

Full-Scale Air Transport Category Fuselage Burnthrough Tests

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16. Abstract This report represents the observations, test data, and conclusions obtained during the course of six full-scale fuselage burnthrough tests. These tests were conducted at the Laurinburg-Maxton Airport, Maxton, North Carolina, in conjunction with Charlotte Aircraft Corporation. 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. <u>TEST RESULTS.</u> 1. The aluminum skin provides protection from a fully developed fuel fire for 30 to 60 seconds. 2. The fiberglass 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 cawlrthrough, that are not acoustically insulated are more vulnerable to burnthrough than other parts of the insulated fuselage.					
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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 Technical Center personnel at the Laurinburg-Maxton Airport, Maxton, North Carolina, in conjunction with Charlotte Aircraft Corporation. 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.

TEST RESULTS.

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

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. 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, motionpicture, and video coverage was provided for each test (appendix A).

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

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 adjacent compartments from the fuel fire. Temperature and heat flux measuring devices were installed to record the thermal conditions within the aircraft and the external fuel fire. 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.

Gas analyzers were used to measure the environmental conditions within the passenger compartment. The levels of oxygen, carbon monoxide, and carbon dioxide were measured throughout the test (appendix A).

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

The size of the fuel pit was varied to provide optimum exposure of the test compartment to the fuel fire. Sufficient fuel was provided to insure 6 to 8 minutes of undiminished 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 Federal Aviation Administration (FAA) installed water deluge sprinkler system.

The 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 #	Plane	Mode	Section	Wind	Duration* (Minutes)
1	DC-8	wheels up	Aft	Calm	2:37
2	DC-8	wheels up	Nose	3 kns	3:13
3	DC-8	wheels up	Center	Calm	6:42
4	CV-880	wheels down	Aft	3-7 kns	6:00
5	CV-880	wheels down	Nose	3-6 kns	4:50
6	CV-880	wheels down	Center	Calm	4:01

*Water sprinklers turned on; pool fire extinguishment started.

DC-8

DC-8 FUSELAGE PARTITIONING.

The DC-8 was partitioned into three compartments by constructing two partitions within the fuselage. 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 500. 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
- Five starboard side windows

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 liferaft 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

COMPARTMENT 3. The third compartment extended aft of the second partition located at station 1160 to the aft pressure bulkhead. This compartment was approximately 27 feet long. It 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 crawlthrough including the outflow valves
- Six right side windows

Each compartment also had the following in common:

- 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 were constructed of woven fiberglass on the floor and sidewall and unidirectional fiberglass on the ceiling.
Cabin floor carpeting

TEST No. 1 DC-8 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. The fire took approximately 50 seconds to cover the entire pool. By the 68-second mark, flames had penetrated the door seals of the aft service door and smoke and momentary flames (1/10 second 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.

EXTERIOR FIRE DAMAGE.

Skin Penetration. The aluminum skin melted away in an area below the floor centered about the aft service door (figure B-1). The damage extended approximately 6 feet forward and 5 feet aft of the door. The skin was buckled near the melted area, extending approximately 30 inches on all sides. 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.

Fiberglass Insulation. The insulation exposed by the melted skin was charred but mostly intact. The insulation extended downward 30 inches from the floor level. The insulation had fallen away in the cheek area, approximately 3 feet forward of the aft service door, exposing the cargo compartment to the fire. The cargo liner was cracked and scorched in the 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 mechanism and interior panel to the fire. The door window exterior pressure pane was opaque and bulged toward the fire but remained intact. The interior fail-safe pane was clear and undamaged.

CARGO COMPARTMENT. The cargo liner was cracked and burnt 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 fiberglass insulation bonded to the interior 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 when it was detected. The cabin side of the ceiling panel was soot covered but undamaged. The back side of the ceiling panels that form the overhead were burnt 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 equipment bay 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, allowing access to the overhead.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature. The air temperature in this test did not rise significantly during the test. The maximum temperature recorded at the ceiling was 105 degrees Fahrenheit (°F) just prior to sprinkler activation.

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 from ignition, but the cabin never became fully obscured.

Toxic Gases. There were no provisions for toxic gas measurement for this test.

TEST No. 2 DC-8 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. 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 port 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 into the test. Fire penetrated the cargo door seals at 110 seconds into the test. By 140 seconds, the cabin and cargo compartment became totally obscured.

The test was terminated at 3 minutes and 13 seconds by activating the sprinkler system and extinguishing the pool fire.

EXTERIOR FIRE DAMAGE.

Skin Penetration. The aluminum skin was extensively destroyed from the fire barrier located at the compartment partition forward approximately 16 feet (figure B-2). The damage extended from ground level up to the center or the top of the aircraft. 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 the frames.

Fiberglass Insulation. Most of the bagged insulation remained in place and was heavily charred on the fire side.

Forward Service Door. The skin on the door was completely melted away. Both the door window pressure and fail-safe panes were gone from the 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. The inner door panel was also completely destroyed allowing direct fire access to the cargo compartment.

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 with no significant damage. 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. 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 panel.

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.

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 cut 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.

Smoke. Smoke penetrated the cabin at 51 seconds from ignition with total obscuration occurring at 2 minutes and 13 seconds.

Toxic Gases. Provisions were made for measurement of carbon dioxide, carbon monoxide, and oxygen.

CO₂: 4.4 percent at 90 seconds from ignition (maximum value).

CO: 130 ppm at 90 seconds (maximum value).

O₂: 15 percent at 90 seconds (minimum value).

TEST No. 3 DC-8 CENTER SECTION.

The starboard side of the center section of the DC-8 was exposed to a 12- by 38-foot pool fire containing 400 gallons of Jet A fuel. 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 half way 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 from 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 and 42 seconds, the sprinkler system was activated and the pool fire was extinguished by the standby firemen, terminating the test.

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 (figure B-3). There was a small hole above the wheel well, 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 exposing the cargo liner. 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.

