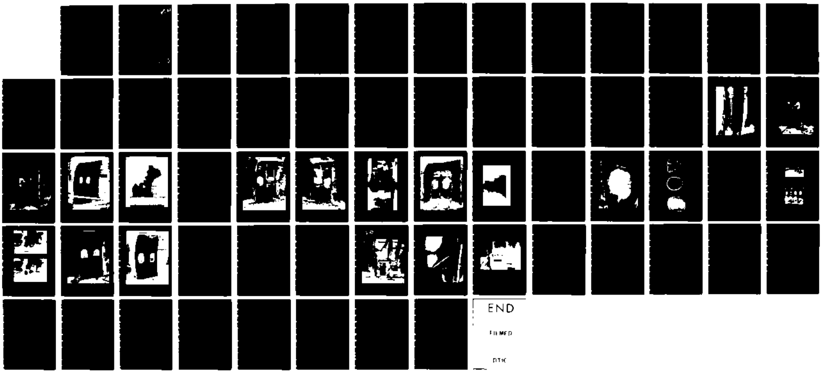
AD-A143 263 EVALUATION OF AN IMPROVED FLAME RESISTANT AIRCRAFT 1/1
WINDOW SYSTEM(U) FEDERAL AVIATION ADMINISTRATION
TECHNICAL CENTER ATLANTIC CITY NJ G B GEYER ET AL.
UNCLASSIFIED MAY 84 DOT/FAA/CT-83/10 F/G 1/3 NL



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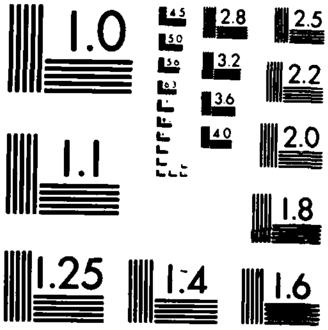

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Evaluation of an Improved Flame Resistant Aircraft Window System

George B. Geyer
Charles H. Urban

Final Report
May 1984

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US Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-83/10	2. Government Accession No. AD A143 [illegible]	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF AN IMPROVED FLAME RESISTANT AIRCRAFT WINDOW SYSTEM		5. Report Date May 1984 6. Performing Organization Code ACT-350
7. Author(s) George B. Geyer and Charles H. Urban		8. Performing Organization Report No. DOT/FAA/CT-83/10
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Information was obtained by conducting a series of representative fire modeling experiments of aircraft cabin window systems employing salvaged segments of a McDonnell Douglas DC-10 aircraft. Experiments were performed in which a thermally improved window system was installed adjacent to a standard window configuration and exposed to flame impingement from a JP-4 fuel fire. The results of test 1 indicated that the thermally improved DC-10 window configuration, employing the stretched acrylic pressure pane and the new EX 112 fail-safe pane, provided an overall improvement in flame resistivity over the standard all acrylic window system of at least 79 seconds (1.3 minutes). During this experiment, the silicone rubber window gasket provided adequate thermal and mechanical stability toward preventing flame penetration into the cabin through the improved fail-safe (EX 112) window system for 225 seconds (3.75 minutes), which was the duration of fire exposure. The average failure time of the stretched acrylic and thermally improved (EX 112) fail-safe window panes in tests 2, 3, and 4 was 198 seconds (3.3 minutes) and 249 seconds (4.15 minutes), respectively, after fuel ignition. These data indicated that, on average, an improvement in fire resistivity of 51 seconds (0.85 minute) was obtained by the improved (EX 112) window configuration over the standard stretched acrylic window system. Comparative tests performed with representative DC-10 fuselage components employing the cabin interior honeycomb panel (test 3) and the aluminum panel (test 4) configurations, showed that the honeycomb panel provided a minimum inprovement in flame resistivity of 67 seconds over the aluminium interior panel.

17. Key Words Aircraft Windows Fire Tests Aircraft Accidents Aircraft Fuel Fires Improved Aircraft Windows	18. Distribution Statement Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	61	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. Joe W. Kozmata of Douglas Aircraft Company, Long Beach, California for providing the DC10 aircraft interior panel configurations employed in tests 3 and 4. Also, to Dr. John A. Parker of the National Aeronautical and Space Administration, Ames Research Center, Moffett Field California for providing all of the standard acrylic and thermally improved EX112 window systems used in this project.

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EXECUTIVE SUMMARY

This document presents the results of tests performed on 3.3-foot wide by 4.2-foot high segments cut from a 20-foot long section of a salvaged McDonnell Douglas DC-10-10 aircraft fuselage. Each segment comprised portions of the skin, doubler and belt containing two adjacent window openings. Experiments were performed in which a thermally improved window configuration was installed adjacent to a standard window system and exposed to flame impingement from an adjacent external JP-4 fuel fire.

The results of test 1 indicated that the thermally improved DC-10 window configuration employing the stretched acrylic pressure pane and the new EX 112 fail-safe pane, provided an overall improvement in flame resistivity over the standard all acrylic window system of at least 79 seconds (1.3 minutes). During this experiment, the silicone rubber window gasket provided adequate thermal and mechanical stability toward preventing flame intrusion into the cabin through the improved fail-safe (EX 112) window system for 225 seconds (3.75 minutes), the duration of fire exposure. A similar silicone rubber gasket, mounting the stretched acrylic pressure and fail-safe panes, became fused to the edges of the panes which melted, shrank, burned, and fell into the fire pool in approximately 146 seconds (2.4 minutes) after fuel ignition.

The average failure time of the stretched acrylic and thermally improved (EX 112) fail-safe window panes in tests 2, 3, and 4 was 198 seconds (3.3 minutes) and 249 seconds (4.15 minutes), respectively, after fuel ignition. These data indicate that, on average, an improvement in fire resistivity of 51 seconds (0.85 minute) was obtained by the improved (EX 112) window configuration over the standard stretched acrylic window system. This information was obtained from film analyses and heat flux measurements through the window openings at the time of failure.

Comparative tests performed with representative DC-10 fuselage components employing the cabin interior honeycomb panel (test 3) and the aluminum panel (test 4) configurations showed that the aluminum panel reached the incipient melting temperature of aluminum in 164 seconds (2.7 minutes) after fuel ignition, while the honeycomb panel required 231 seconds (3.85 minutes) before obtaining the same temperature. This difference of 67 seconds (1.11 minutes) represents a significant delay in the temperature rise between the two interior panel configurations.

INTRODUCTION

PURPOSE.

The project objective was to evaluate the burn-through resistance of a thermally improved aircraft cabin window configuration to flame penetration from an adjacent aviation fuel fire.

BACKGROUND.

The accident investigation of the Continental Airlines McDonnell Douglas DC-10-10 aircraft, flight 603, from Los Angeles International Airport to Honolulu, Hawaii on March 1, 1978, showed evidence that the extensive fuel spill fire around the left wing melted the aluminum skin over a wide area of the fuselage and destroyed adjacent window panes but did not penetrate through the interior paneling. However, the effects of early flame ingress through the windows were observed on some nearby cabin materials.

The overall effectiveness of the fire rescue mission in this accident was attributable to the rapid and effective response of the Los Angeles Airport fire rescue services and the thermal resistivity of the DC-10 aircraft fuselage.

DISCUSSION

GENERAL.

The documented early failure times of cabin window transparencies identified a requirement for the thermal improvement of the aircraft window system to prevent flame penetration into the passenger cabin during the evacuation of occupants in fire emergencies. The window "system" comprises the window pressure transparencies, seals, inner anacoustical dust shield and reveal panel. Because of the large numbers of cabin windows in wide-bodied aircraft (DC-10 120, approximately 127 square feet), their premature failure constitutes a significant potential breech in the thermal integrity of the cabin environment.

Recent developments in high molecular weight polymer chemistry by the Chemical Research Projects Office, NASA-Ames Research Center culminated in the experimental production by Goodyear Aerospace Corporation, of a high char yield transparency (trimethoxy boroxine modified epoxy resin) for aircraft cabin window systems. This new polymeric transparency is identified as EX 112.

CONFIGURATION OF THE DC-10 CABIN WINDOW ASSEMBLY.

A typical commerical aircraft cabin passenger window assembly is comprised of a dual pressure pane configuration and an anacoustic dust shield or scratch pane. The pressure window system consists of an outer or structural pane from 0.400- to 0.440-inch thick fabricated of stretched acrylic (polymethylacrylate) capable of sealing the cabin against the pressure differential created by high altitude flight. An inner or fail-safe pane from 0.180- to 0.210-inch thick, fabricated of the same material is spaced 0.125 inch from the outer pane. This fail-safe pane must posess sufficient strength to maintain the required cabin pressure until the aircraft can be brought down to a safe altitude if the pressure pane fails. These two panes are held in position by an elastomeric (silicone) gasket and clipped to the window frame (figure 1), which hermetically seals the window system to the fuselage structure. In the thermally improved window system, the inner acrylic fail-safe pane was replace by one fabricated of the new polymeric material (EX 112). The EX 112 fail-safe panes, on average, were approximately 8.77 percent heavier than the stretched acrylic type.

A third component in the window system is the cast acrylic anacoustical dust shield, approximately 0.060 inch thick, set in a seal against the interior trim reveal panel. Its principal functions are to serve as an anacoustical barrier and protective shield for the fail-safe pane and to be readily replaced if damaged.

TEST BED CONFIGURATION.

DC-10 WINDOW SYSTEM. A 20-foot long section comprising portions of the skin, doubler and belt was salvaged from the Continental Airlines DC-10 accident and cut into segments containing two adjacent window openings, thereby providing a means of evaluating the standard and thermally improved window systems under identical fire conditions. These segments were riveted to steel frames suitable for mounting in the doorway opening of a C-133 test fuselage. A schematic diagram of the window system mounted in the test article is presented in figure 2 and the window system is shown mounted in the steel frame in figure 3.

The two adjacent windows were separated internally by means of a 3-foot by 4-foot vertical steel sheet as illustrated in figure 4 to visually and thermally isolate each window system. Figure 4a shows the standard (acrylic) window system with thermocouples embedded in the center of the pressure and fail-safe panes while figure 4b shows the experimental window system (EX 112) with identical instrumentation. Appendix A identifies all of the instrumentation employed on each of the four DC-10 fuselage test segments.

Each test segment was backed by a 2- to 3-inch thick layer of insulating material to conform generally with the requirements of the DC-10 aircraft fuselage for a thermal and high frequency sound-deadening barrier.

AIRCRAFT (C-133) FIRE TEST BED. The DC-10 window fire exposure tests were conducted in a fire-hardened surplus C-133 aircraft fuselage, which had been modified internally to resemble a wide-bodied passenger cabin. The window segments were mounted in a forward door opening in the fuselage above an external 80-square foot steel fire pan positioned at floor level as shown in figure 5. The fire pan was capable of being charged with variable quantities of aviation fuel to provide the required burning time, after which it could be rapidly extinguished by means of a remotely controlled foam and carbon dioxide extinguisher system.

The flame penetration time for various parts of the DC-10 fuselage segment was monitored from the C-133 cabin interior by means of two thermally protected closed circuit television cameras and one instrumentation motion picture camera exposing 16mm color film at 24 frames per second. Critical events and thermal data were observed and recorded for instant replay during each test from inside the instrument control room. The experiment was terminated when flame destroyed the windows and penetrated the cabin interior, at which time the fire was extinguished.

TESTS OF THE STANDARD AND THERMALLY IMPROVED DC-10 WINDOWS.

DESCRIPTION OF TEST 1. The first window test segment was backed up by a 3-inch thick layer of high temperature resistant ceramic fiber (Kaowool™) insulation which was secured in position by means of wire bands. The Kaowool was employed to simulate the DC-10 fuselage glass fiber insulation batt without being subjected to thermal disintegration from flame penetration through the aircraft skin prior to the completion of the experiment.

Radiometers were employed as a means of estimating the heat flux through each window system and to assess the rate and relative quantity of char buildup as a function of fire exposure time from the attenuation of radiant energy. One radiometer was positioned inside the C-133 cabin in the center and 18 inches from each fail-safe pane, as shown in figure 4. Additionally, the radiometers provided a means of verifying the visual burn-through time of each window system obtained from the instrumentation and television cameras.

The temperature rise of the DC-10 fuselage components was monitored by means of four thermocouples. One thermocouple was mounted in the middle of the belt between the two windows. Two thermocouples were positioned in the skin with one above and the other below the belt thermocouple. The fourth thermocouple was located between the fuselage skin and Kaowool batt as indicated in figure 5.

The test was performed by charging the fire pan with 28 gallons of JP-4 aviation fuel which was sufficient to provide a burning time of four minutes at maximum intensity. The fuel was ignited by means of a high intensity electrical spark activated from a remote observation point. The characteristic configuration of the flame plume as it impinged on the window segment is shown in figure 6. The test was terminated when flame ingress through any part of the DC-10 fuselage segment was deemed hazardous to the safety of the C-133 fuselage test bed monitoring equipment. Flame penetration was closely monitored on the closed circuit television equipment and the fire extinguished remotely by means of the carbon dioxide and foam extinguisher systems shown in figure 6. After the test, the panel was photographed in position and subsequently removed for additional photographic documentation and assessment of the fire damage.

RESULTS: The temperature rise of the DC-10 fuselage segment during fire exposure in test 1 is indicated by the profiles presented in figure 7 for the aluminum skin and belt areas. These data show that the aluminum skin above the windows started to melt in 64 seconds (1.07 minutes) which was confirmed by an analysis of the photographic coverage. However, the skin below the windows and belt area did not reach the incipient melting temperature for aluminum of 900° F until 198 seconds (3.3 minutes) after fuel ignition. The fire damage to the skin above the improved (EX 112) window system is shown in figure 8 and above the acrylic window in figure 9. A more detailed interior view of the failure mode of the fuselage skin in these areas is presented in figure 10. An overall exterior view of the fire damage sustained by the DC-10 fuselage segment is presented in figure 11.

