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Investigation of Accidental DC-7 Fire Damage Occurring June 28, 1989

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16. Abstract

Three groups of investigators were formed to determine the circumstances that caused an accidental, fuselage-destroying fire that occurred on June 28, 1989, in the research and development area of the FAA Technical Center. From interviews with witnesses and analysis of the structural fire damage to the fuselage, a probable sequence of events was developed and an analysis of the contributing causes of the damage was determined. A number of recommendations for future test scenarios were established in order to prevent the extensive fire damage that resulted during this test.

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PREFACE

This report reflects the combined efforts of a large group of people in the Fire Safety Branch. The chief investigator was Richard Hill, and three investigative groups contributed substantially to writing this report. The co-authors of the report are Harry Webster, lead person of the Structures Group; Thomas Guastavino, lead person of the Human Factors Group; Patricia Cahill, lead person of the Systems Group; and Thor Eklund, who furnished the analysis and recommendations.

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OBJECTIVE.

The objective of this investigation was to determine the factual occurrences leading up to and during the accidental burning of the DC-7 fire test article which took place during a routine fire test in building 275 of the research and development area at the FAA Technical Center at approximately 3:00 p.m. on June 28, 1989.

APPROACH.

In order to systematically determine the facts surrounding the incident, the investigator in charge formed three groups to investigate particular areas of concern. The first group was to investigate the human factors involved in the incident and interview the witnesses who were involved in the test work or who were present during the test. This group was named the Human Factors Group.

The second group was to investigate the aircraft systems which were part of the original configuration and to determine what effect, if any, these systems had on the damage to the test article. This group was named the Systems Group.

The third group was to investigate the structural aspects of the pre-test and post-test aircraft configuration. This included the fire hardening aspects of the test article for the purpose of withstanding the expected high temperatures in certain areas and the structural failures resulting from the unexpected high temperatures experienced during the test. This group was named the Structures Group.

BACKGROUND.

The DC-7 modified fuselage was positioned in the large fire test area in building 275 for the specific purpose of evaluating the fire suppression potential of an onboard water mist fire suppression/extinguishment system. The aircraft was modified to permit exposure to a kerosene pan fire external to the fuselage; the details will be discussed later in this report. A number of other tests had been successfully conducted with this test article without serious difficulties. These tests were of a 5-minute duration, with and without the implementation of the water mist. In all cases, instrumentation was used and the fire department was standing by for assistance if required.

This particular test was run similar to prior ones (water mist was not used) with the exception of the implementation of two fans for the purpose of simulating ambient wind conditions at the site of a post-crash fire. The resulting fire damage to the fuselage and the structural failure of aft components are of primary concern in this investigation. Determining the factors leading to this scenario was also involved in this investigation.

RESULTS

PRE-TEST CONDITIONS.

The following systems were removed from the aircraft prior to the subject test: hydraulic system, oxygen system, flare release system, tail/anti-icing system, and most of the electrical system (with only a small portion of some wiring remaining in the section aft of the pressure bulkhead). The control cables in the tail section remained. Video equipment was placed in the section aft of the pressure bulkhead and in the forward wing area of the cabin. This equipment was housed in an insulated box that was continuously purged with compressed air.

The aircraft was specially modified to be used as a fire test article. The wings were removed outboard of the landing gear, and the tail was cut off at the root, with the horizontal stabilizer cut, leaving a stub 60 inches outboard from the fuselage. The exterior of the fuselage was fire hardened in the vicinity of the aft passenger entry door which was removed. The doorway and the fuselage around the doorway were covered by steel sheeting installed over a layer of KAOWOOL™ insulation blanket. The fire hardening extended from the top center of the fuselage to 12 inches below the doorway, 6.5 feet forward of the doorway, and 6.5 feet aft of the doorway. An 8- by 10-foot fire pan was installed at the base of the doorway to simulate an external fuel fire (see figure 1).

The interior of the aircraft was fire hardened from station 533 to station 782. (These stations are in 1-inch intervals and are shown in figure 2.) The floor, was covered by steel sheeting, while the sidewalls, and ceiling were covered by steel sheeting over kaowool blankets. The cabin partitions, seats, galleys, and lavatories were removed from the aircraft with the exception of the forward lavatory compartment and the cockpit bulkhead. The entire cabin forward and aft of the fire hardened section retained the original panels and acoustical insulation.

A hole was cut in the aft pressure bulkhead and a plexiglass window installed. A hole was cut into the port side of the fuselage just forward of the horizontal stabilizer, 23 inches wide and 50 inches high. This allowed entry into the tailcone area behind the pressure bulkhead. A 3/4-inch-thick plywood floor was installed behind the bulkhead. A motion picture camera was installed in the compartment to record test data. It was not in use at the time and was destroyed by the fire.

Two large fans were installed to blow the pan fire into the cabin. The wind velocity, measured after the fuselage was removed, was 28 knots. The fans were in use for the first 1 1/2 minutes of the 5-minute test. This was the first test with the fans operational.

A British supplied "SAVE" water mist sprinkler system was installed in the fuselage. This was not in use during the 5-minute test or the subsequent cabin fire.

The cabin was instrumented with thermocouples, calorimeters, smoke transmissometers, and gas measuring devices. Sensors for oxygen, carbon monoxide, carbon dioxide, and temperature sensors were operating during the test. The mass spectrometer was not in operation. Two television cameras were inside the fuselage and another television camera was monitoring the pan fire. The video images from all three cameras were observed on television monitors located in the control room. The inside cameras were being recorded while the outside camera was not.

Thermocouples were mounted at the following five locations in the fuselage: stations 10, 24, 42, 58, and 72. (These stations were designated by the test crew and were measured in feet beginning with station 0 being located at the aft pressure bulkhead. As a point of reference, the fire door was centered at station 16.) Each station had eight thermocouples positioned 1 to 8 feet above the floor. All temperatures and gas data were recorded on a computer and are presented in figures 3 to 20. Gas concentrations were continuously monitored at the following three stations in the fuselage: stations 32, 46, and 66. The sensors were located at a 5-foot height at all stations and at a 3-foot height at station 32 only.

CONDITIONS DURING AND AFTER TEST.

All personnel in attendance during the test were interviewed in an attempt to determine the sequence of events that occurred as the test progressed. The personnel interviewed were the following:

Tim Marker, Project Engineer
Richard Hill, Supervisor
Tom O'Conner, Project Technician
Jack Berry, Project Technician
David Lichtenfeld, Deputy Fire Chief
Fireman Ney
Fireman McGrory
Gus Sarkos, Observer and Branch Manager, Fire Safety Branch

From these interviews it was obvious that the aircraft could not be directly observed from the control room, where all personnel, except the two firemen, were located. The only visual contact they had was by means of the television monitors.

The following time sequence was deduced from the information obtained from the interviews of the investigation and is defined as the most probable timing sequence of the incident:

TIME	
00:00	Pan fire started.
00:02	Fans turned on.
01:30 +/-	Inside cabin TV obscured by smoke. Temperatures inside the cabin rising fast (recordings). Fans turned off. Temperature inside the plane lowers dramatically (recordings).

	Observation indicated that the fans had pushed the pan flames inside the plane.
05:00	Test was stopped. Light water (AFFF) started in pan. Flames were seen (TV camera) inside the plane.
05:30	Doors opened (typical procedure). Fans turned on to clear smoke.
05:40	CO_2 turned on. First 10 seconds were air. Next 10 seconds were CO_2. Total 20 seconds.
05:45	Flames propagating in aft section (charts). As doors opened, 2 firefighters in cab outside door experienced a ball of flames passing them. They turned on the turret water gun while remaining outside and called the deputy fire chief with warning.
05:45-06:00	Deputy fire chief went around DC-10 fuselage, saw fire, called for backup.
06:00	CO_2 off, fire not extinguished. First firefighter went to front of plane.
06:05	Fans and electrical breakers for inside of plane were turned off.
06:10	Warnings given to evacuate plane, to turn on CO_2 again, but was not done.
06:30	Fire chief returned to control room and told of fire and second alarm. Much activity!! Smoke meter in DC-10 went off (alarm).
07:30-07:45	Tail fell off (eyewitnesses). Circle of fire formed by burning hull was described.
07:45	Backup fire engine arriving.
07:45	Firefighter fell off of ladder (Bernie Ney).
08:00	Hurt fireman helped out by other firemen.
08:30-09:00	Fire contained, all firemen working.

A post-test inspection of the fuselage revealed that the entire cabin interior aft of the steel fire hardening was destroyed by the fire. The sidewall panels in this area were completely consumed in the fire. The cabin floor and floor supports were destroyed from station 741 aft including 3 feet of floor that was protected on the top surface with steel sheeting. One transverse floor support located at station 800 was still attached on the starboard side extending 17 inches from the sidewall. The balance of the support had collapsed into the cargo compartment.

The fiberglass acoustical insulation remained intact on the sidewalls in most areas up to the top of the windows. Inspection of the insulation revealed the vinyl bagging destroyed on the cabin side and mostly intact on the outer side. The acoustical insulation on the DC-7 consisted of a 1-inch fiberglass mat installed against the fuselage skin. This mat was unfaced. A second layer of vinyl bagged fiberglass insulation was installed between the ribs. Where the insulation remained in place, there was some charring of the inner layers, with the outer sections remaining undamaged.

The aft pressure bulkhead was completely consumed by the fire. The tail section aft of the bulkhead separated from the aircraft and collapsed to the ground. The tail section remained attached by a 2-foot section of skin on the belly of the aircraft.

The plywood floor that had been installed behind the pressure bulkhead was heavily charred on the top surface. The underside of the plywood was clean and undamaged. The ribs and skin located under the plywood floor were clean and undamaged with no signs of heat or smoke damage. The fuselage section extending from the aft pressure bulkhead to the leading edge of the horizontal stabilizer and above the plywood floor was completely consumed in fire. This was a section approximately 76 inches long.

The top surface of the plywood had globs of melted aluminum splattered on it, trailing aft. There were also some melted resinous material.

The rib section even with the leading edge of the horizontal stabilizer was approximately 80 percent consumed. The next rib aft had only the webbing melted.

The entire tailcone was uniformly, heavily sooted, exhibiting no soot trails or shadowing.

The fire hardened section of the cabin was sooted but undamaged. Some aluminum sheeting and supports had been installed to simulate ceiling and overhead bins. These were consumed from station 660 aft. The cabin forward of the fire hardening was undamaged but heavily sooted. The cockpit was undamaged.

It should be noted that this aircraft had been used extensively for fire tests in the past and much of the soot was residual.

Cargo Compartment. The forward cargo compartment was not involved in the fire and was undamaged. The aft cargo compartment was destroyed in the fire. The fiberglass cargo liner on the ceiling of the compartment was destroyed. The floor support members as well as the floor above the cargo compartment were destroyed. The melted debris from the floor had fallen into the bottom of the cargo compartment. The floor was melted through to station 741, even with the aft edge of the passenger door, under the steel sheeting installed on top of the floor.

There was a large hole burned through the cargo compartment on the starboard side (fuel pan was on port side) aft of the cargo door. This hole measured 60 inches long by 67 inches high. A portion of the outer skin was still attached, bent out and downward. The lower edge of this flap exhibited hardened molten aluminum.

There were two holes in the cargo compartment on the port side. The forward hole was 55 inches long by 6 inches high, located at station 807 to 862. The aft hole was 55 inches long by 20 inches high, located at stations 911 to 969.

The bottom of the fuselage was littered with debris.

External Fuselage. The upper fuselage cabin area aft of the passenger entry door was heavily damaged by fire. The empennage and tail cone separated from the aircraft at the pressure bulkhead, except for a portion of the belly skin. A 6-foot section of the fuselage extending aft from the pressure bulkhead to the leading edge of the horizontal stabilizer was completely destroyed except for the belly section located under the plywood floor. There were three holes in the fuselage into the cargo compartment area (figure 21).

There was no external damage to the fuselage forward of the passenger entry door.

Starboard Side. The skin rivets at station 946 were melted out or the skin had pulled through the rivet heads on the starboard side from the floor level to the center of the belly (figure 22).

There was a horizontal crack on the starboard side, 14 inches below the emergency exit (station 935), approximately 6 inches long. A second crack was 16 inches long, 2 inches lower and extended forward of the first crack.

There was a hole, 20 inches long by 7 inches high, on the starboard side at station 916, 48 inches below the bottom of the window.

There was a large hole, 67 inches wide by 60 inches long located aft of the cargo door (station 800-867). A portion of the fuselage skin was still attached, bent out and downward.

The cargo door was blackened and charred on the inside but appeared undamaged from the exterior. The door did not open when the mechanism was tried.

All windows on the starboard side were charred but intact.

Port Side. Below the horizontal stabilizer, on the port side, there was some sooting of the skin and an area of blistered paint. There were two horizontal cracks and bulged and blistered skin toward the bottom of this area (figures 23 and 24).

The windows located at station 933 and 905 on the port side of the aircraft were cracked and burned through. The remaining windows were charred only.

There was a large hole, 55 inches long by 20 inches high, located on the port side, 40 inches below the bottom of the windows extending from station 911 to 966. The skin around the hole had sagged and bent downward.

There was a large hole, 55 inches long by 6 inches high, located just aft and below the protective steel fire hardening on the port side (station 807-862). The damaged aluminum skin in this area was deflected in towards the interior of the aircraft. The soot on the fire hardening around the passenger entry door was burned off, trailing downward and below the fire pan. This "burned clean" area continued down the fuselage across the hole.

The skin forward of the steel fire hardening on the port side above the windows (station 581 to 541) was buckled and the paint was burned off. There was a vertical crack in the skin, 35 inches long located at station 580.

There were two large holes through the cabin ceiling. The forward hole extended from station 800 to 884, 3 feet wide and 7 feet long. Aft of this hole and continuing to the end of the fuselage was a second hole, 7 feet wide and 9 feet long (station 870 to 978). An overall view of the damage to the aircraft was presented in figure 25, a view looking forward from behind the aircraft.

Wing and Flight Control Surfaces. The left and right wings were intact with no apparent fire damage. The horizontal stabilizer had no apparent fire damage.

Landing Gear. The nose and main gear were extended and locked with no evidence of damage. All tires were inflated.

