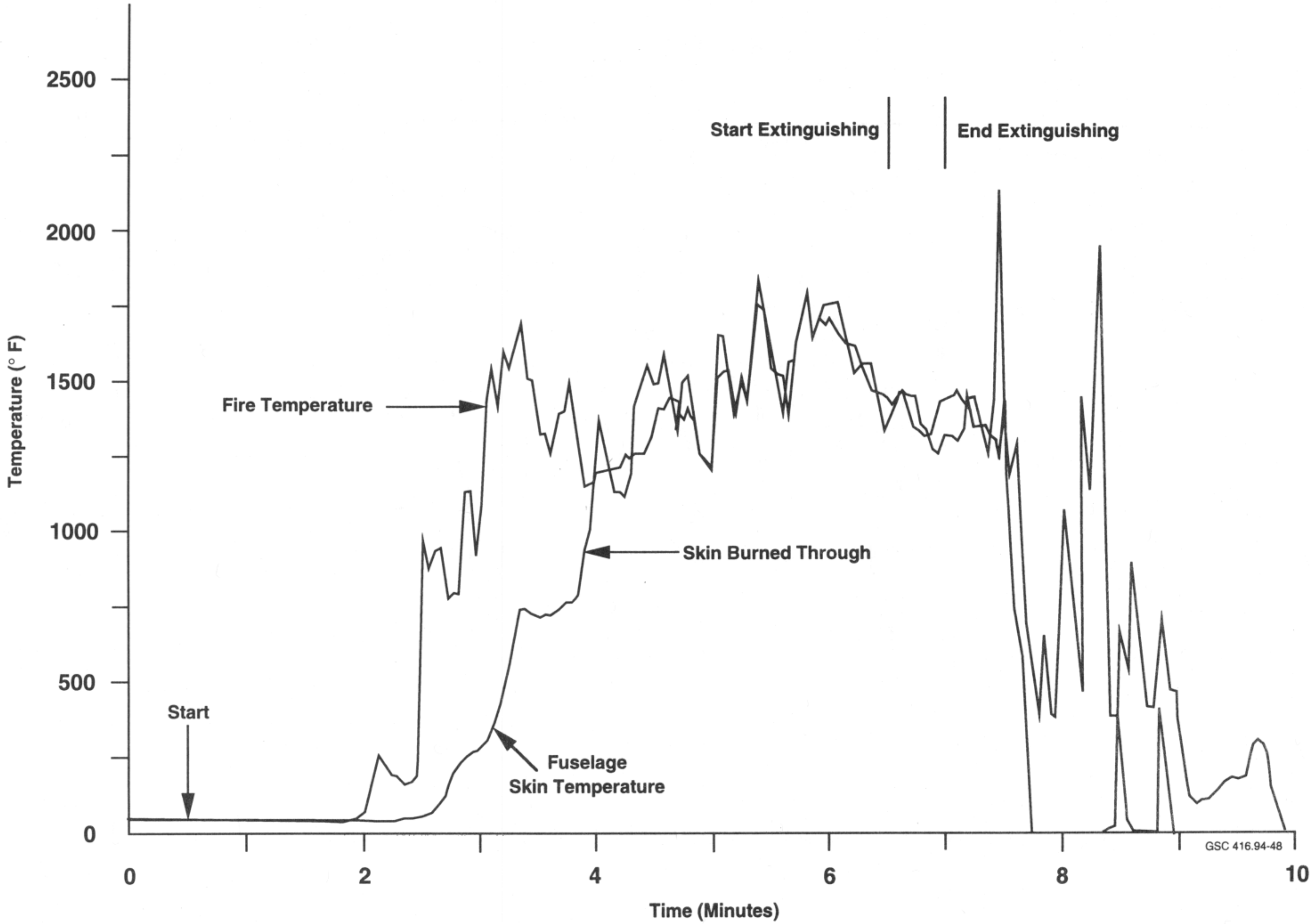

FIGURE D-14. TEST 4 FIRE AND FUSELAGE SKIN TEMPERATURES PORT SIDE (LOWER) AT STATION 1184

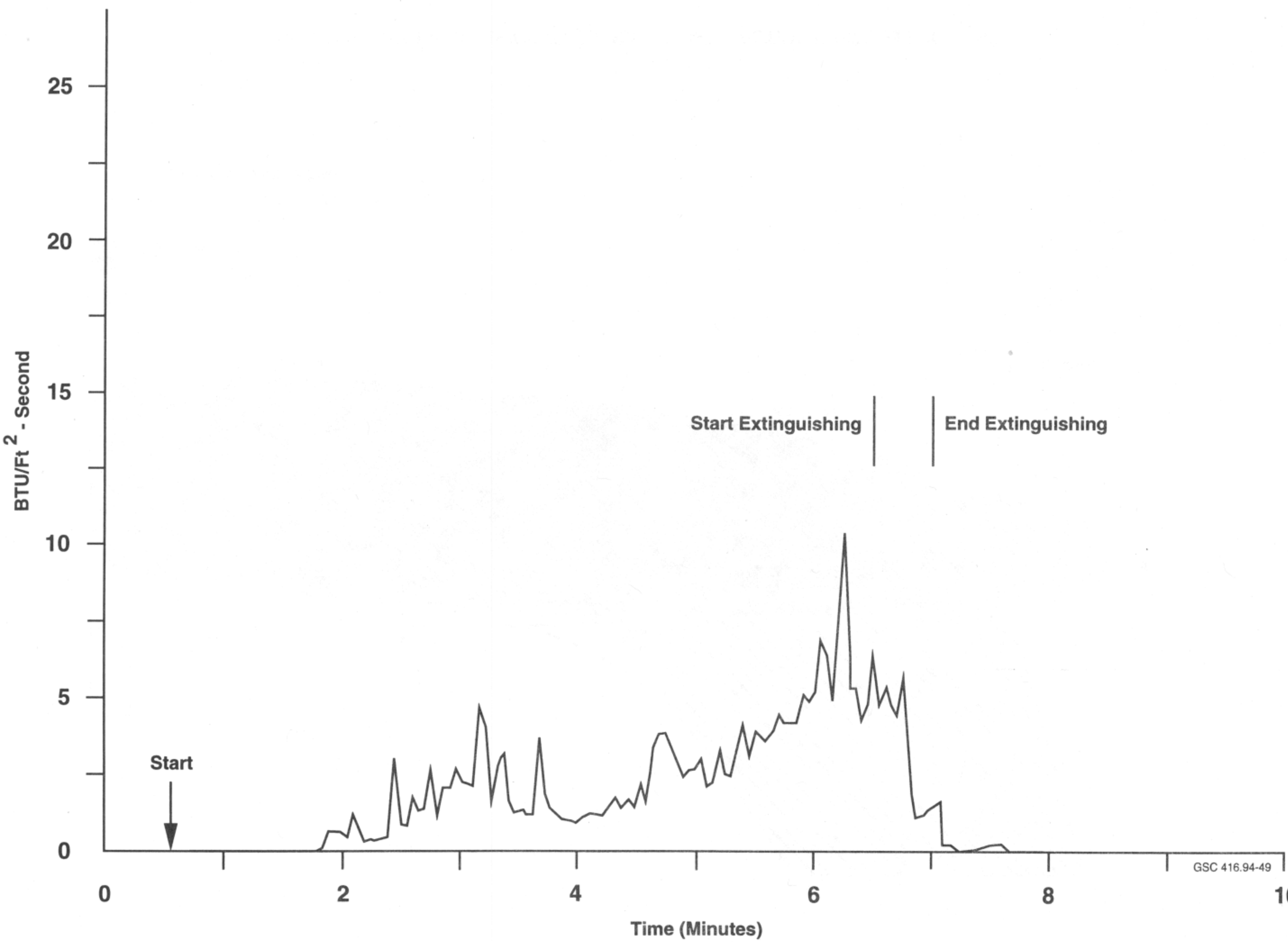

FIGURE D-15. TEST 4 EXTERNAL HEAT FLUX, PORT SIDE AT STATION 1184

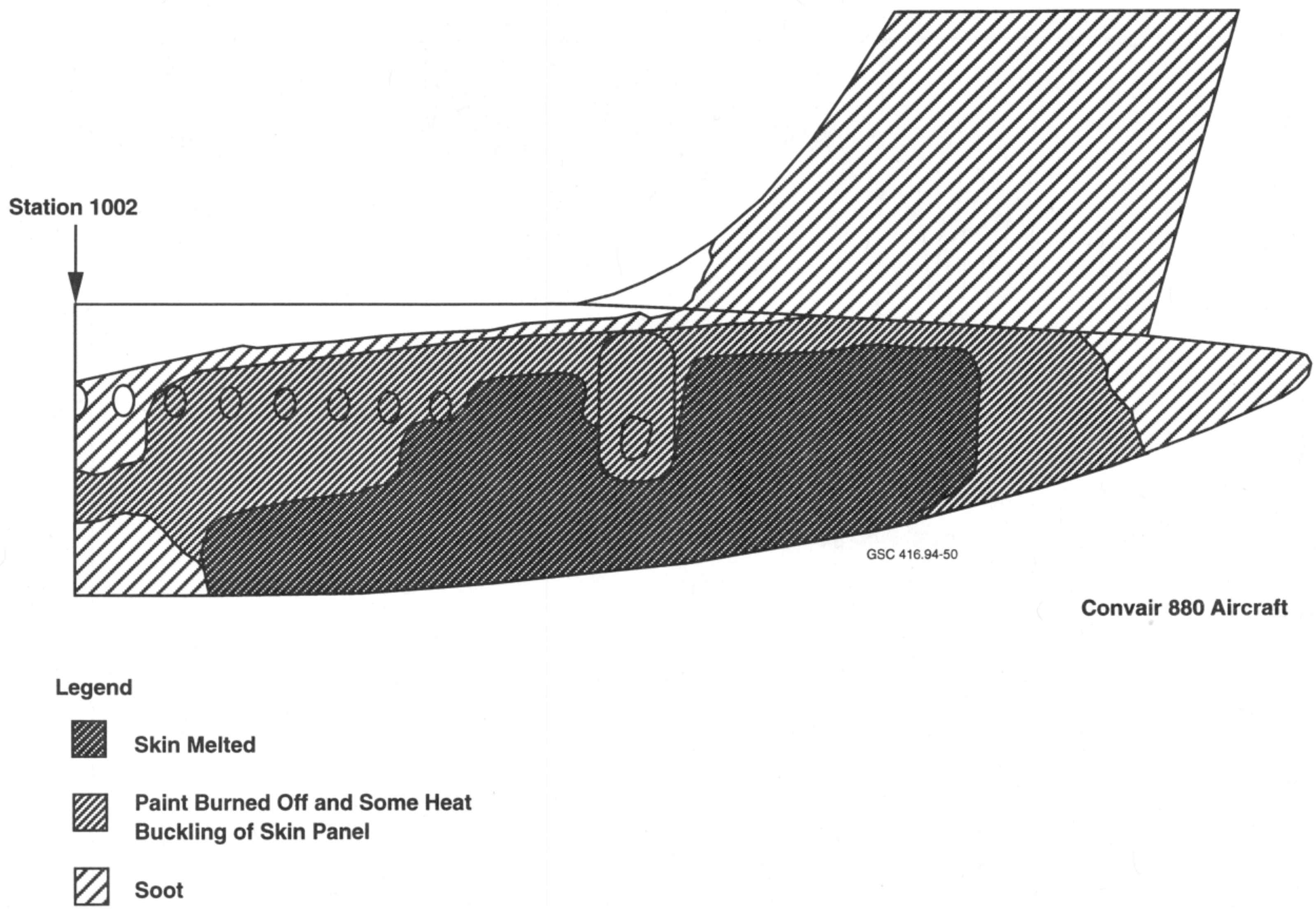

FIGURE D-16. TEST 4 EXTERIOR FIRE DAMAGE, AFT SECTION FUSELAGE PORT SIDE

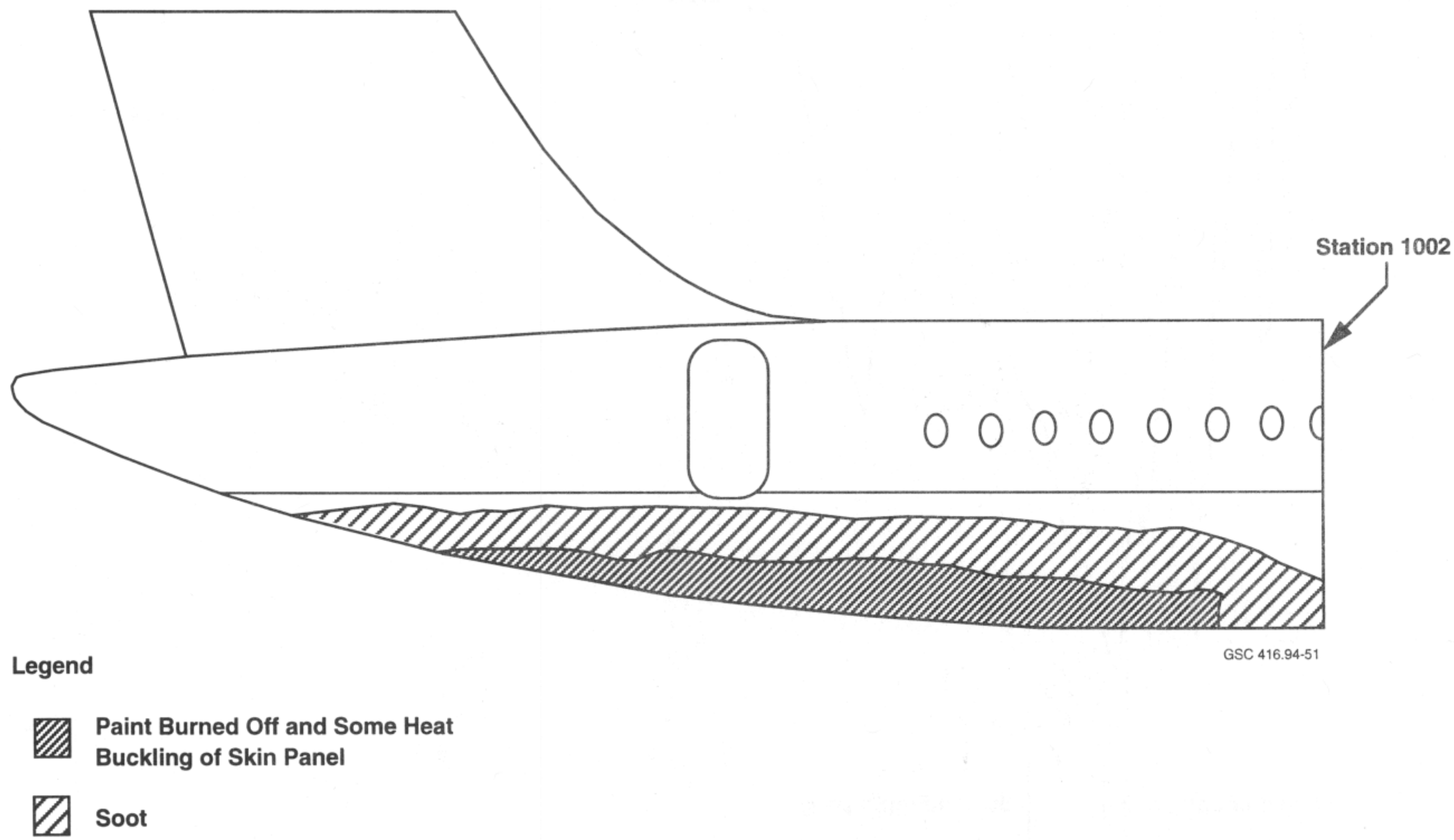

FIGURE D-17. TEST 4 EXTERIOR FIRE DAMAGE AFT SECTION FUSELAGE STARBOARD SIDE

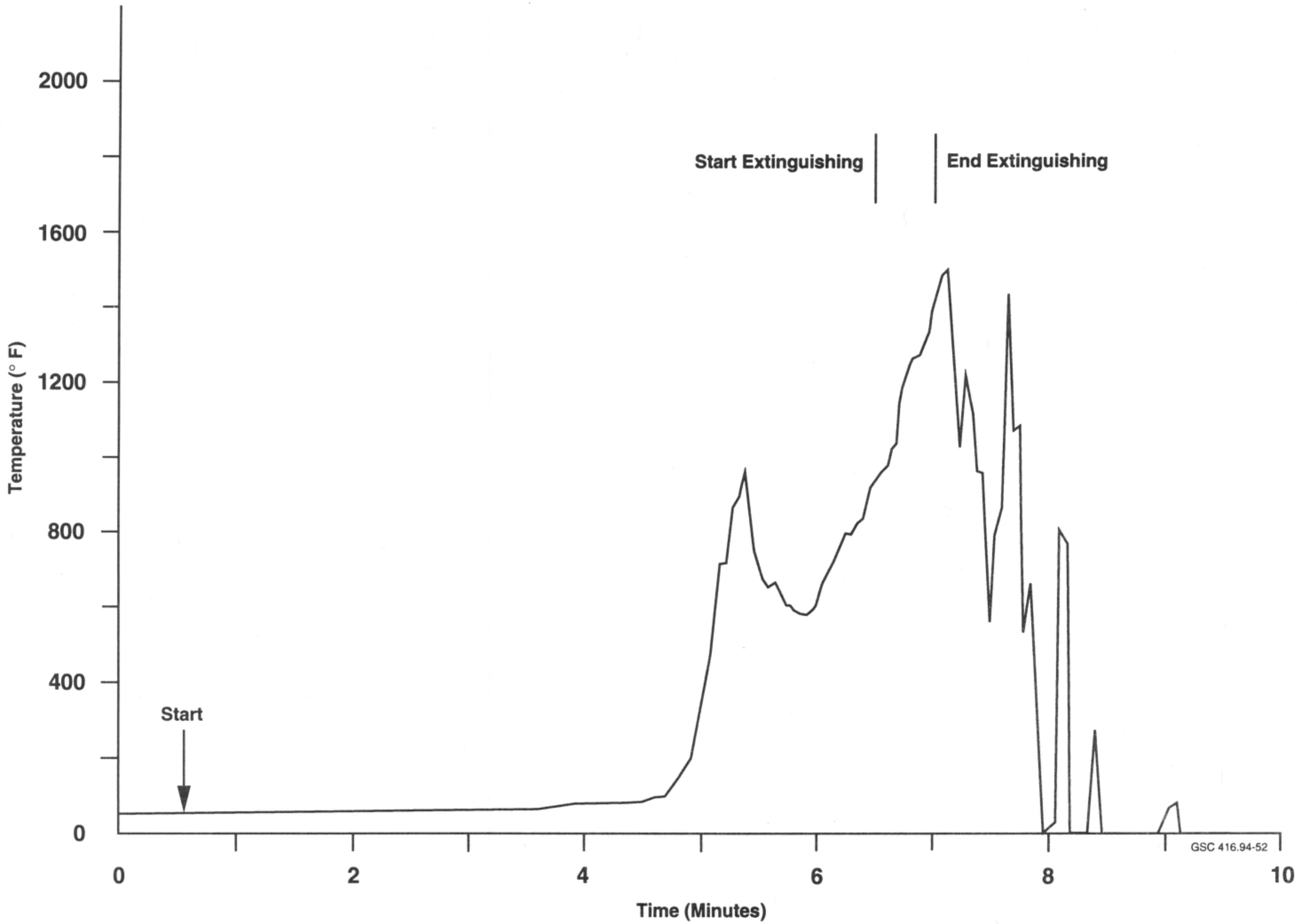