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. 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 aluminum skin on the forward hatch was sooted and heat damaged but not melted. The skin on the aft hatch was 50 percent melted away.

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 burnt off all the way to the ceiling. The sidewall panel even with the trailing edge of the wing also had the vinyl covering burnt but only 12 inches above the grill. There were soot trails above the other floor grills. The vinyl covering was also burnt around the penetrated window.

Fiberglass Insulation. Removal of the sidewall panels exposed the insulation. The insulation was heavily charred where the skin had been breached. In some cases the backside of the sidewall panels was charred also.

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 with Halon 1211 at the test termination. 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 burnt.

Floor. The rug near the floor grill flame penetration was burnt in a semi-circle 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. This allowed access to the floor grills. Fire did penetrate 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 sidewall panels surrounding and above the window ignited as well as the ceiling panel. The ceiling overhead 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.

Smoke. Smoke penetrated the cabin at 50 seconds into the test, total obscuration occurred at 5 minutes.

Toxic Gases. No data taken.

CONVAIR 880

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. It created a compartment approximately 30 feet long and included the following:

- Cockpit
- Radio rack
- Nose wheel and well
- Electronic compartment
- Most of the forward cargo compartment
- First class cabin
- Port entry door
- Starboard service door
- Cargo compartment hatch
- Cabin windows

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 wells
- Center fuel tank
- Air conditioning compartment
- Hydraulic compartment
- Thirty-five feet of cabin

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

Each compartment had the following in common:

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

Cabin floor carpeting
Cabin interior panels

TEST No. 4 880 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 centered under fuselage between stations 1050 and 1362. The fire took approximately 40 seconds to cover the entire pool. At 1 minute and 26 seconds, smoke penetrated the cabin floor just forward of the aft port lavatory. A small fireball 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 and 7 seconds. Ten seconds after the smoke appeared, flames were visibly penetrating the aft cargo bulkhead. The cargo compartment became completely obscured 3 minutes and 46 seconds into the test. Six minutes from ignition, the sprinkler system was activated and the pool fire was extinguished by standby firemen.

EXTERIOR FIRE DAMAGE.

Skin Penetration. The pool fire, though centered under the fuselage, damaged the port side significantly more than the starboard due to crosswind. The wind blew at 3 to 7 knots across the fuselage from the starboard side to the port side. The underside of the aircraft was completely destroyed from station 1040 aft to station 1350 (figures B-4 and B-5). 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. The remainder of the skin was buckled and perforated. The starboard side sustained minor damage with some slight sooting of the paint.

Port Entry Door. The door and the surrounding frame was 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. The resistance heating elements for the deicer system hung from the stabilizer. The underside was sooted and scorched. 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. The starboard side was clean and undamaged.

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

CARGO COMPARTMENT.

The cargo compartment was completely destroyed. The aft pressure bulkhead was completely gone. The ceiling of the compartment was 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.

EMPENNAGE CRAWLTHROUGH.

The belly and the port side of the fuselage were completely destroyed. The floor above the crawlthrough was completely burned through.

CABIN INTERIOR.

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 unsafe to walk on.

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

Ceiling. 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.

FIRE PATHS.

The initial penetration into the aircraft occurred in the empennage crawlthrough area behind the cargo compartment. This area was not 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 in 1 minute and 43 seconds; the cargo compartment in 2 minutes and 14 seconds. The cargo compartment appeared to provide some protection to the cabin against a pool fire of this type.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature. Six minutes from ignition (sprinkler activation), the ceiling temperature had reached 800 °F. The temperature at the floor was only 115 °F.

Smoke. Smoke penetrated the cabin at 1 minute and 26 seconds from ignition. Complete obscuration occurred at 2 minutes.

Toxic Gases.

CO₂: no data
CO: no data
O₂: 15 percent at 6 minutes

TEST No. 5 CONVAIR 880 FORWARD SECTION.

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. The fire took approximately 25 seconds to cover the entire pool. The wind was blowing across the fuselage from the starboard side to the port side at 3 to 6 knots. Thirty seconds into the test, smoke began to pour into the cabin from the cockpit. At 49 seconds from ignition, smoke penetrated the port entry door seals. At 1 minute and 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 and 49 seconds from 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 and 25 seconds, the nose began to sag. At 4 minutes and 28 seconds, the sprinkler system was activated and the firemen began to put the pool fire out. At 4 minutes and 50 seconds, the nose crashed to the ground. It took another 3 1/2 minutes to put the interior fire out.

EXTERIOR FIRE DAMAGE.

Skin Penetration. The nose section was severely damaged by the fire (figures B-6 and B-7). The port side was completely destroyed up to the centerline of the top of the fuselage. 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 away up to the floor level. 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. The nose gear was retrieved after the test 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 were 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.

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.

CABIN INTERIOR.

The interior of the aircraft was consumed by the fire. There was nothing left of the cabin interior 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.

CABIN ENVIRONMENTAL CONDITIONS.

Cabin Air Temperature.

Ceiling:

450 °F at 1.5 minutes
975 °F at 4.5 minutes (sprinklers on)

Four-foot level:

250 °F at 3 minutes
550 °F at 4.5 minutes (sprinklers on)

Floor level:

90 °F at 3.5 minutes
240 °F at 4.5 minutes (sprinklers on)

Smoke. Smoke penetrated the cabin at 30 seconds from ignition; total obscuration occurred at 1 minute and 10 seconds.

Toxic Gases.

CO₂: No data
CO: 4500 ppm at 3 minutes
O₂: 19 percent at 3 minutes

The sample line became clogged at 3 minutes.

TEST No. 6 CONVAIR 880 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. There was a zero wind condition at the time of the test. 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 and 5 seconds, smoke began to rise from the floor of the cabin at station 980. At 1 minute and 35 seconds, a momentary fire flash occurred at floor level, station 736. At the 1-minute and 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 onboard sprinkler system was broken when the plane fell to the ground.