As a consequence of the wide variation (134 seconds) in the recorded melting times between the aluminum fuselage skin above and below the doubler layers, the potential flame impingement temperature profiles on the test segment are considered significant. An approximation of the temperature gradiant within the flame plume of this size fire, together with a superimposed diagram of the DC-10 window test segment is presented in appendix B. Inside the luminous flame boundary in the central region of the flame plume from 2- to 6-feet above the fuel surface, the temperatures may range from 1245° to 1974° F. This size fire is in the turbulent flow region where the burning rate becomes independent of the fire size (area). The diagram in appendix B shows that the top skin of the DC-10 test segment was exposed to higher flame temperatures than the bottom skin and consequently was subject to more rapid heating. The highest temperature zone for this 8-foot wide aviation fuel pool fire is shown to be 6 feet above the fuel surface and approximately 5.7 feet in diameter at that height. However, it is apparent from the photographs presented in figures 6 and 12, taken under actual test conditions, that the temperature profiles depicted in appendix B for an "idealized" free-burning pool fire are not necessarily valid for a similar size fire adjacent to an aircraft fuselage. Accordingly, instantaneous temperatures over the surface of the C-133 fuselage could vary significantly due to thermal updrafts, thereby influencing the temperature profiles during each individual test.

The temperature data obtained from the thermocouples embedded in the pressure and fail-safe window panes for both the experimental (EX 112) and standard (acrylic) window systems are presented in figure 13. The profiles numbered 3 and 7 show that the temperature rise of the pressure panes on the experimental and standard window systems reached 900° F in 144 seconds (2.4 minutes) and 152 seconds (2.5 minutes), respectively. The temperature profiles obtained for the experimental (EX 112) and standard acrylic fail-safe panes show that the EX 112 pane reached approximately 314° F in 199 seconds (3.3 minutes) and that the temperature data for the acrylic pane was lost. Additional data superimposed on the time temperature profiles in figure 13 show that the first visual flame penetration through the standard acrylic window system occurred in 146 seconds (2.4 minutes) after fuel ignition. While only very minor flame intrusion was observed through several small cracks in the EX 112 fail-safe pane (figure 14) after 225 seconds (3.75 minutes), which was the duration time of the test. The condition of the standard acrylic and experimental EX 112 fail-safe panes with their respective silicone rubber gaskets are shown in figure 15.

The thermal response of the radiometers to the radiant energy transmitted through the standard and thermally improved window systems is indicated by the profiles in figure 16. Preliminary experiments performed with the two window configurations indicated that the transmittance was equivalent for both systems. The profile generated for the standard window system indicates that incipient failure (0.2 BTU/ft^2-s) occurred within 149 seconds (2.5 minutes) after fuel ignition which confirms the failure time observed in the photographic analysis. The data further show that within 24 seconds (0.4 minute) after flame penetration was detected through the standard window system the heat flux rose from 0.2 to 2.0 Btu/ft^2/-s, thereby confirming the complete destruction of the standard window system. After the failure of the standard acrylic windows, the heat flux through the experimental window system rose from 0.2 to 0.5 Btu/ft^2/-s in 43 seconds (0.7 minute). This delay in transmittance was attributable, in part, to the gradual development of a carbonized surface layer that insulated the substrate from further pyrolysis for the duration of the test.

Another critical component contributing to the structural and thermal integrity of the window system is the silicone rubber gasket which hermetically seals the window panes to the fuselage structure. The photographic analysis revealed small transient yellow flames licking around the exposed interior surface of the gaskets starting at different times after fuel ignition. Flaming started within 112 seconds (1.9 minutes) around the standard acrylic window, at which time the belt temperature was 630° F. After 133 seconds (2.2 minutes) the belt temperature had reached 705° F and flaming started around the improved EX 112 window gasket. The difference in the starting time of gasket flaming between the experimental and standard window system of 21 seconds (0.35 minutes) is attributable in part, to the earlier failure time of the standard acrylic fail-safe pane over the thermally improved (EX 112) fail-safe pane.

The information presented in table 1 (taken from Baer, Engineering Design for Plastic Polymer Science and Engineering Series, Reinhold Publishing 1964) lists some of the flammable pyrolysis products produced by silicone rubber at 932° F (approximate incipient melting temperature of aluminum) and at 1472° F. From these data it is evident that the residue yield from silicone rubber is high and that the pyrolysis products produced have relatively low ignition temperatures in terms of the overall crash fire environment (fuel burning range 1800° F to 2000° F). Therefore, burning ethylene, methane, benzene vapor and hydrogen could all serve as ignition sources for adjacent class A materials, if present.

TABLE 1. PYROLYTIC PRODUCTS OF ABLATIVE RESIN (IN VACUO)
(Taken from Engineering Designs for Plastics, 1964, by Baer)

SILICONE RUBBER

Volatilized Components	Temperature 932° F	Temperature 1472° F	Flash Point °F	Ignition Temperature °F
Benzene	72.4	51.4	12	1044
Carbon Dioxide	0.6	0.6	--	----
Ethylene	--	1.6	--	842
Hydrogen	--	18.4	--	1085
Methane	6.3	14.7	--	999
High Molecular Weight	8.7	13.3	--	----
Resin Volatilization	6.0%	13.0%		
Resin Residue	94.0%	87.0%		

A detailed examination of the condition of the silicone gasket after it was removed from the window frame revealed it had retained a large part of its structural integrity and flexibility (figure 15). The thermal resistivity demonstrated by the gasket under severe fire exposure is noteworthy and its survival is attributable in part, to the thermal resistance of the EX 112 fail-safe pane, the relatively high specific heat of aluminum and the mass of metal comprising the belt system.

The higher heat resistance of the belt system over the fuselage skin is evident in the photographs presented in figure 17 of the Continental Airlines DC 10-10 accident on March 1, 1978 at the Los Angeles International Airport. This failure mode, in general, was consistent with that observed in the first and subsequent tests conducted in the C-133 fire test bed.

Concurrently with the failure of the acrylic window system, the external fire plume penetrated into the cabin interior. The series of photographs presented in figure 18 show the flame plume pulsating at approximately one second intervals through the window opening after the destruction of the acrylic window panes. This condition continued for the duration of the test and would pose a severe threat to passenger survival during egress from an aircraft and serve as an ignition source for the interior cabin furnishings.

The sequence in which the fuselage components failed in this first test is considered noteworthy. The data in figure 7 shows that the aluminum skin (0.090 inch thick) above the belt was the first element to fail (64 seconds or 1.1 minutes), followed by the pyrolysis of the silicone rubber gaskets in 112 seconds (1.9 minutes) for the standard acrylic window and in 133 seconds (2.2 minutes) for the improved (EX 112) window, which was followed by visual flame penetration through the standard acrylic window in 146 seconds (2.4 minutes). The bottom fuselage skin, belt (0.350-inch thick) and the thermocouple between the fuselage skin and Kaowool insulation all reached the incipient melting temperature of aluminum (900° F) in 198 seconds (3.3 minutes). Only minor flame penetration was observed through several narrow cracks in the experimental EX 112 fail-safe pane over the duration of the test which was 225 seconds (3.75 minutes). Therefore, the desirability of increasing the thermal resistivity of the aircraft windows to flame penetration from an adjacent fuel fire to maintain fuselage integrity is apparent.

TESTS OF THE SIMULATED DC-10 FUSELAGE SECTION WITH STANDARD AND THERMALLY IMPROVED WINDOWS.

DESCRIPTION OF TEST 2. The second test was performed in a manner to more closely approximate the interior sidewall configuration of the DC-10 aircraft than did the first experiment. This was achieved, in part, by substituting the standard glass fiber insulation for the Kaowool blanket used in the first experiment. The standard insulation employs the bag system which is comprised of a 2- to 3-inch thick glass fiber batt containing 30 percent phenolic binders and covered by metalized Tedlar™ 0.002 inch thick (figure 19), which resulted in an overall density of 0.4 pounds per cubic foot. A fiber glass sheet was employed to simulate an interior cabin panel and hold the insulation batt in place (figure 20).

The fire test conditions and procedures were the same as those employed in the first experiment.

RESULTS: The temperature rise of the principal components of the DC-10 fuselage segment is shown by the profiles presented in figure 21. These data indicate that the aluminum skin above the windows reached the incipient melting temperature of aluminum (900° F) within 70 seconds (1.2 minutes) after fuel ignition while the skin area below the windows required 119 seconds (1.98 minutes). This could not be verified visually because of the presence of the fuselage insulation and glass fiber panel. However, the recorded temperature between the window panes reached 900° F in 185 seconds (3.1 minutes) after fuel ignition, while the thermocouple between the glass fiber insulation batt and the glass fiber panel reached 900° F in 206 seconds (3.4 minutes), thereby indicating the imminent failure of these components.

The temperature data (figure 22) provided by the thermocouples imbedded in the standard (acrylic) window panes indicate that the pressure pane reached the melting point of aluminum (900° F) in 91 seconds (1.5 minutes), which is approximately 695° F above the hot distortion temperature of acrylic polymers (205° F under 265 pounds per square inch); therefore, it is assumed that the outer acrylic pane failed. However, the fail-safe pane did not reach 900° F until 168 seconds (2.8 minutes) after fuel ignition, which was only 12 seconds (0.2 minute) longer than the observed (visual) failure time of 156 seconds (2.6 minutes) for the standard window system.

The failure times of the DC-10 windows as determined from the thermal response of the radiometers is indicated by the profiles presented in figure 23. These data show that the heat flux through the standard acrylic and experimental EX 112 windows was low (0.2 Btu/ft^2-s) until the time of severe failure when the heat flux rose rapidly to 2.0 Btu/ft^2-s. This massive failure (2.0 Btu/ft^2-s) required 184 seconds (3.1 minutes) for the standard acrylic window and 209 seconds (3.5 minutes) for the experimental EX 112 window. Visual observation showed that there was an approximate difference of 26 seconds (0.4 minutes) between the time the first flicker of flame penetrated the fail-safe acrylic pane and the EX 112 fail-safe pane.

The visual fire damage to the aluminum fuselage structure around the thermally improved and standard window configuration is shown in figure 24. A more detailed interior view of the fire damage to the improved EX 112 window system is presented in figure 25. Figure 24 shows a portion (approximately 25 percent) of the silicone rubber gasket still mounted in position in the window opening around the thermally improved window system. From these photographs it is evident that the integrity of any window system comprising a pressure and fail-safe pane mounted in a rubber gasket is dependent heavily upon maintaining the structural and thermal integrity of the belt and window framing material.

The sequence in which the major fuselage components failed during fire exposure in the second test is significant in identifying the most heat sensitive component in the exterior fuselage structure. The information presented in figure 21 shows that the aluminum skin (0.090 inch thick) above the belt failed in 70 seconds and that the skin below the belt failed in 119 seconds. Visual flame penetration through the standard acrylic window system occurred within 156 seconds and through the thermally improved window (EX 112 fail-safe pane) in 182 seconds, thereby demonstrating an improvement in flame resistivity of 26 seconds. The belt (0.350 inch thick) reached the incipient melting temperature of aluminum (900° F) shortly (3 seconds) after flames were observed to penetrate the EX 112 fail-safe pane. The temperature between the glass fiber insulation batt and the glass fiber interior panel rose to 900° F within 206 seconds after fuel ignition. These data show that the failure time of the EX 112 fail-safe pane was approximately equal to the failure time of the belt system.

TEST OF THE DC-10 FUSELAGE SECTION EMPLOYING THE INTERIOR HONEYCOMB PANEL CONFIGURATION WITH STANDARD AND THERMALLY IMPROVED WINDOWS.

DESCRIPTION OF TEST 3. The third experiment was performed using a built-up segment, which was an exact duplication of the fuselage structure currently in use on some DC-10 aircraft. The segment was comprised of an aluminum skin section (figure 2) salvaged from the Continental DC-10 accident, containing two adjacent window openings and backed by a glass fiber insulation batt which was faced internally with a honeycomb type wall panel. In this test, two rows of four passenger seats each were installed in their relative positions with the window locations (figure 26). As in previous tests, the forward window opening contained the thermally improved fail-safe (EX 112) pane. The electrical monitoring systems and photographic coverage were similar to that provided in the two previous tests.

The test sequence was started by igniting 75 gallons of JP-4 aviation fuel, which was sufficient to provide a burning time of 9 minutes at maximum intensity. The fuel was ignited by means of a high intensity electrical spark and extinguished at the conclusion of the test by activating the foam and carbon dioxide extinguisher systems from the instrument control room. The time to flame penetration through the fuselage section was monitored on the closed circuit television equipment, and the fire was extinguished after the flames intruded through the window openings, ignited the adjacent passenger seats, and spread to the side panels and ceiling areas.

RESULTS: The temperature rise of the aluminum structural components of the aircraft fuselage are shown by the profiles presented in figure 27. These data indicate that the aluminum skin (0.090 inch thick) above the belt (0.35 inch thick) reached the incipient melting temperature of aluminum (900° F) within 68 seconds (1.1 minutes) after fuel ignition, while the skin below the belt required 96 seconds (1.6 minutes). The recorded temperature between the windows (belt area) reached 900° F in 150 seconds (2.5 minutes) after fuel ignition. Therefore, it is evident that the fuselage skin above the windows failed (melted) approximately 28 seconds (0.47 minutes) before the bottom skin as a consequence of the temperature gradient within the flame plume (appendix B). The longer survival time (150 seconds) demonstrated by the belt resulted from the sheer mass of aluminum which had to be heated to 900° F in this area.

The thermocouple mounted between the glass fiber insulation batt and the back of the honeycomb panel reached 900° F in 231 seconds (3.9 minutes) which strongly suggests that the bulk of the glass fiber insulation had been destroyed by this time.