FIGURE D-18. TEST 4 CARGO COMPARTMENT AIR TEMPERATURE AT STATION 1182

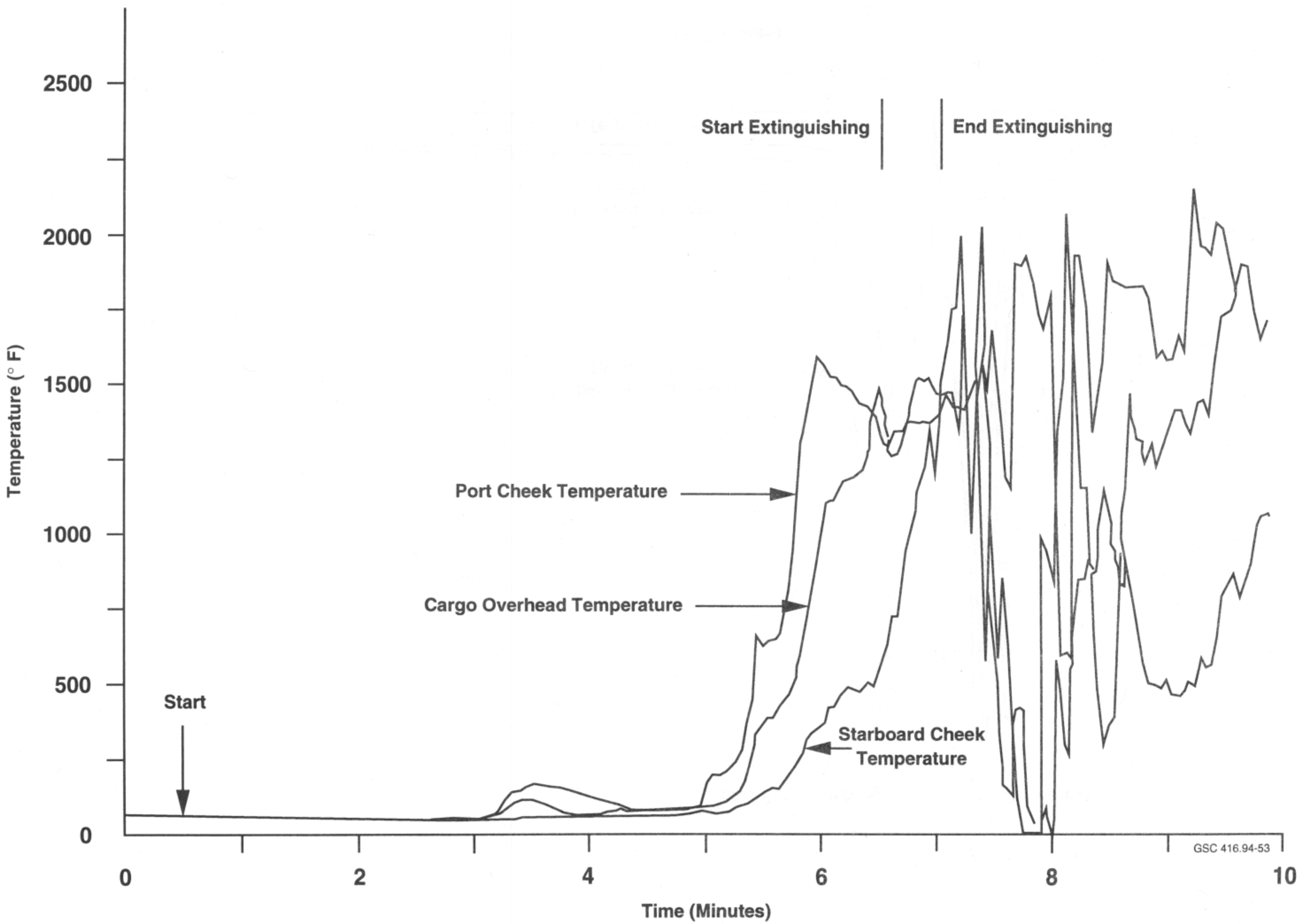

FIGURE D-19. TEST 4 PORT AND STARBOARD CHEEK AND CARGO OVERHEAD TEMPERATURE AT STATION 1182

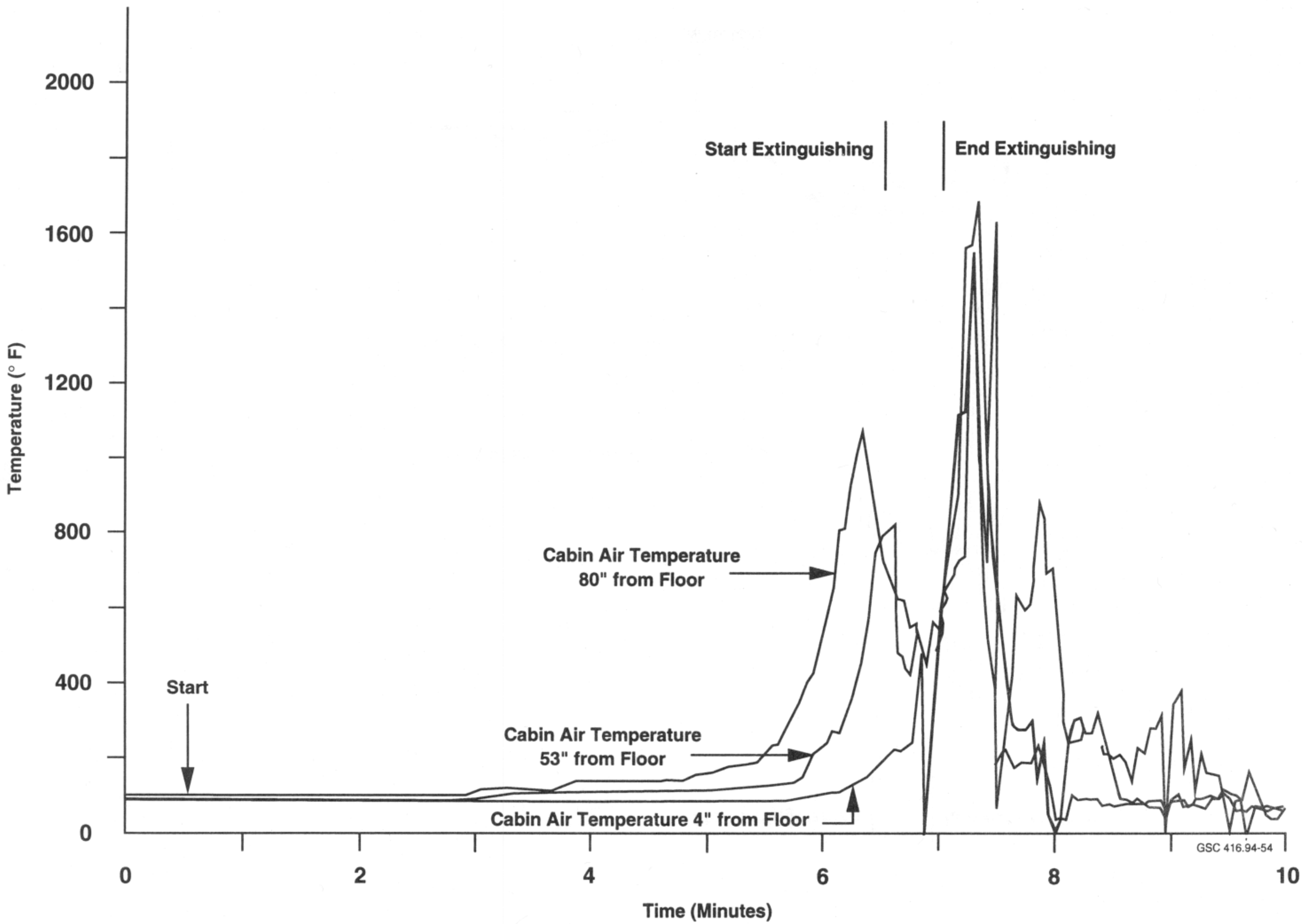

FIGURE D-20. TEST 4 CABIN AIR TEMPERATURES AT STATION 1144

APPENDIX E

CONVAIR 880 TEST 5 NOSE SECTION

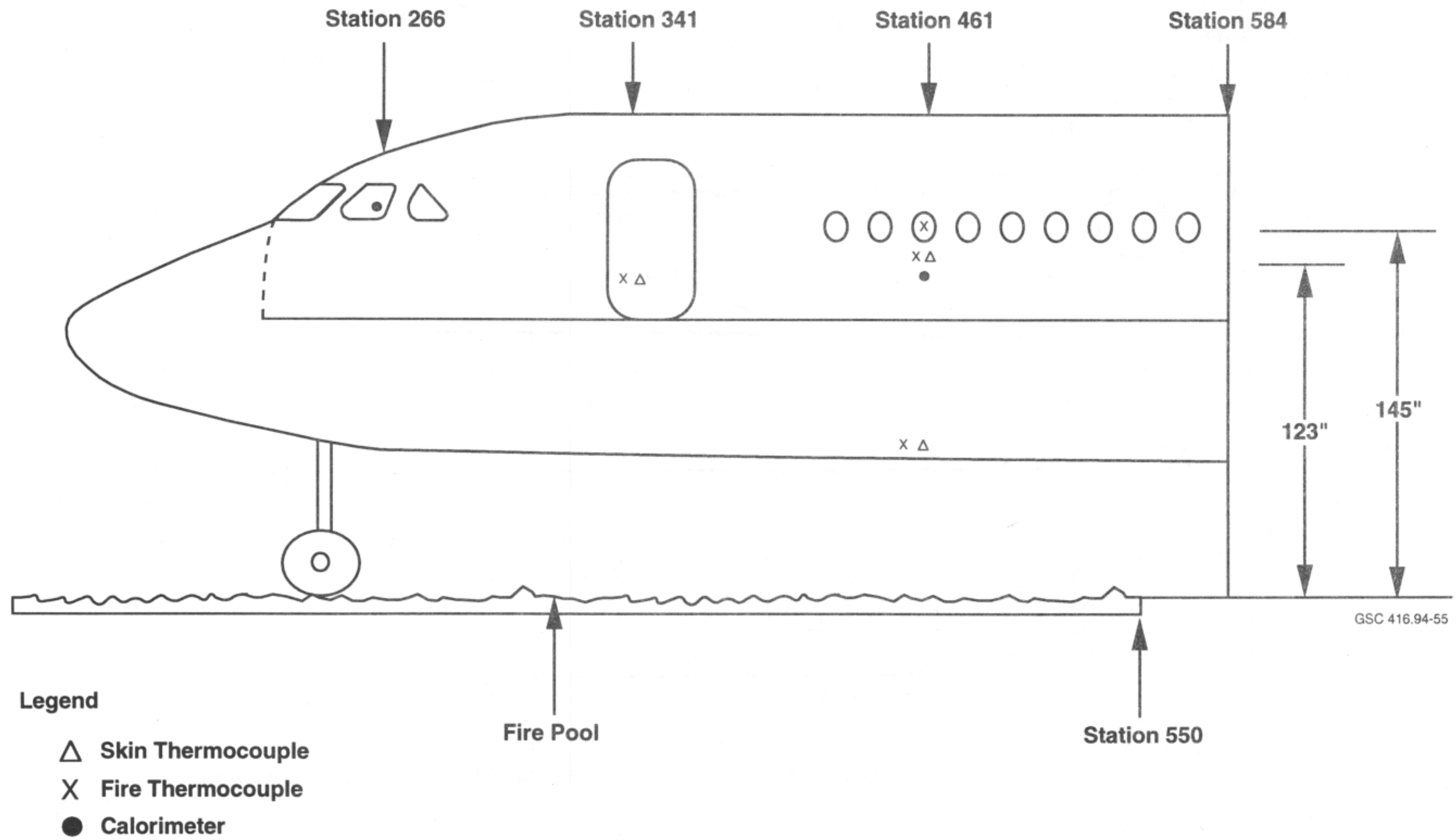

FIGURE E-1. TEST 5 CV-880 INSTURMENTATION LOCATIONS PORT SIDE

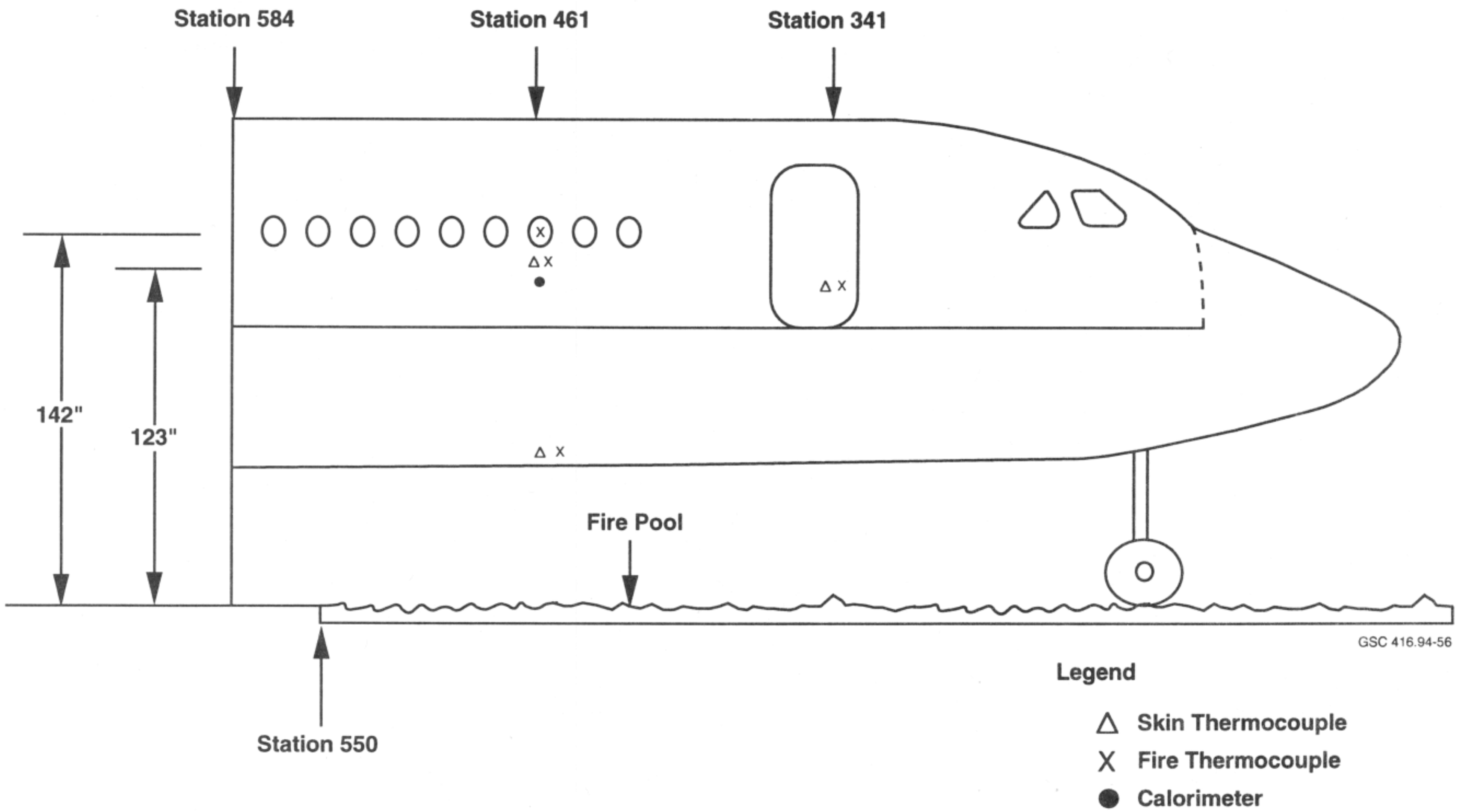