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 B-8 and B-9). 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 584. The exposed ribs at the aft end were buckled. The windows aft of the wing had the outer pressure pane completely burned away, but the inner fail safe pane was 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. 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 in all cases was heavily charred but intact.

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 surface 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.

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, show 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.

Ceiling:

200 °F at 4 minutes (test termination)

Four-foot level:

160 °F at 4 minutes

Floor:

90 °F at 4 minutes

Smoke. Smoke penetrated the cabin at 1 minute and 5 seconds; total obscuration occurred at 1 minute and 30 seconds from ignition.

Toxic gases.

CO₂: 3.75 percent at 4 minutes (test termination)

CO: 4400 ppm at 3 minutes and 45 seconds,
unit over-ranged at this point

O₂: 16 percent at 4 minutes

TEMPERATURE DATA SUMMARY

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 about 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 aluminum skin is melting. Where the skin is exposed to a rapid fire buildup (ambient to 1800 °F in less than 30 seconds), melting generally begins 15 to 30 seconds later. After the skin melted, the thermocouples were exposed directly to the fire and functioned as a fire temperature measurement.

INNER PANEL TEMPERATURES.

The instrumentation generally provided a temperature profile through the fuselage from the fire to the skin through the insulation 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 1800 °F in 30 seconds, the skin melted 20 seconds later, the inner panel took 2 minutes and 30 seconds more to reach 200 °F.

CABIN AIR TEMPERATURES.

A thermocouple tree was provided for each test that measured cabin air temperatures at floor level, 4 feet above floor level, and 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/ft²-sec were normal. A fully developed fire averaged 15 Btu/ft²-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 and 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.

WINDOW PANE TEMPERATURES.

The window panes, made of a stretched acrylic resin, were effective flame barriers. The outer pressure pane showed 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 12 inches from the window registered near zero heat flux being transmitted through the stretched acrylic window panes due to the charring of the pressure pane.

SMOKE DATA

An optical smoke meter was provided for most tests located at the 4-foot level in the center of the cabin compartment. This unit provided information on cabin visibility measured in percent light transmission. In most cases, once smoke began to enter the cabin, total obscuration occurred in approximately 1 to 2 minutes.

GAS DATA

A limited number of gas measurements were made during the Convair 880 testing. Analyzers were provided to measure the concentrations of carbon monoxide, carbon dioxide, and oxygen. For the center section of the Convair 880, the carbon dioxide level peaked at 8 percent 4 minutes and 50 seconds into the test and the oxygen level decreased to 4 percent. The carbon monoxide level went off-scale 3 minutes and 55 seconds into the test at 4500 parts per million.

CONCLUSIONS

1. Aluminum skin can be expected to provide protection from a fully developed pool fire for 30 to 60 seconds.
2. Windows are effective flame barriers until they are consumed by the fire which allows penetration.
3. Fiberglass acoustical insulation is an effective thermal barrier under the test conditions.
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.
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.

APPENDIX A

INSTRUMENTATION EQUIPMENT

IBM PC/AT Computer, Labtech Notebook,
Burr-Brown Data Acquisition System.

Data General One, Omega Data Acquisition System.

Measuring Devices:

Thermocouples: Thermo Electric Type K
Chromal/Alumel, P/N K116U-304-0-24-OX

Heat Flux Transducers: Thermogage, Model No.
1000-1, Ranges 0-5, 0-12, 0-15, 0-30
BTU/FT²-sec.

Smoke Meter: In-house FAA Design. Light
Source, Magna-light pen light; Receiver,
Hugen Weston Photronic Cell, Model No.
856-9901011-YR.

Gas Analyzers: Beckman Model 865 Infrared
Analyzers for CO and CO₂. Beckman Oxygen
Analyzer.

Video Cameras.

Motion Picture Cameras.