Aircraft Materials. The floor material used in the DC-7 consisted of an upper two sheets of aluminum separated by hat channels and fiberglass insulation. The upper aluminum measured 0.035 inch thick, the hat channels also 0.035 inch, and the lower aluminum 0.025 inch thick. The fiberglass insulation consisted of two layers of bat insulation separated by fiberglass cloth.

The interior panels in the undamaged forward part of the aircraft were constructed of plywood with a decorative cloth facing. The entire panel measured approximately 3/16 inch thick.

The forward cargo compartment had aluminum cargo liners. The liners were made up of 0.035 inch aluminum sheets. The aft cargo compartment was inaccessible in the forward, less-damaged portion, but most likely constructed of similar materials.

The forward part of the aircraft (forward of the steel fire hardening) was charred but relatively undamaged.

Several representative samples of the aircraft skin were removed and measured. The aluminum thicknesses all measured 0.45 inch thick.

A sample was removed from the fragment of the remaining pressure bulkhead. The aluminum thickness measured 0.35 inch.

Temperature and Gas Environment. From figures 3 through 7, it should be noted that the temperatures within the cabin reached extremely high levels with the maximum indicated at close to 2000 degrees at 90 seconds into the test at station 24. Once the peak temperature was reached, the subsequent temperatures remained between 1000 and 1500 degrees at the upper thermocouple locations.

From figures 8 through 11, it should be noted that the concentrations of oxygen were reduced to about 5 percent at all the sampling stations by the conclusion of the test. Also, the concentrations of carbon dioxide rose to 10 percent after about 2 minutes and remained there, as indicated by figures 12, 13, and 14. The carbon monoxide levels reached between 1.5 and 2 percent during the latter half of the test, as indicated by figures 15 through 18. The smoke density data indicate practically no visibility after about the first minute of the test.

All of these data indicate a very severe environment within the cabin area during the 5 minutes the test lasted.

ANALYSIS

The destructive results of this test can be attributed exclusively to the use of the fans to drive the pool fire into and onto the fuselage. While the precise details of the fire progression can never be known, there is adequate information to develop a credible estimate of the probable sequence of the fire development. It might be noted that most eyewitness accounts center on what happened in the control room during the 5-minute test and what happened in the test bay after the 5-minute test period was over. There is minimal witness information of what happened in the test bay and in the aircraft during the 5-minute test. Thus, the probable sequence is based upon the reports of the fact-finding teams and known behavior of fires.

The size of the fans and their resultant wind speeds (28 mph) resulted not only in substantive fire penetration into the door, but also pushing of the fire plume to the left and over the fuselage as well as to the right with fire trailing over and under the fuselage. A static pool fire is generally a sluggishly mixed burning plume with apparent temperatures of approximately 1850 ^{o}F. Use of fans, as in this case, would cause an extremely efficient oxygen delivery to the hydrocarbon vapor as well as adequate turbulence to cause intense local mixing. It is likely that the apparent temperature of the wind-blown plume was well in excess of 2000 ^{o}F. Since the thermal impact of fires of this size is predominantly radiative and since the radiative output goes up with the fourth power of temperature, the high temperatures would likely have resulted in burnthrough times of less than a minute. Since the fan was in operation for a minute and a half, it is possible that the damage to the aircraft bottom to the rear of the fire door was all done during the period while the fan was in operation. This damage in this time interval also would include the melting of the aft floor beams, the destruction of the cargo liners, and the collapse of the aft cabin floor. This damage to the lower part of the aircraft could not have been caused by the cabin fire burning simultaneously above because of the data recorded on the thermocouple trees, along with the fact that interior fires burn upward rather than downward.

In the same period of fan operation, the flames blown into the door produced flashover conditions at the beginning of the test because of the heat released into the cabin by the burning plume in the doorway. These flashover conditions were maintained over the entire period of fan operation as is evidenced by thermocouple and gas measurement data. Since the cabin was firehardened only to station 792, the cabin lining materials between stations 792 and 978 would have been rapidly brought to their ignition temperatures. The same holds true for the plexiglas window in the aft pressure bulkhead which would have been melting and burning at this time. It is further probable that once the fire broke through the plexiglas window, a path opened for fresh air to pass through the burnthrough openings in the bottom, into the cabin, through the failed window, into the tail, and out the cut-out that had been made for photographic access.

In the 3 1/2 minutes of testing after the fan was turned off, the above ventilation pattern probably supported the combustion of the cabin lining materials; and this is why the fire never spread to the forward part of the cabin. Furthermore, the flow of hot combustion products melted away the pressure bulkhead. Since there was no insulation against the skin aft of the bulkhead, the hot gases were able to heat and melt the upper part of the fuselage aft of the bulkhead. This is what caused the eventual collapse of the tail. Overall, there was rapid fuselage damage due to the wind-blown fire in the first minute and a half. The rate of damage and burning was slower and more sporadic through the end of the 5-minute test and beyond due to the lack of oxygen in the cabin, which caused the interior fire to be a ventilation limited fire.

RECOMMENDATIONS

1. Test aircraft used in building 275 should be totally gutted of their original lining materials prior to testing.*

2. If pool fire penetration into the fuselage is needed for a test scenario, the penetration should be caused by suction of the fire by means of an air-moving device placed at another doorway or fuselage opening. The practice of blowing the fire at the fuselage should be discontinued.

3. At least two dedicated surveillance cameras should be positioned in the test bay with views along each side of the aircraft.

4. A checklist for timing, procedure, and safety steps should be prepared and adhered to for each test.

*Recommendation 1 does not apply to outdoor fire tests.