The temperature data provided by the thermocouples embedded in the standard (acrylic) window panes and the thermally improved experimental (EX 112) window system are presented in figures 28 and 29, respectively. The profiles presented in figure 28 show that the pressure pane reached the incipient melting point of aluminum in 126 seconds (2.1 minutes) and the fail-safe pane in 207 seconds (3.5 minutes) in the standard acrylic window system. Figure 29 indicates that the pressure pane in the thermally improved window system reached 900° F within 153 seconds (2.6 minutes) after fuel ignition while the fail-safe pane (EX 112) required 228 seconds (3.8 minutes) of fire exposure. The failure time of 228 seconds (3.8 minutes) for the EX 112 pane correlates well with the incipient failure time of 225 seconds (3.75 minutes) obtained in the first experiment.

Although these values are useful for comparing the relative heating rates of the two window systems, they do not necessarily represent the actual time of flame penetration into the aircraft cabin. The actual time for flame penetration through the windows was determined from an analysis of the radiometer profiles in figure 30 and from the motion picture coverage. The radiometer profiles show that the standard and experimental window systems failed in 188 seconds (3.1 minutes) and 247 seconds (4.1 minutes), respectively, as evidenced by a surge in energy equivalent to 2.0 Btu/ft2-s, when the flames penetrated the cabin.

The data presented in figure 31 summarizes the basic information obtained during the third test which employed a faithful mockup of a DC-10 fuselage section using a honeycomb interior cabin panel. It is noteworthy that the failure times obtained for the standard acrylic window panes were 190 seconds (3.2 minutes) by visual observation (cameras) and 188 seconds (3.1 minutes) based upon heat flux measurements (radiometers) which resulted in a difference of only 2 seconds between the two methods, for an overall average of 189 seconds (3.2 minutes).

A similar comparison of the failure time for the experimental window system showed that the flames penetrated into the C-133 aircraft cabin in 250 seconds (4.2 minutes) based on visual observation (cameras) and in 247 seconds (4.1 minutes) based upon heat flux measurements (radiometers) which resulted in a difference of only 3 seconds, for an average of 248.5 seconds (4.1 minutes). Therefore, the improved fail-safe pane (EX 112) provided a 59.5 second (0.99 minute) improvement over the standard (acrylic) pane in resisting flame penetration under identical fire test conditions.

The sequential failure times (attainmemt of 900° F) of the test segment components in test 3 were; the aluminum skin above the belt in 68 seconds (1.1 minutes), the skin below the belt in 96 seconds (1.6 minutes), and the belt area in 150 seconds (2.5 minutes). The standard acrylic window system failed in 189 seconds (3.2 minutes) and the thermally improved (EX 112) window system in 248.5 seconds (4.1 minutes) after fuel ignition. The temperature on the outside surface of the honeycomb panel reached 900° F in 231 seconds (3.9 minutes) after fuel ignition at which time the glass fiber batt is assumed to have failed. However, at this point in time, the external flames were pulsating through the acrylic window pane opening and starting through the EX 112 fail-safe pane which ignited adjacent seats, side walls and ceiling panels. Therefore, the desirability of increasing the thermal resistivity of the aircraft windows to flame penetration from an adjacent aircraft fuel fire, to improve fuselage integrity, is evident. Furthermore, the superior burn-through resistance of the honeycomb panel compared to the acrylic window system, as evidenced during the Continental DC-10 accident, was matched by these experiments.

TESTS OF THE DC-10 FUSELAGE SECTION EMPLOYING THE INTERIOR ALUMINUM PANEL CONFIGURATION WITH STANDARD AND THERMALLY IMPROVED WINDOWS.

DESCRIPTION OF TEST 4. The fourth experiment was performed using a built-up segment which was an exact duplication of the fuselage structure currently in use on some DC-10 aircraft. The segment was comprised of an aluminum skin section (figure 3) salvaged from the Continental DC-10 accident containing two adjacent window openings and backed by a glass fiber insulation batt which was faced internally with an aluminum type wall panel. In this test, two rows of four passenger seats each were installed in their relative positions with regard to the window locations, as provided in test 3 (figure 26). As in previous experiments the forward window opening (left, inside view) contained the thermally improved fail-safe (EX 112) pane. The electrical monitoring system and photographic coverage was similar to that provided in previous tests.

The test sequence was started by igniting 75 gallons of JP-4 aviation fuel which was sufficient to provide a burning time of nine minutes at maximum intensity. The fuel was ignited by means of a high intensity electrical spark and extinguished at the conclusion of the test by activating the foam and carbon dioxide extinguisher systems from the instrument control room. The time to flame penetration through the fuselage section was monitored on the closed circuit television equipment and the fire extinguished after the flames had penetrated through the windows and ignited the adjacent passenger seats and spread to the side panels and ceiling areas.

RESULTS: The temperature rise of the aluminum structural components of the DC-10 fuselage section are indicated by the profiles presented in figure 32. These data show that the aluminum skin above the belt reached the incipient melting temperature of aluminum (900° F) in 82 seconds (1.4 minutes) after fuel ignition, while the skin below the belt required 228 seconds (3.8 minutes) to failure. The temperature of the belt between the windows reached 900° F in 164 seconds (2.7 minutes) after fuel ignition. Accordingly, the fuselage skin above the windows failed (melted) approximately 146 seconds (2.4 minutes) before the bottom skin as a consequence of the temperature gradient within the flame plume (appendix B). The longer survival time (82 seconds, 1.4 minutes) demonstrated by the belt (0.35 inch thick) resulted from the greater mass of metal which had to be heated.

The thermocouple mounted between the glass fiber insulation batt and the back of the aluminum panel reached 900° F in 164 seconds (2.7 minutes) which suggests that the bulk of the glass fiber insulation had been destroyed by this time.

The temperature data provided by the thermocouples embedded in the standard (acrylic) window system and the thermally improved experimental (EX 112) window system are presented in figures 33 and 34, respectively. The profiles presented in figure 33 show that the pressure pane reached the incipient melting point of aluminum (900° F) in 192 seconds (3.2 minutes) and the fail-safe pane in 229 seconds (3.8 minutes) in the standard window system.

Figure 34 indicates that the pressure pane in the thermally improved window system reached 900° F within 208 seconds (3.5 minutes) after fuel ignition while the fail-safe pane (EX 112) apparently required only 154 seconds (2.6 minutes) to attain the same temperature. This anomalous performance by the thermocouple embedded in the (EX 112) pane is attributable to a malfunction in the monitoring equipment. The rationale is evidenced by the visual (cameras) incipient failure time of the EX 112 fail-safe pane in 216 seconds (3.6 minutes) and by the heat flux measurements (figure 35) through the window opening of 2.0 Btu/ft^2-s in 308 seconds (5.1 minutes) upon failure.

The real-time flame penetration through the windows was determined from an analysis of the radiometer profiles in figure 35 and from the motion picture coverage. The radiometer profiles show that the standard and experimental window systems failed in 225 seconds (3.75 minutes) and 308 seconds (5.1 minutes), respectively, as evidenced by a surge in heat flux equivalent to 2.0 Btu/ft^2-s when the flames penetrated the cabin.

The difference in the failure times of the two window systems of 83 seconds (1.4 minute), based upon the time for each to permit a heat flux of 2.0 Btu/FT^2-s to enter the aircraft cabin, was attributable to the charring characteristics of the EX 112 fail-safe pane in contrast with the standard acrylic fail-safe pane which simply shrank, melted, burned, and fell from the window opening.

The flame penetration times through the windows, based upon an analysis of the instrumentation camera data, indicated that incipient failure occurred in 201 seconds (3.4 minutes) and 216 seconds (3.6 minutes) for the standard and experimental (EX 112) window systems, respectively. These data show the basic performance differences encounterd in assessing flame resistivity by means of incipient flame penetration and the massive ingress of flames into the cabin. Visual flame penetration through the EX 112 fail-safe pane occurred only 15 seconds after flames were detected through the acrylic fail-safe pane. However, massive flame penetration, equivalent to a heat flux of 2.0 Btu/ft^2-s, was delayed for 83 seconds (1.4 minutes) after flames had penetrated the acrylic fail-safe pane.

The sequential failure times of the test segment components in test 4 were: the aluminum skin above the belt in 82 seconds (1.4 minutes), the skin below the belt in 228 seconds (3.8 minutes), and the belt area in 164 seconds (2.7 minutes). The standard acrylic window system failed in 201 visual seconds (3.4 minutes) and the thermally improved (EX 112) window system in 216 visual seconds (3.6 minutes) after fuel ignition. The temperature on the outside surface of the interior aluminum panel reached 900° F in 164 seconds (2.7 minutes) after fuel ignition at which time the glass fiber batt is assumed to have failed. These data indicate that the interior decorative aluminum panel reached the incipient melting temperature of 900° F at 37 seconds (0.6 minute) prior to the visual failure time of the acrylic fail-safe panel and 52 seconds (0.9 minute) before the failure of the EX 112 fail-safe pane.

A comparison of the failure time (231 seconds) of the interior honeycomb decorative panel (test 3) and the interior aluminum decorative panel (164 seconds) (test 4) tends to indicate that the honeycomb panel configuration provided an improved thermal resistance of 67 seconds (1.1 minutes) over the aluminum panel based upon the time of each to reach 900° F, the incipient melting temperature of aluminum.

A general summary of pertinent information obtained from each of the four comparative fire tests is presented in table 2.

TABLE 2. SUMMARY OF FIRE TEST RESULTS OF THE STANDARD AND THERMALLY IMPROVED DC10 AIRCRAFT WINDOW SYSTEMS

	TEST 1		TEST 2		TEST 3		TEST 4	
WEIGHT OF PANES	INITIAL	AFTER TEST	INITIAL	AFTER TEST	INITIAL	AFTER TEST	INITIAL	AFTER TEST
EX 112	806.5 grams	776.8 grams	807.2grams	Destroyed	809.6 grams	Destroyed	814.9 grams	Destroyed
Acrylic	756.2 grams	87% grams	759.1 grams	Destroyed	736.2 grams	Destroyed	725.6 grams	Destroyed
WEIGHT OF GASKET								
EX 112	174.7 grams	167.0 grams	162.5 grams	Destroyed	175.9 grams	Destroyed	169.2 grams	Destroyed
Acrylic	174.0 grams	109.2 grams	166.0 grams	Destroyed	164.4 grams	Destroyed	165.3 grams	Destroyed
VISUAL FLAME PENETRATION								
EX 112	Very minor at 225 seconds		182 seconds		250 seconds		216 seconds	
Acrylic	146 seconds		156 seconds		190 seconds		201 seconds	
GASKET FLAMING (PYROLYSIS)								
EX 112	133 seconds		Not Visible		Not Visible		Not Visible	
Acrylic	112 seconds		Not Visible		Not Visible		Not Visible	
HEAT FLUX THROUGH WINDOWS	BTU/FT^2-S	Seconds	BTU/FT^2-S	Seconds	BTU/FT^2-S	Seconds	BTU/FT^2-S	Seconds
EX 112	0.05	201	2	209	2	247	2	308
Acrylic	2	189	2	184	2	188	2	225
SKIN MELTING TIME (900°F)								
Top	64 seconds		70 seconds		68 seconds		82 seconds	
Bottom	198 seconds		119 seconds		96 seconds		228 seconds	
CONDITION OF INSULATION AFTER TEST	Kaowool/Intact		Glass Fiber Destroyed		Glass Fiber Destroyed		Glass Fiber Destroyed	
CONDITION OF PANEL AFTER TEST	None Used		Fiberglass Destroyed		Honeycomb Destroyed		Aluminium Destroyed	

SUMMARY OF RESULTS

The results obtained from fire tests employing representative sections cut from a DC-10 fuselage and fitted with standard (acrylic) and thermally improved (EX 112) fail-safe window panes, mounted in adjacent window openings and exposed to JP-4 fuel fires are:

1. The estimated failure time of the standard acrylic window system in test 1 was 189 seconds (3.2 minutes) based upon a heat flux through the window opening of 2.0 Btu/ft^2-s, while visual burn-through started at 146 seconds (2.4 minutes) after fuel ignition.

2. The thermally improved DC-10 window system employing the EX 112 fail-safe pane in test 1, showed low radiant energy (0.05 Btu/ft^2-s) through the windows in 201 seconds (3.4 minutes) followed by very minor flame penetration observed after 225 seconds (3.8 minutes), which was just prior to fire entinguishment.

3. The silicone rubber window gasket employed with the thermally improved window system lost approximately 4.4 percent of its mass after exposure to flame impingement for 225 seconds (3.8 minutes) during test 1.

4. The silicone rubber window gasket employed to mount the stretched acrylic window panes in test 1 became fused and charred and fell from the window opening during exposure to flame impingement for 225 seconds (3.8 minutes).

5. The pyrolysis of volatile components in the silicone rubber window gasket started approximately 112 seconds (1.9 minutes) and 133 seconds (2.2 minutes) for the standard (acrylic) and experimental (EX 112) windows, respectively, after fuel ignition, which was evidenced by the small transient yellow flames that circulated around the inside rim of the gasket.

6. The initial visual flame penetration through the thermally improved (EX 112) and the standard stretched acrylic window systems varied by 79 seconds (1.3 minutes), 26 seconds (0.4 minute), 60 seconds (1 minute) and 15 seconds (0.25 minute) for tests 1 through 4, respectively.

7. The difference in incipient aluminum skin melting times (i.e., time to reach 900° F) for positions above and below the belt and doubler areas varied by 134 seconds (2.2 minutes), 49 seconds (0.8 minute), 28 seconds (0.47 minute), and 200 seconds (3.3 minutes) for tests 1 through 4.

8. The estimated failure time of the honeycomb panel in test 3 based upon its attaining a surface temperature of 900° F was 81 seconds (1.4 minutes) longer than the failure time (900° F) of the aluminum belt supporting the aircraft windows and 163 seconds (2.7 minutes) longer than the melting time of the aluminum aircraft skin.