FIGURE E-2. TEST 5 CV-880 INSTURMENTATION LOCATIONS STARBOARD SIDE

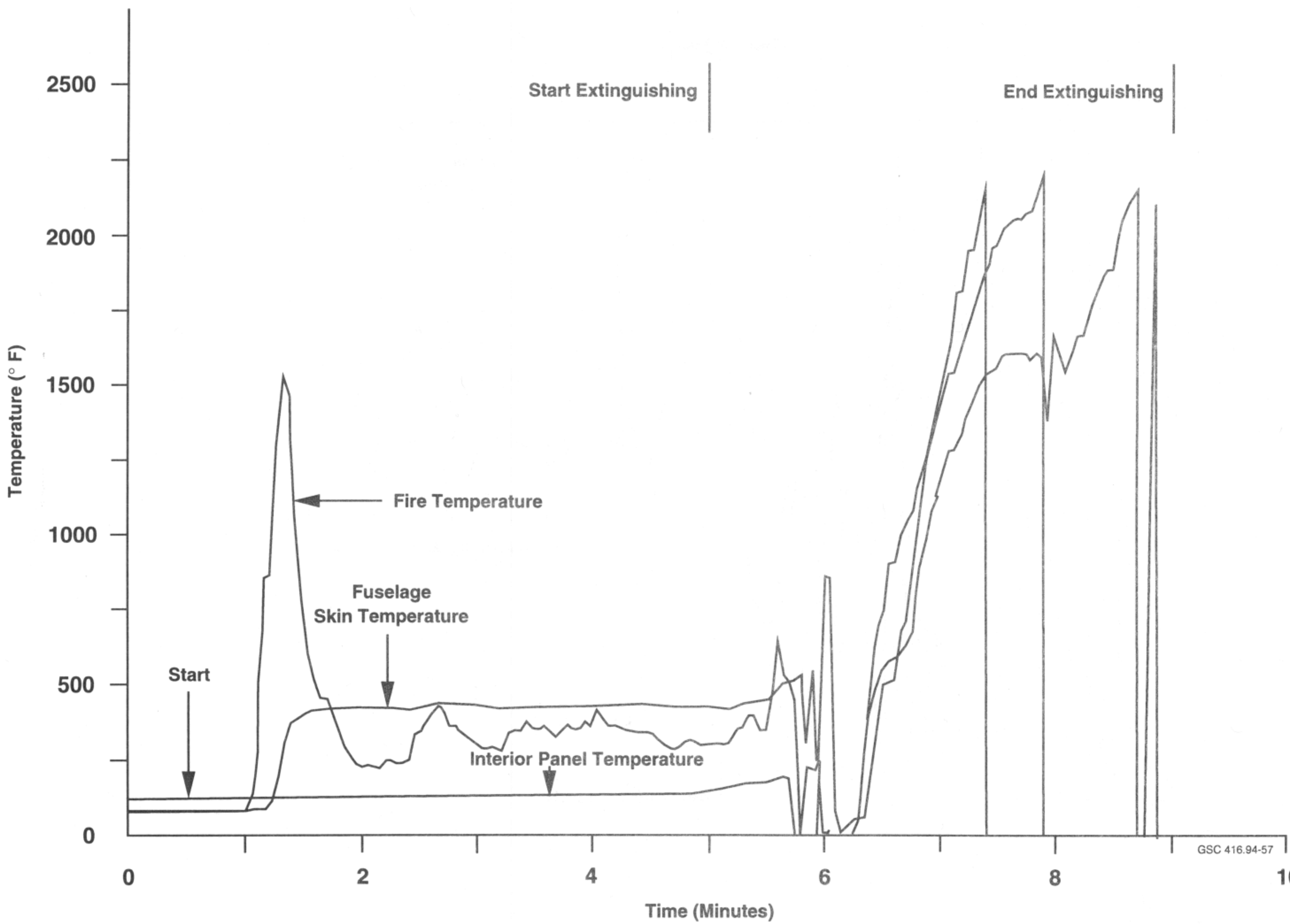

FIGURE E-3. TEST 5 FIRE, FUSELAGE SKIN, AND INTERIOR PANEL TEMPERATURES (UPPER)STARBOARD SIDE AT STATION 461

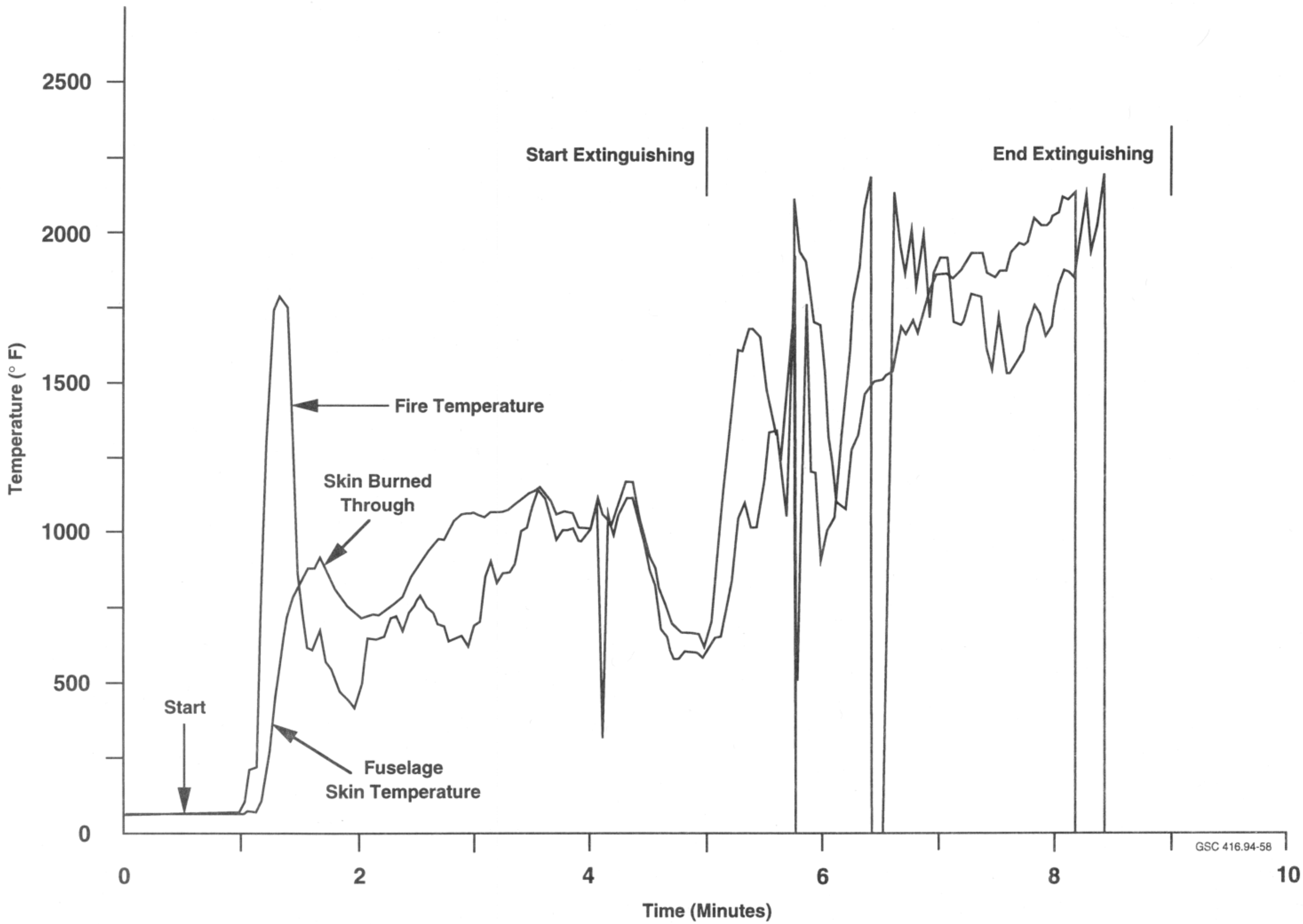

FIGURE E-4. TEST 5 FIRE AND FUSELAGE SKIN TEMPERATURES (LOWER) AT STATION 461

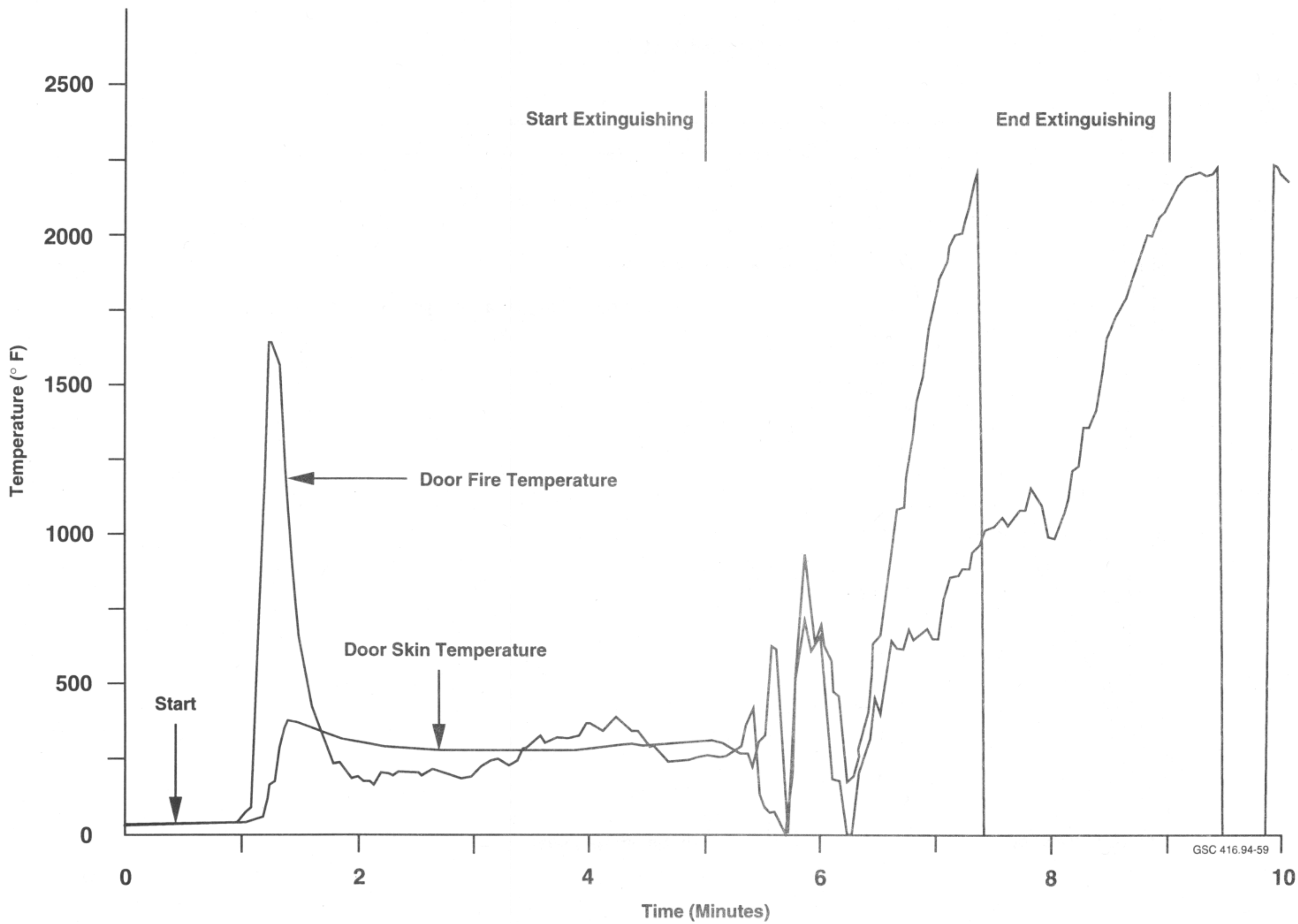

FIGURE E-5. TEST 5 EXTERNAL FIRE AND STARBOARD SERVICE DOOR SKIN TEMPERATURES AT STATION 341

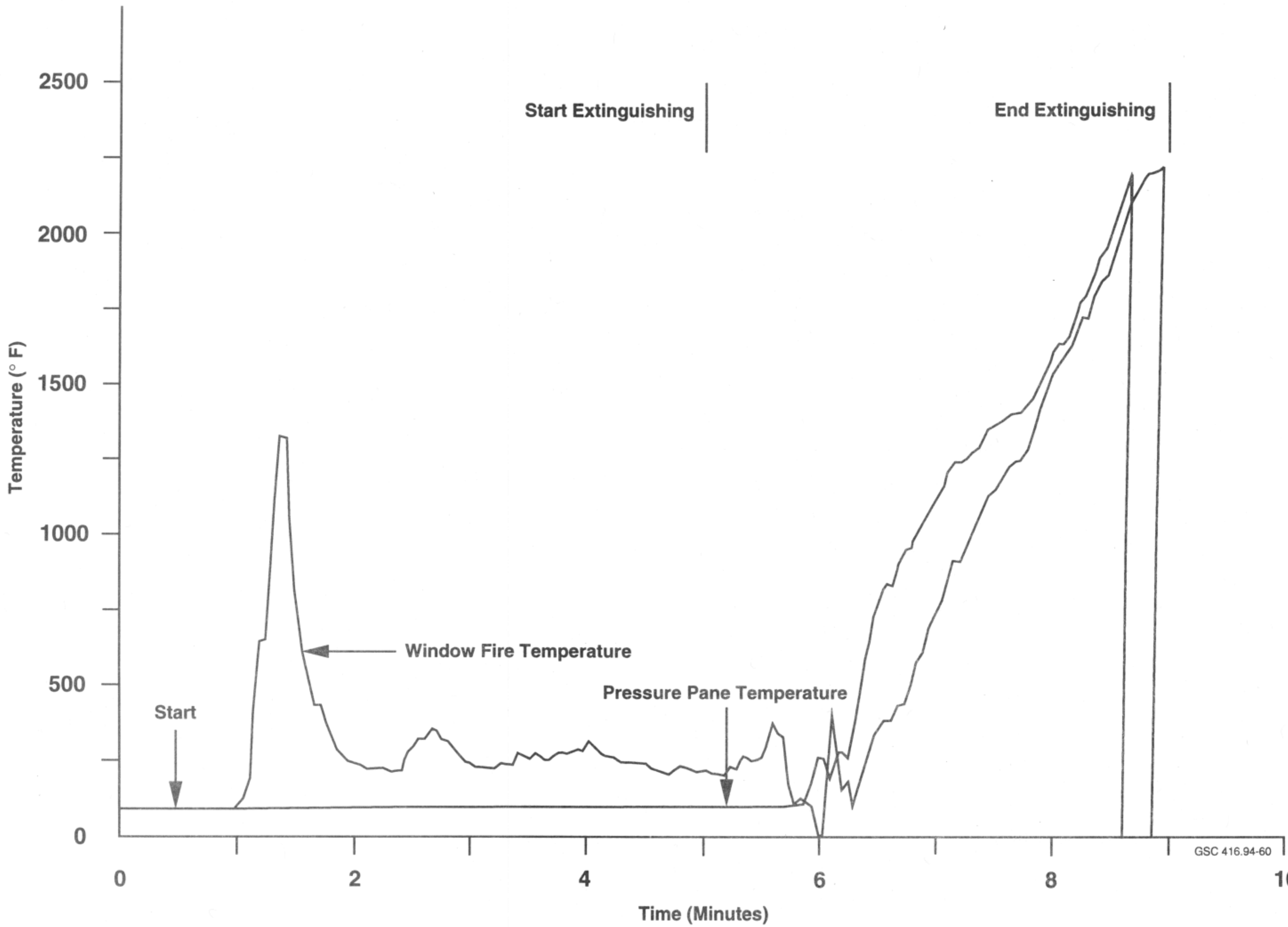