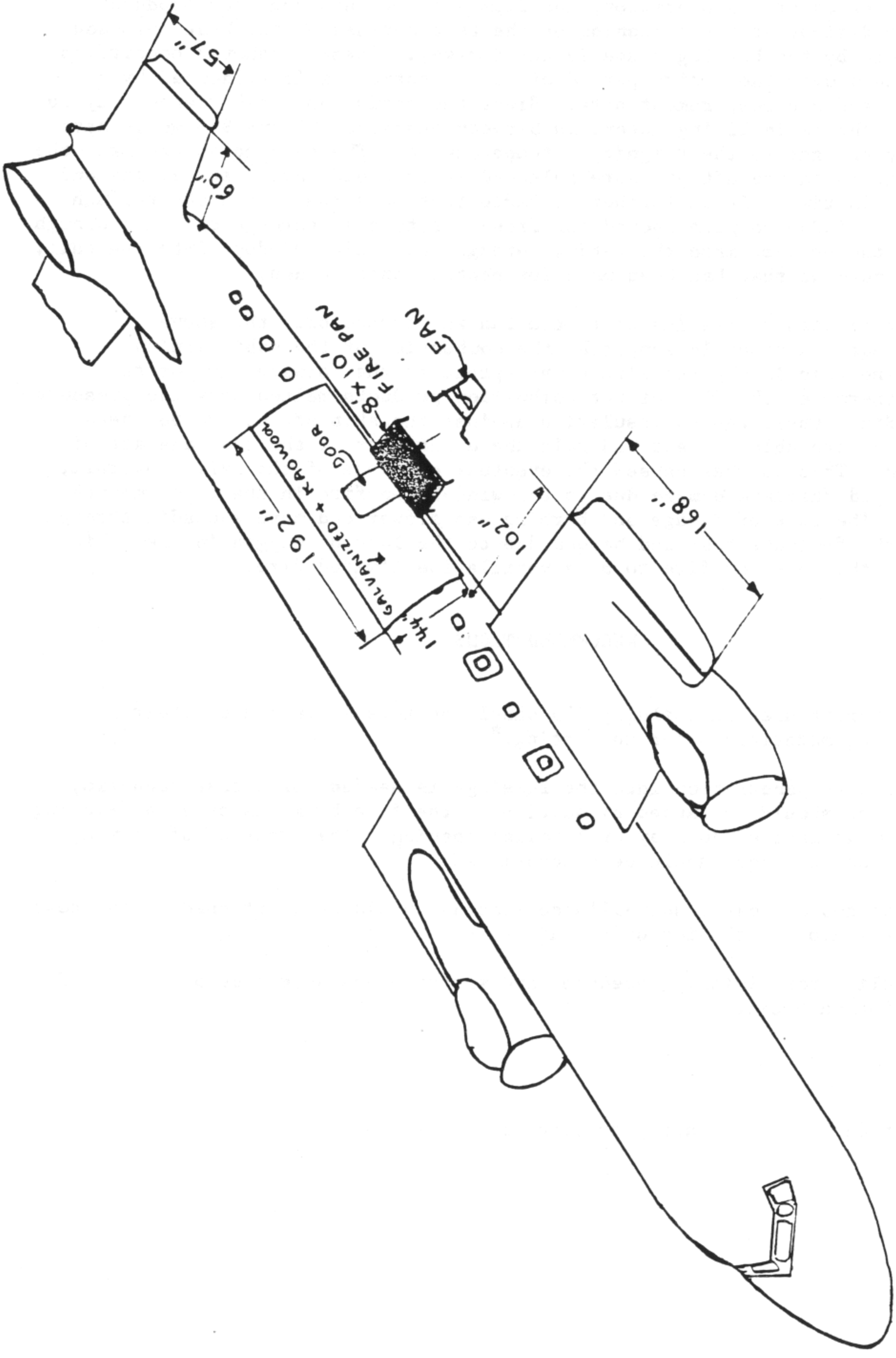

FIGURE 1. DC-7 TEST MODIFICATIONS

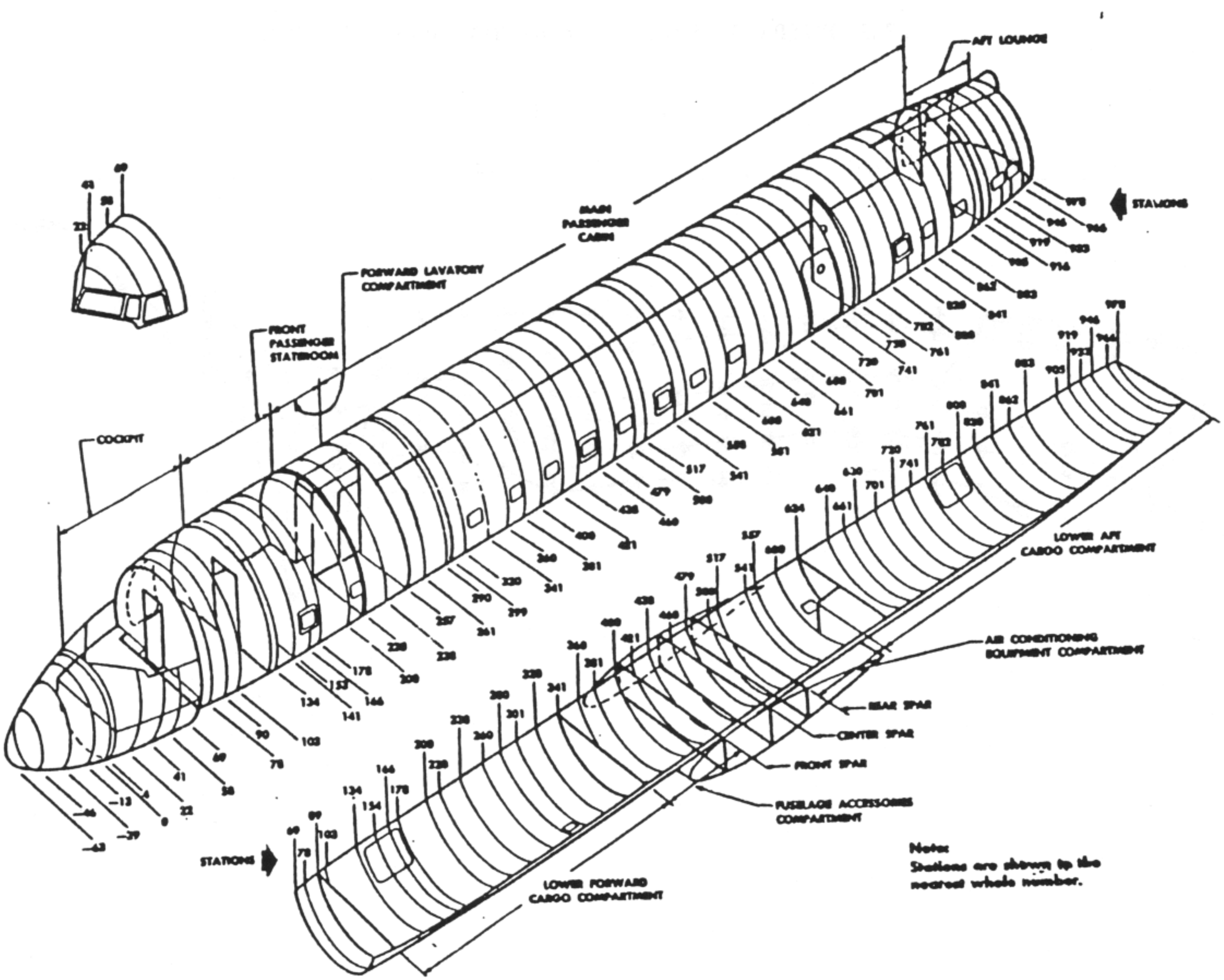

FIGURE 2. FUSELAGE STATIONS

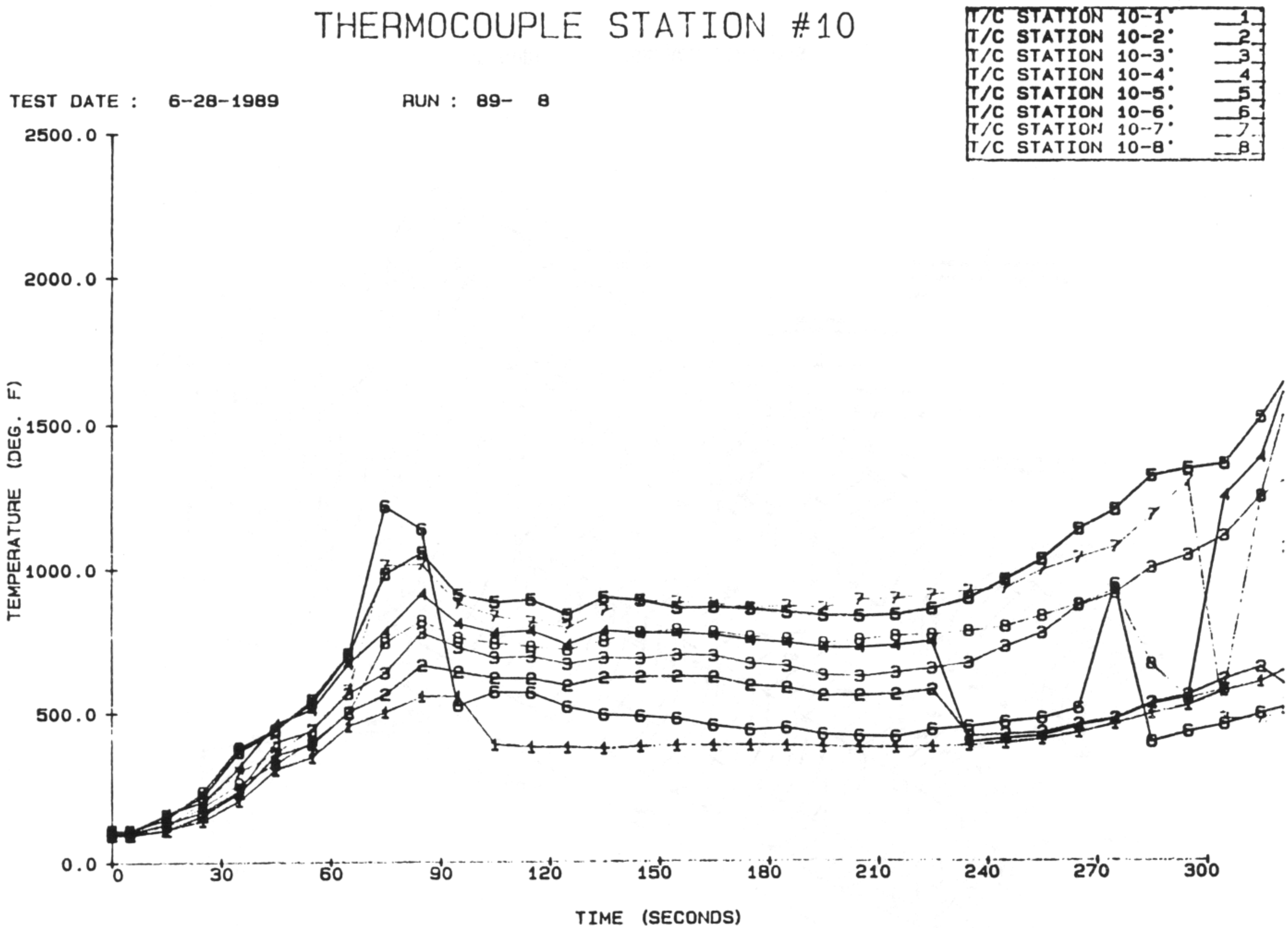

FIGURE 3. TEMPERATURES AT STATION 10 DURING TEST

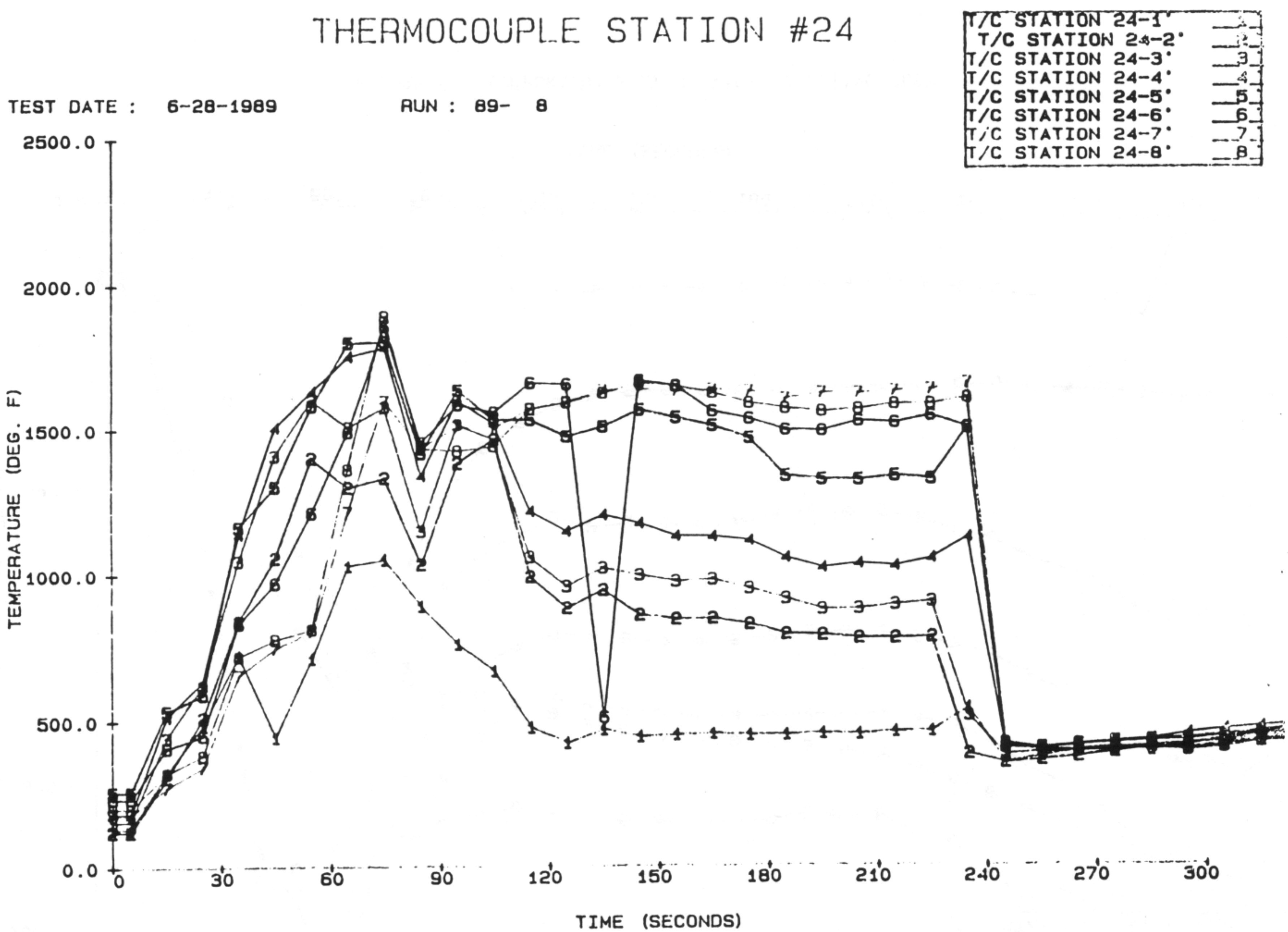

FIGURE 4. TEMPERATURES AT STATION 24 DURING TEST

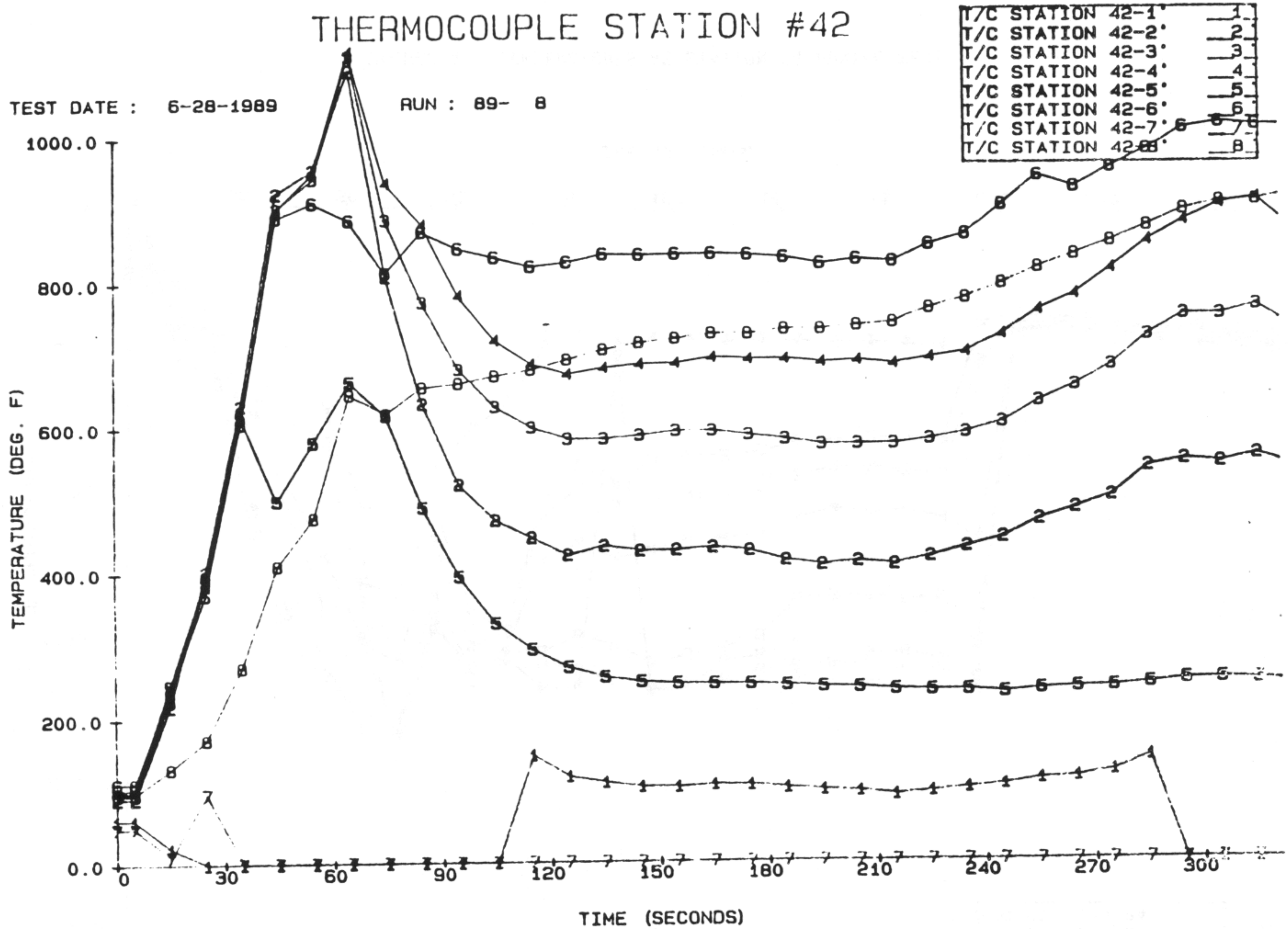

FIGURE 5. TEMPERATURES AT STATION 42 DURING TEST