9. The estimated failure time of the interior aluminum panel in test 4 based upon its attaining a surface temperature of 900° F was 164 seconds (2.7 minutes) which was the same time as that required for the belt supporting the windows to attain the same temperature (900° F) and 82 seconds (1.4 minutes) longer than the melting time of the exterior aluminum aircraft skin.

10. The times required for the DC-10 aircraft honeycomb and aluminum interior cabin panels to reach 900° F were 231 seconds (3.9 minutes) and 164 seconds (2.7 minutes) after fuel ignition.

CONCLUSIONS

Based upon the results of simulated fuel spill fire tests exposing representative DC-10 fuselage sections containing standard acrylic and thermally improved window systems, it is concluded that:

1. The flame resistance provided by the thermally improved EX 112 fail-safe DC-10 window pane in test 1 was significantly longer than that provided by the standard stretched acrylic type.

2. The silicone rubber gasket employed with the improved EX 112 fail-safe window pane in test 1 demonstrated adequate structural support under flame impingement from an adjacent aviation fuel fire to maintain the integrity of the window system for the test duration (225 seconds).

3. The structural and thermal failure time of the silicone rubber gasket employed with the standard stretched acrylic windows was concurrent with the burning, shrinking, and collapse of the pressure and fail-safe window panes.

4. The temperature rise of the DC-10 aircraft interior honeycomb panel configuration in test 3 was significantly slower than that of either the aluminum fuselage skin or belt areas, thereby, delaying flame intrusion into the cabin interior from the adjacent fuel fire.

5. The time required for the DC-10 aircraft interior aluminum panel configuration in test 4 to reach the incipient melting temperature of aluminum was the same as that required for the aluminum belt area and significantly longer than that required for the aircraft skin.

6. The DC-10 aircraft interior honeycomb panel resisted a temperature rise to 900° F from the adjacent fuel fire for a significantly longer period of time (67 seconds) than the aluminum interior panel, thereby, providing a potential barrier to flame penetration into the aircraft cabin.

7. The times-to-failure of the interior honeycomb decorative panel (test 3) and the interior aluminum decorative panel (test 4) indicate that the honeycomb panel configuration provided an improved thermal resistance of 67 seconds (1.1 minutes) over the aluminum panel based upon the time of each to reach 900° F, the incipient melting temperature of aluminum.

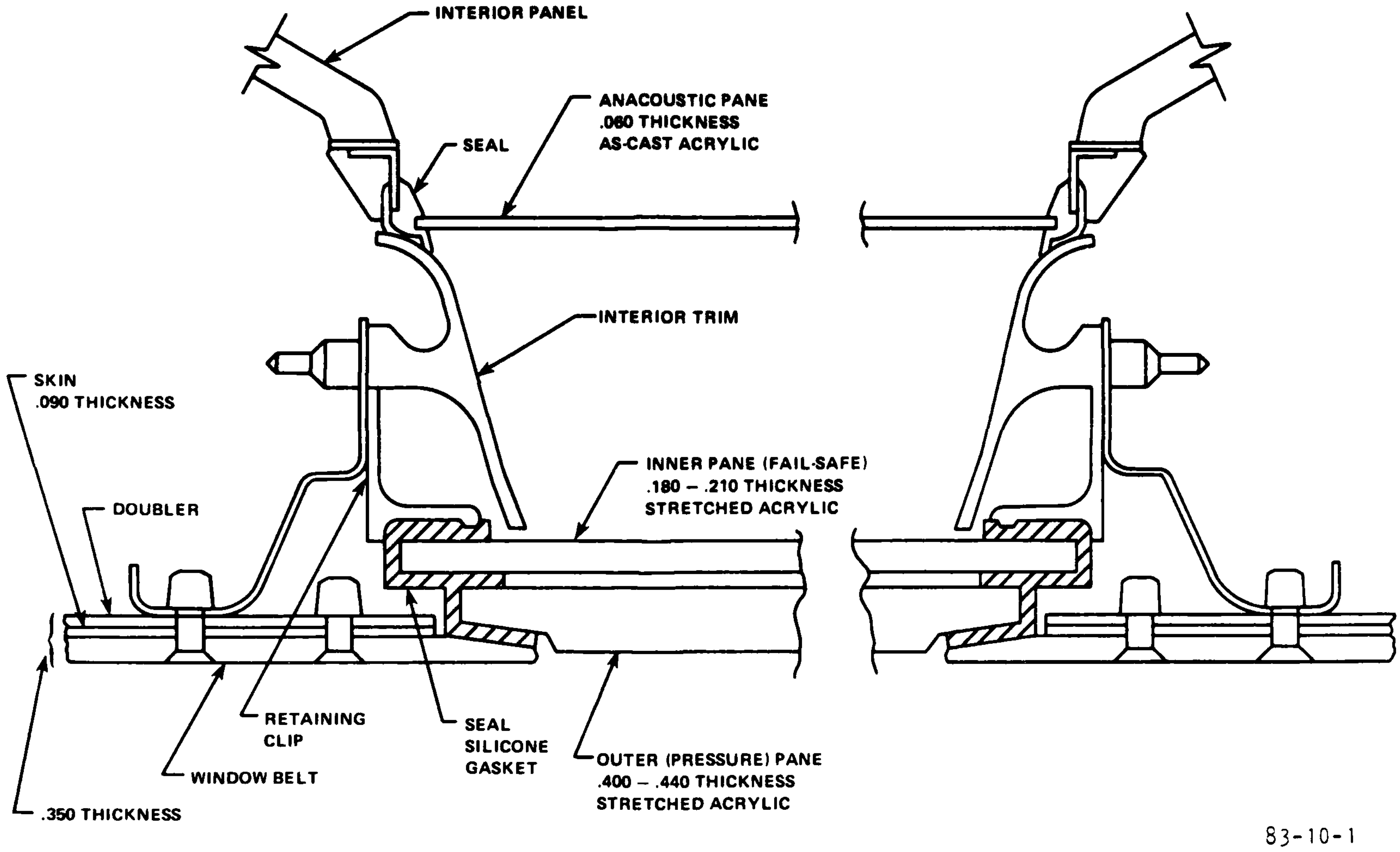


FIGURE 1. CROSS SECTIONAL DIAGRAM OF THE DC-10 CABIN WINDOW

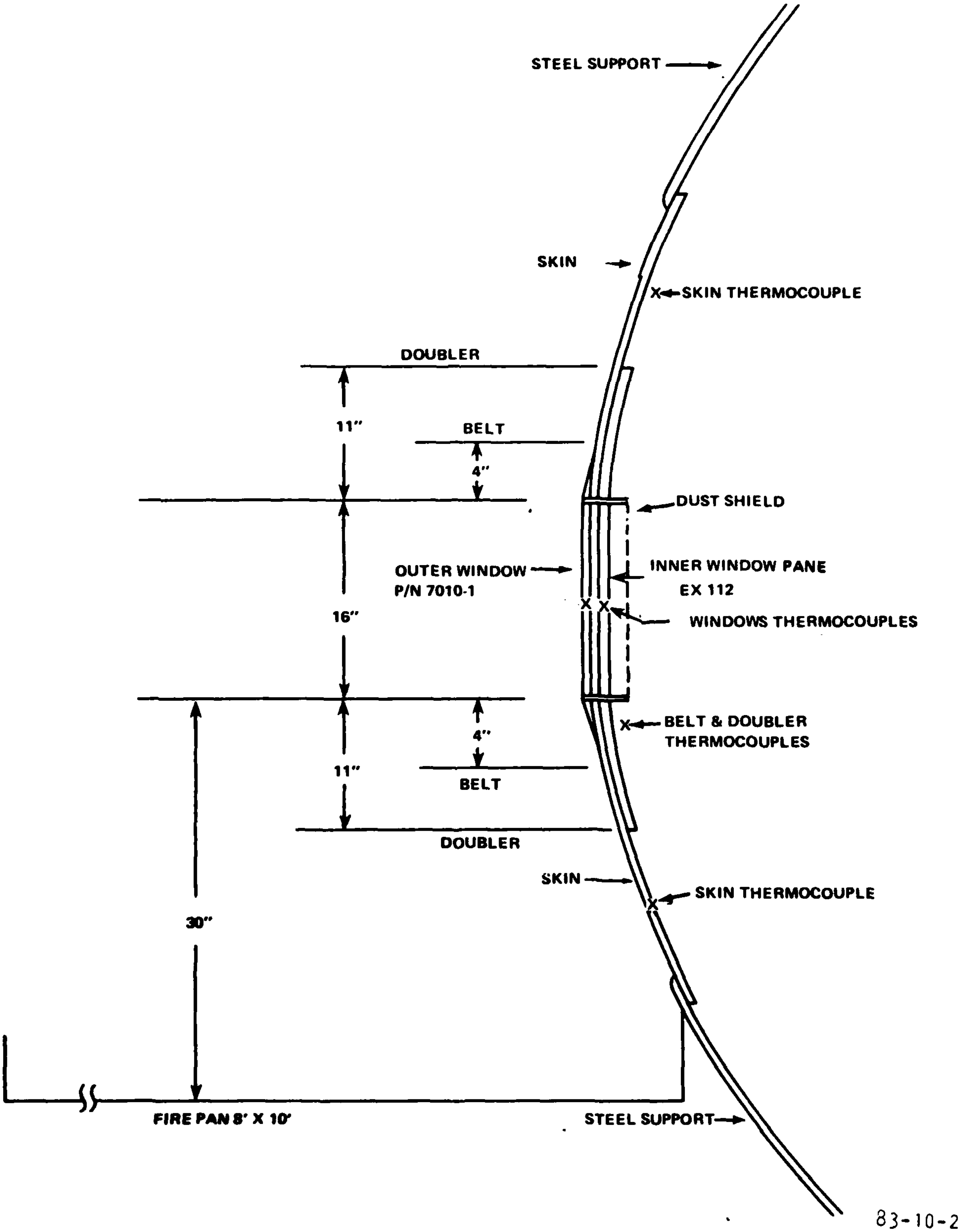


FIGURE 2. CROSS SECTION OF THE MOUNTED DC-10 WINDOW SEGMENT (NOT TO SCALE)