APPENDIX B

DC-8 AND CONVAIR 880 EXTERIOR FUSELAGE DAMAGE FROM FIRE TESTS

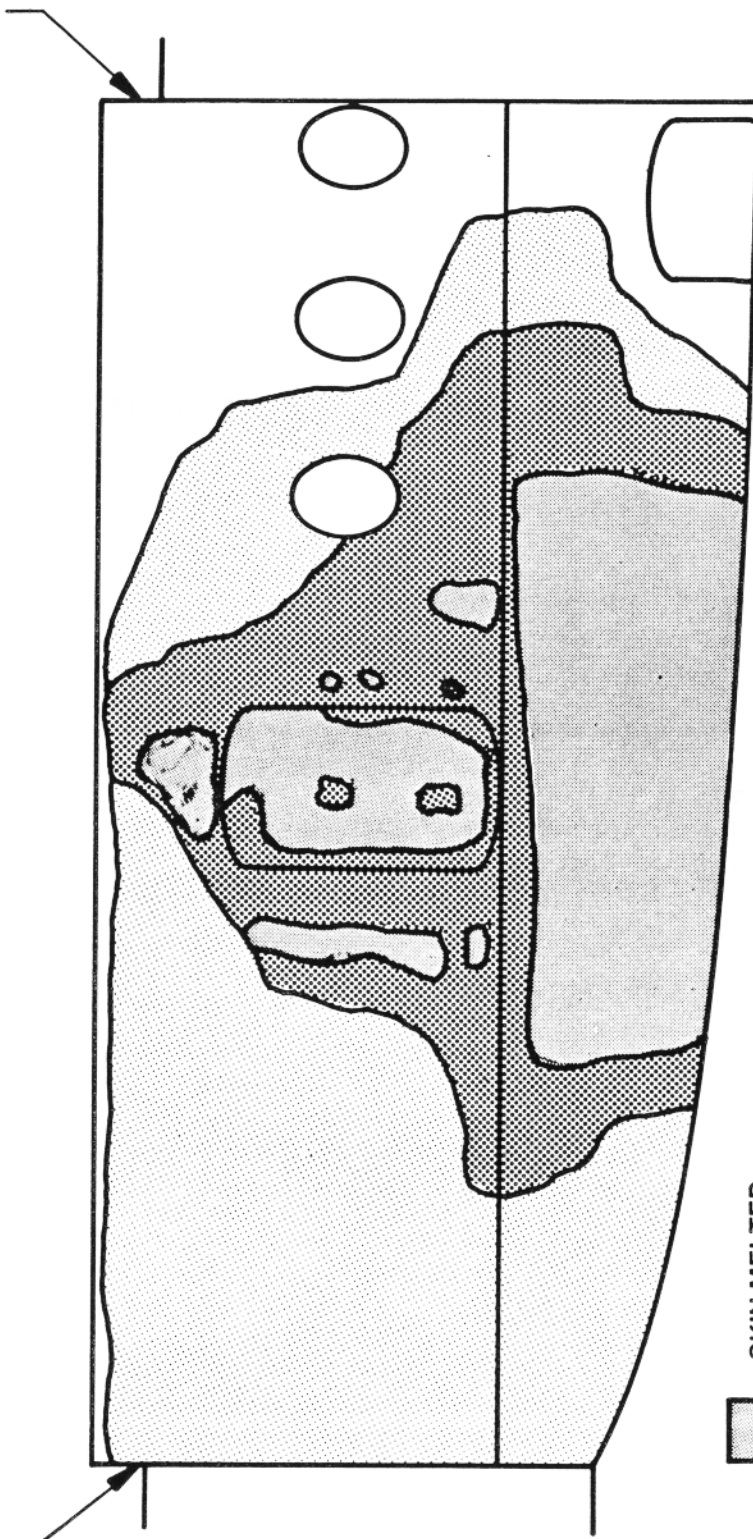
DC-8

Test No. 1: Aft Section
Test No. 2: Forward Section
Test No. 3: Center Section

Convair 880

Test No. 4: Aft Section
Test No. 5: Forward Section
Test No. 6: Center Section

ST 1160



ST 1476

SKIN MELTED

PAINT BURNT OFF AND SOME HEAT BUCKLING
OF SKIN PANEL

SOOT

DC-8 AIRCRAFT
TEST #1

FIGURE B-1. EXTERIOR FIRE DAMAGE: AFT SECTION FUSELAGE STARBOARD SIDE

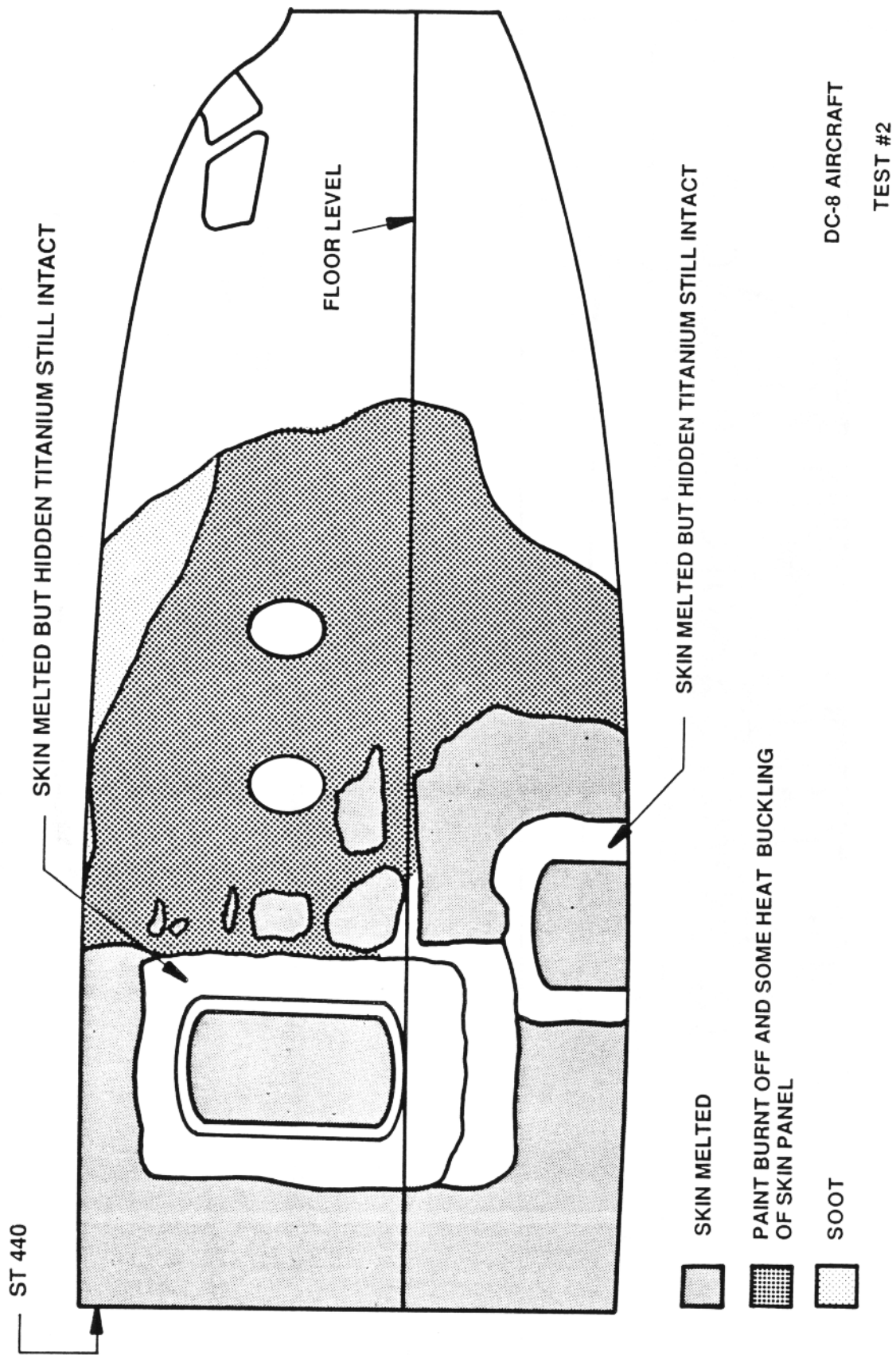
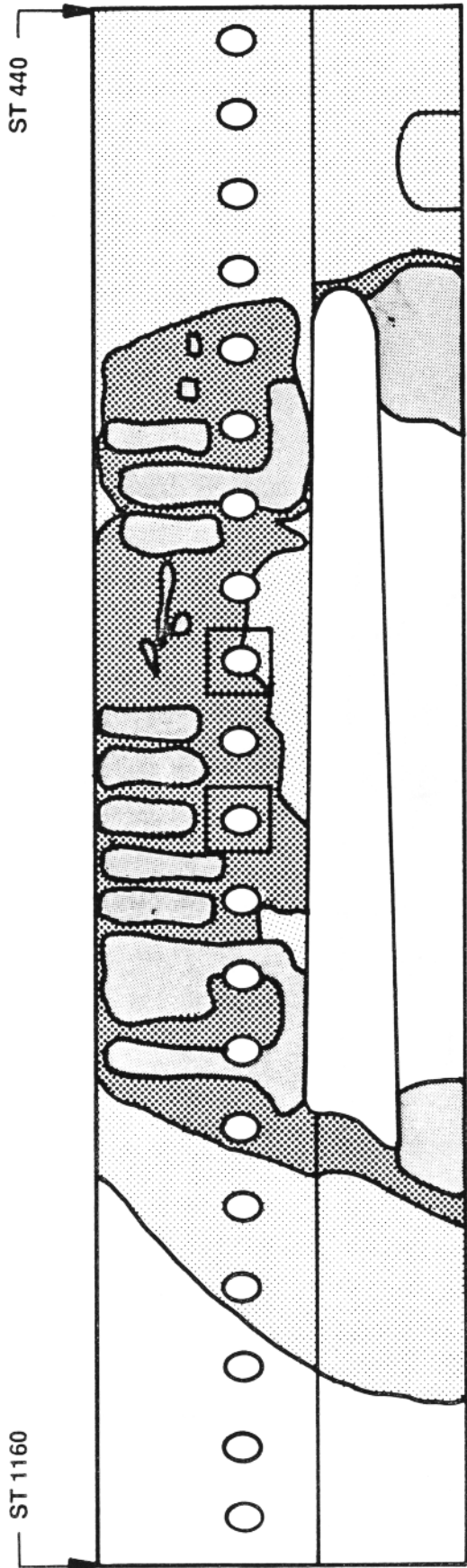