FIGURE E-6. TEST 5 EXTERNAL FIRE AND WINDOW PRESSURE PANE TEMPERTURES, STARBOARD SIDE AT STATION 460

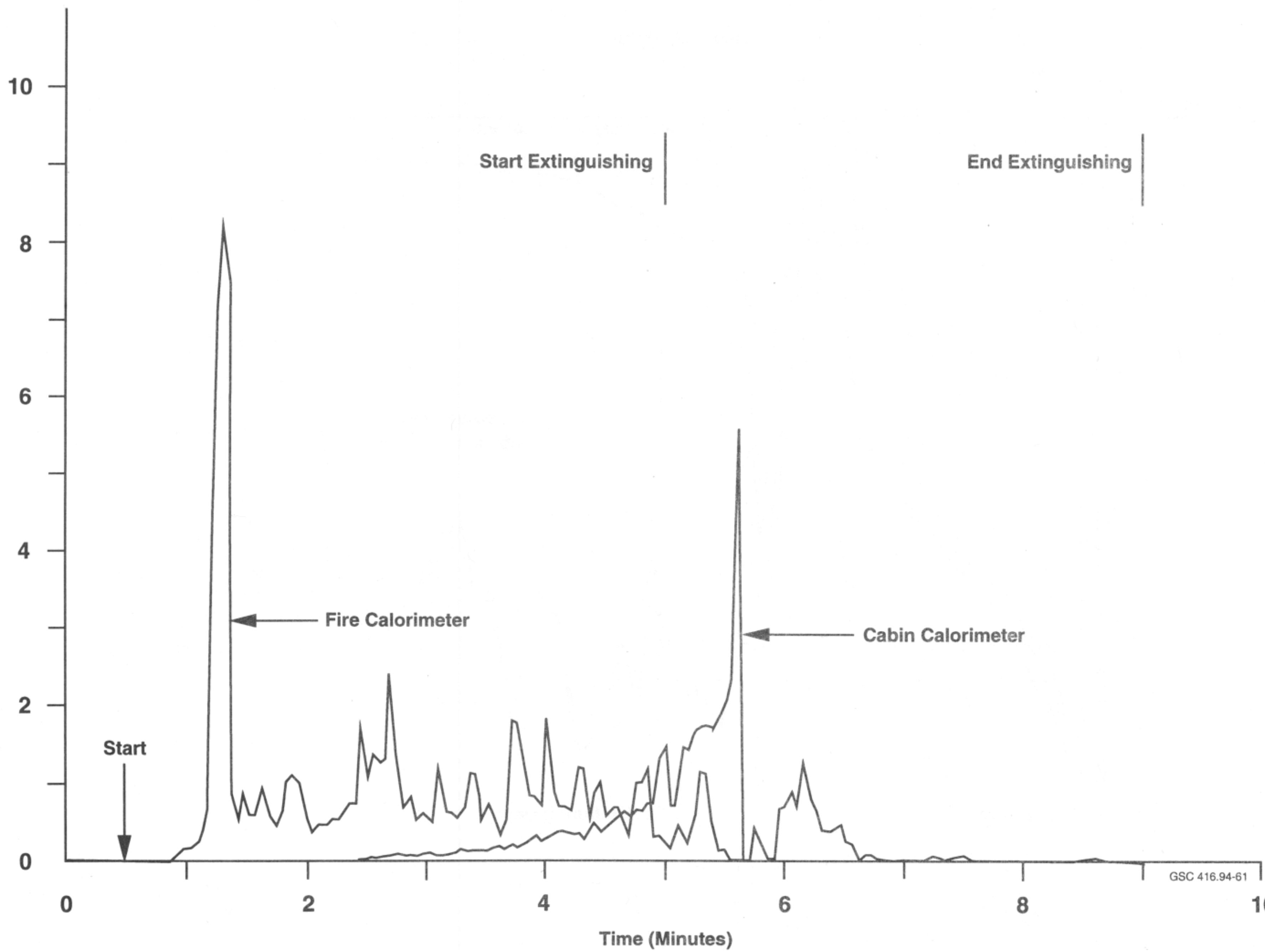

FIGURE E-7. TEST 5 INTERNAL AND EXTERNAL HEAT FLUX AT STATION 461

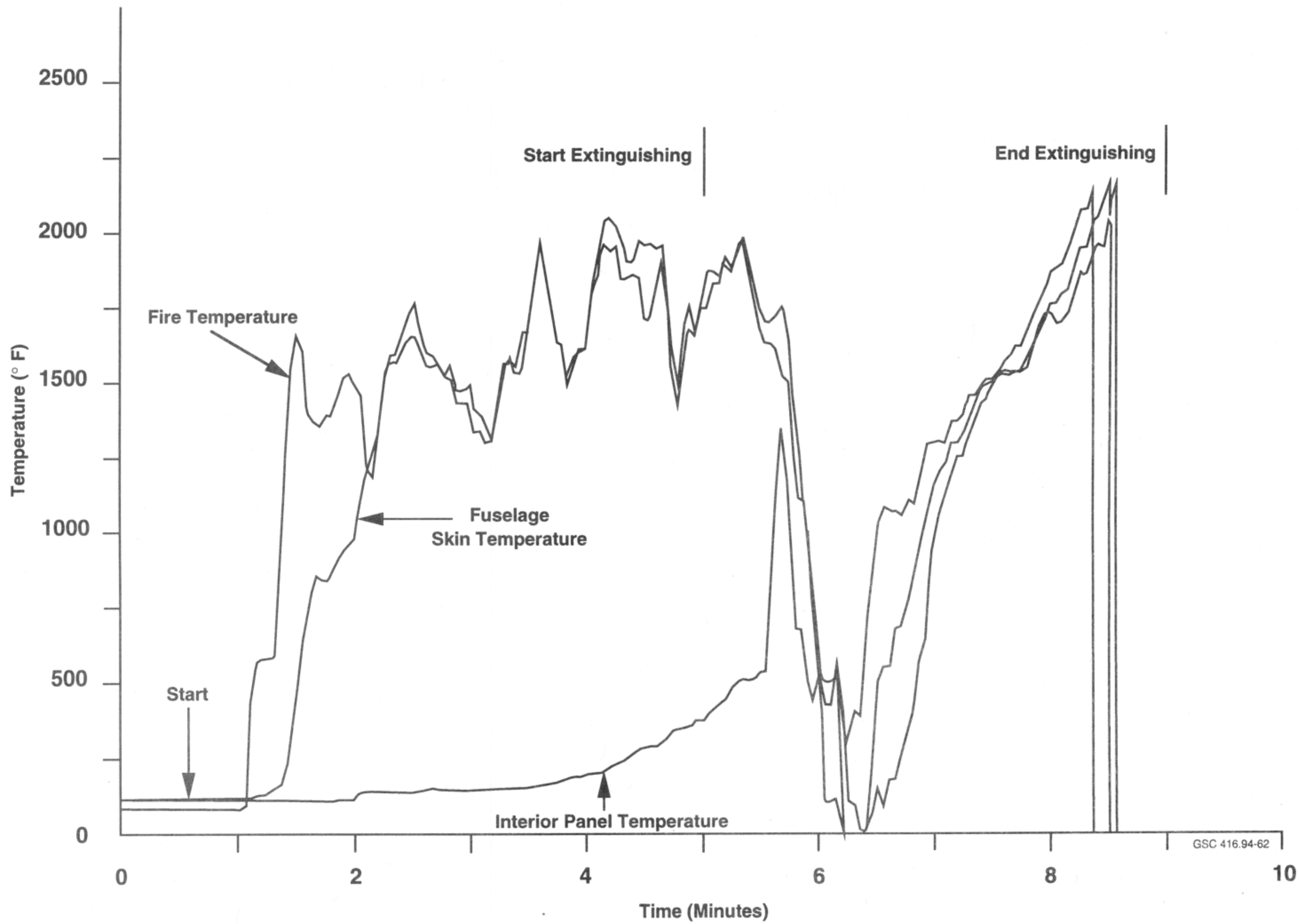

FIGURE E-8. TEST 5 FIRE, FUSELAGE SKIN, AND INTERIOR PANEL TEMPERATURES (UPPER), PORT SIDE AT STATION 461

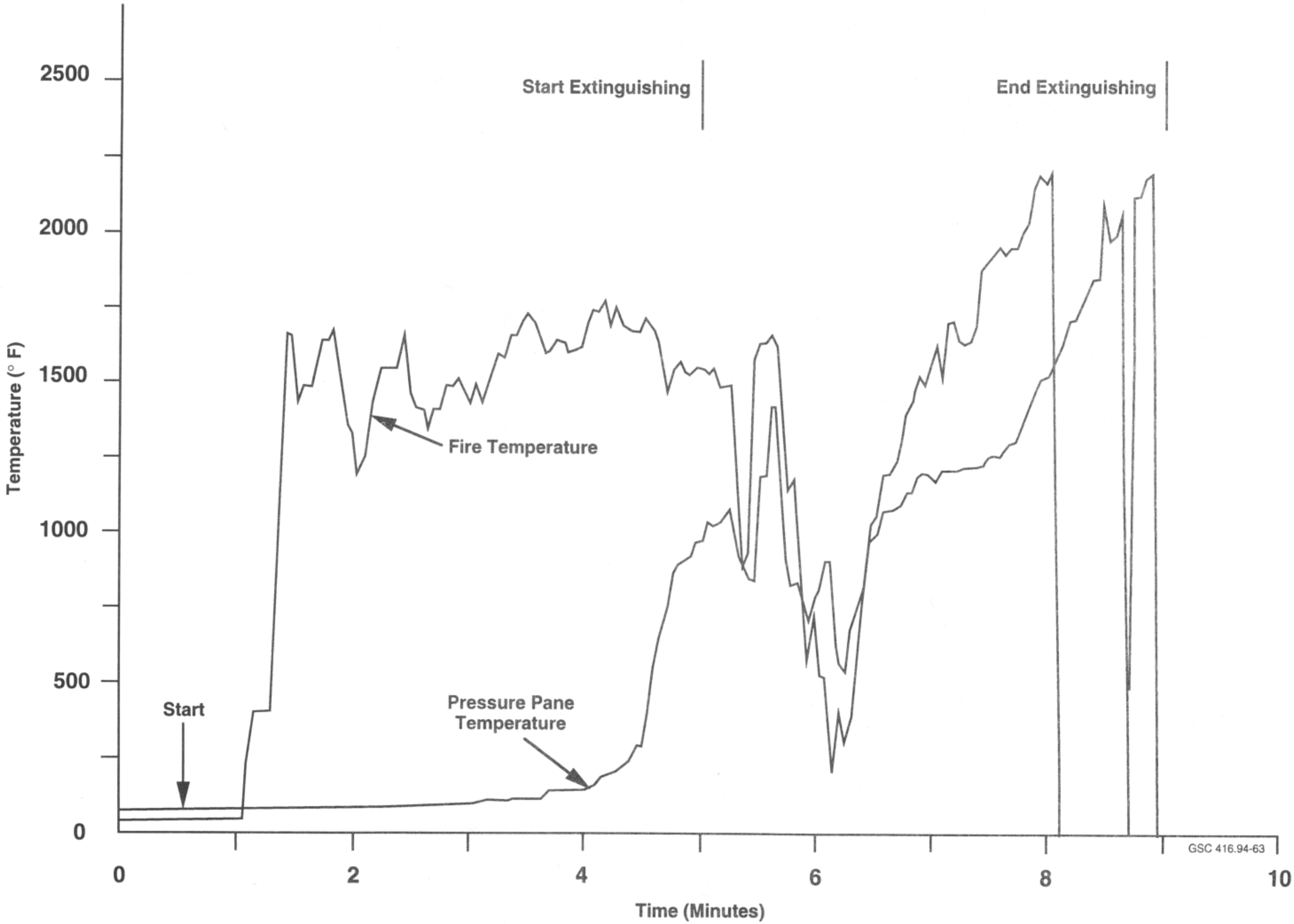

FIGURE E-9. TEST 5 EXTERNAL FIRE AND WINDOW PRESSURE PANE TEMPERATURES PORT SIDE AT STATION 461

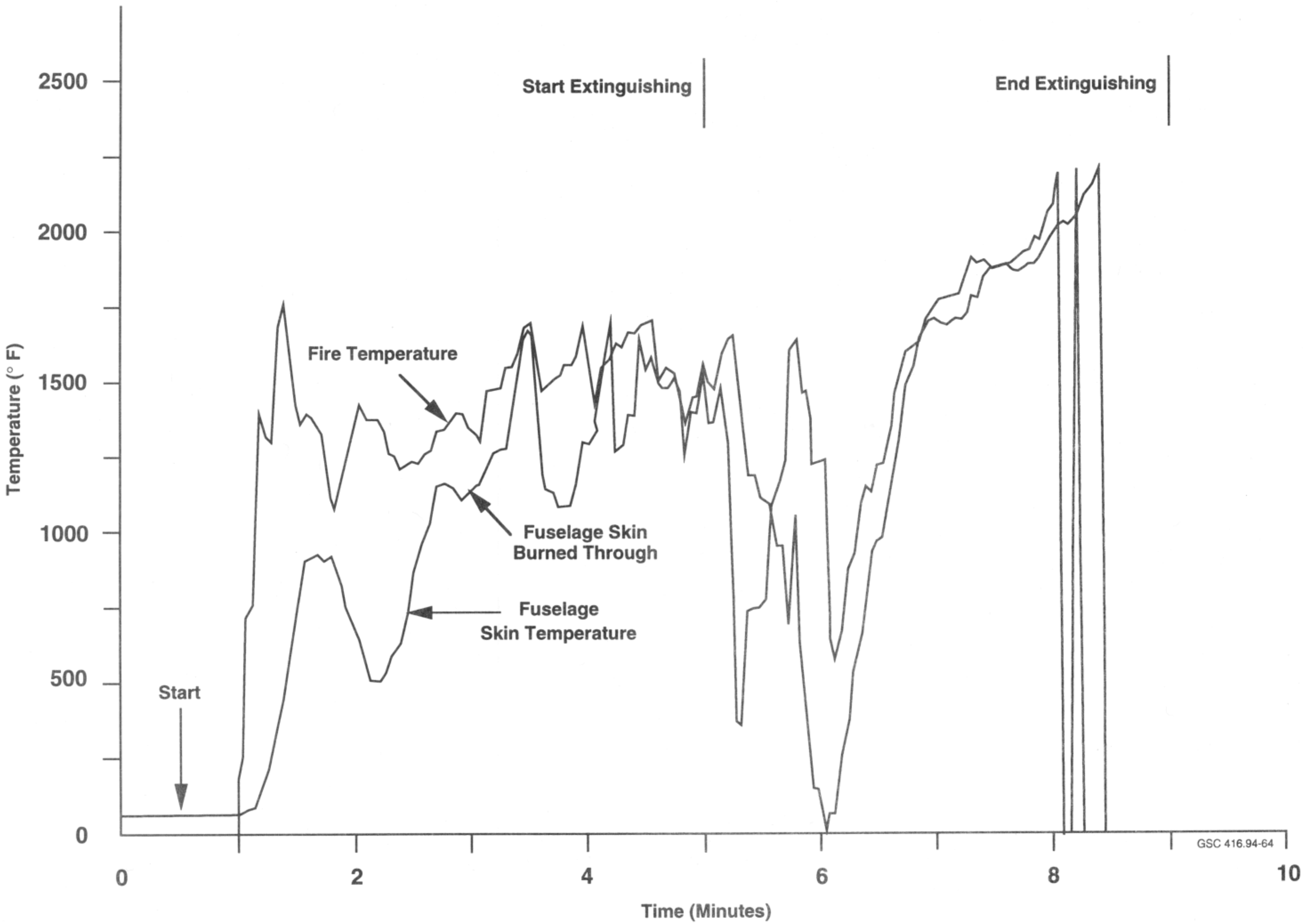