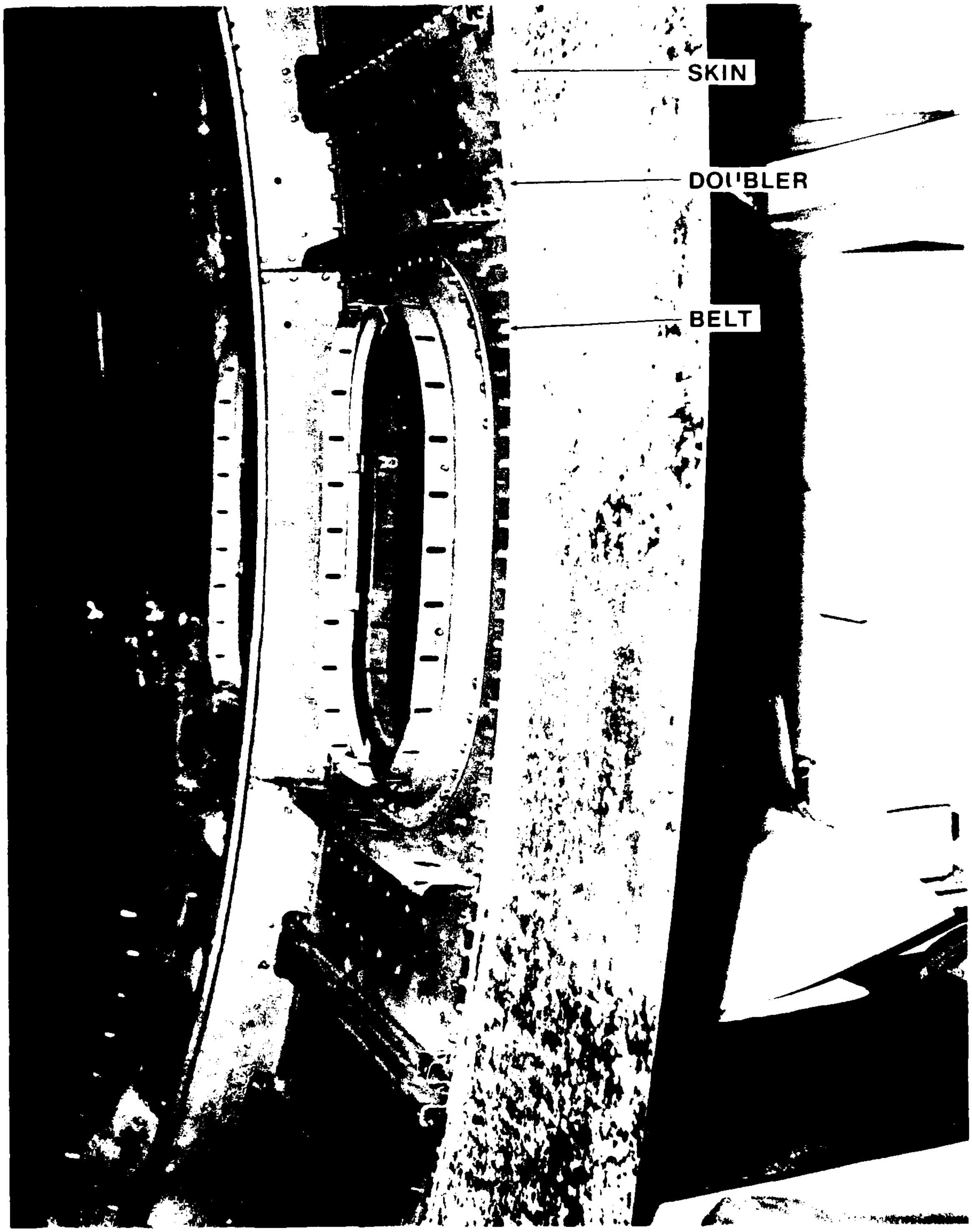
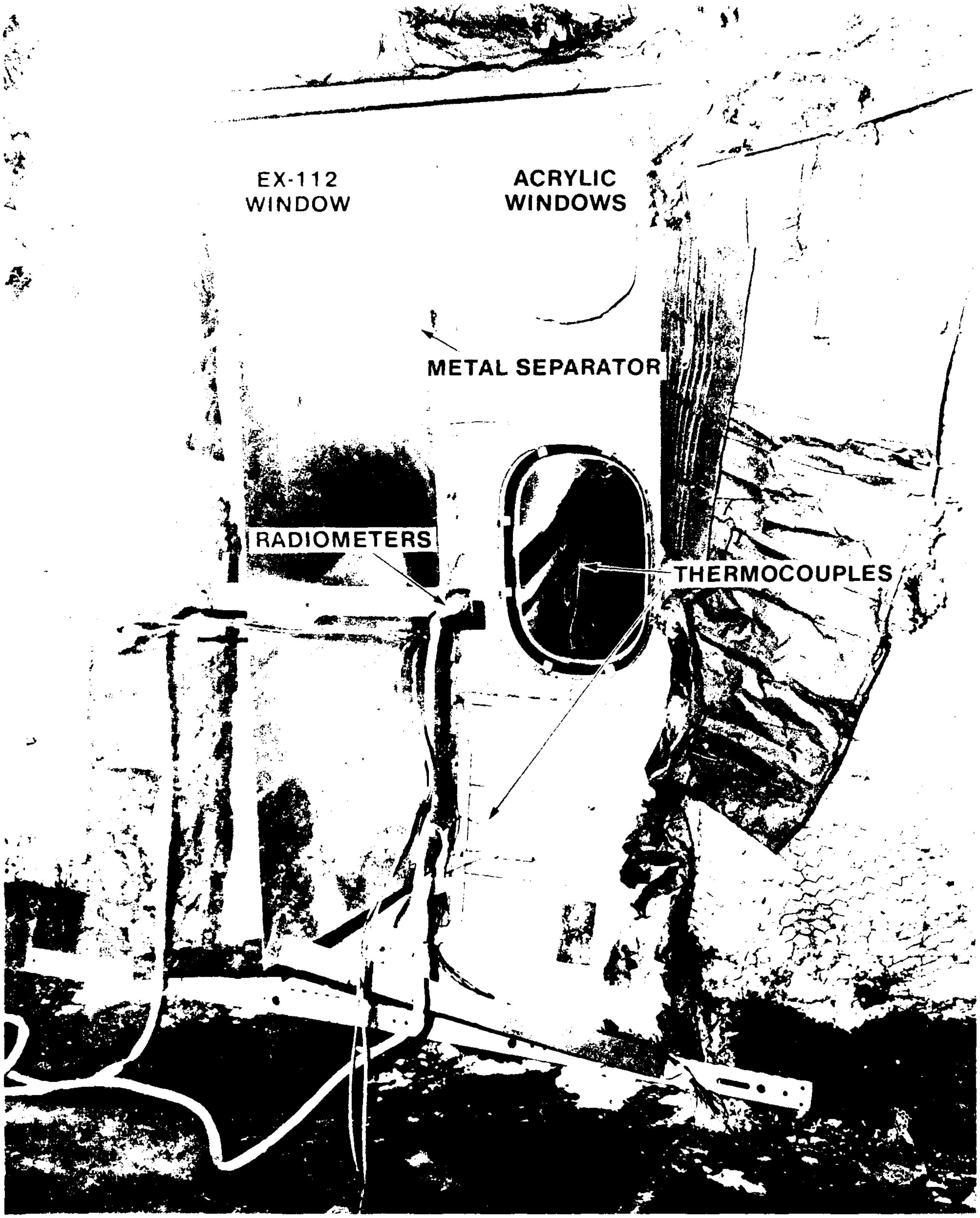
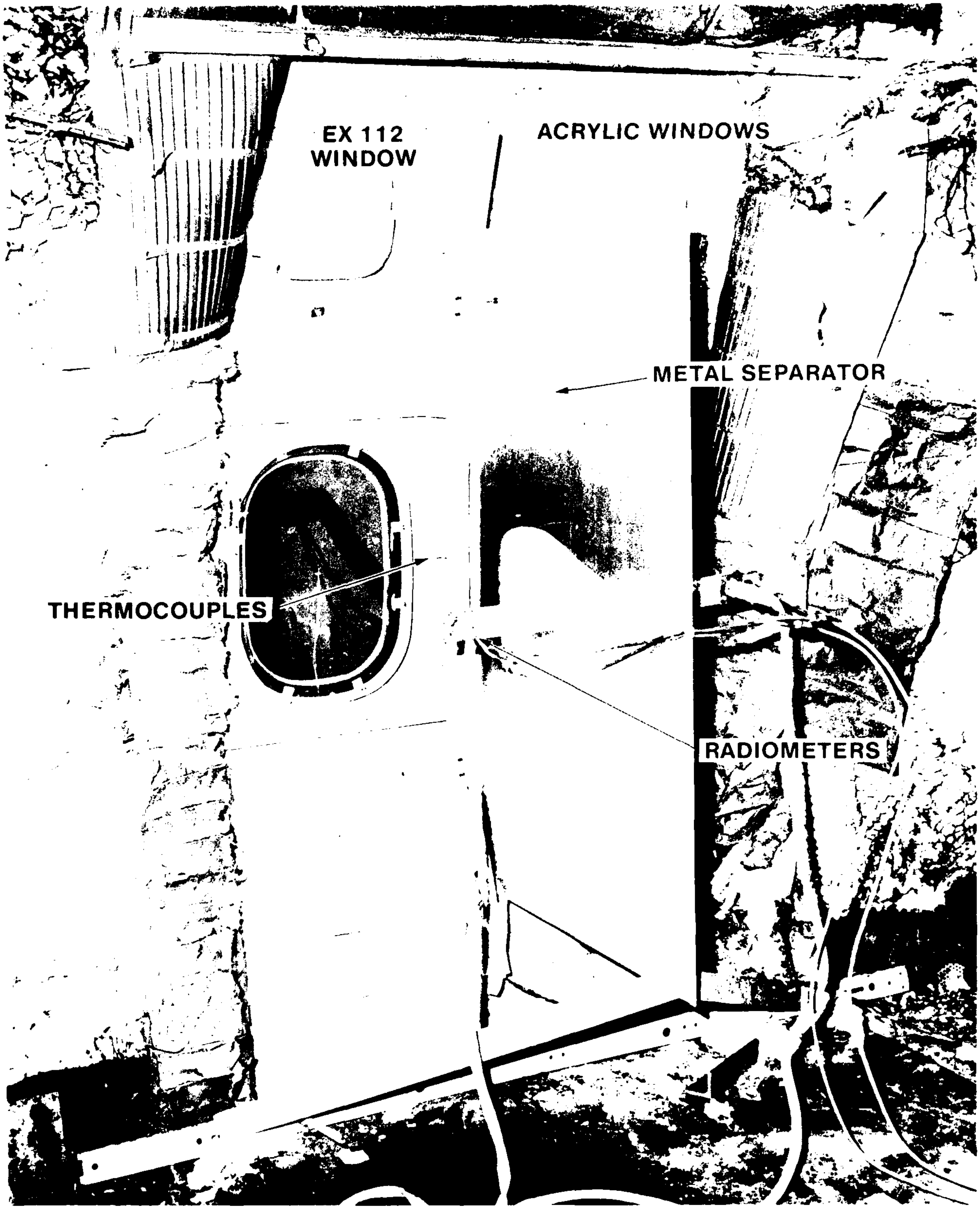


FIGURE 3. SIDE VIEW OF THE DC-10 WINDOW SEGMENT



(a) Standard Window System (Acrylic)

[illegible] INTERNAL VIEWS OF THE DC-10 WINDOWS SEGMENTS INSTALLED IN THE C-133 TEST BED (TEST 1) (1 of 2 Sheets)



(b) Experimental Window System (EX 112)

FIGURE 4. INTERNAL VIEWS OF THE DC-10 WINDOWS SEGMENTS INSTALLED IN THE C-133 TEST BED (TEST 1) (2 of 2 Sheets)

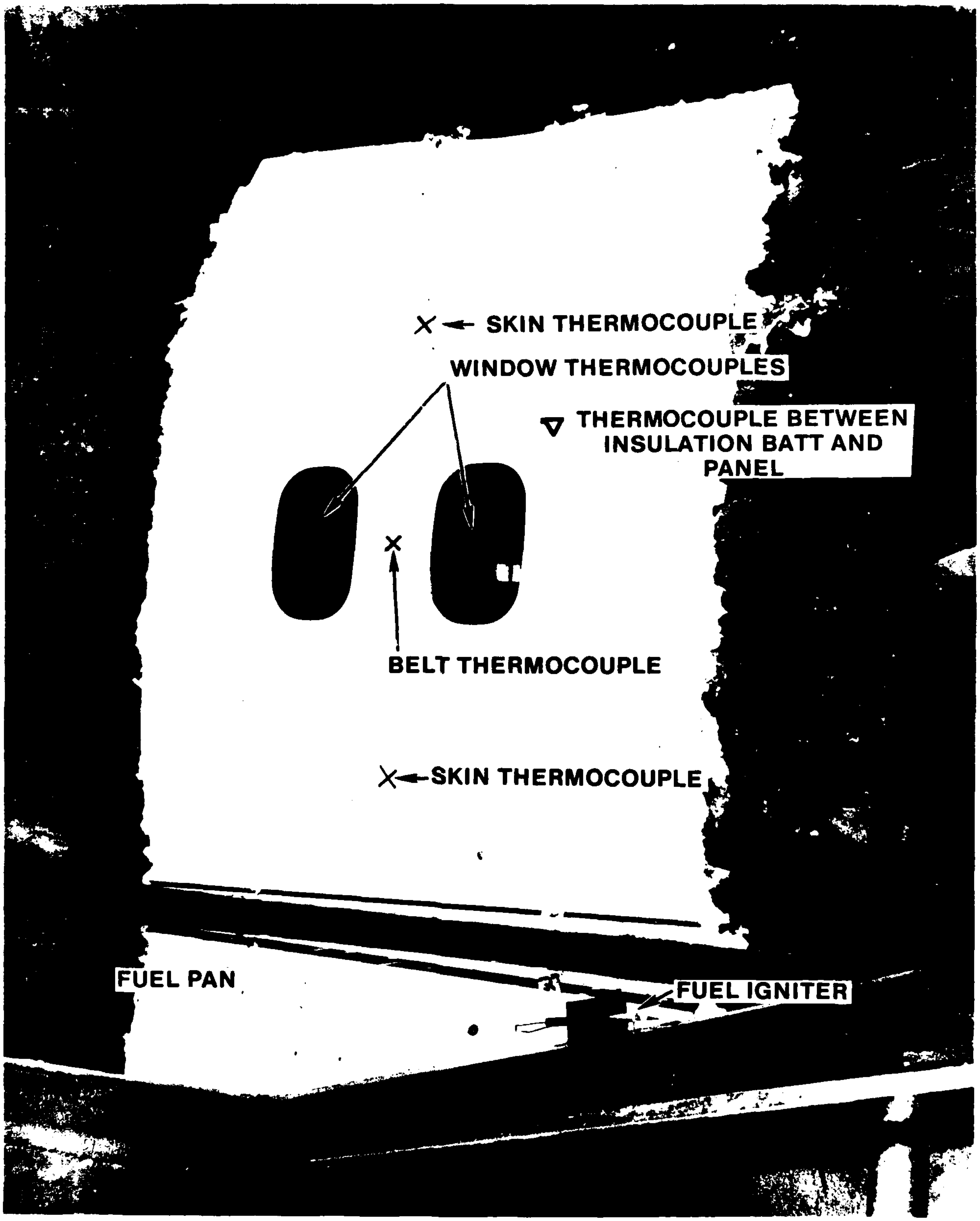


FIGURE 5. EXTERIOR VIEW OF THE INSTRUMENTED DC-10 WINDOW SEGMENT MOUNTED ON THE FUSELAGE OF THE C-133 AIRCRAFT

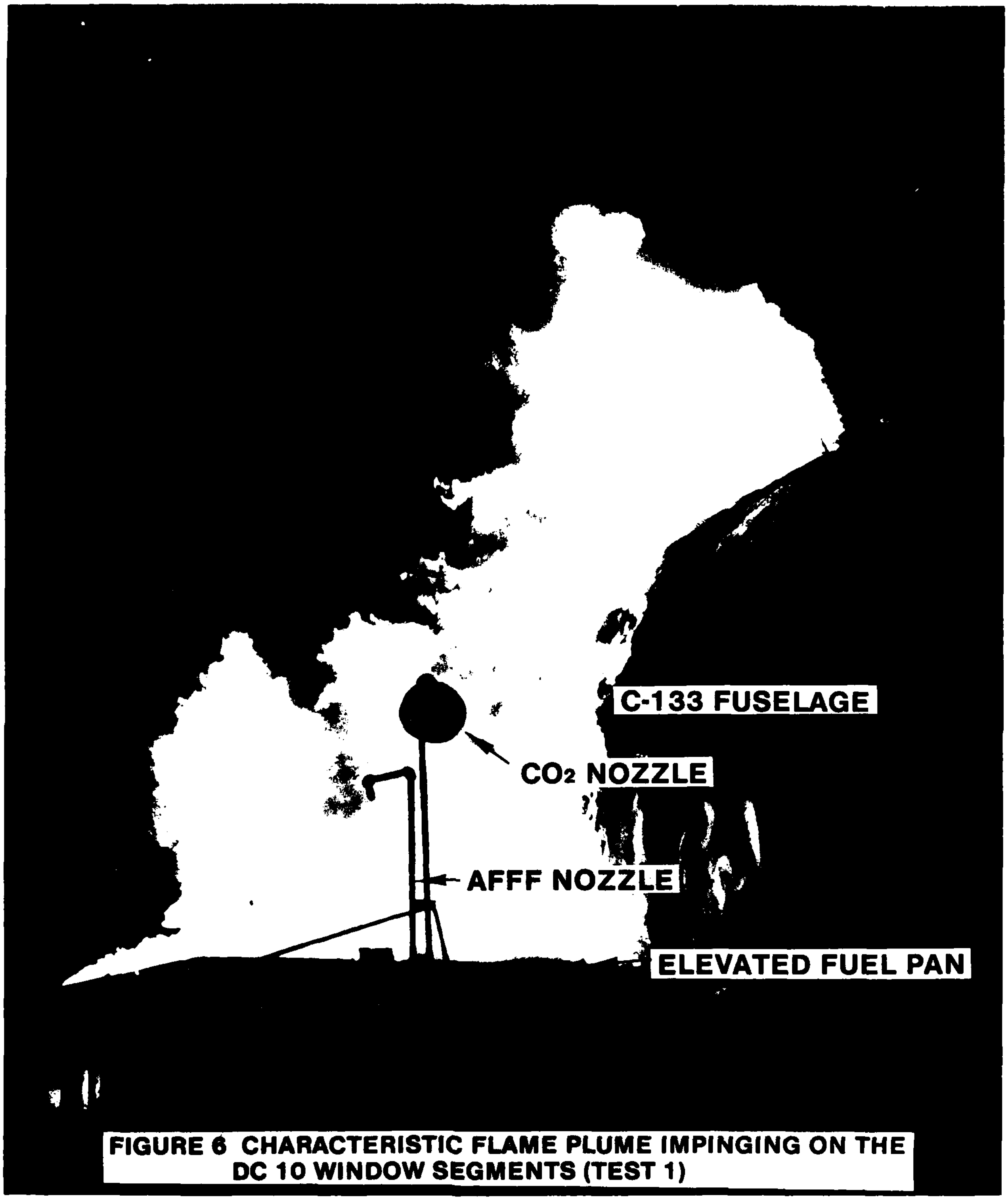


FIGURE 6. CHARACTERISTIC FLAME PLUME IMPINGING ON THE DC-10 WINDOW SEGMENTS (TEST 1)