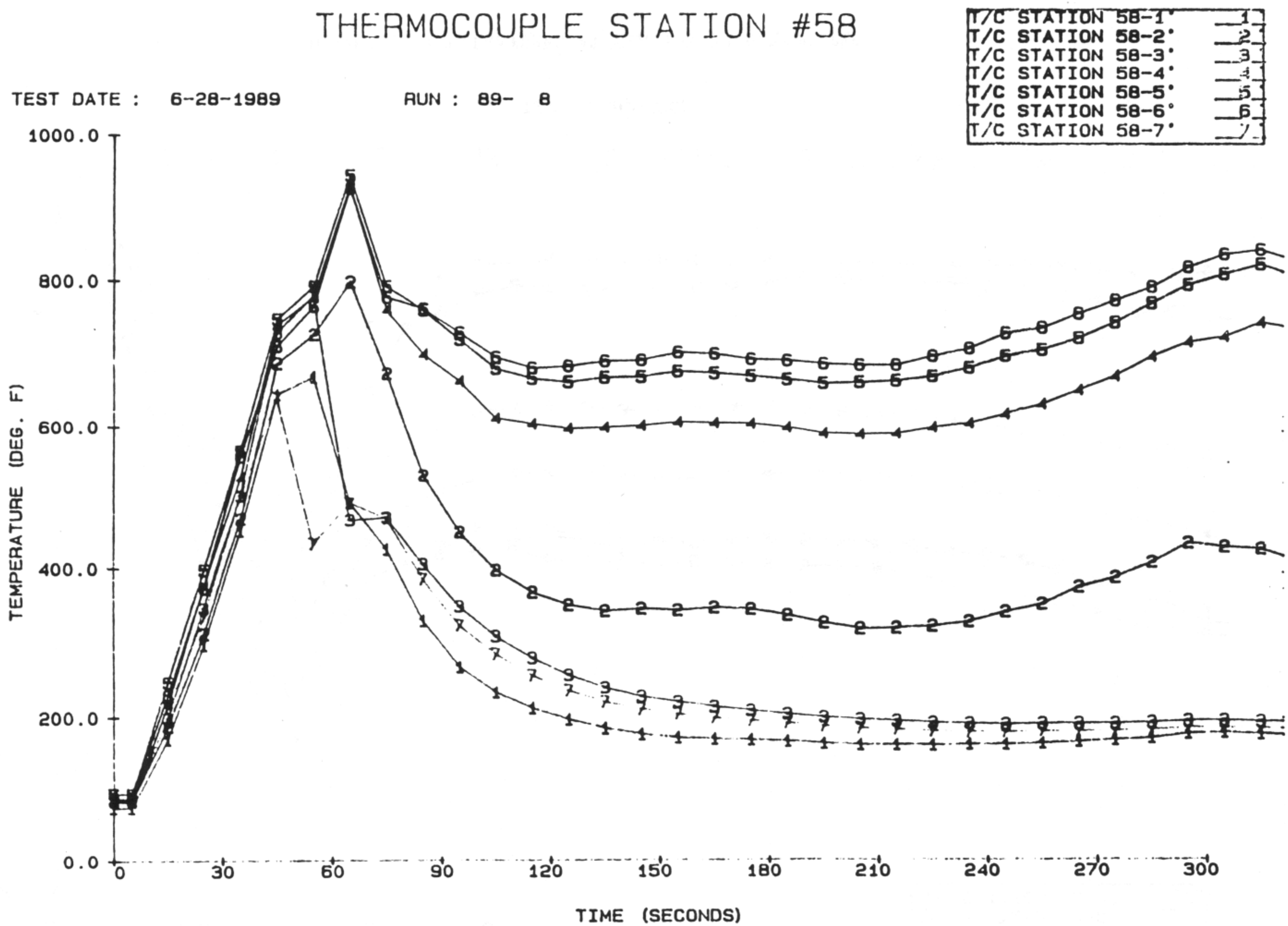

FIGURE 6. TEMPERATURES AT STATION 58 DURING TEST

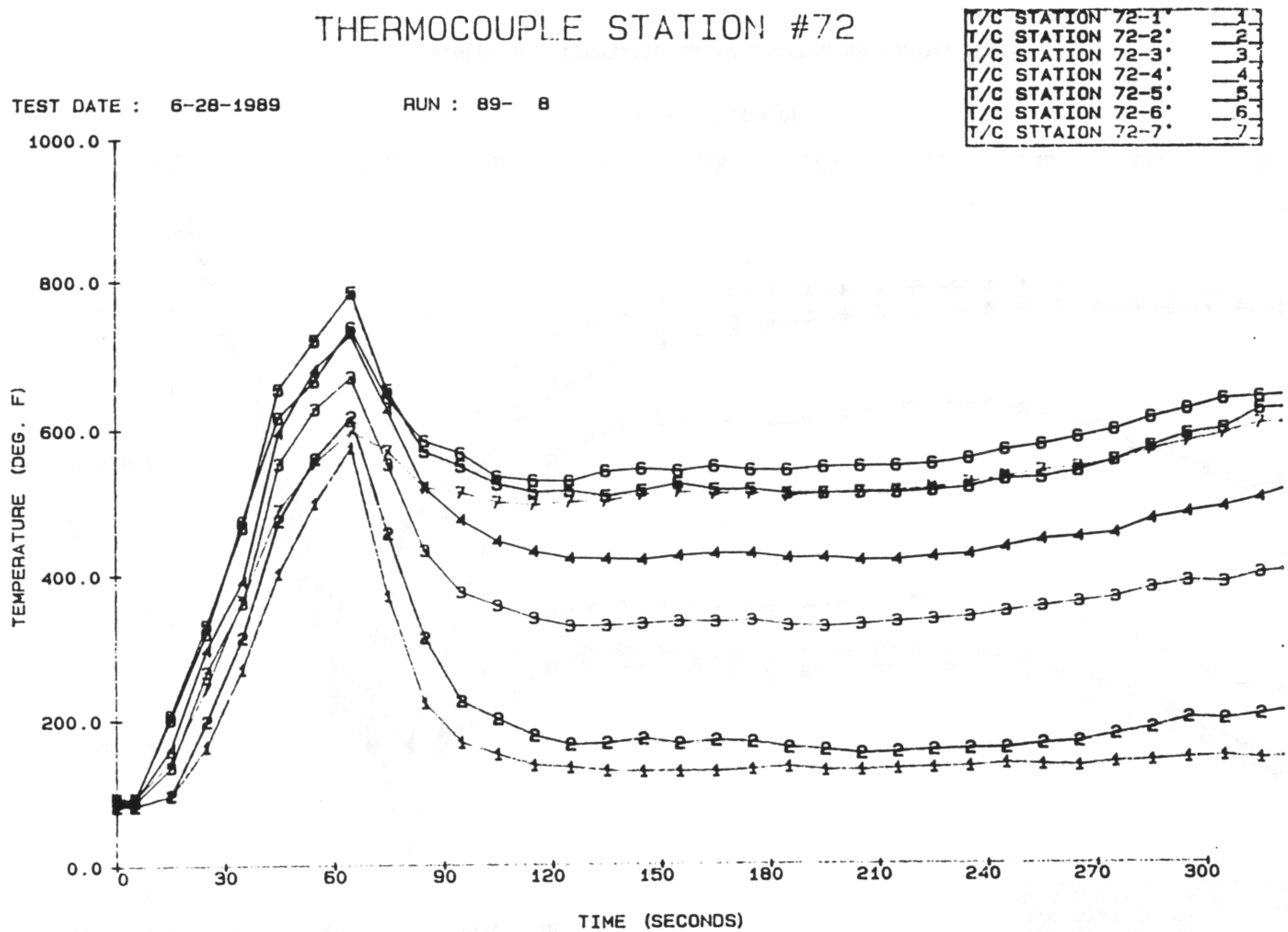

FIGURE 7. TEMPERATURES AT STATION 72 DURING TEST

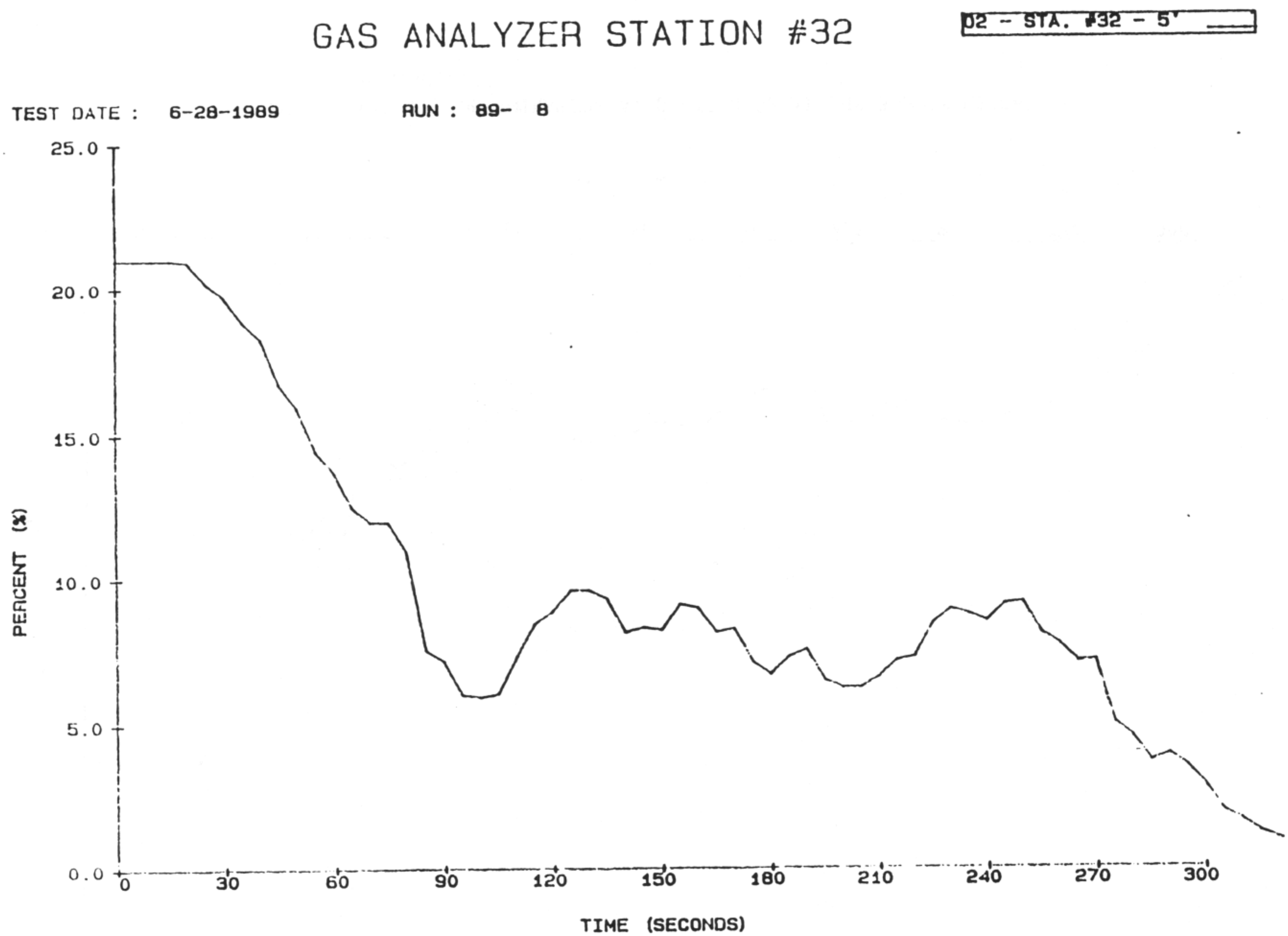

FIGURE 8. OXYGEN CONCENTRATION AT STATION 32 AT THE 5-FOOT HEIGHT DURING TEST

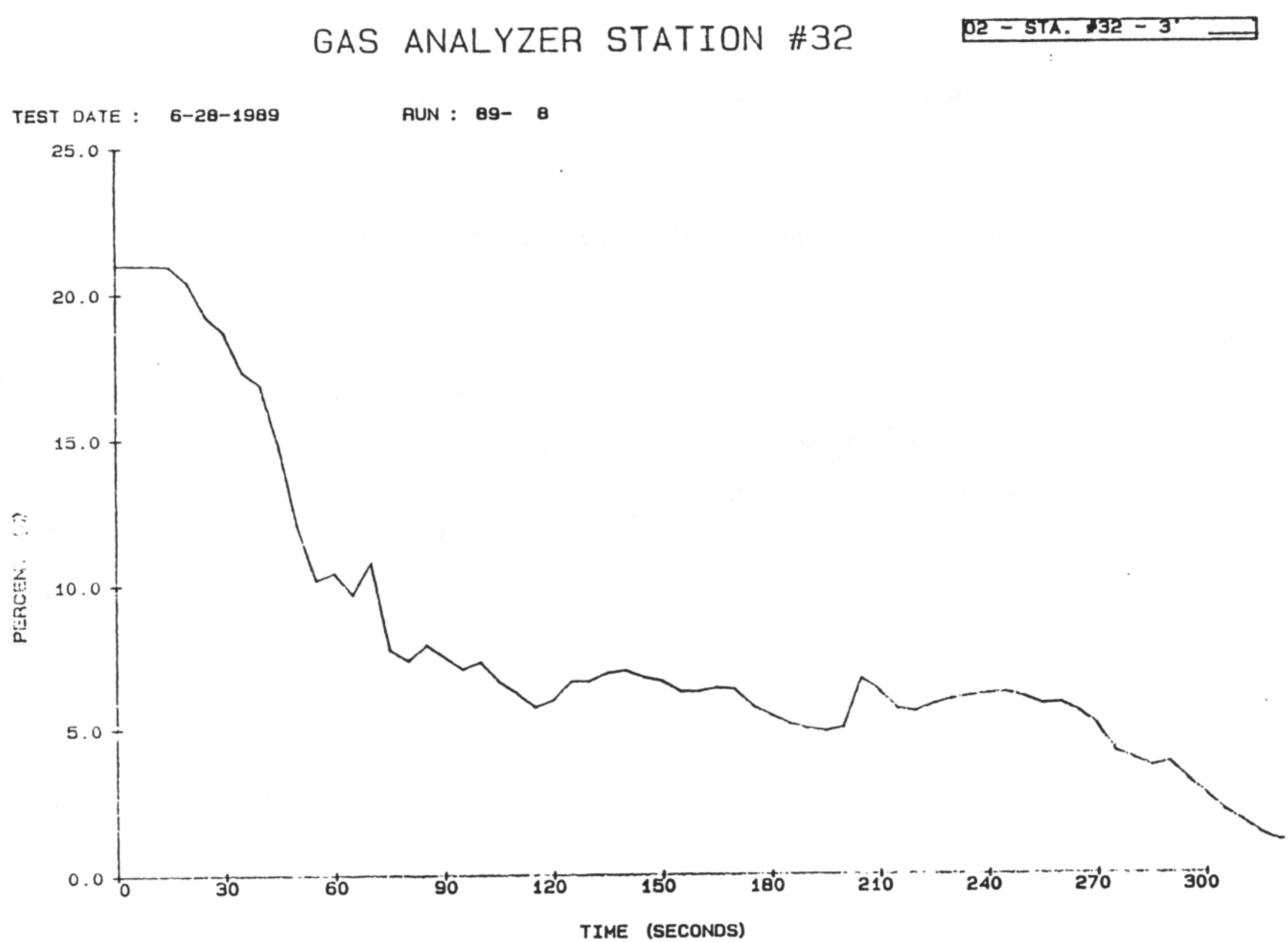

FIGURE 9. OXYGEN CONCENTRATION AT STATION 32 AT THE 3-FOOT HEIGHT DURING TEST