FIGURE E-10. TEST 5 FIRE AND FUSELAGE SKIN TEMPERATURES (LOWER) AT STATION 461

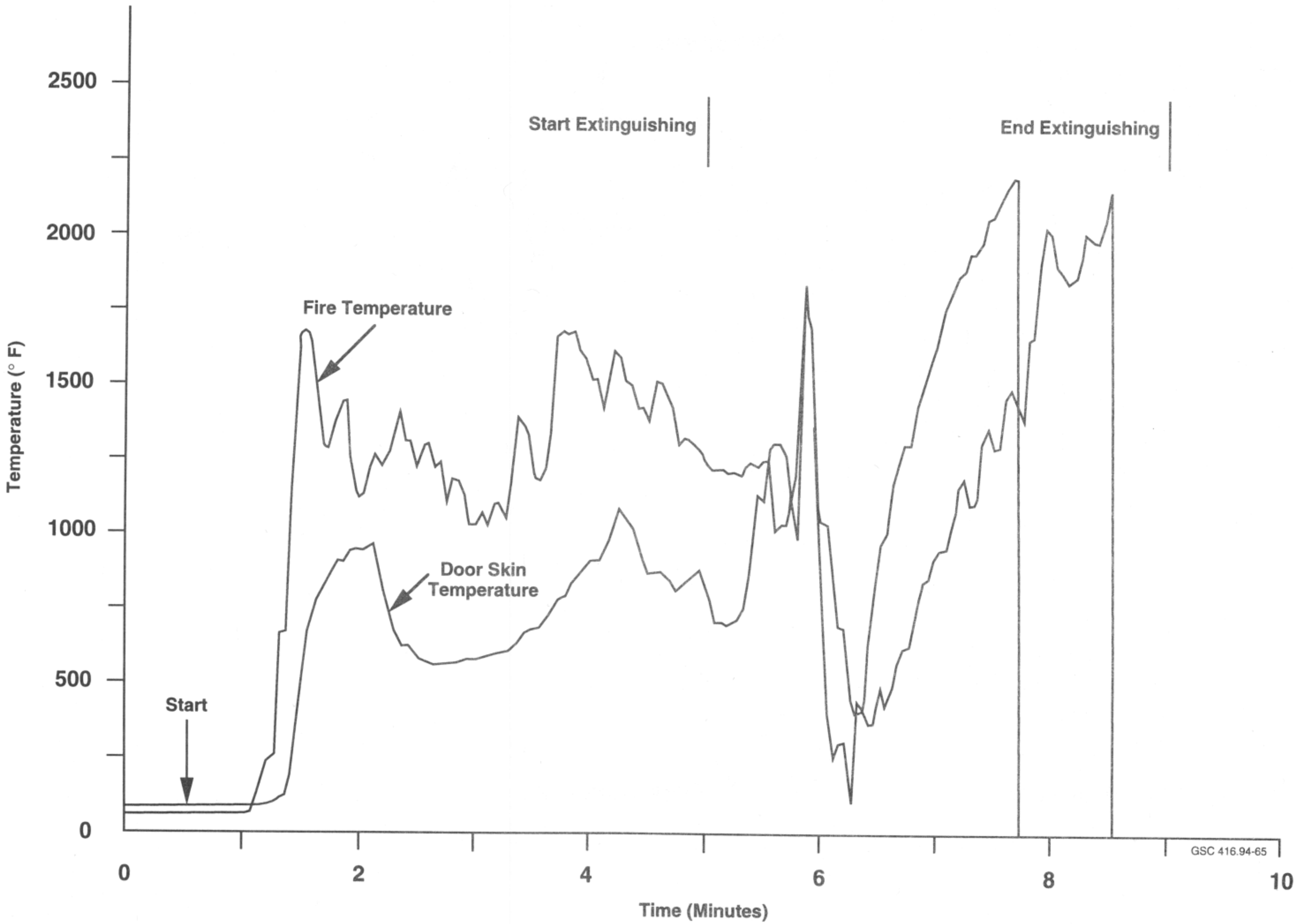

FIGURE E-11. TEST 5 EXTERNAL FIRE AND PORT ENTRY DOOR SKIN TEMPERATURES AT STATION 341

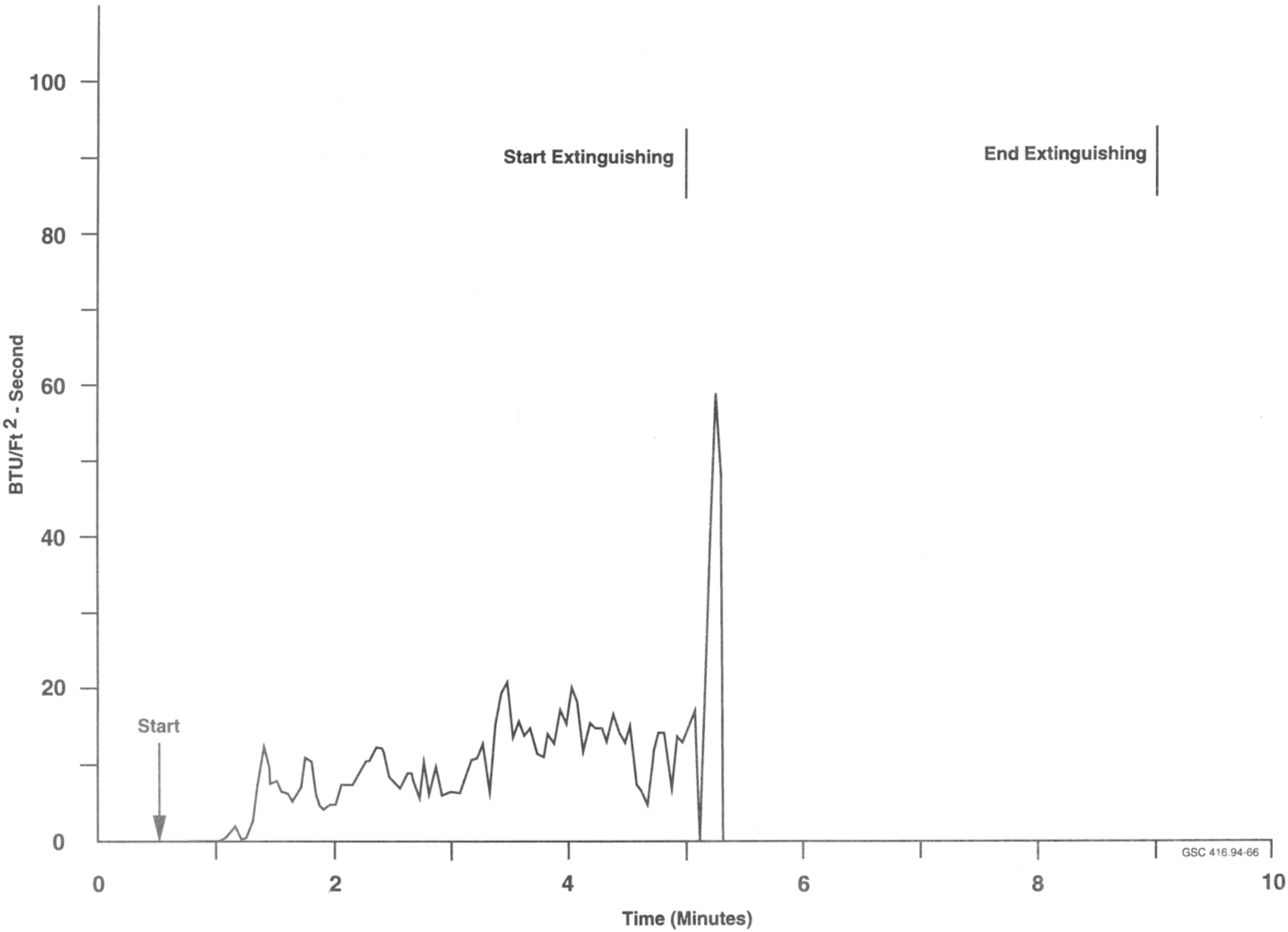

FIGURE E-12. TEST 5 EXTERNAL HEAT FLUX, PORT SIDE AT STATION 461

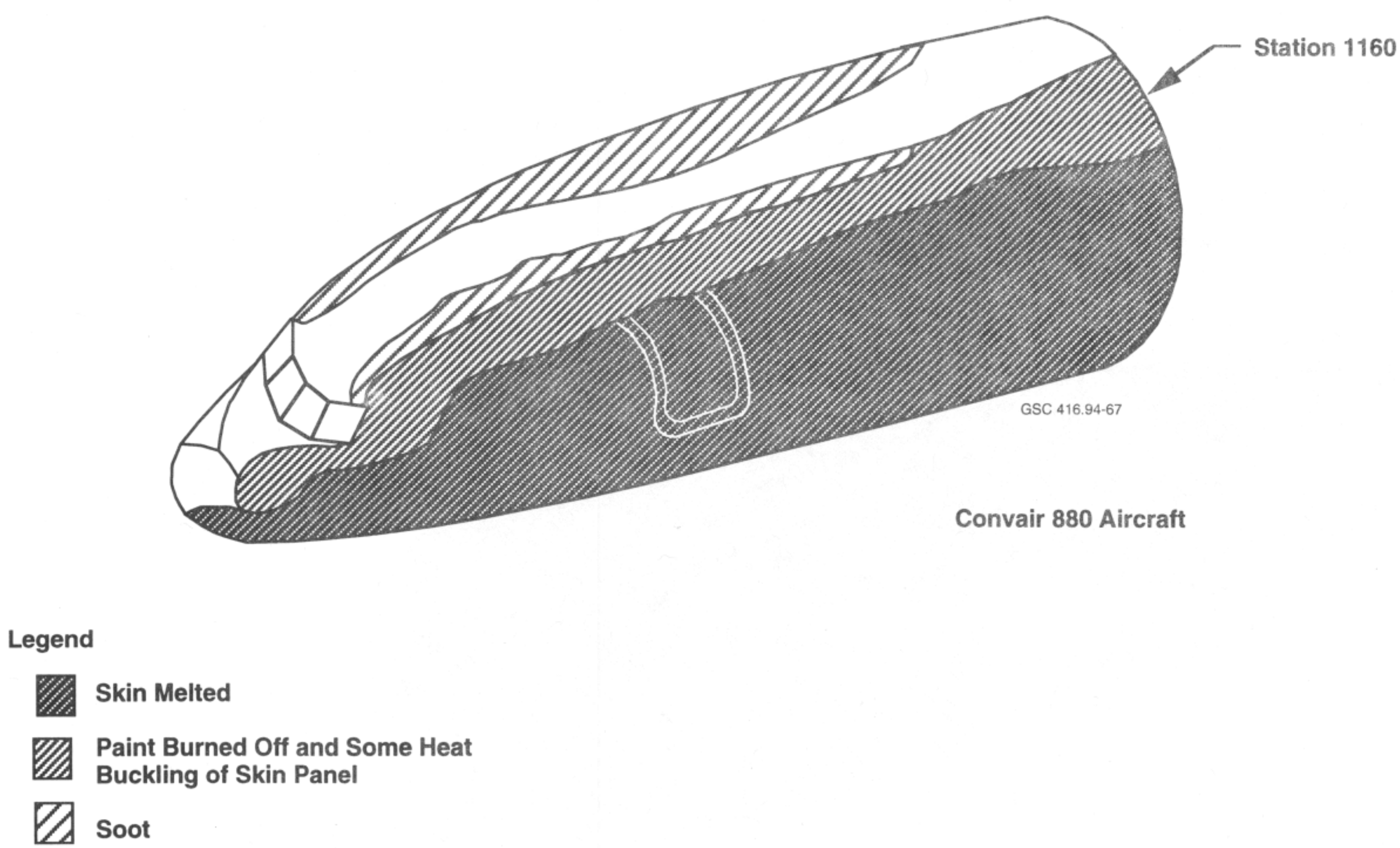

FIGURE E-13. TEST 5 EXTERIOR FIRE DAMAGE, FORWARD SECTION FUSELAGE PORT SIDE

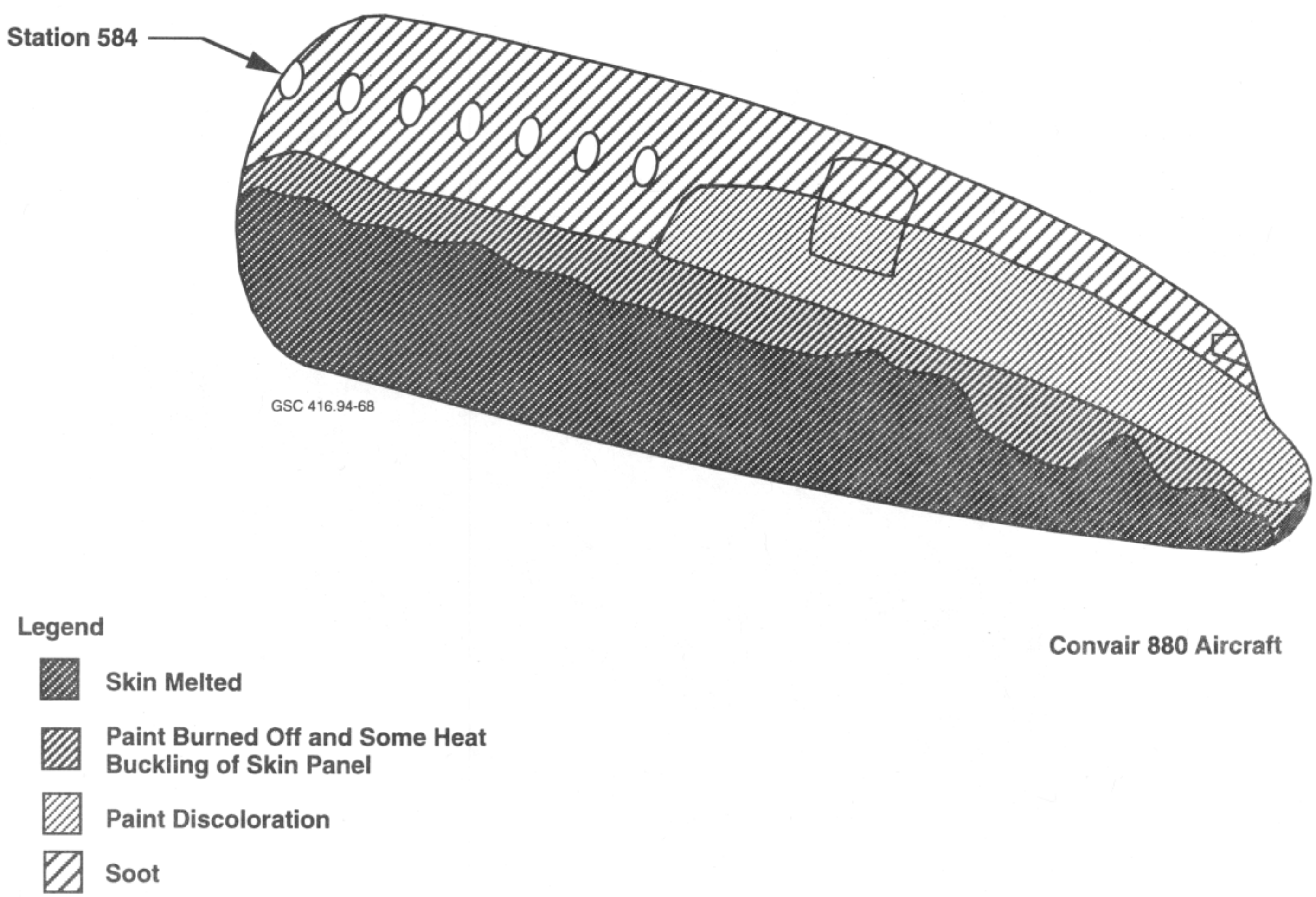