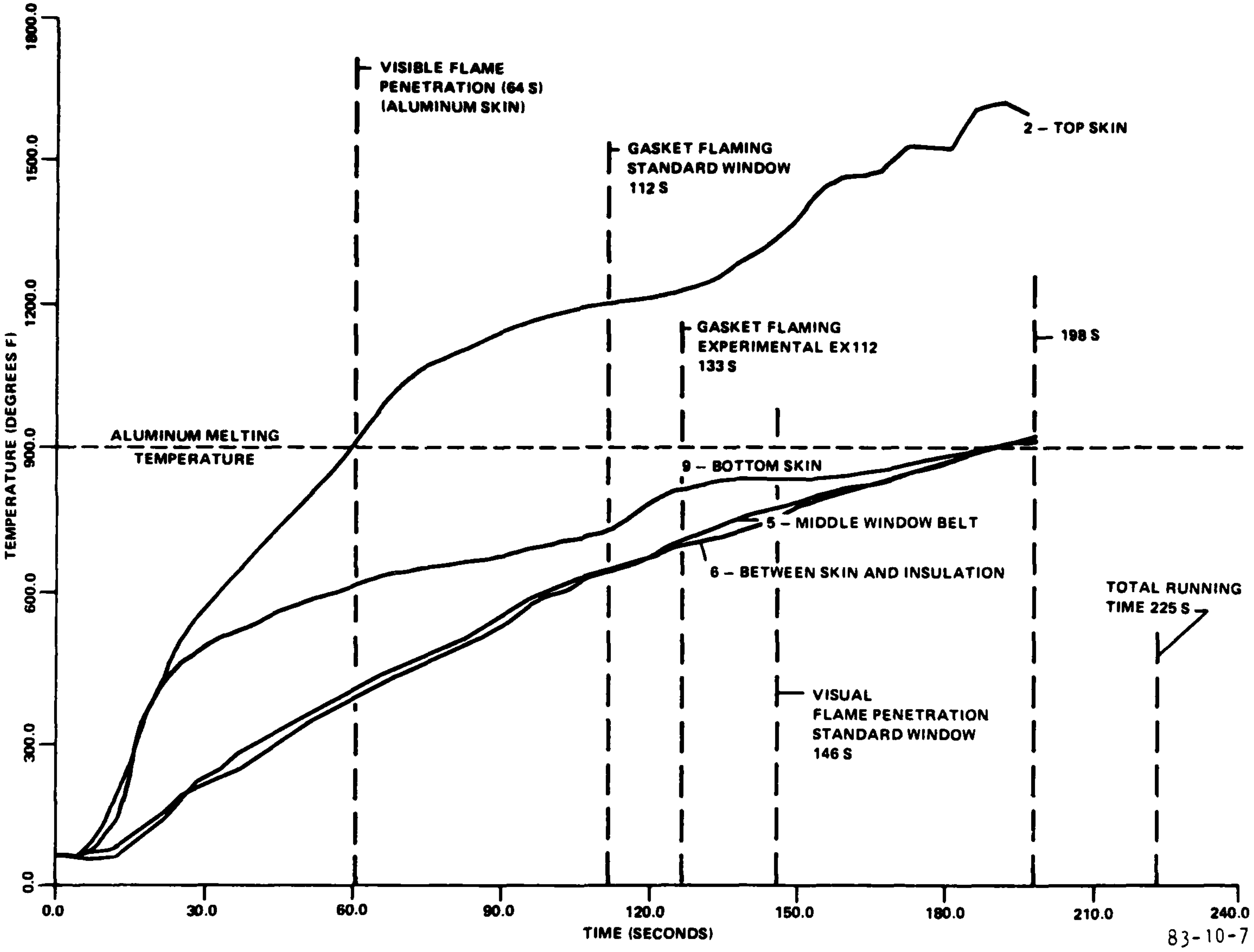


FIGURE 7. TEMPERATURE RISE OF THE DC-10 SKIN, BELT AND THE INTERFACE BETWEEN THE INTERIOR PANEL AND INSULATION BATT (TEST 1)

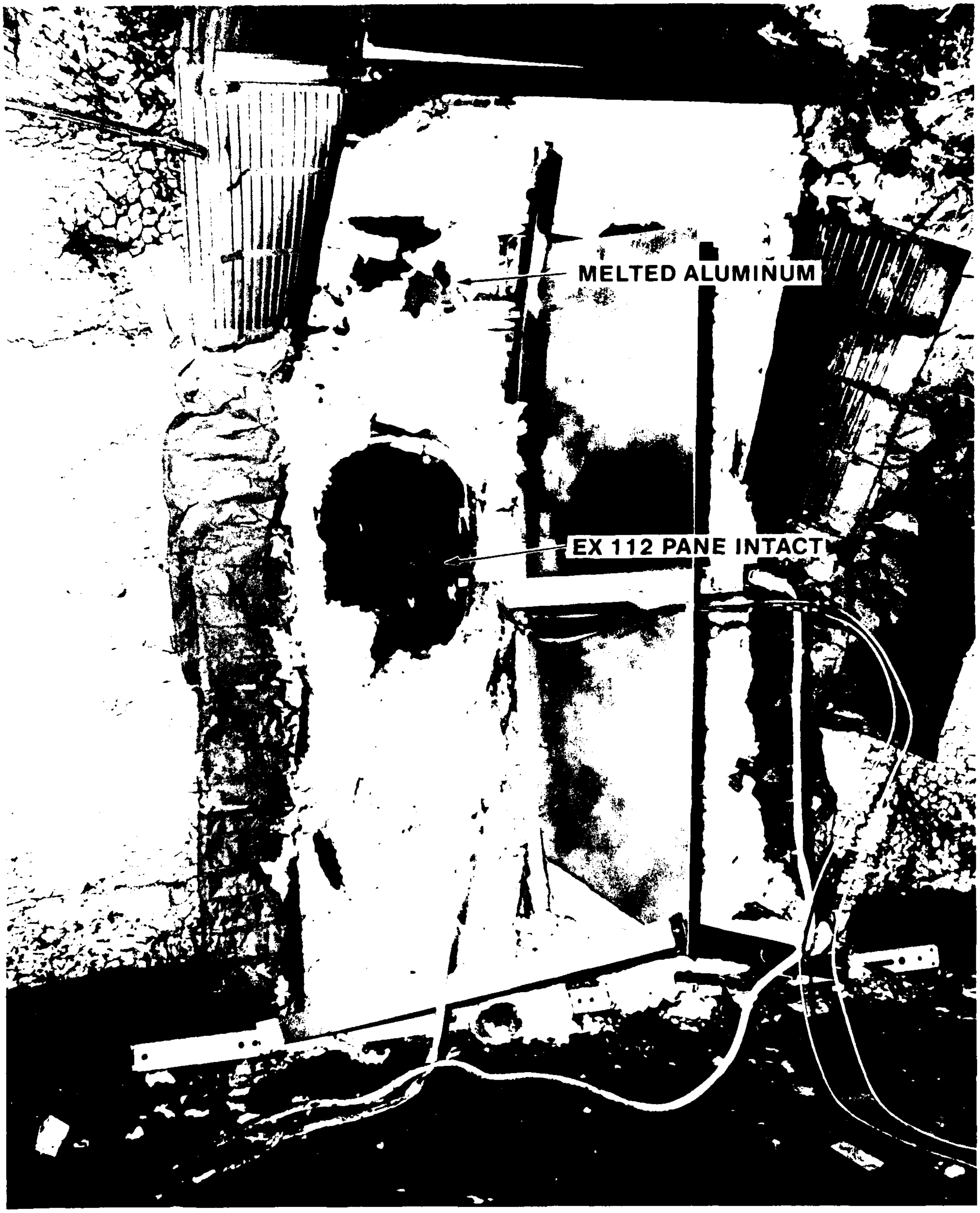
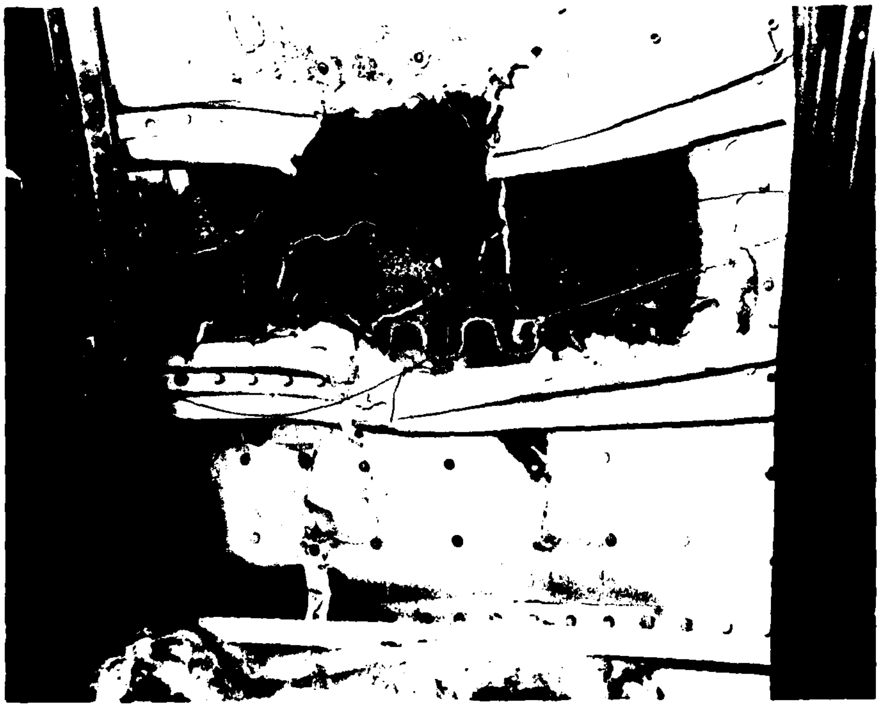


FIGURE 8. FIRE DAMAGE TO THE THERMALLY IMPROVED DC-10 WINDOW SYSTEM SHOWING THE FAIL-SAFE (EX 112) PANE IN PLACE (TEST 1)

FIGURE 9. FIRE DAMAGE TO THE STANDARD DC-10 WINDOW SYSTEM SHOWING THE COMPLETE DESTRUCTION OF THE ACRYLIC WINDOW PANES (TEST 1)