FIGURE B-2. EXTERIOR FIRE DAMAGE: FORWARD FUSELAGE STARBOARD SIDE



ST 1160

ST 440

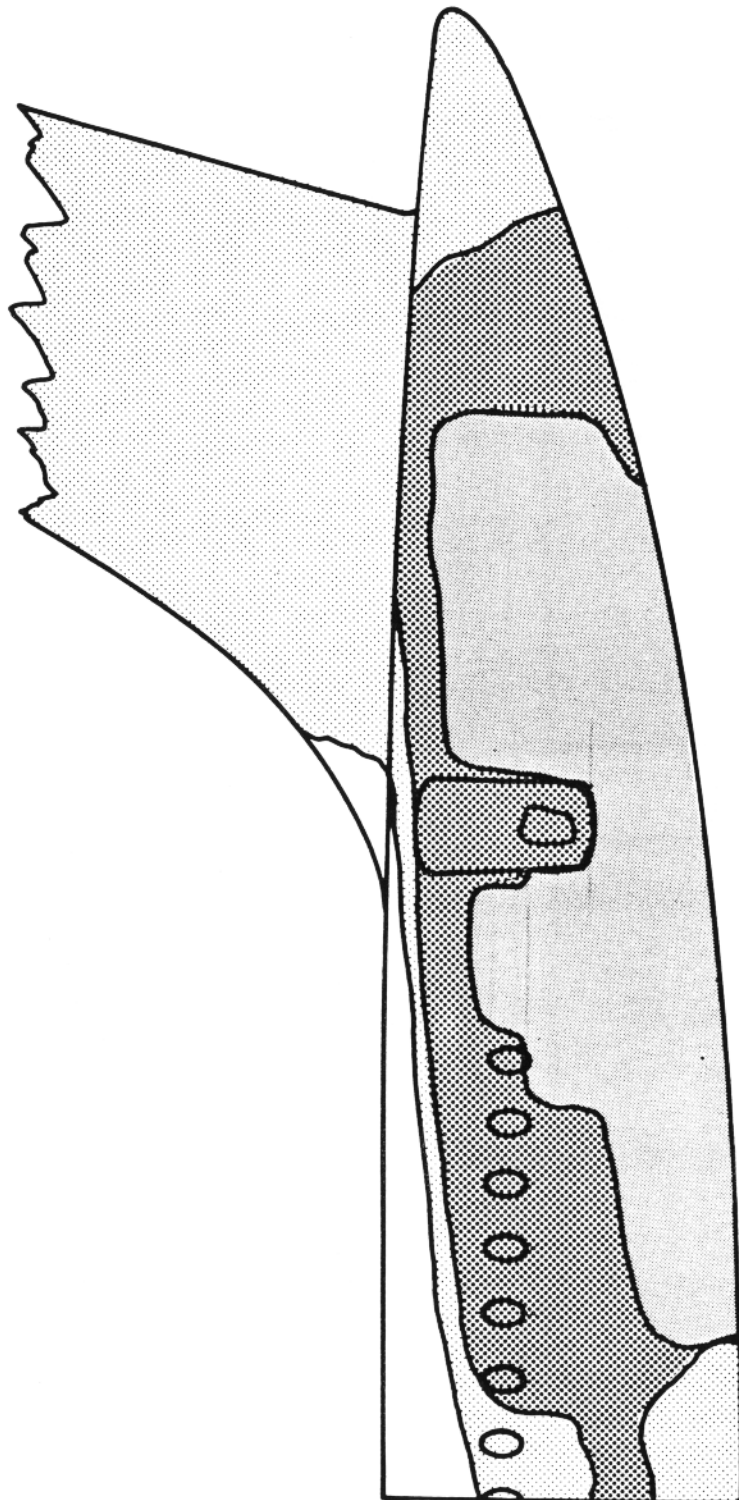
SKIN MELTED

PAINT BURNT OFF HEAT BUCKLING OF SOME SKIN PANELS

SOOT

DC-8 AIRCRAFT
TEST #3

FIGURE B-3. EXTERIOR FIRE DAMAGE: CENTER SECTION FUSELAGE STARBOARD SIDE