FIGURE E-14. TEST 5 EXTERIOR FIRE DAMAGE, FORWARD SECTION FUSELAGE STARBOARD SIDE

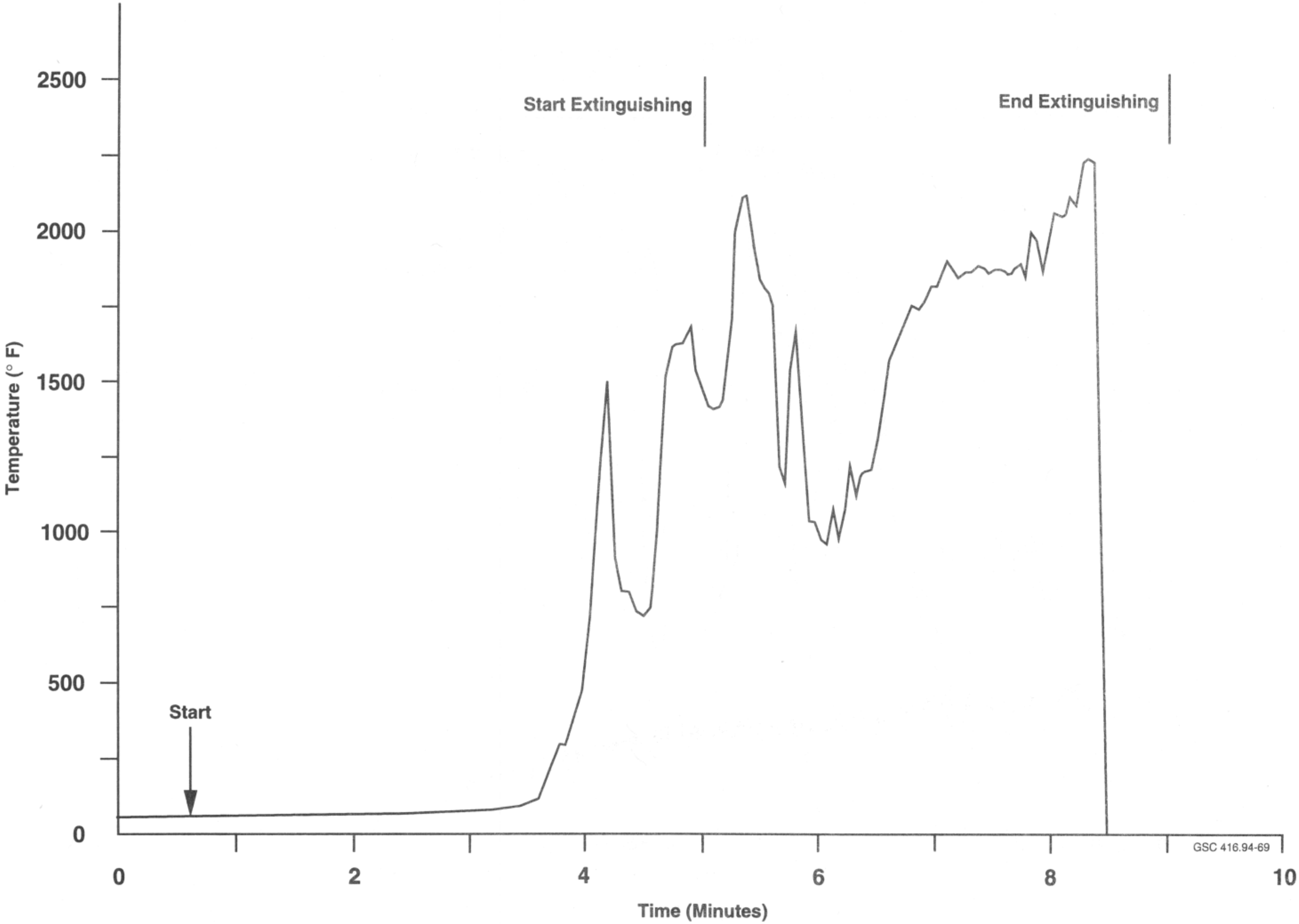

FIGURE E-15. TEST 5 CARGO COMPARTMENT AIR TEMPERATURE AT STATION 460

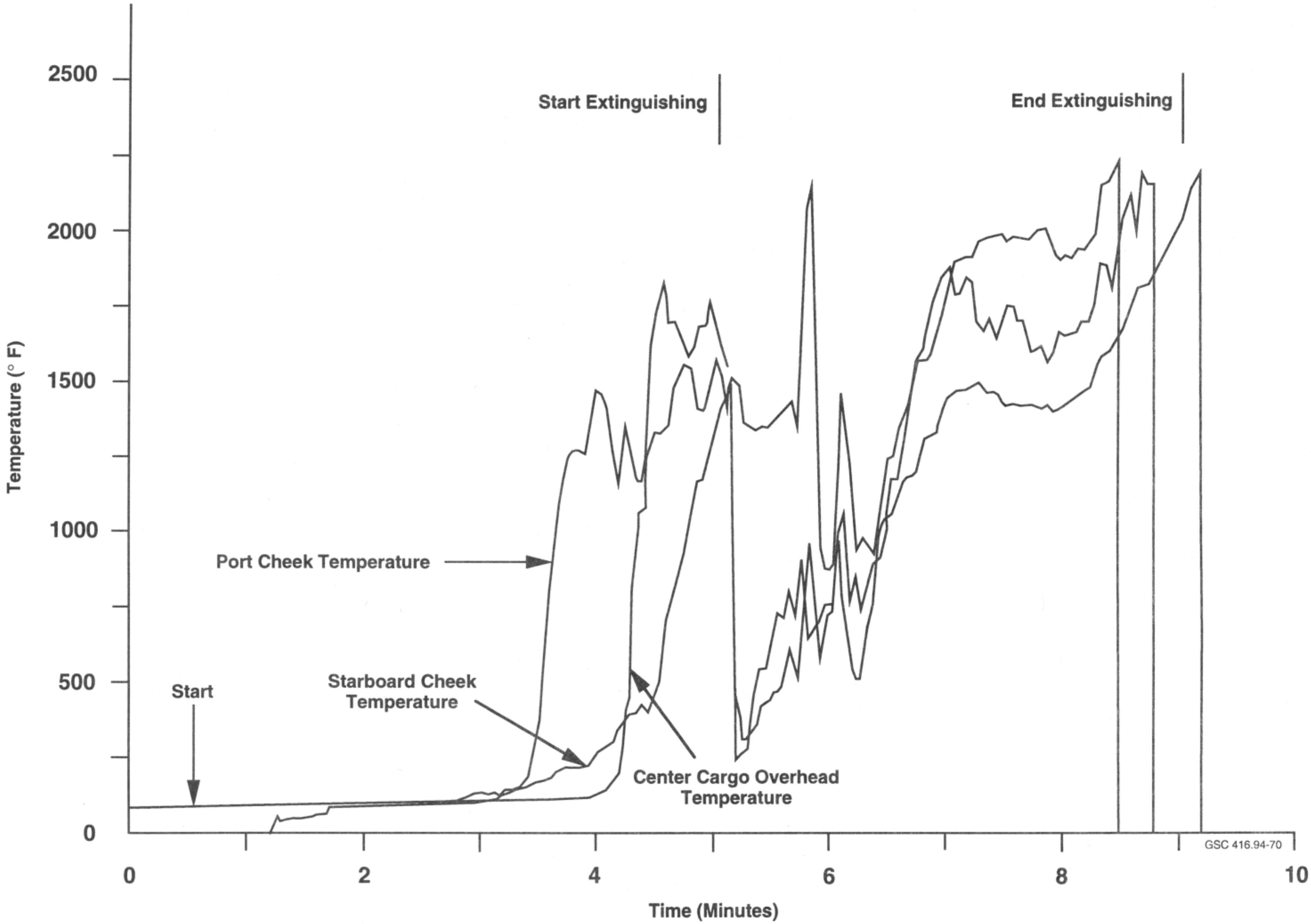

FIGURE E-16. TEST 5 PORT AND STARBOARD CHEEK AND CARGO OVERHEAD TEMPERATURES AT STATION 461

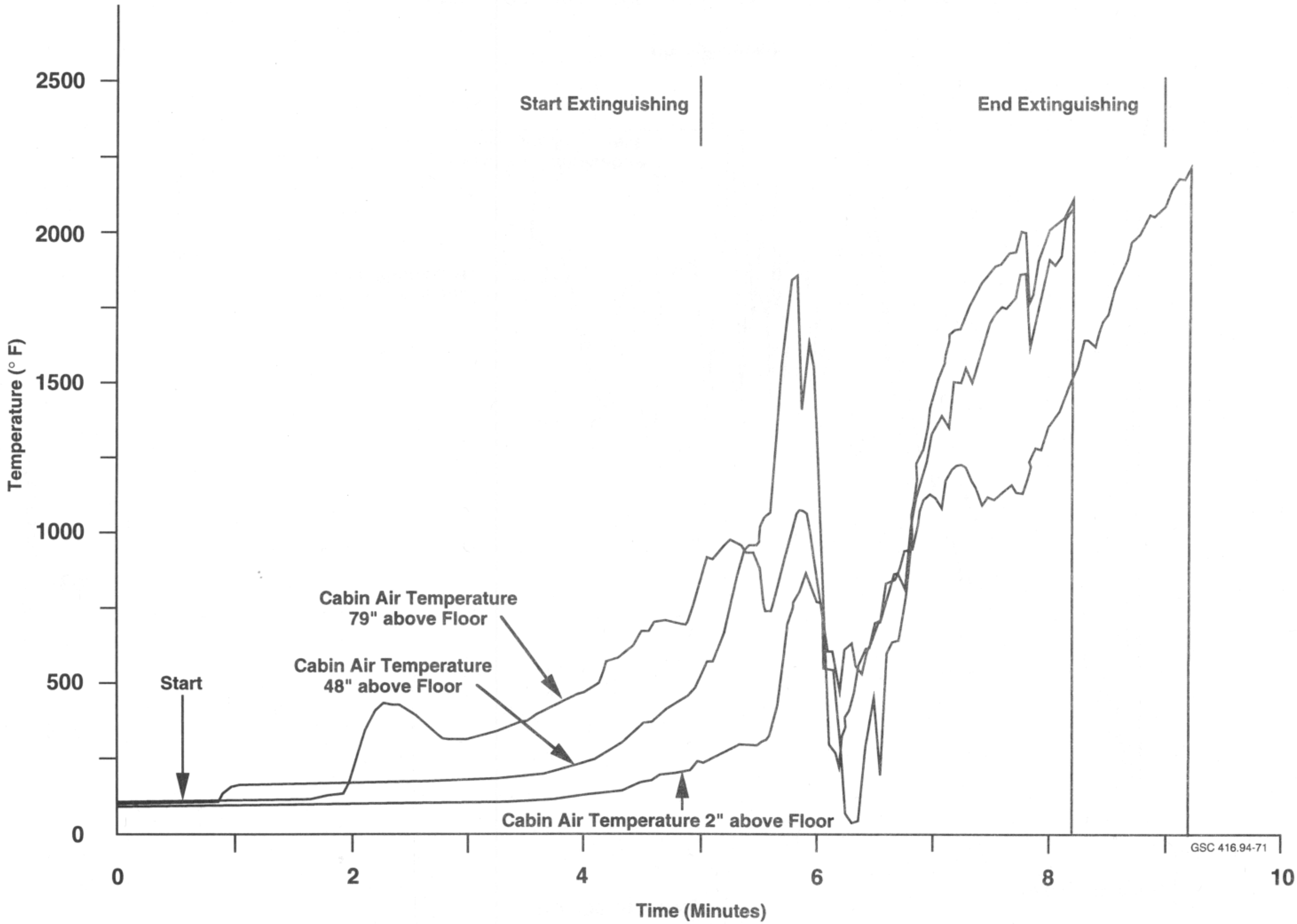

FIGURE E-17. TEST 5 CABIN AIR TEMPERATURES AT STATION 460

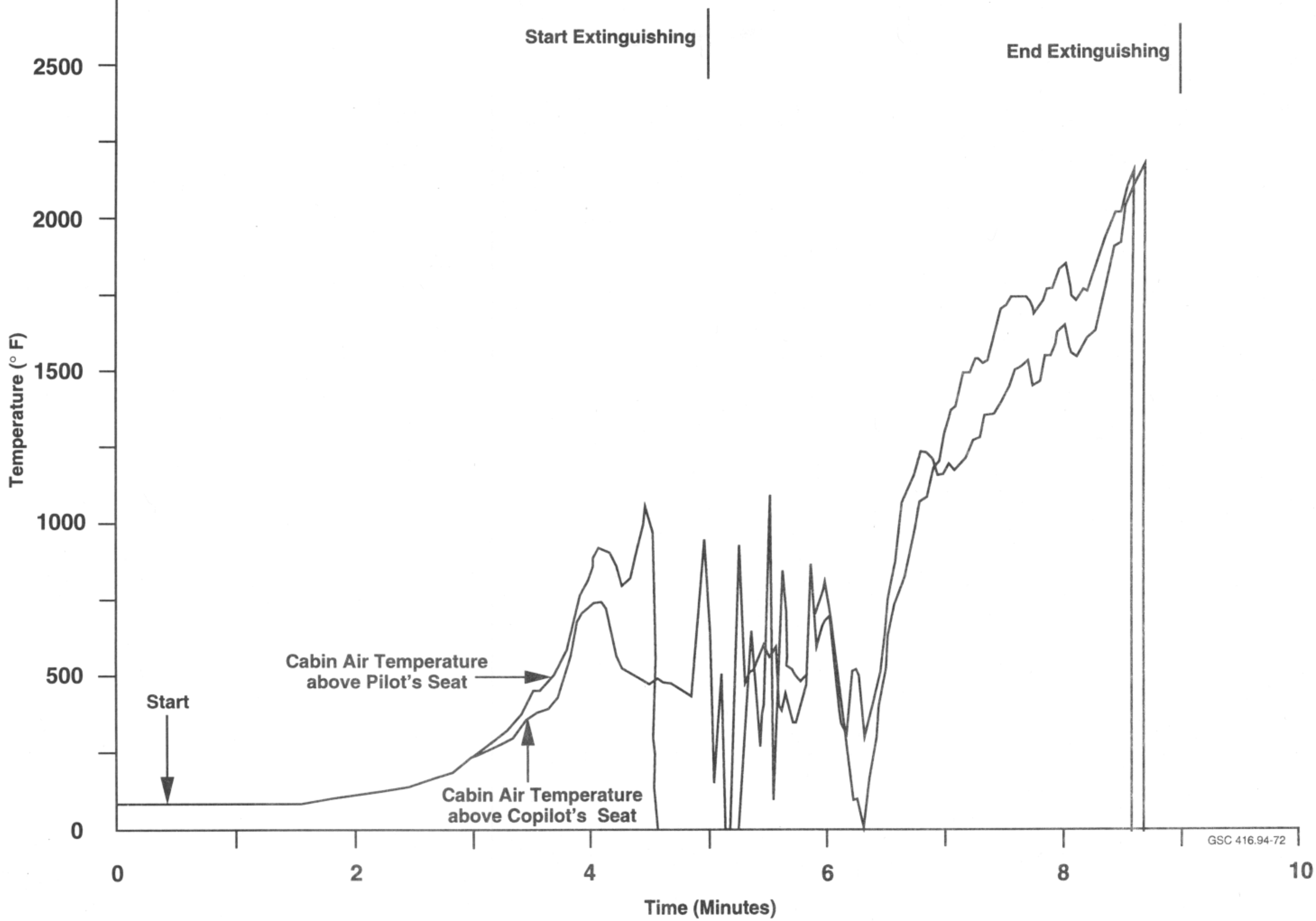

FIGURE E-18. TEST 5 COCKPIT AIR TEMPERATURE AT PILOT'S AND COPILOT'S SEATS AT STATION 238