(a) Thermally Improved (EX 112) Window System



(b) Standard Acrylic Window System

FIGURE 10. ALUMINUM SKIN FAILURE (MELTING) MODES ABOVE THE AIRCRAFT WINDOWS

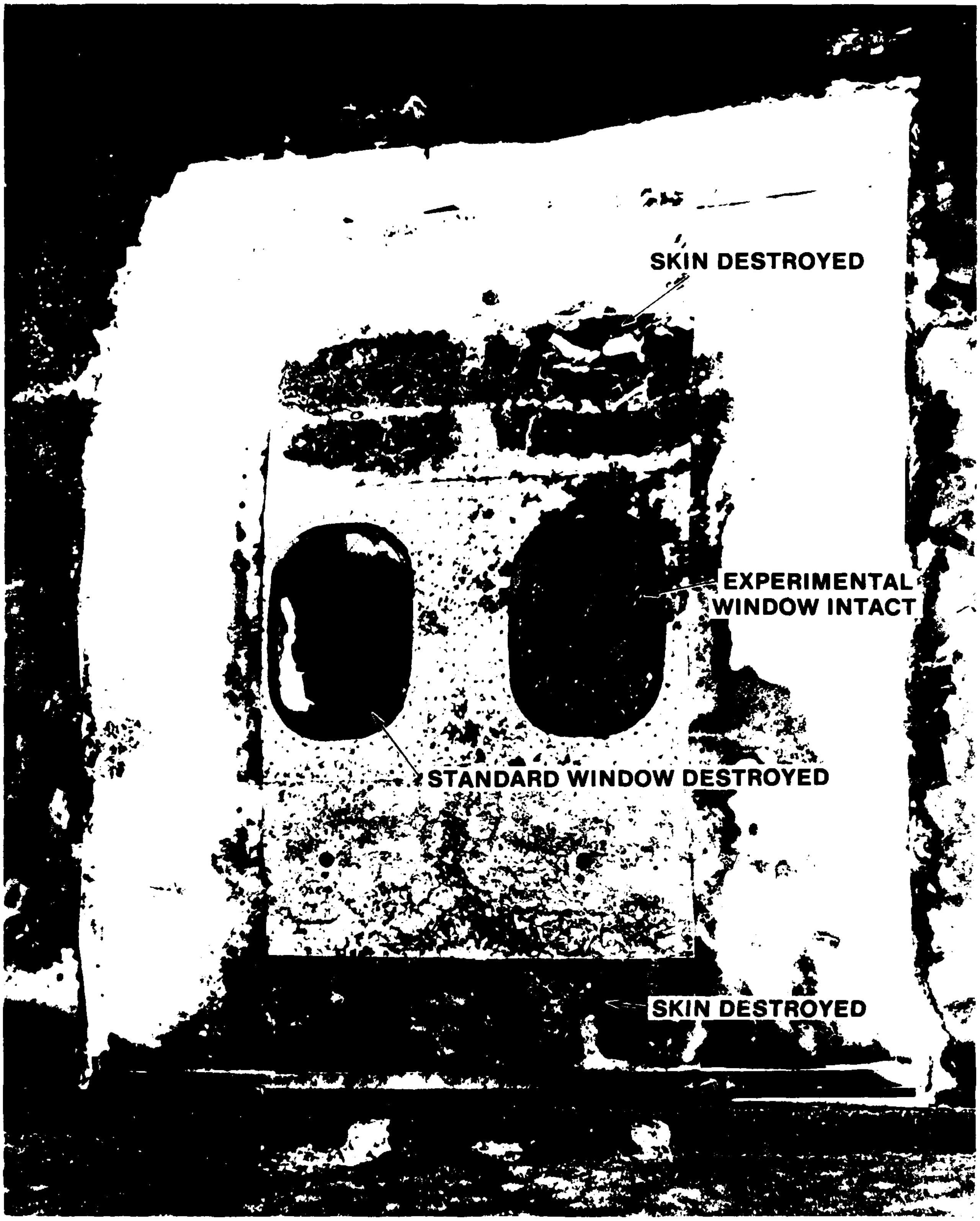


FIGURE 11. EXTERNAL FIRE DAMAGE TO THE DC-10 WINDOW SYSTEMS (TEST 1)

FIGURE 12. VIEW OF THE FIRE PLUME IMPINGING ON THE DC-10 TEST SEGMENT TAKEN PERPENDICULAR TO THE C-133 FUSELAGE

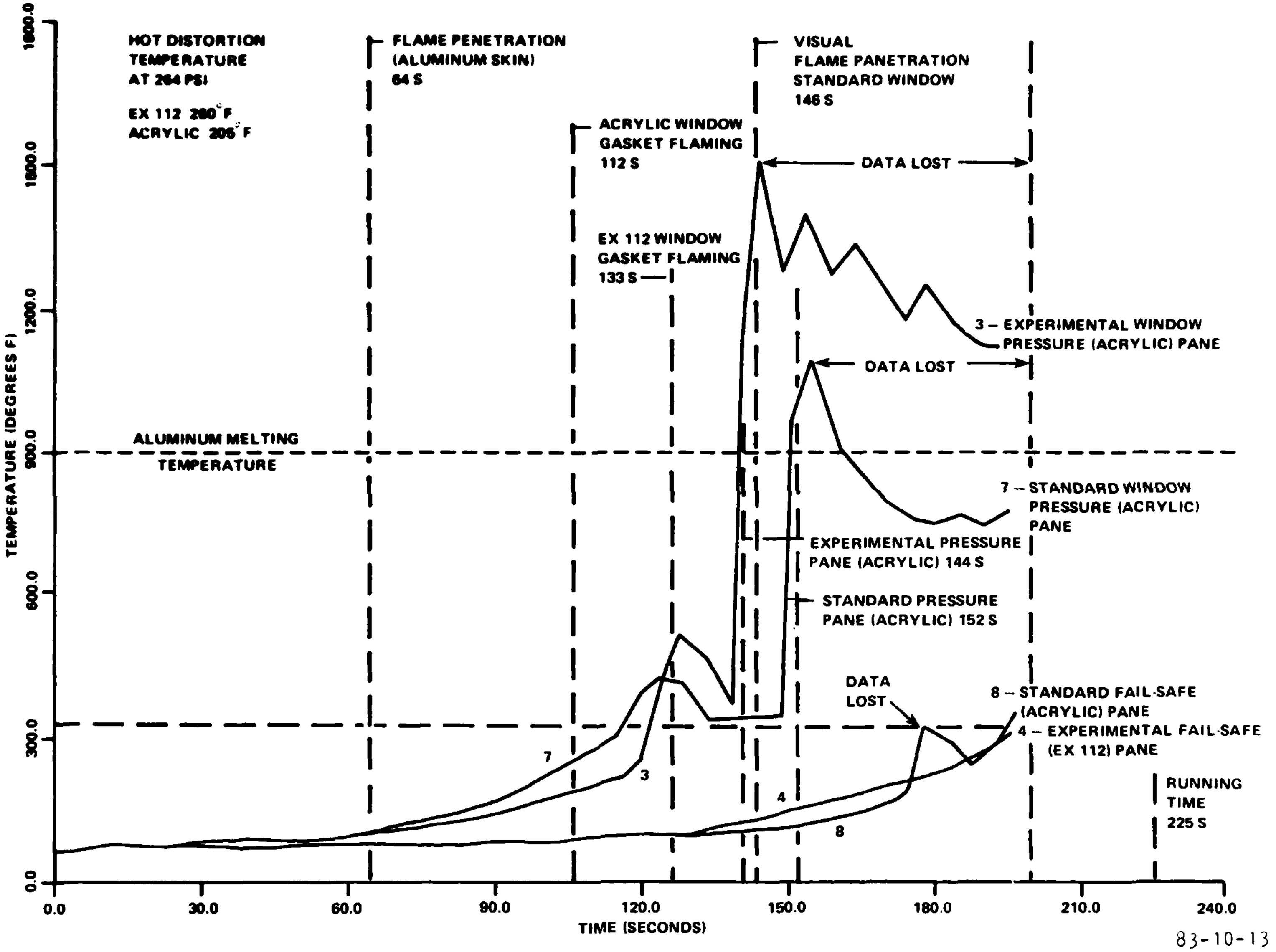


FIGURE 13. TEMPERATURE RISE OF THE STANDARD (ACRYLIC) AND THERMALLY IMPROVED (EX 112) WINDOW SYSTEMS DURING FIRE EXPOSURE (TEST 1)

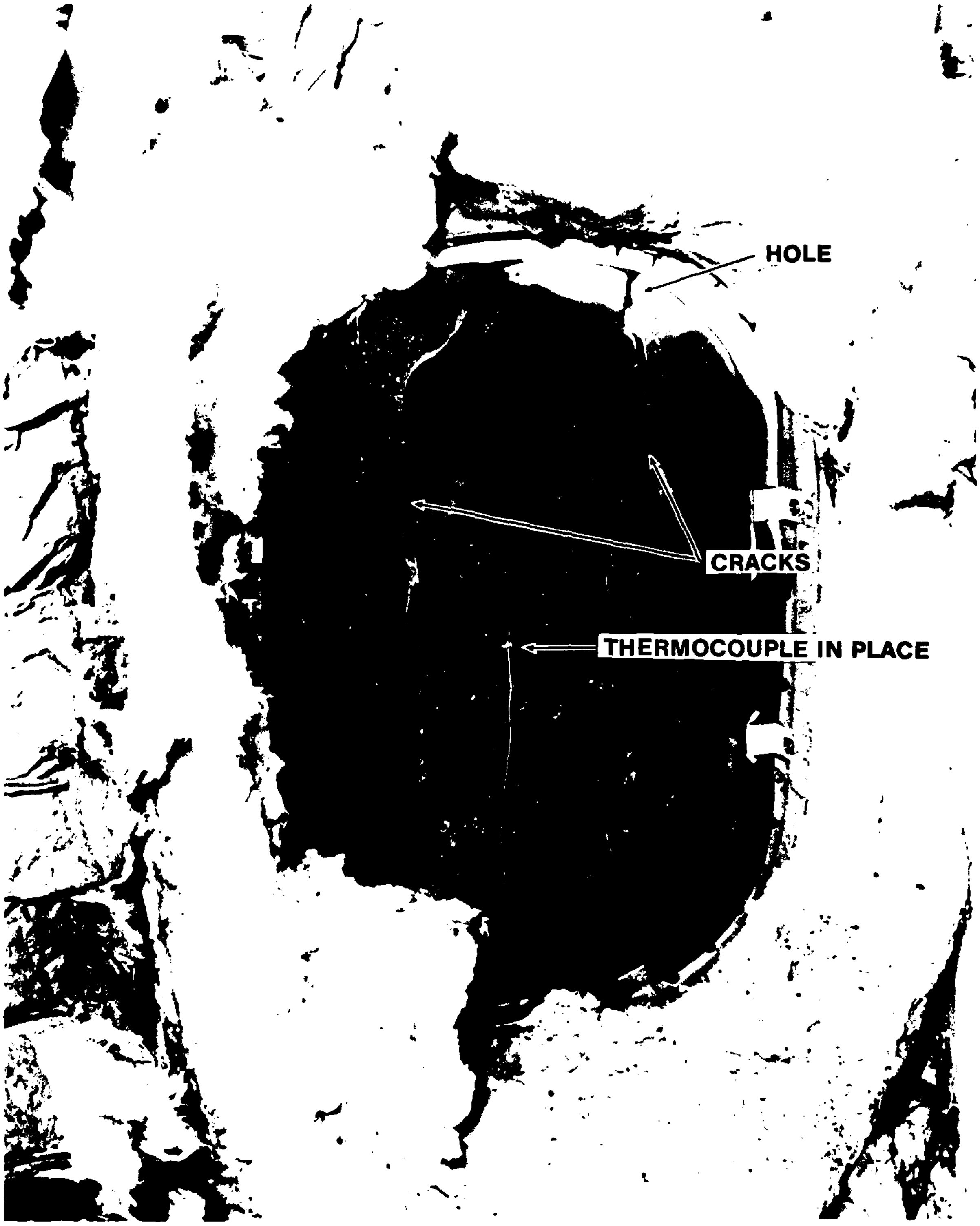


FIGURE 14. CLOSE-UP VIEW OF THE FIRE DAMAGE TO THE FAIL-SAFE (EX 112) WINDOW PANE (TEST 1)

FIGURE 15. FIRE DAMAGE SUSTAINED BY THE IMPROVED EX 112 FAIL-SAFE PANE AND THE STRETCHED ACRYLIC PANE (TEST 1)

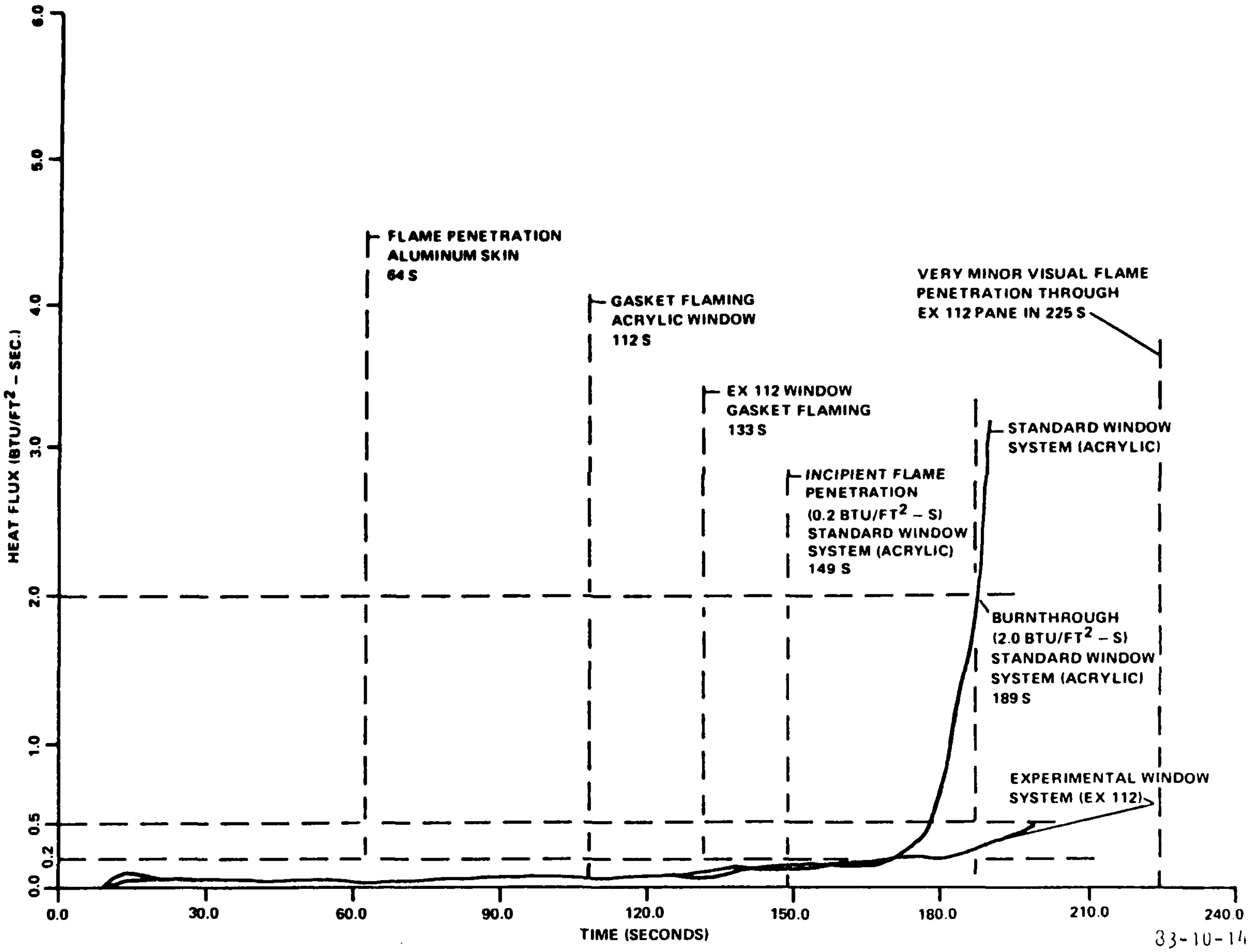
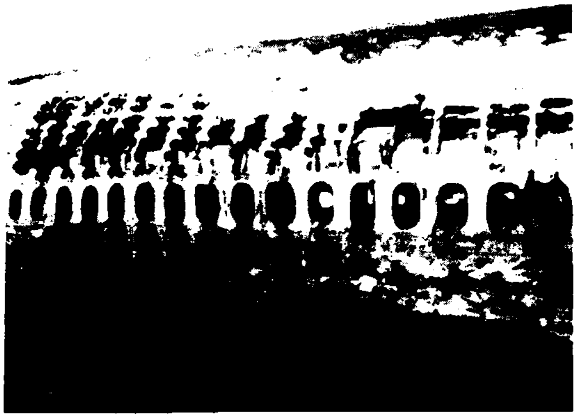