- SKIN MELTED
- PAINT BURN OFF AND SOME HEAT BUCKLING OF SKIN PANEL
- SOOT

CONVAIR 880 AIRCRAFT
TEST #4

FIGURE B-4. EXTERIOR FIRE DAMAGE: AFT SECTION FUSELAGE PORT SIDE

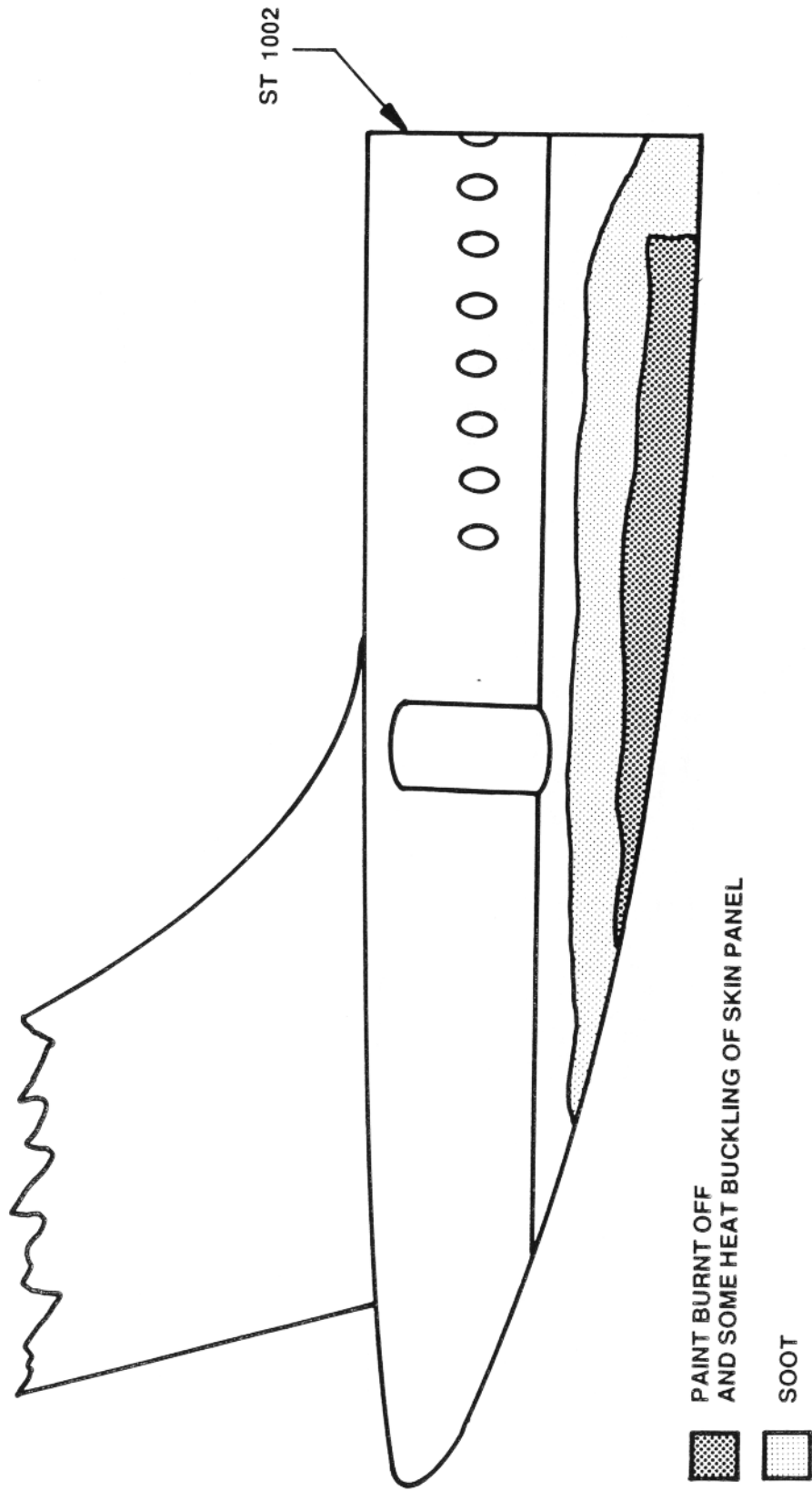
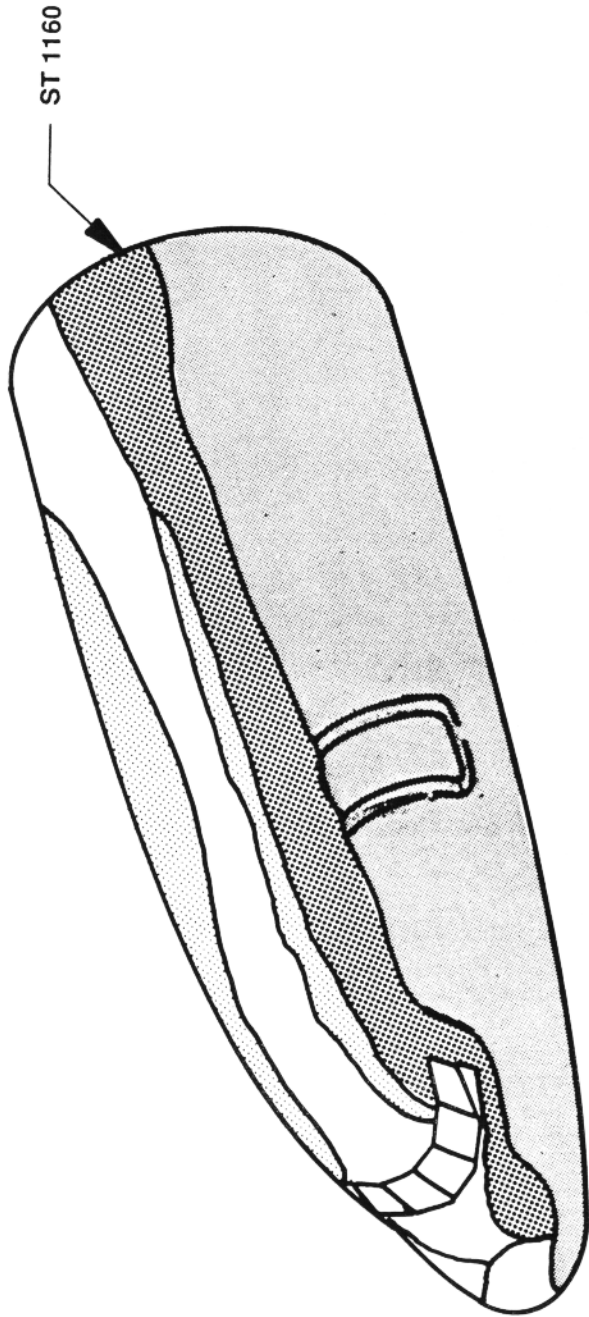