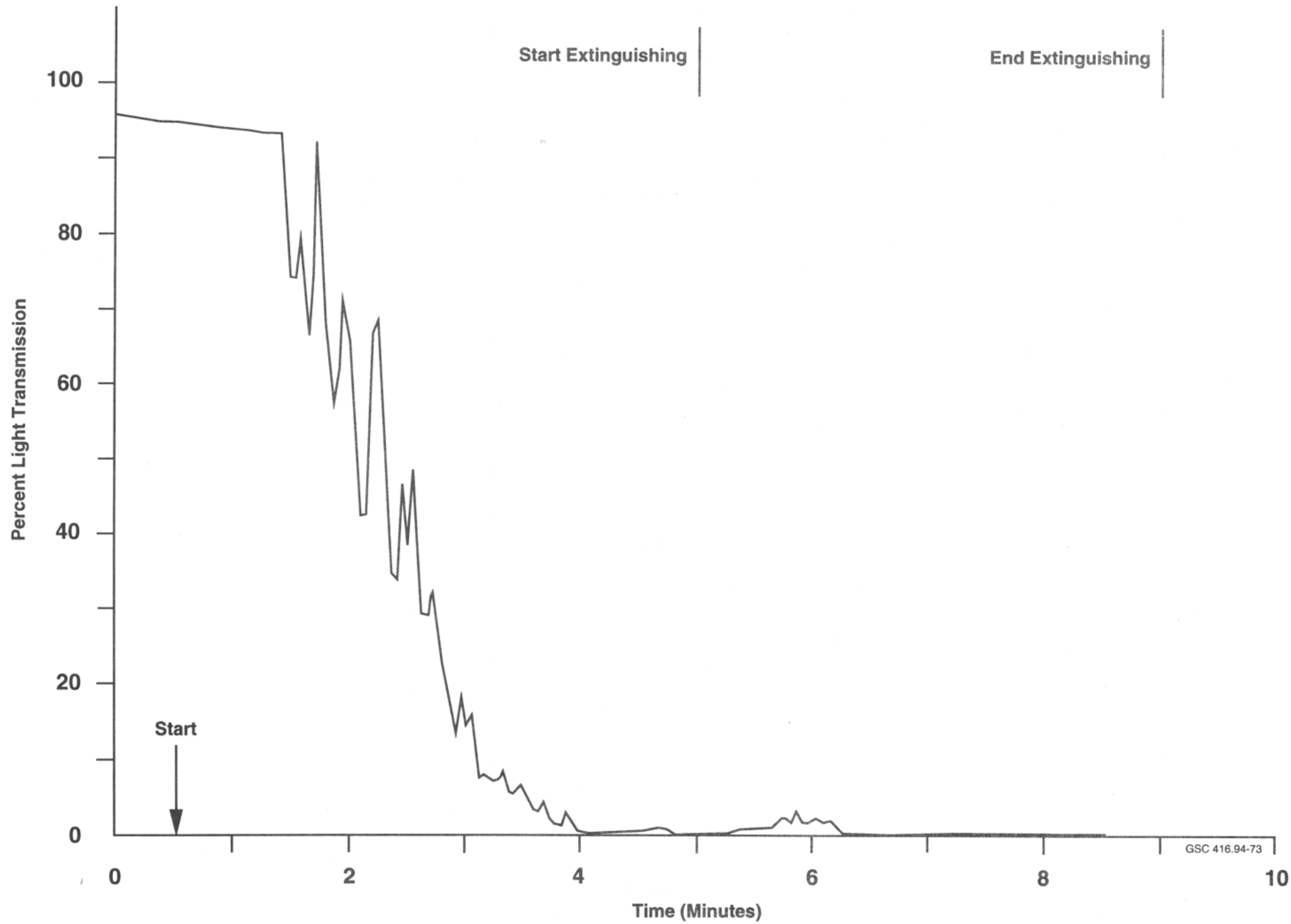

FIGURE E-19. TEST 5 SMOKE DENSITY 48" ABOVE THE FLOOR AT STATION 460

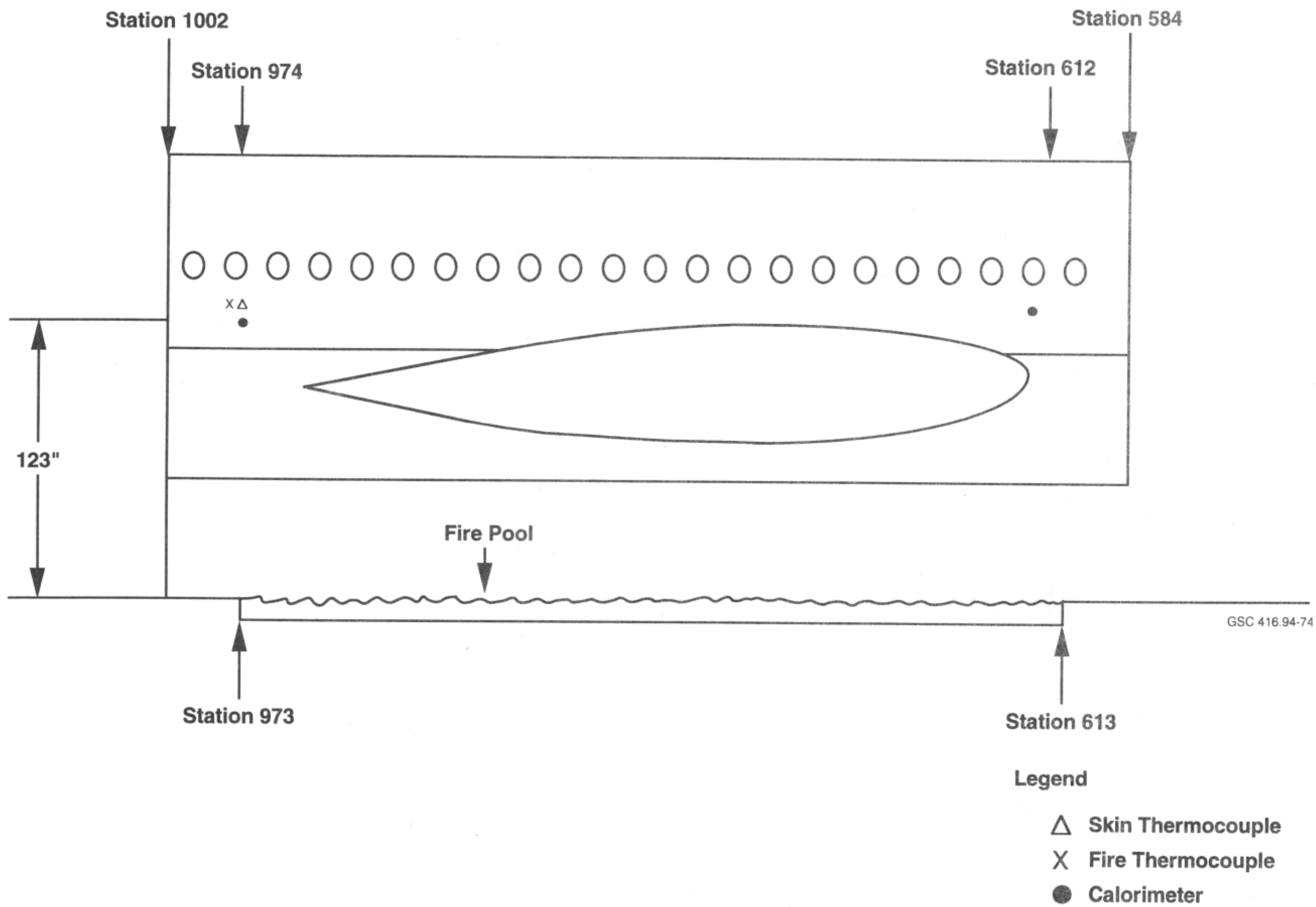

FIGURE F-1. TEST 6 CV-880 INSTRUMENTATION LOCATIONS, STARBOARD SIDE

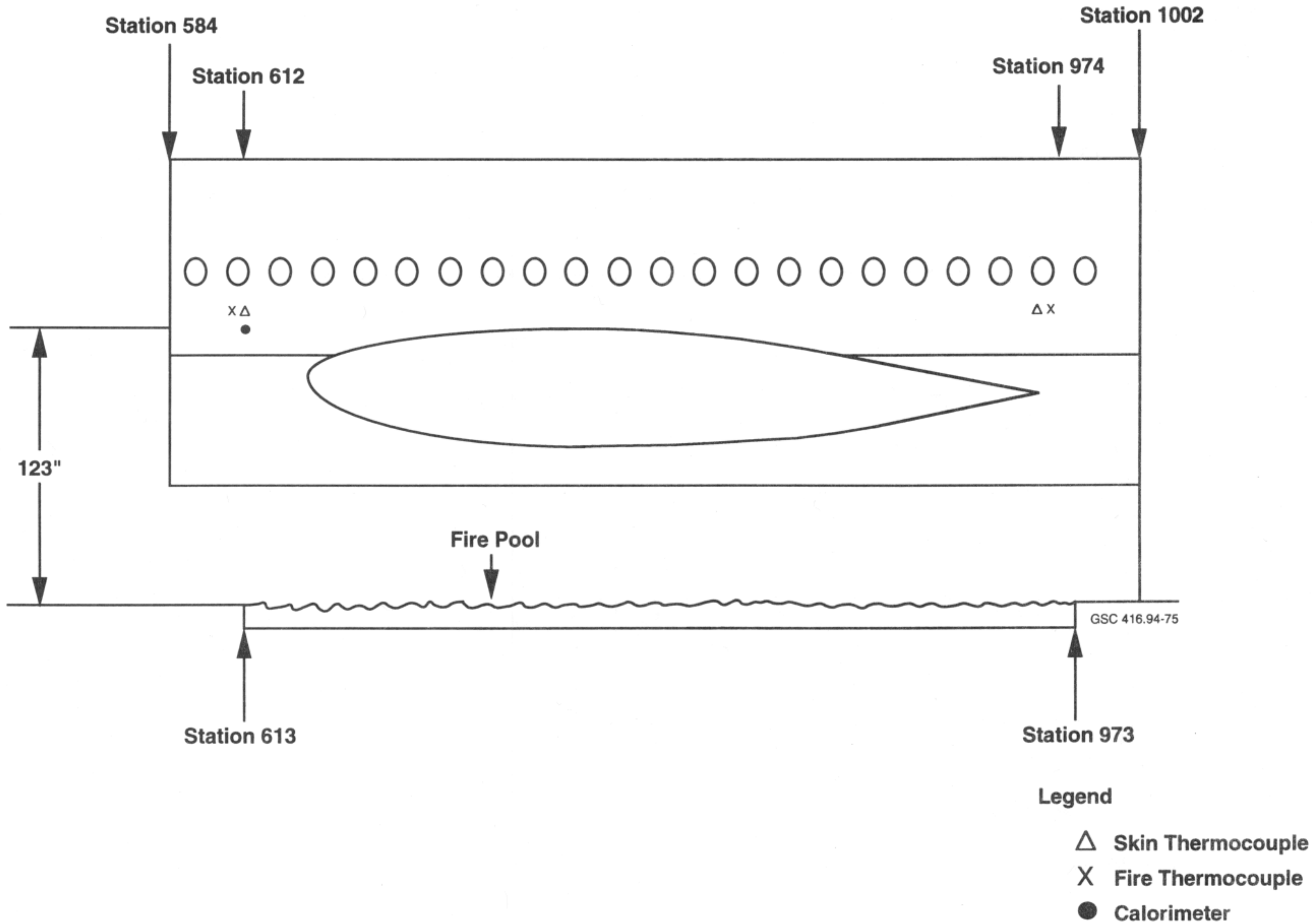

FIGURE F-2. TEST 6 CV-880 INSTRUMENTATION LOCATIONS, PORT SIDE

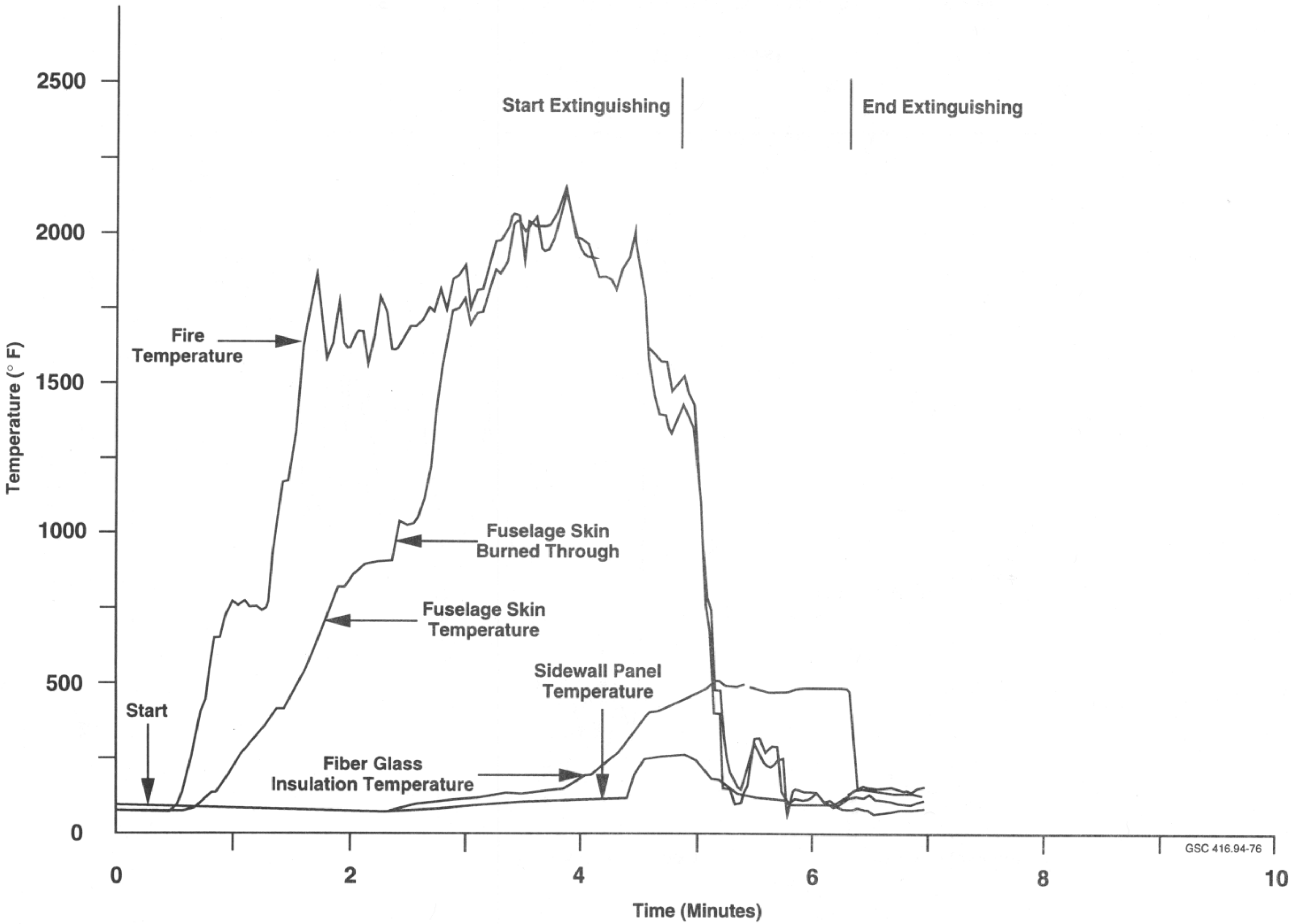

FIGURE F-3. TEST 6 FIRE, FUSELAGE SKIN, FIBER GLASS INSULATION, AND INTERIOR PANEL TEMPERATURES STARBOARD SIDE AT STATION 974