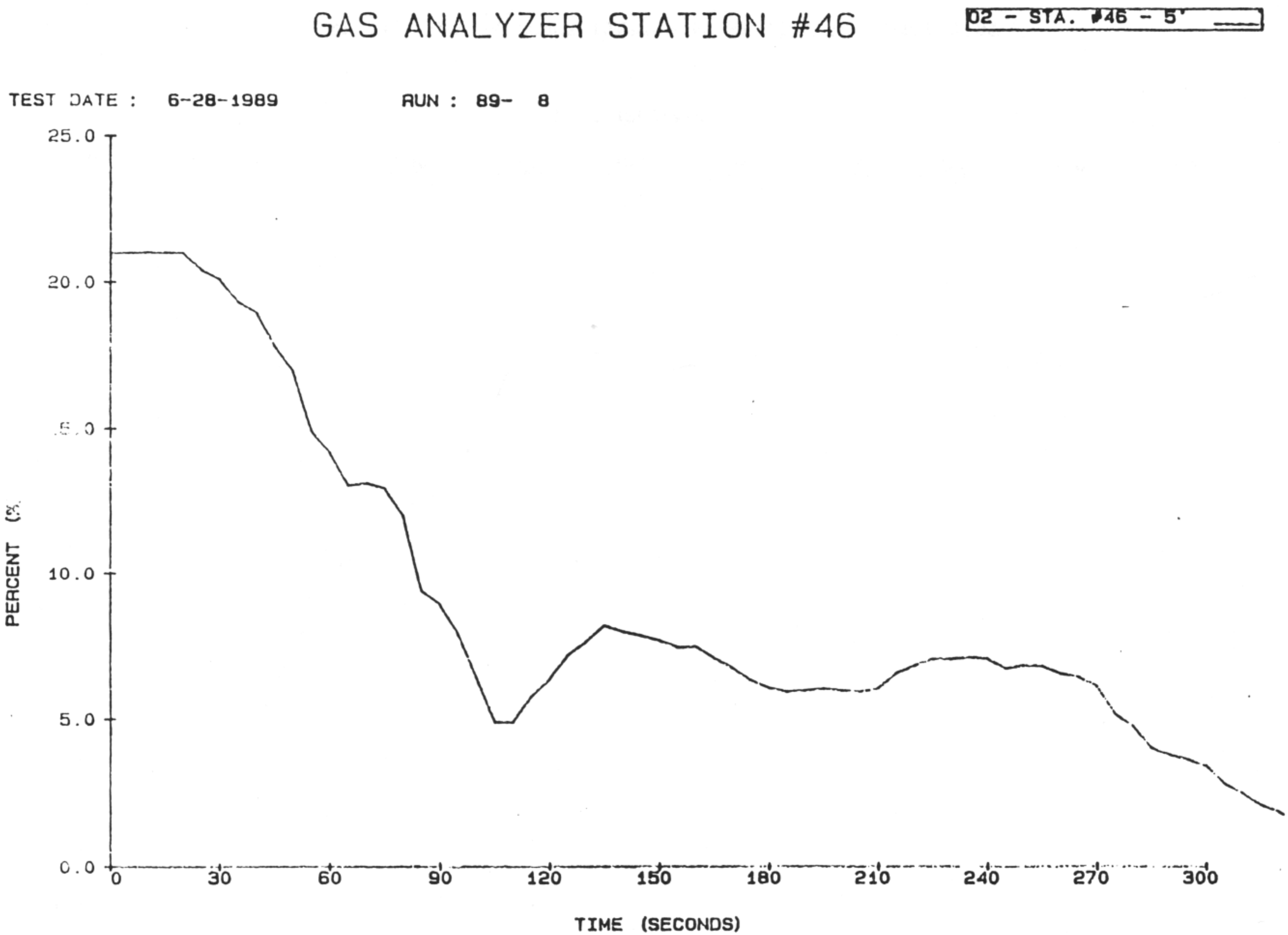

FIGURE 10. OXYGEN CONCENTRATION AT STATION 46 DURING TEST

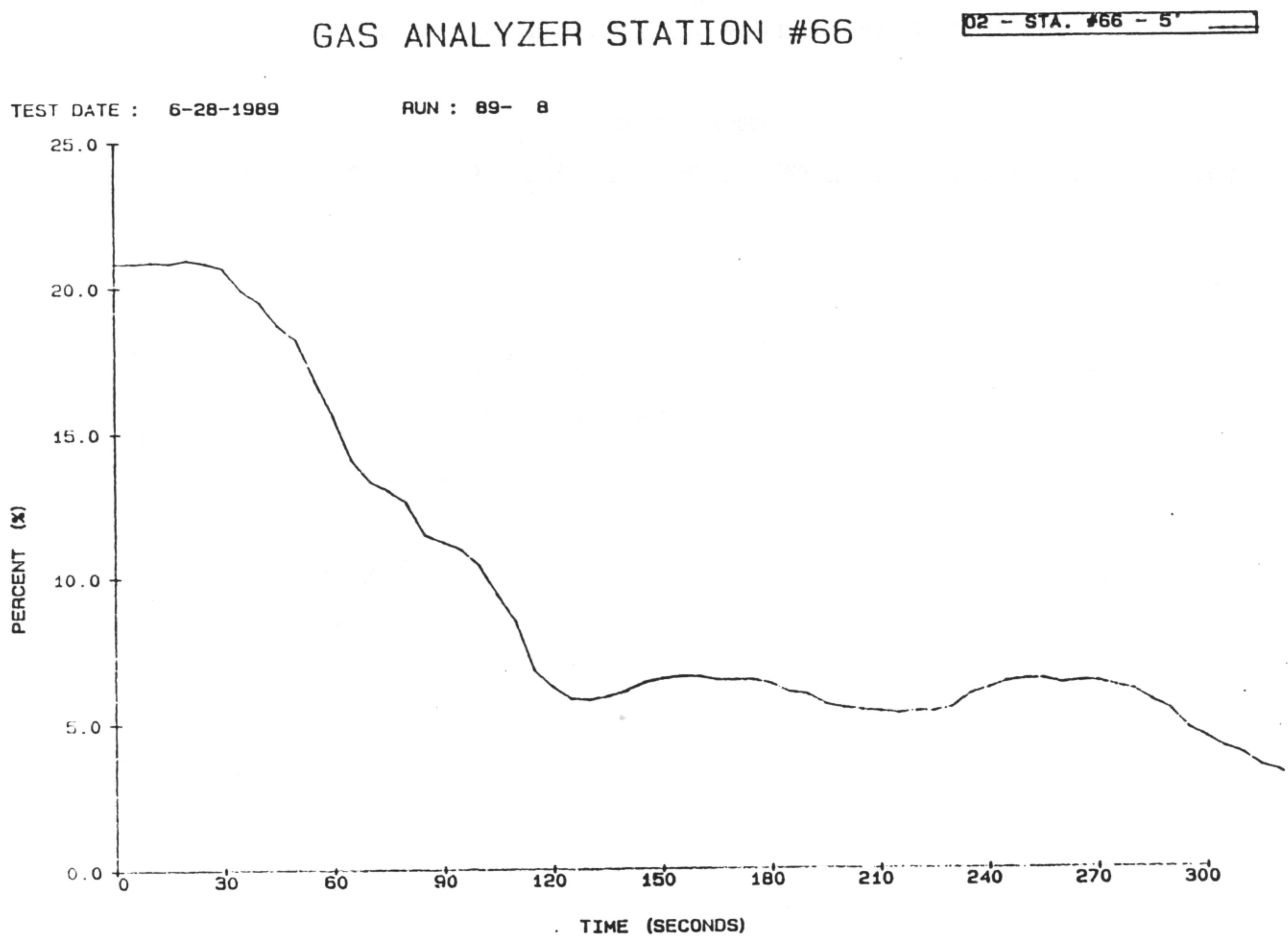

FIGURE 11. OXYGEN CONCENTRATION AT STATION 66 DURING TEST

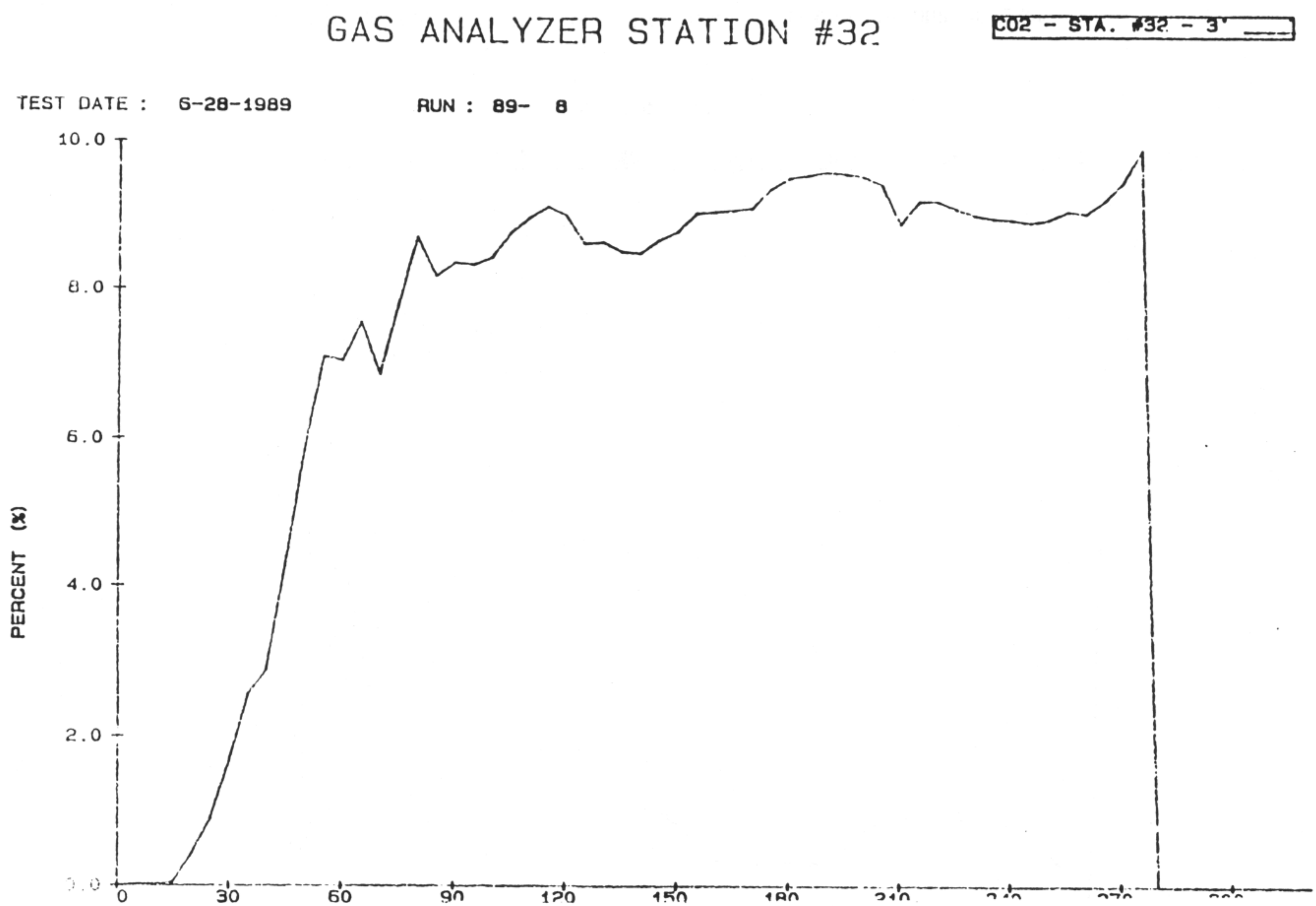

FIGURE 12. CARBON DIOXIDE CONCENTRATION AT STATION 32 DURING TEST

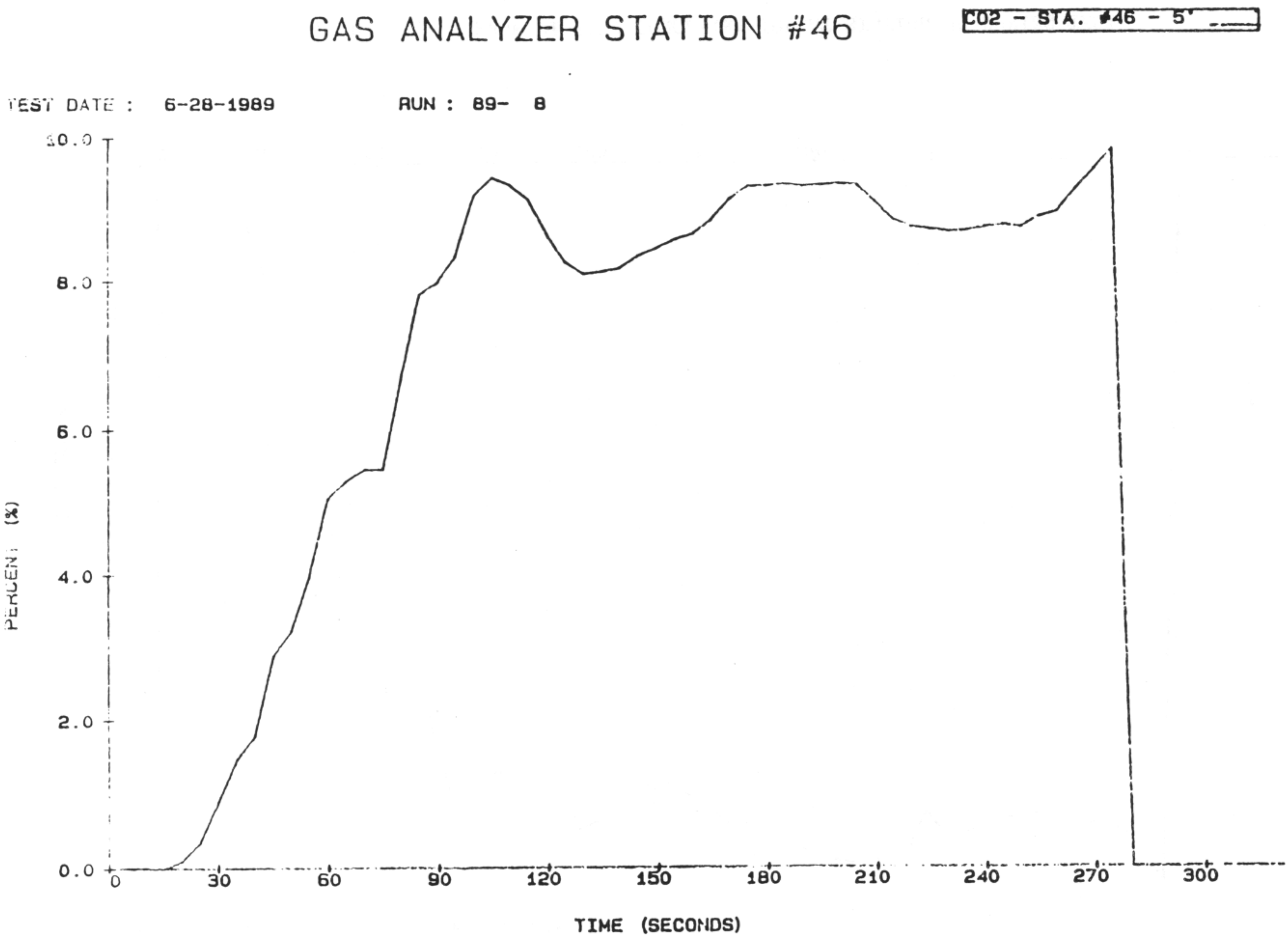