FIGURE B-5. EXTERIOR FIRE DAMAGE: AFT SECTION FUSELAGE STARBOARD SIDE



- SKIN MELTED
- PAINT BURNT OFF AND SOME HEAT BUCKLING OF SKIN PANEL
- SOOT

CONVAIRE 880 AIRCRAFT
TEST #5

FIGURE B-6. EXTERIOR FIRE DAMAGE: FORWARD SECTION FUSELAGE PORT SIDE

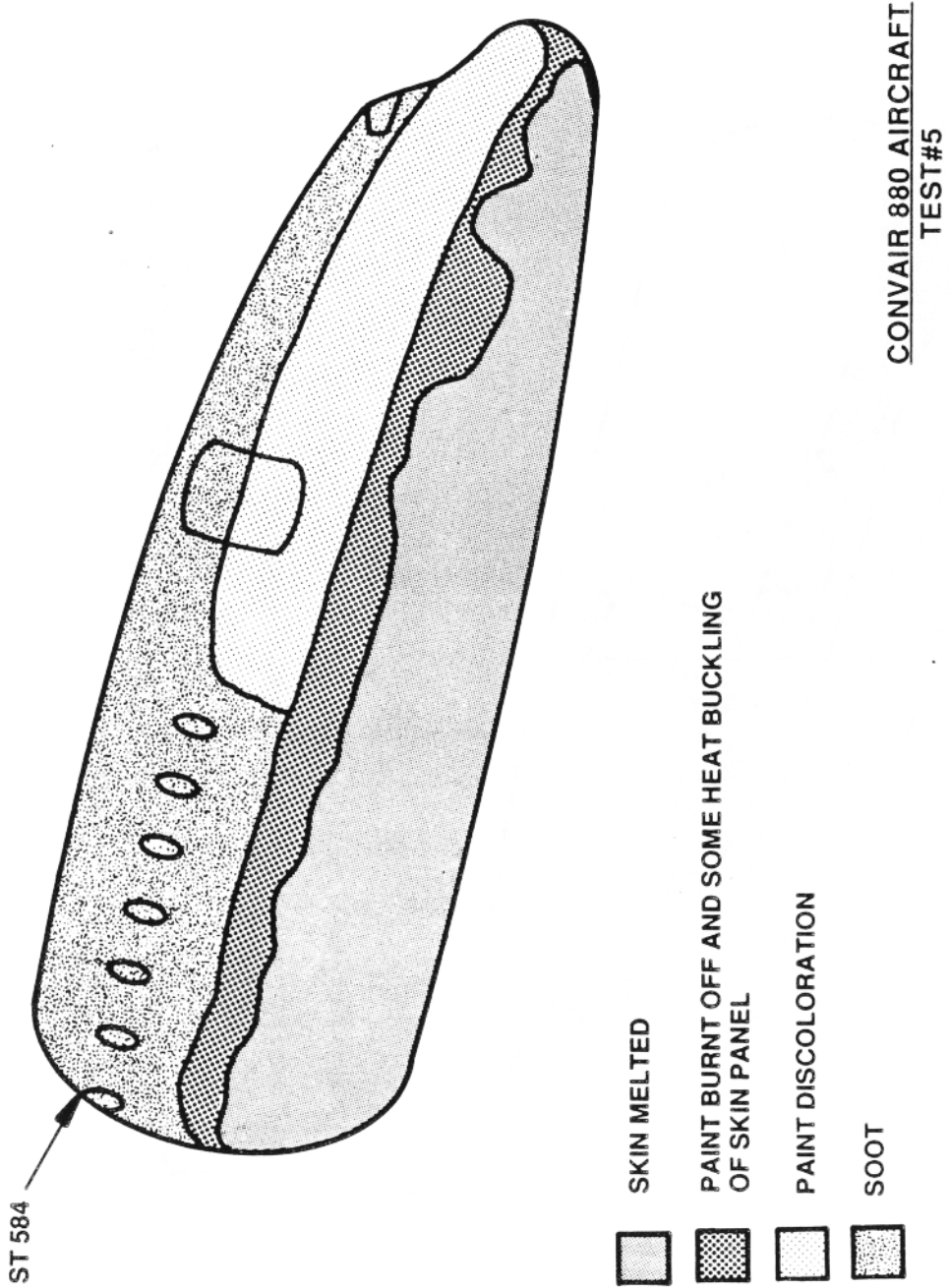
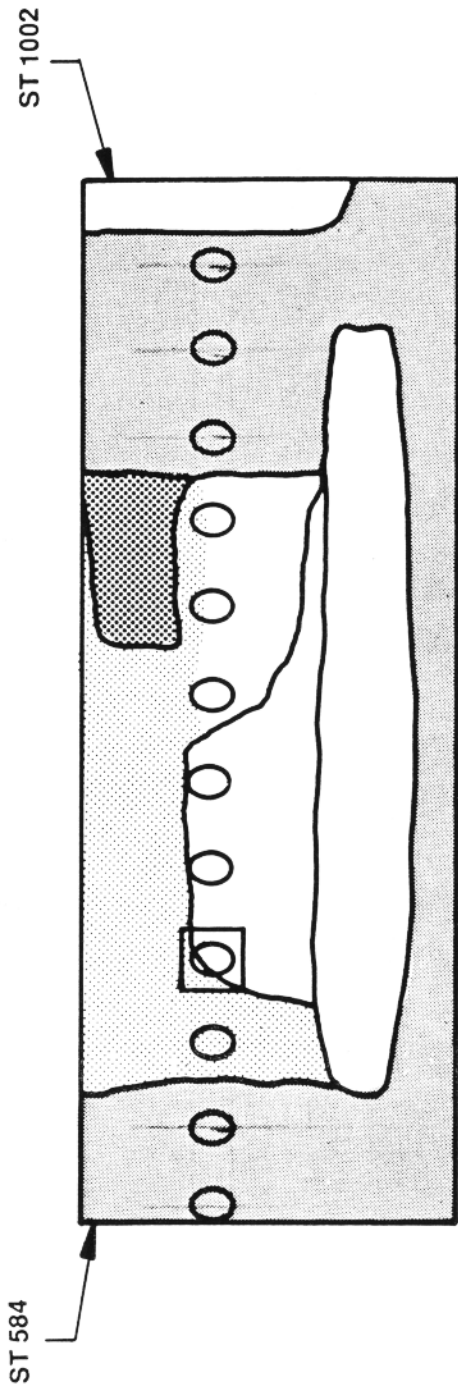