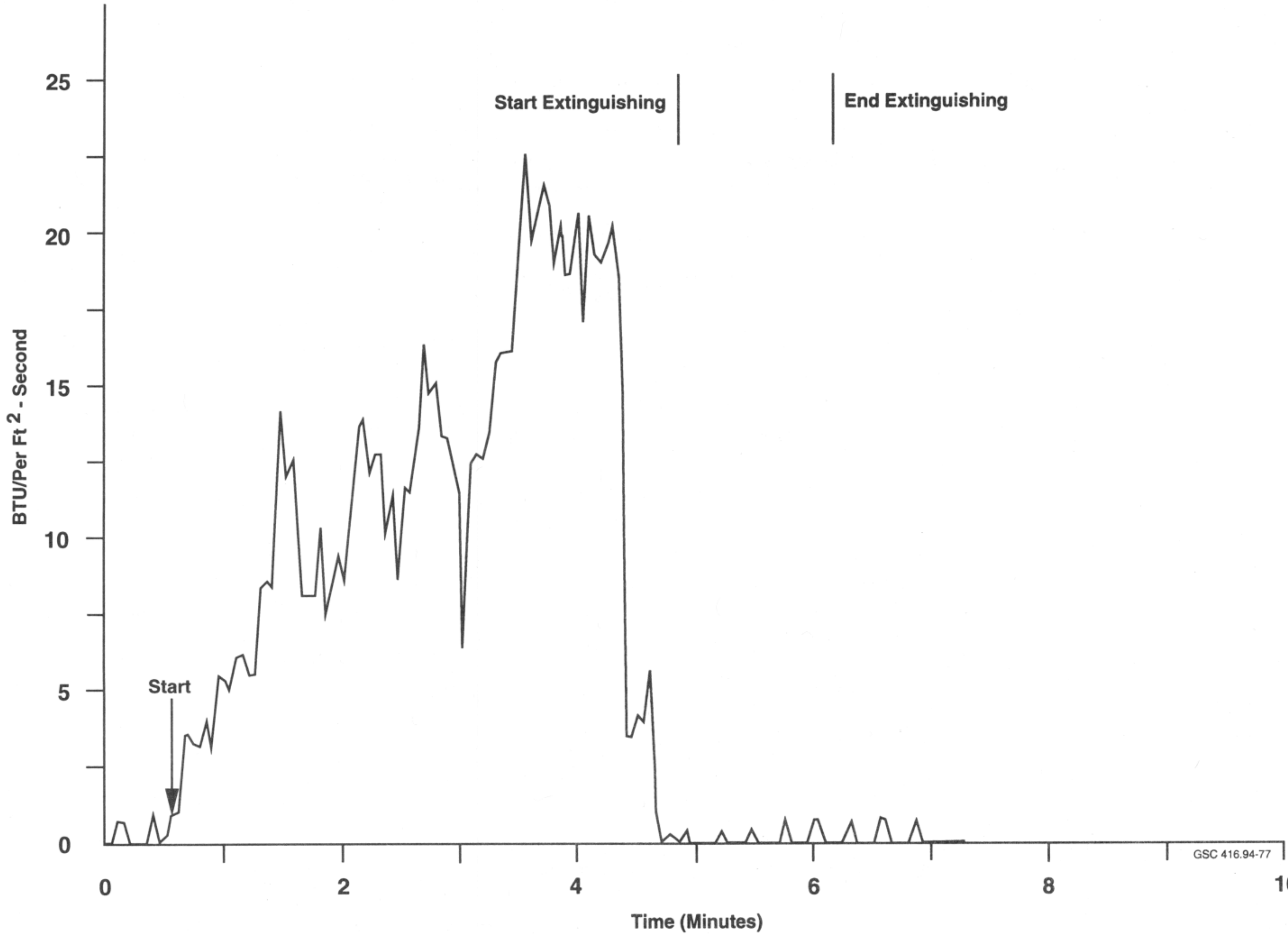

FIGURE F-4. TEST 6 EXTERNAL HEAT FLUX, STARBOARD SIDE AT STATION 974

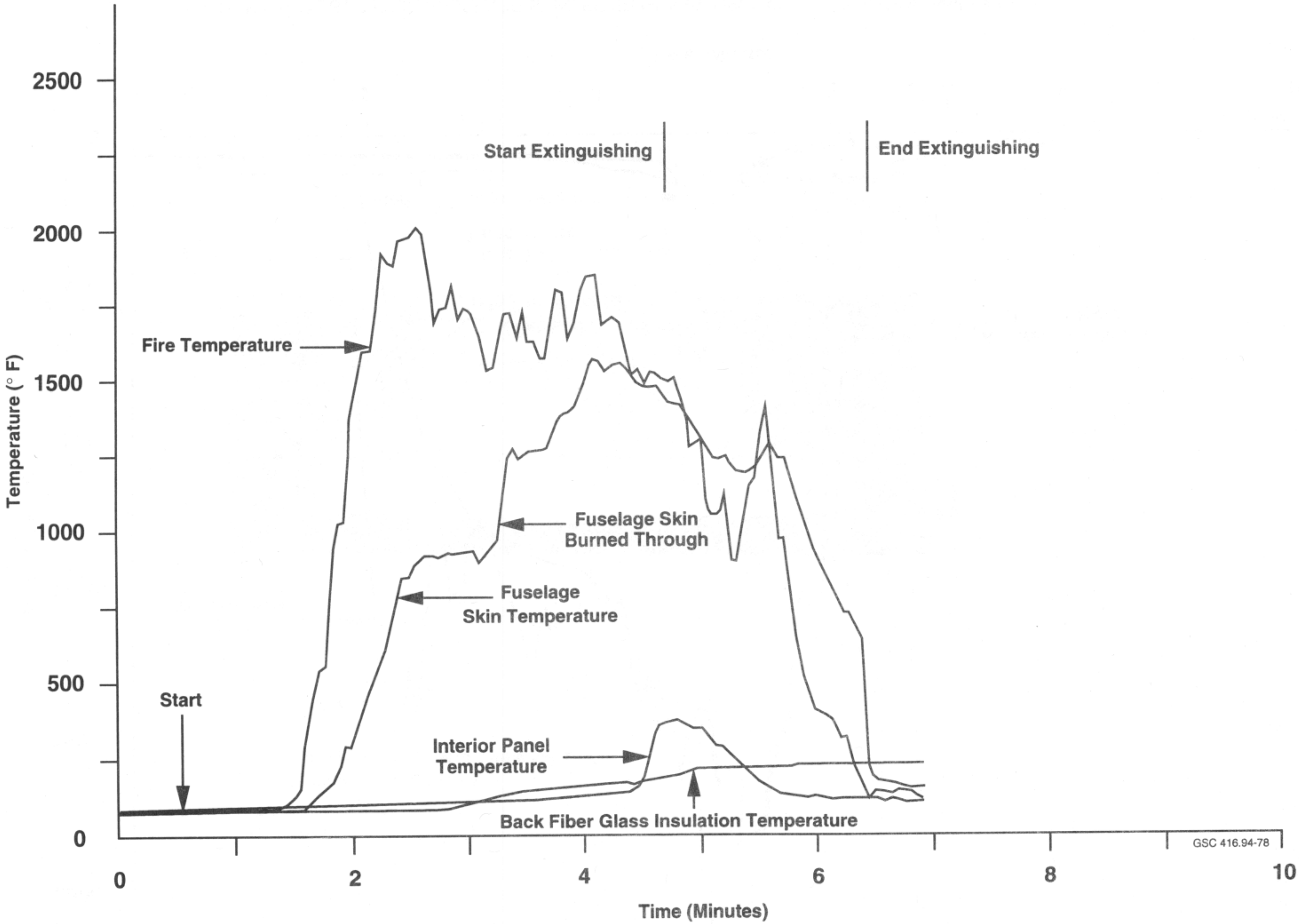

FIGURE F-5. TEST 6 FIRE, FUSELAGE SKIN, FIBER GLASS INSULATION, AND INTERIOR PANEL TEMPERATURES, PORT SIDE AT STATION 974

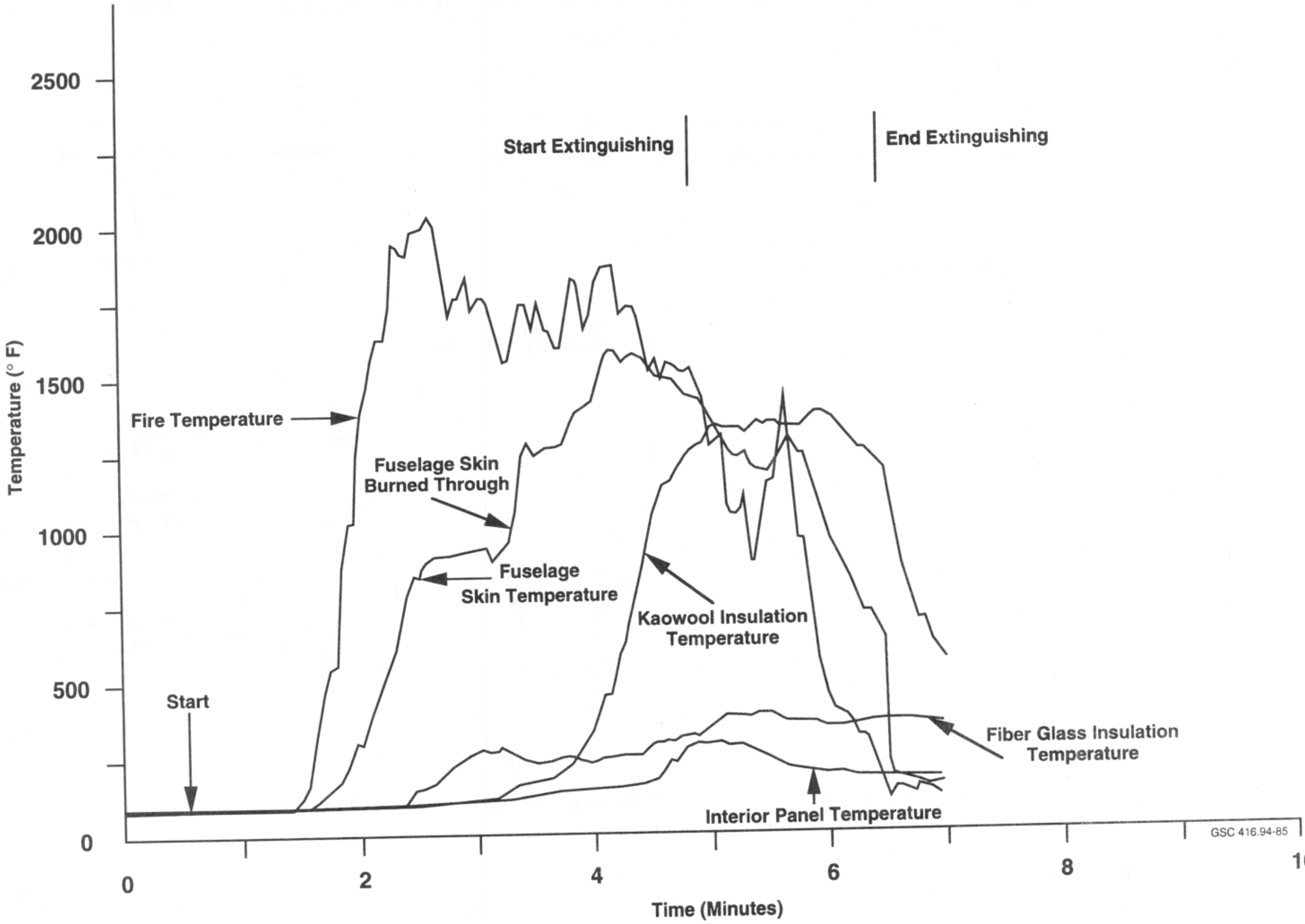

FIGURE F-12. TEST 6 FIRE, FUSELAGE SKIN, FIBER GLASS INSULATION, KAOWOOL INSULATION, AND INTERIOR PANEL TEMPERATURES PORT SIDE AT STATION 955

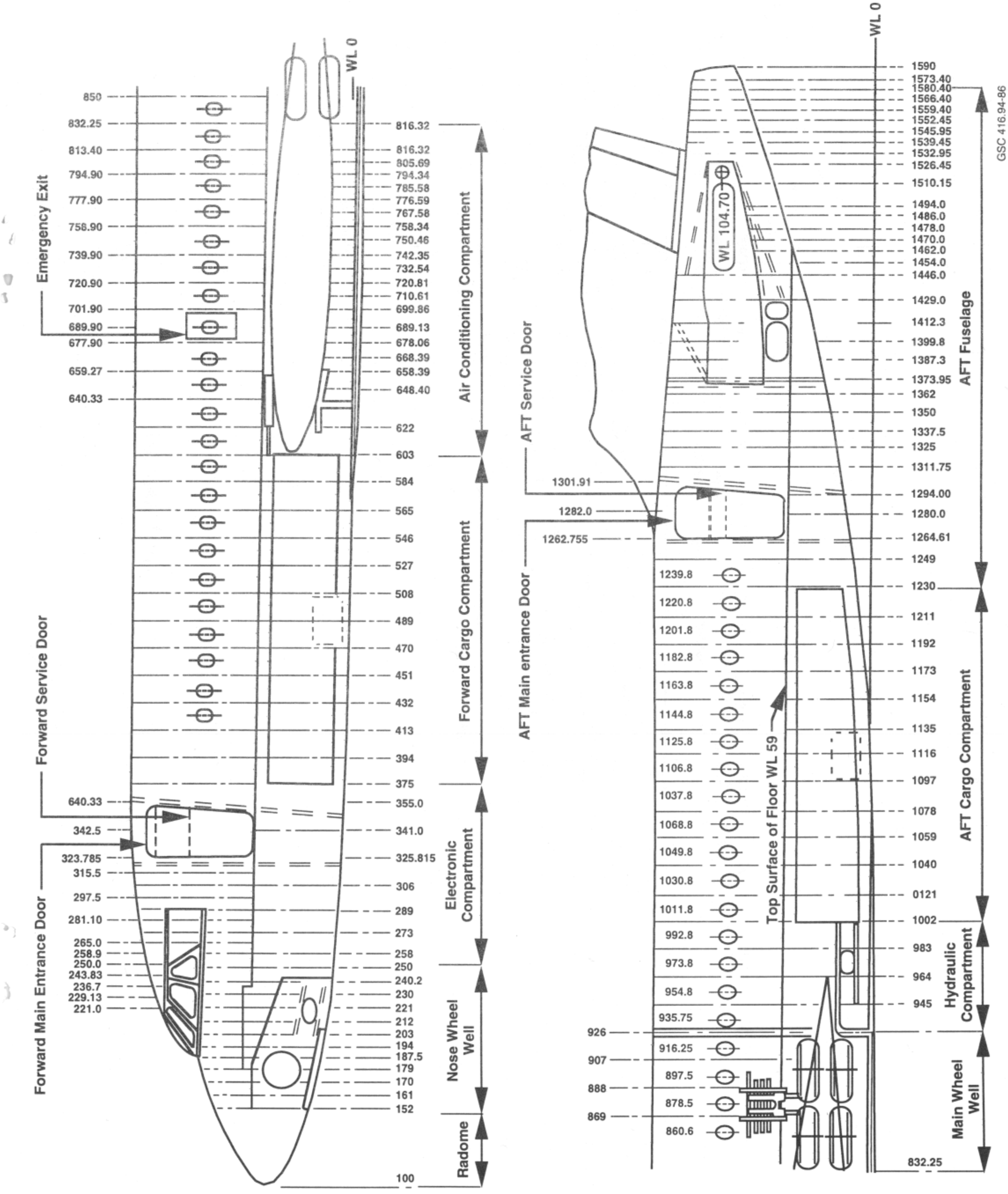

FIGURE G-1. CV-880 FUSELAGE STATION DIAGRAM

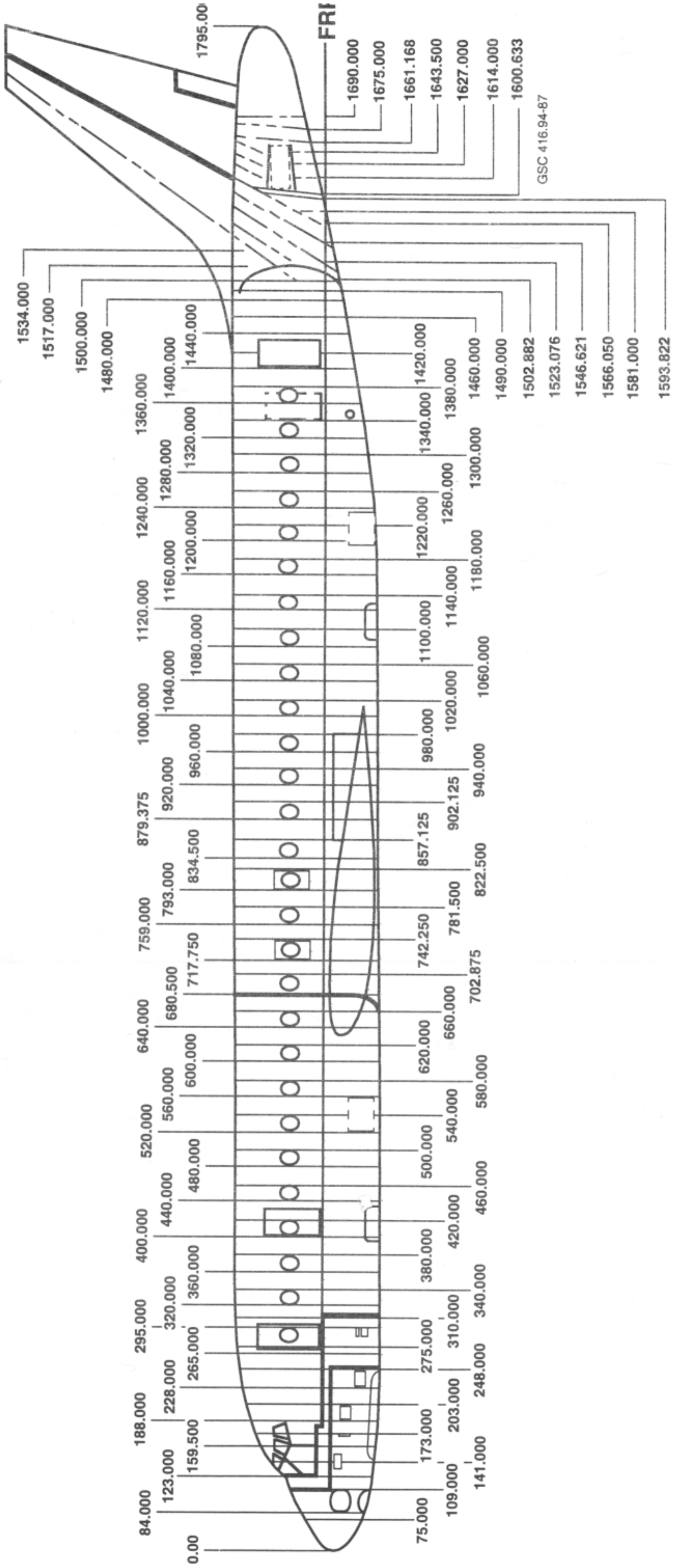

FIGURE G-2. DC-8 STATION DIAGRAM

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