FIGURE 13. CARBON DIOXIDE CONCENTRATION AT STATION 46 DURING TEST

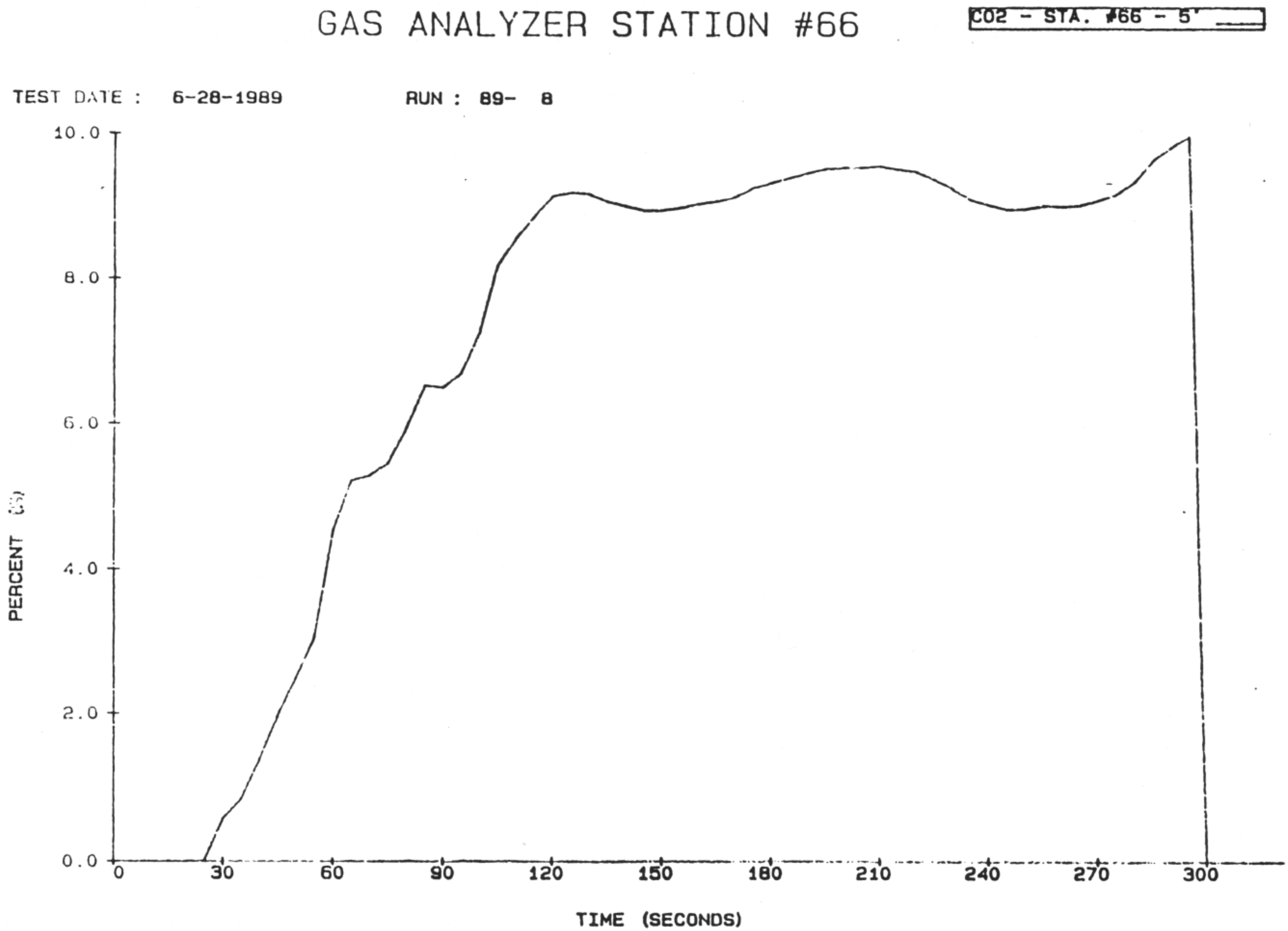

FIGURE 14. CARBON DIOXIDE CONCENTRATION AT STATION 66 DURING TEST

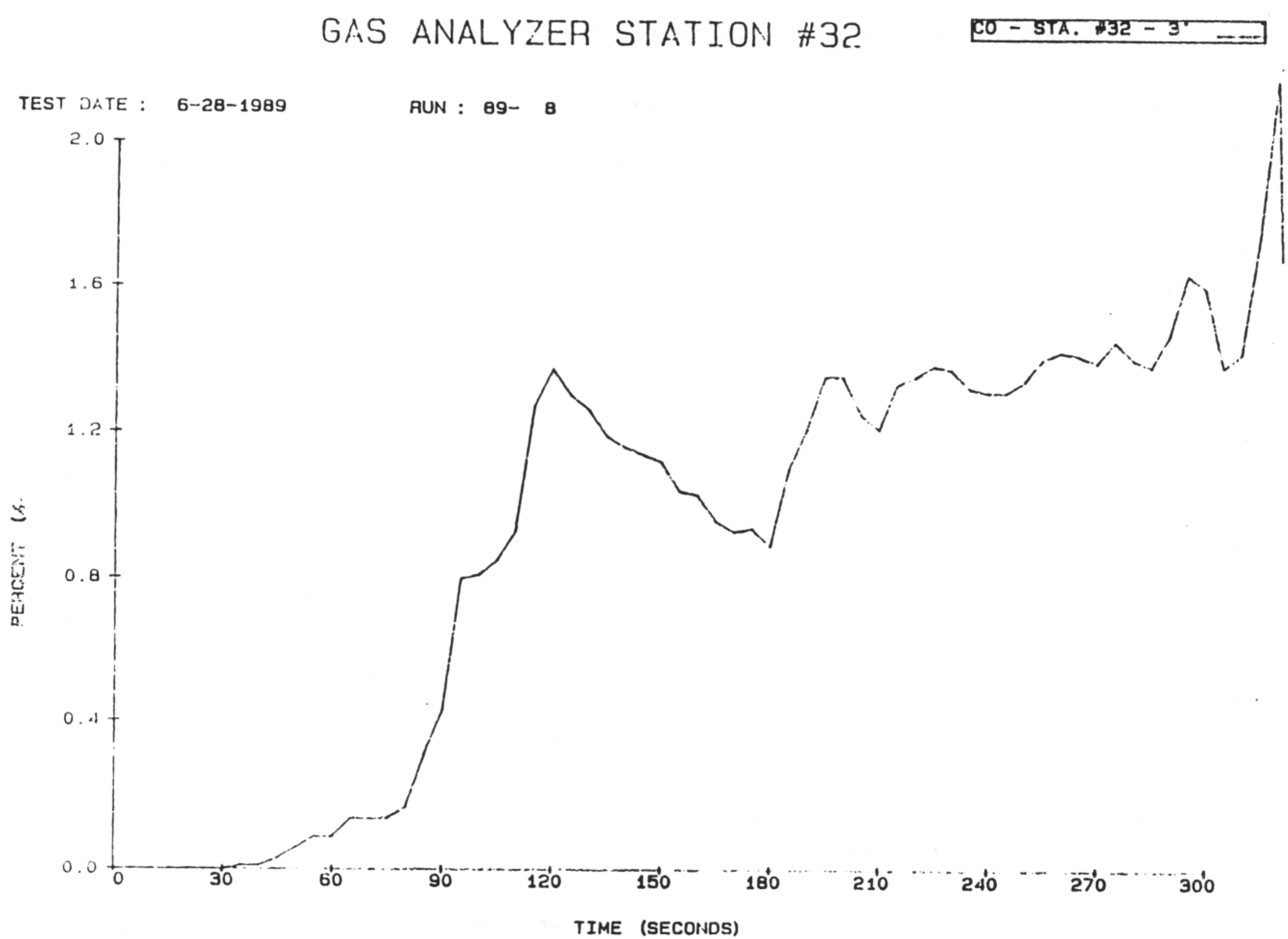

FIGURE 15. CARBON MONOXIDE CONCENTRATION AT STATION 32 AT 3-FOOT HEIGHT DURING TEST

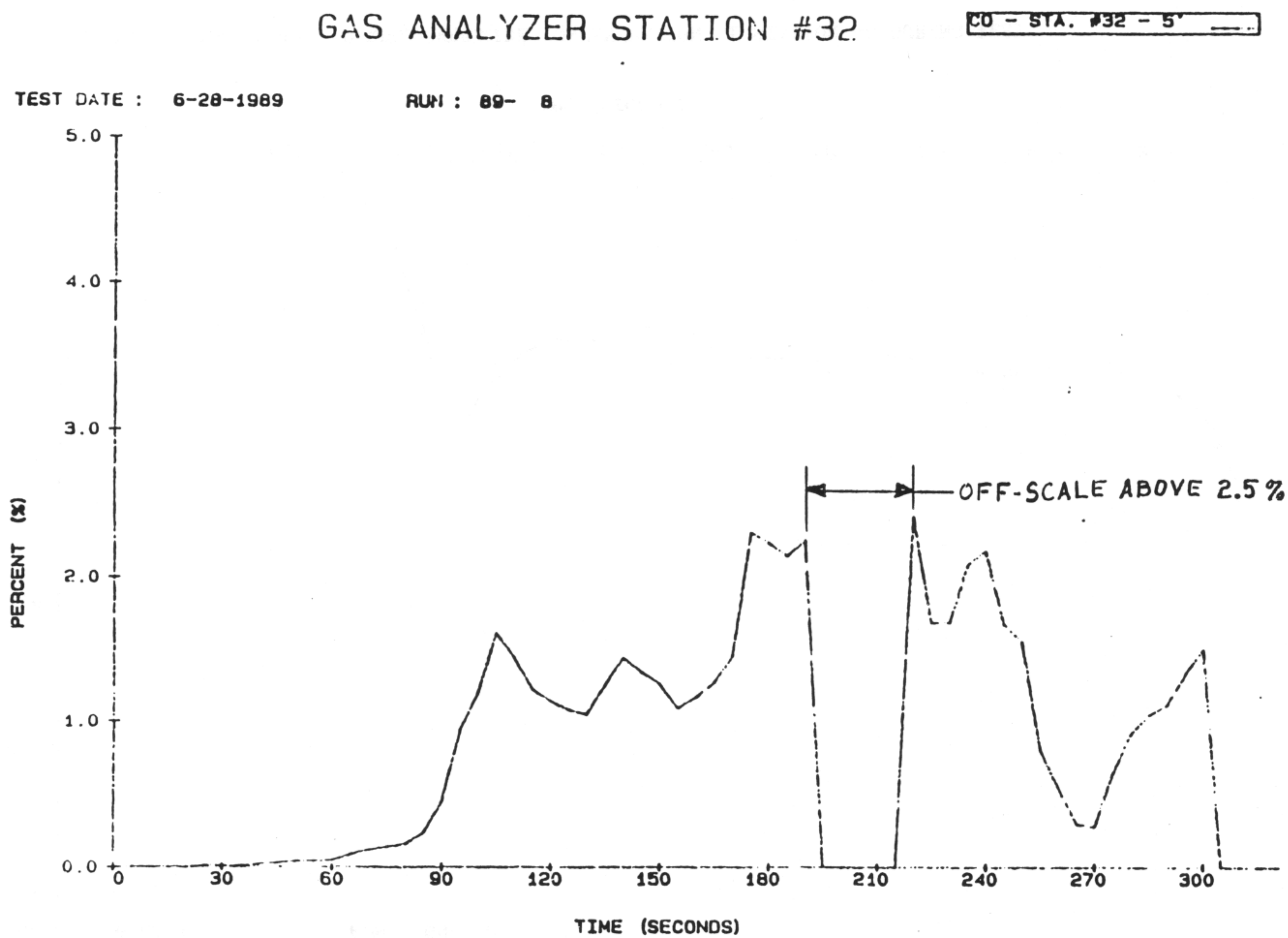

FIGURE 16. CARBON MONOXIDE CONCENTRATION AT STATION 32 AT 5-FOOT HEIGHT DURING TEST