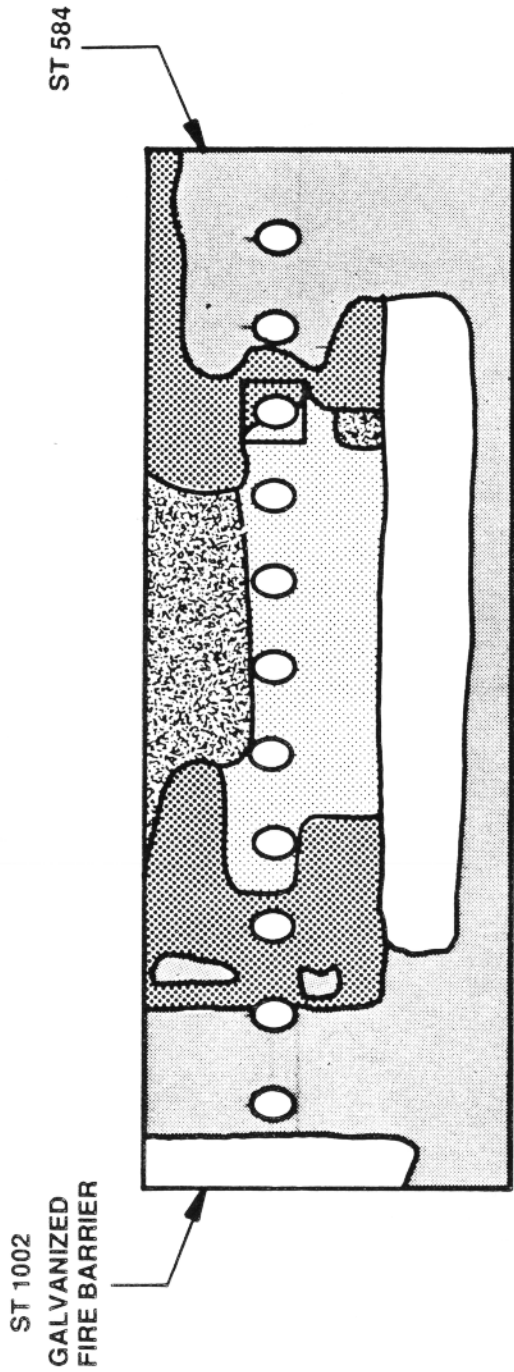
FIGURE B-7. EXTERIOR FIRE DAMAGE: FORWARD FUSELAGE STARBOARD SIDE



CONVAIR 880 AIRCRAFT
TEST #6

-  SKIN MELTED
-  PAINT BURNT OFF AND SOME HEAT BUCKLING OF SKIN PANEL
-  SOOT

FIGURE B-8. EXTERIOR FIRE DAMAGE: CENTER SECTION FUSELAGE PORT SIDE



SKIN MELTED

PAINT BURNT OFF
AND SOME HEAT BUCKLING OF SKIN PANEL

PAINT DISCOLORATION

SOOT

CONVAIR 880 AIRCRAFT
TEST #6

FIGURE B-9. EXTERIOR FIRE DAMAGE: CENTER SECTION FUSELAGE STARBOARD SIDE