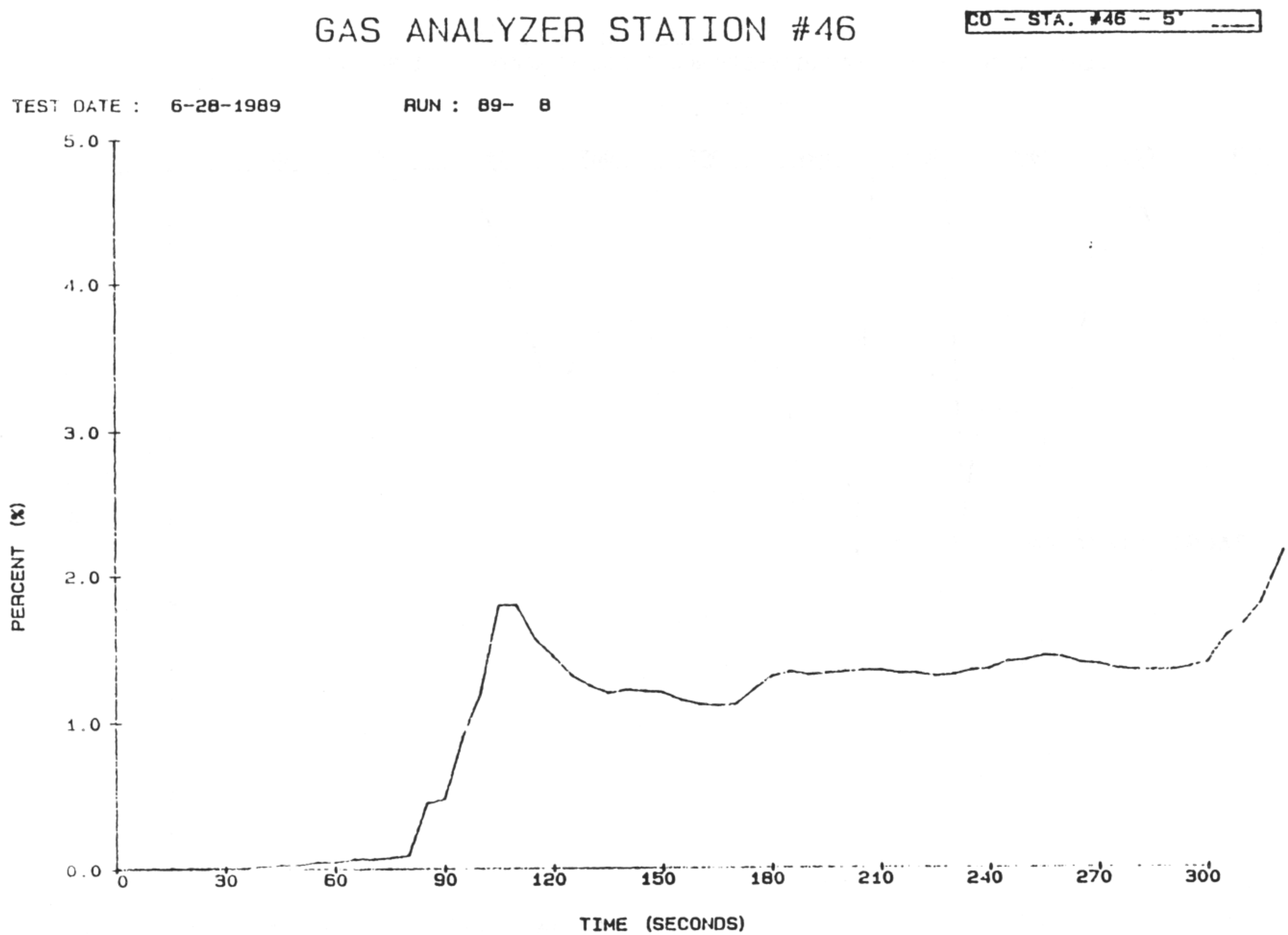

FIGURE 17. CARBON MONOXIDE CONCENTRATION AT STATION 46 DURING TEST

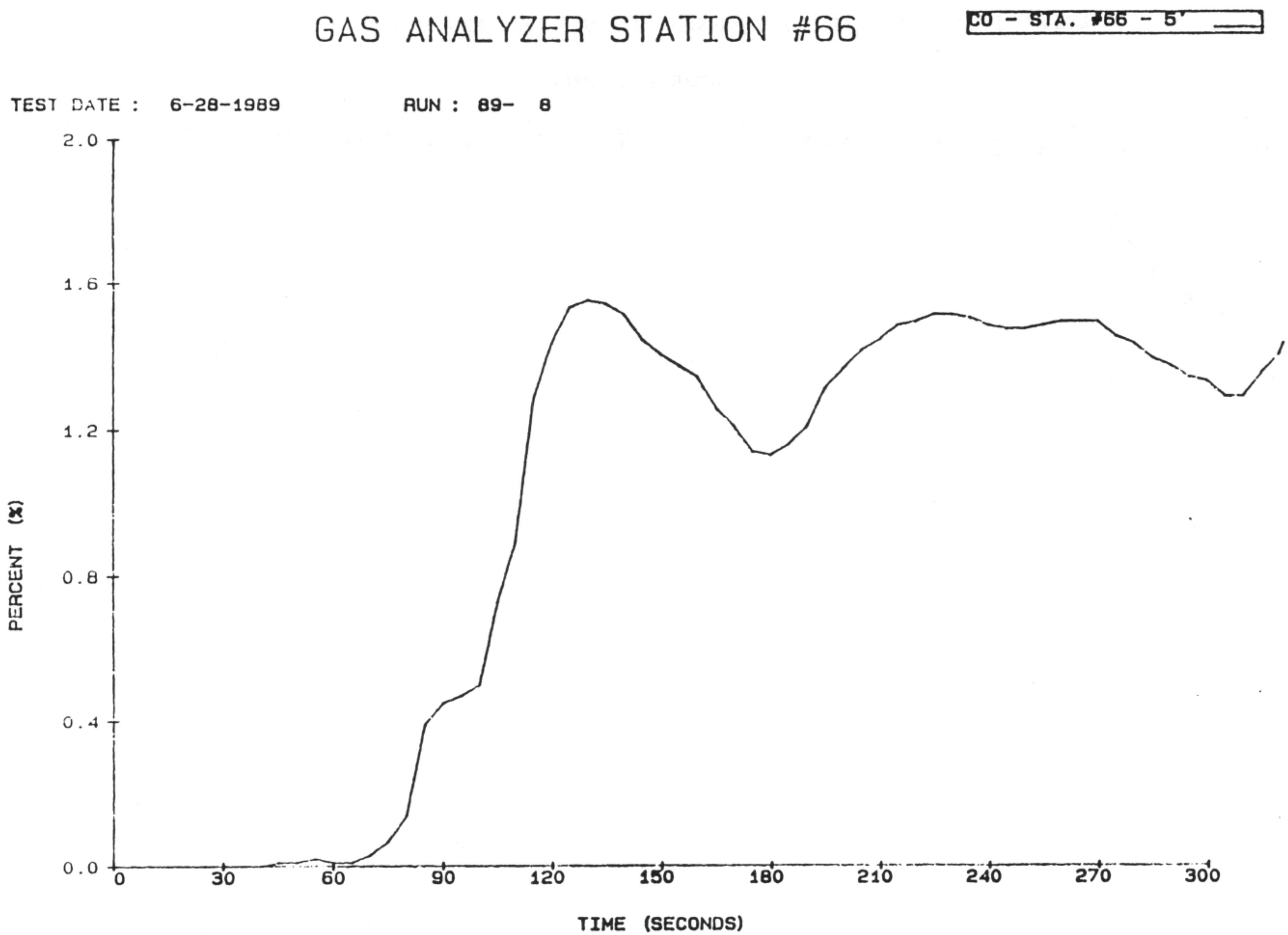

FIGURE 18. CARBON MONOXIDE CONCENTRATION AT STATION 66 DURING TEST

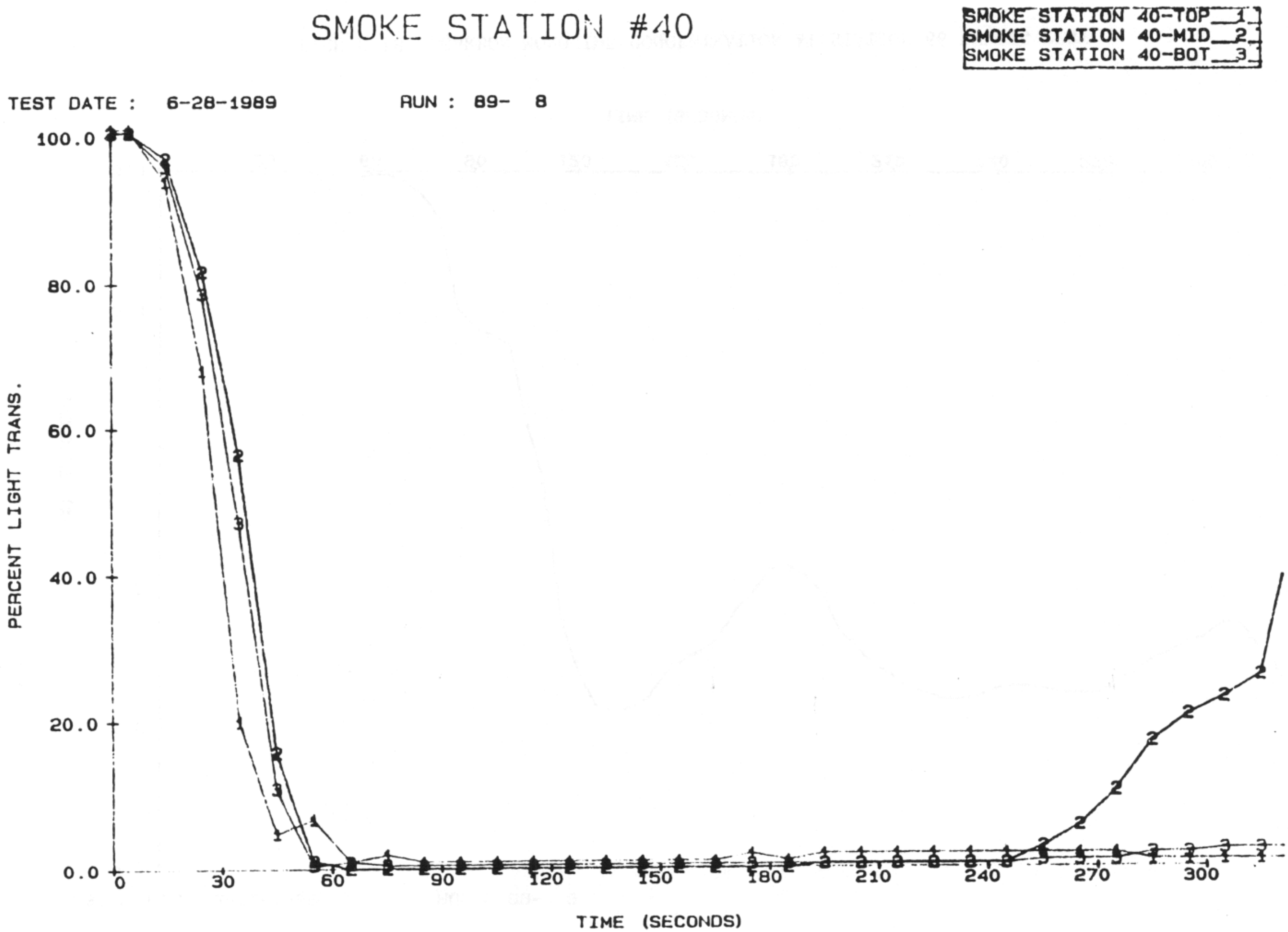

FIGURE 19. SMOKE DENSITY (LIGHT OBSCURENCE) AT STATION 40 DURING TEST

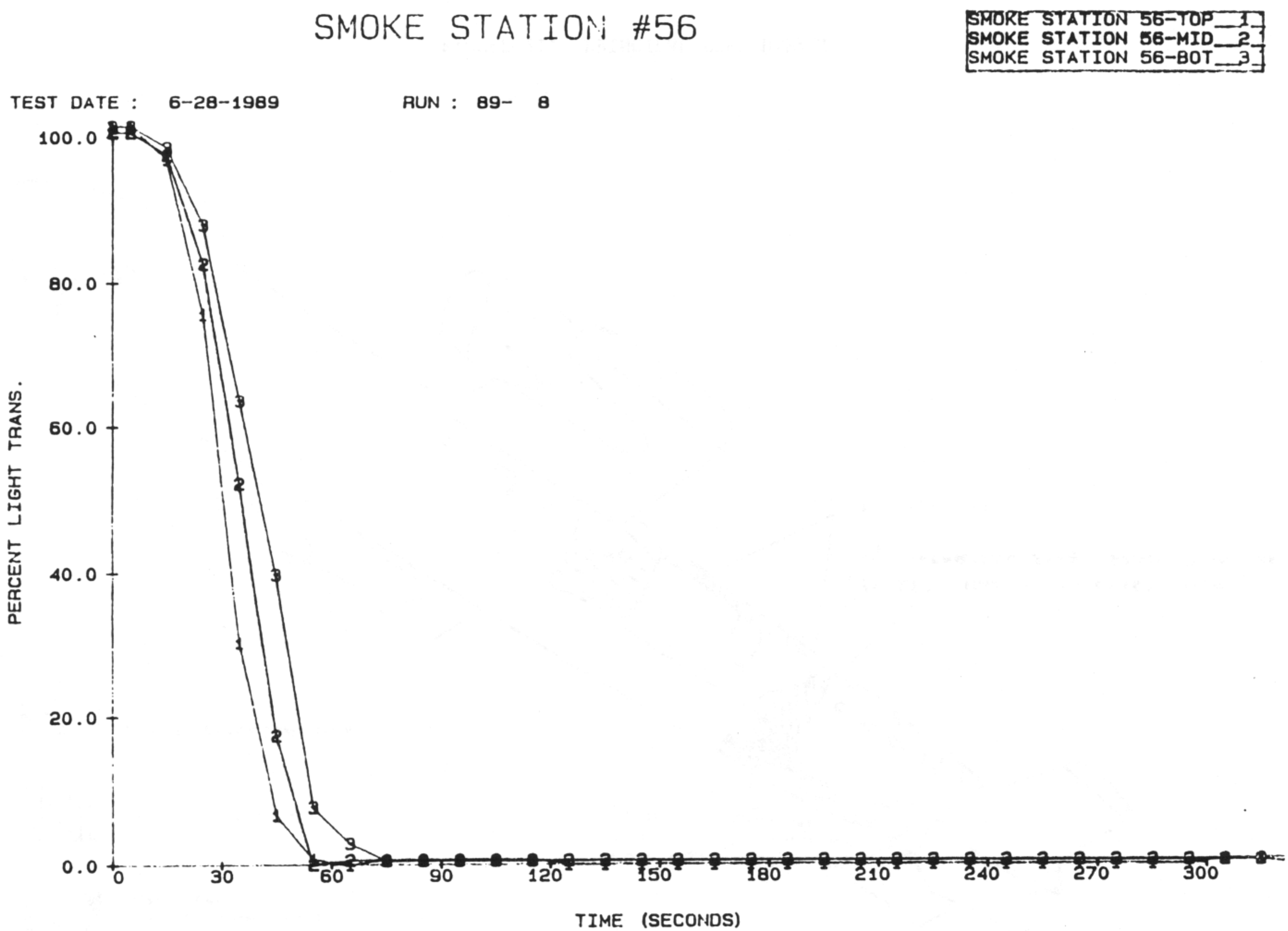

FIGURE 20. SMOKE DENSITY (LIGHT OBSCURENCE) AT STATION 56

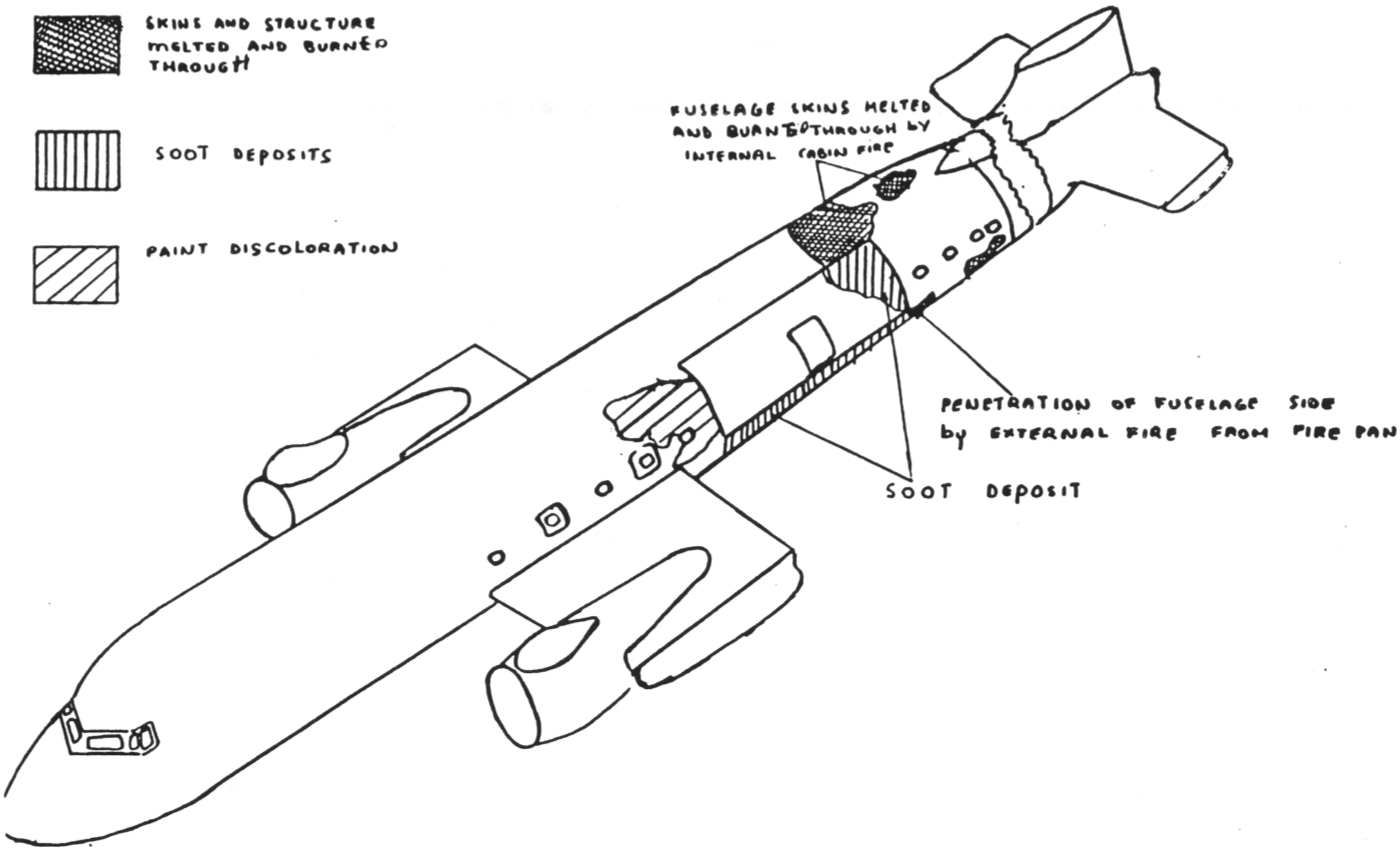

FIGURE 21. PRINCIPAL FIRE DAMAGE

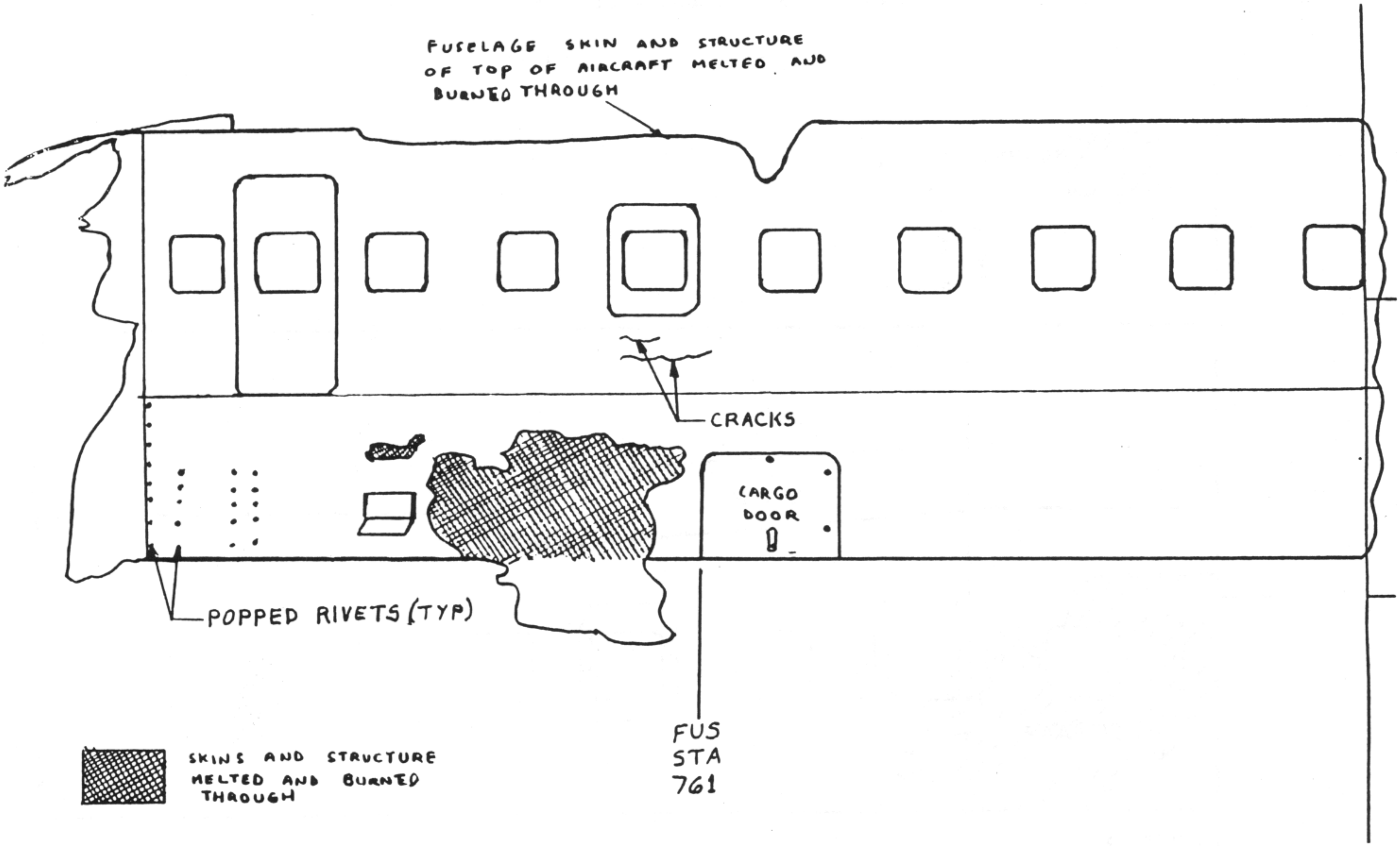

FIGURE 22. VIEW OF STARBOARD SIDE DAMAGE

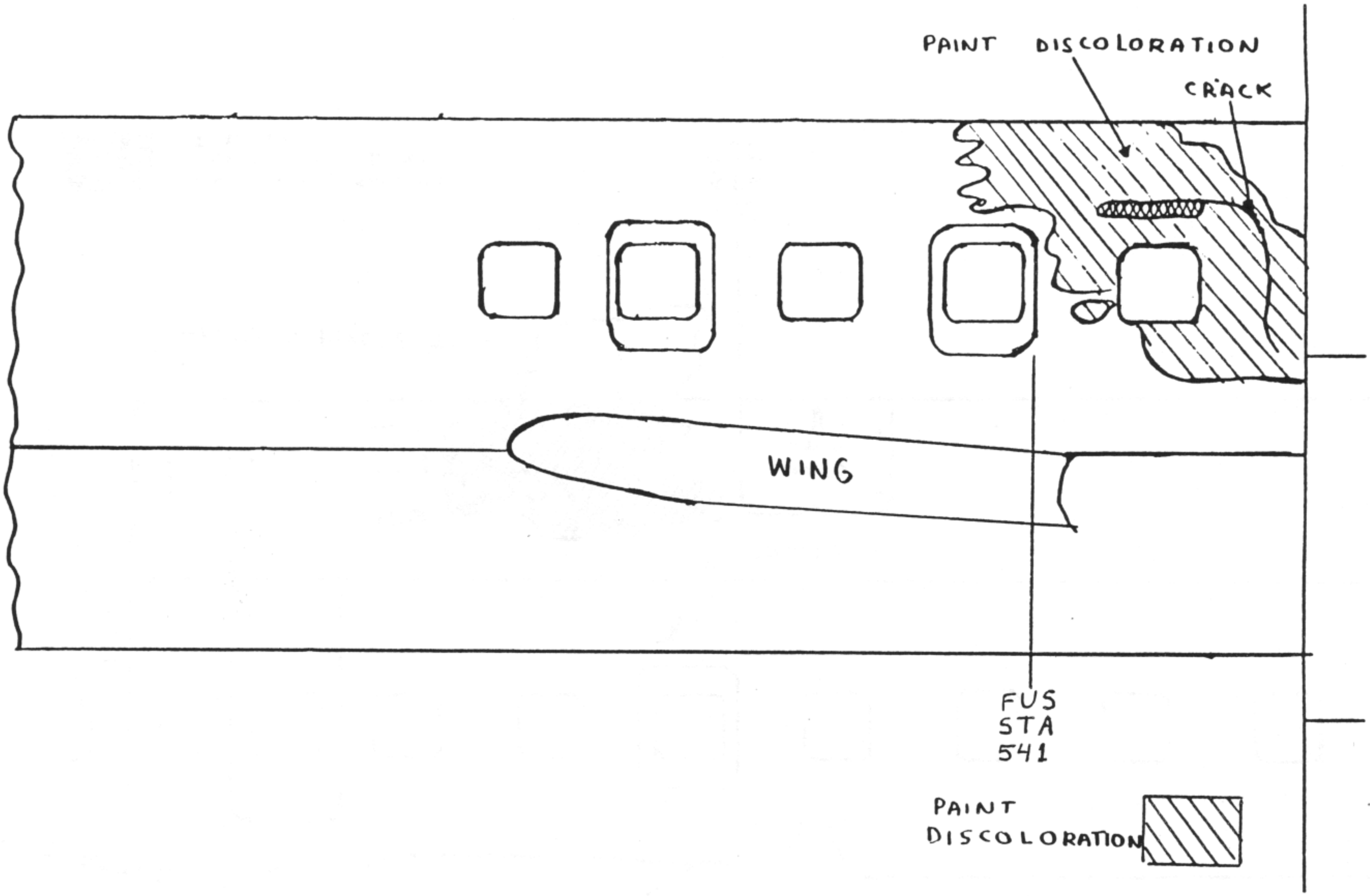

FIGURE 23. VIEW OF PORT SIDE DAMAGE (FORWARD)

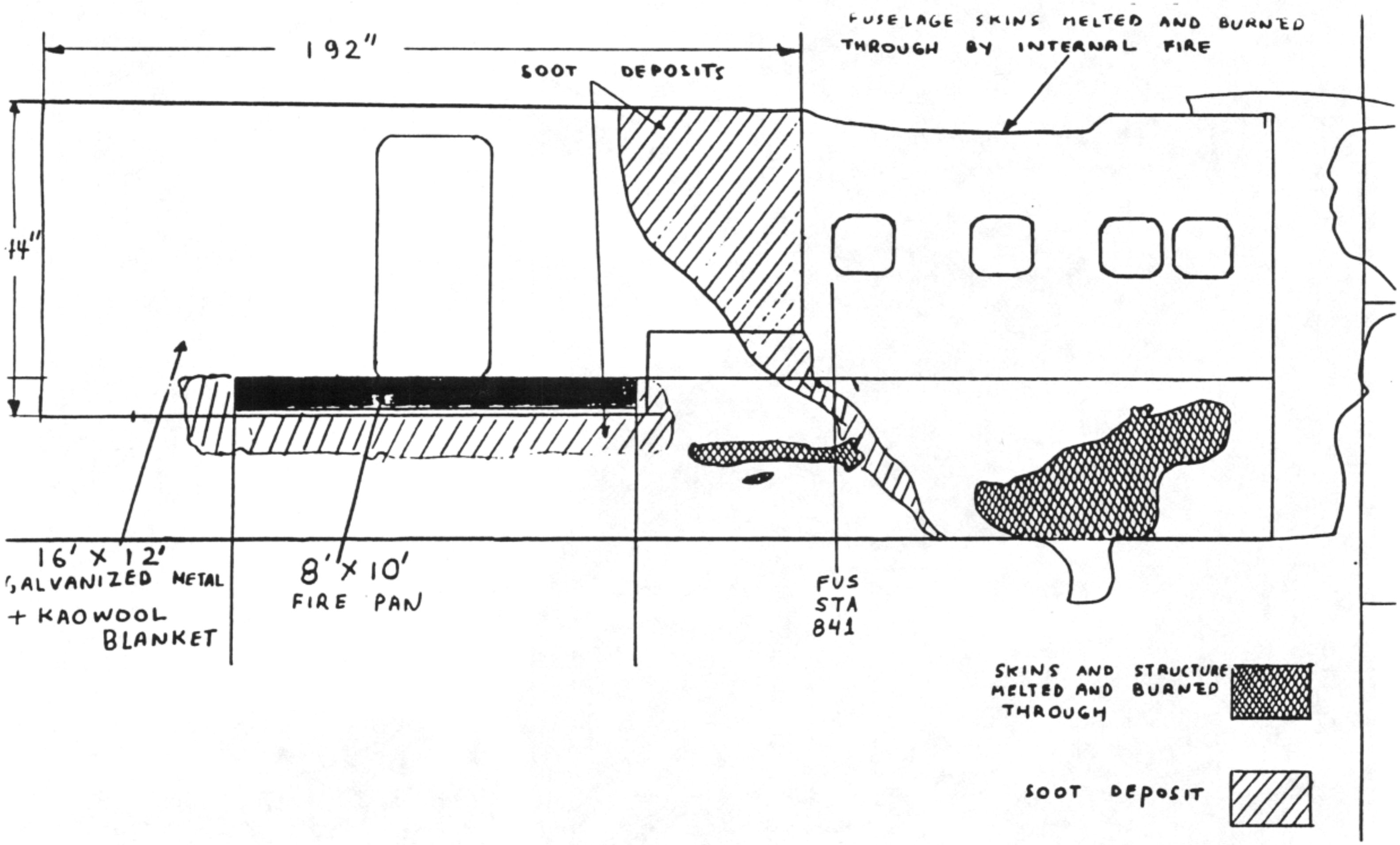

FIGURE 24. VIEW OF PORT SIDE DAMAGE (AFT)

FIGURE 25. AIRCRAFT AFTER FIRE WAS EXTINGUISHED