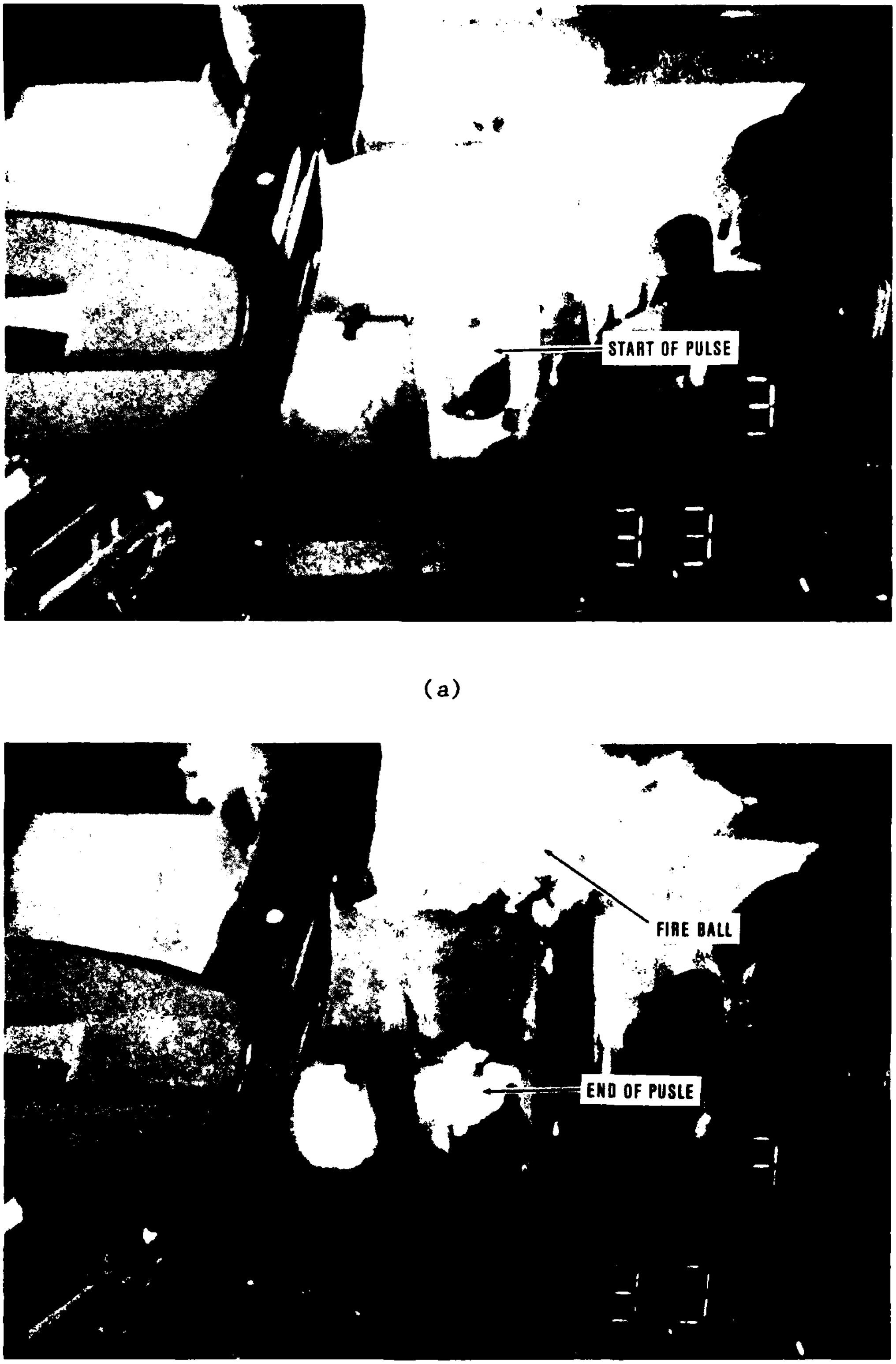
FIGURE 16. HEAT FLUX THROUGH THE STANDARD (ACRYLIC) AND THERMALLY IMPROVED (EX 112) WINDOWS DURING FIRE EXPOSURE (TEST 1)



(a) General View of the Fuselage Damage

(b) Detailed View of the Belt System Area

FIGURE 17. FAILURE MODES OF THE CONTINENTAL AIRLINES DC-10 AIRCRAFT FUSELAGE SKIN AND WINDOW BELT SYSTEM



(a)

(b)

FIGURE 18. PHOTOGRAPHIC SEQUENCE SHOWING FLAME PULSATION THROUGH THE ACRYLIC WINDOW OPENING

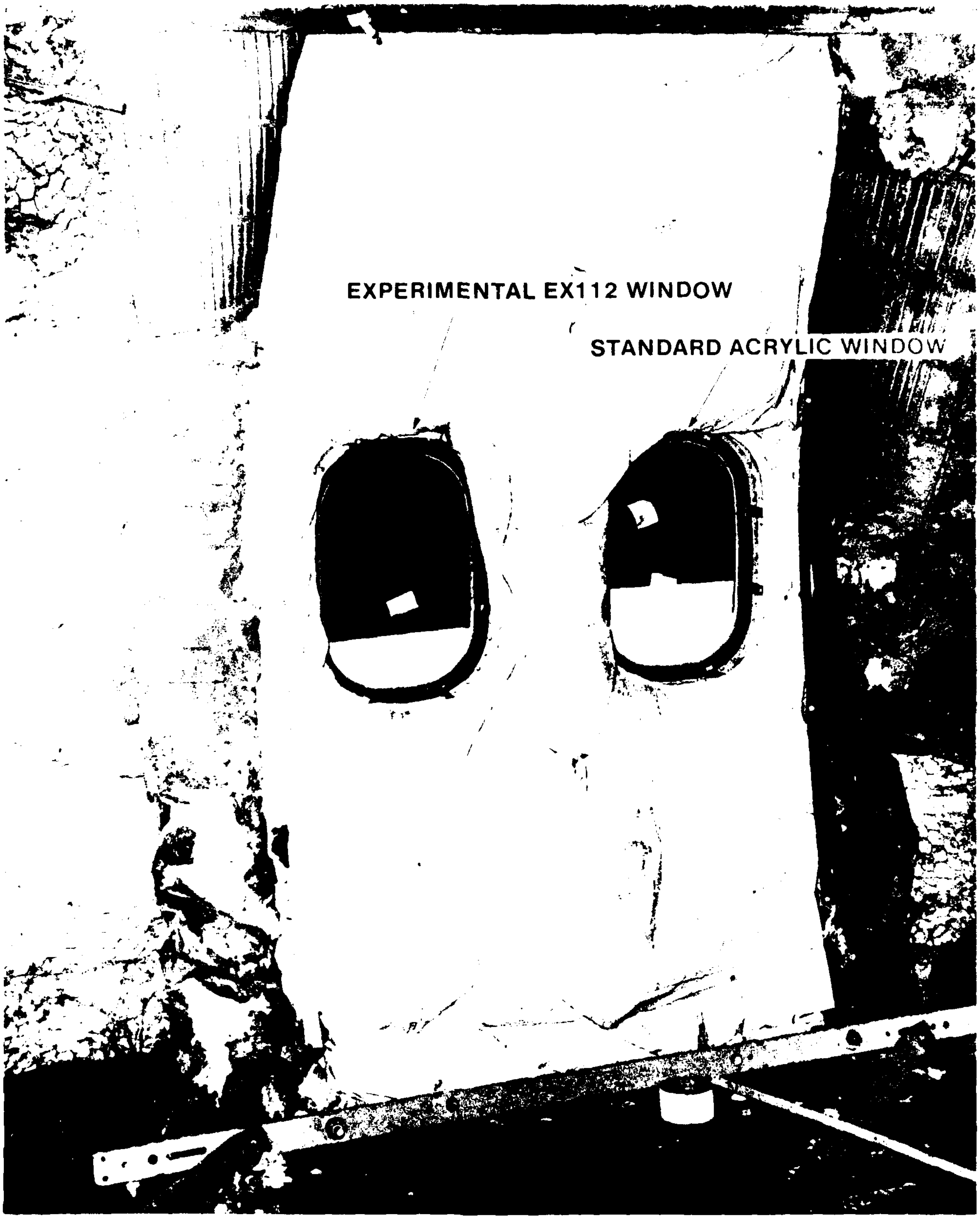


FIGURE 19. STANDARD GLASS FIBER BATT INSULATION INSTALLED IN THE DC-10 WINDOW TEST SEGMENT (TEST 2)

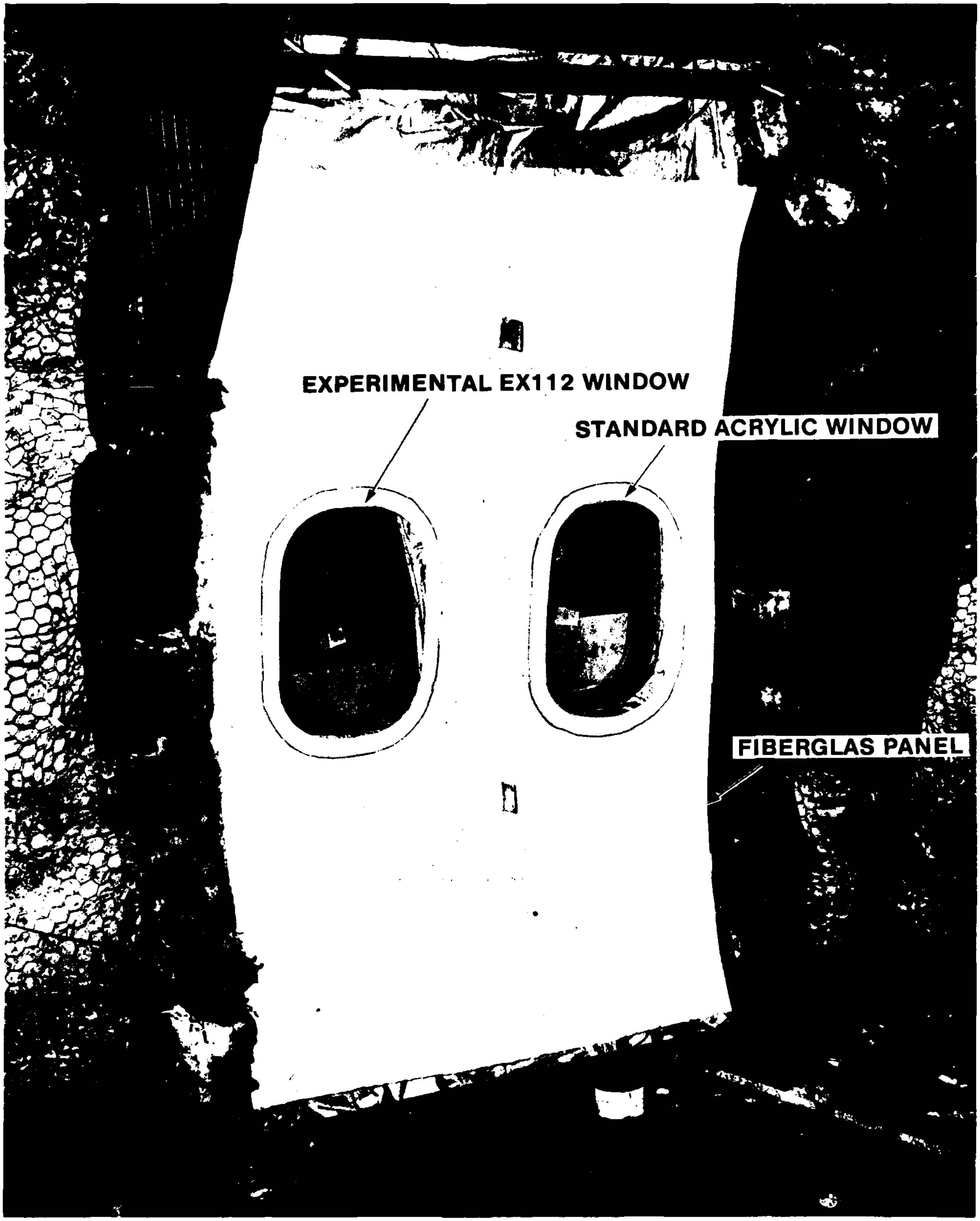


FIGURE 20. FIBERGLASS PANEL IN PLACE OVER THE INSULATION BATT (TEST 2)

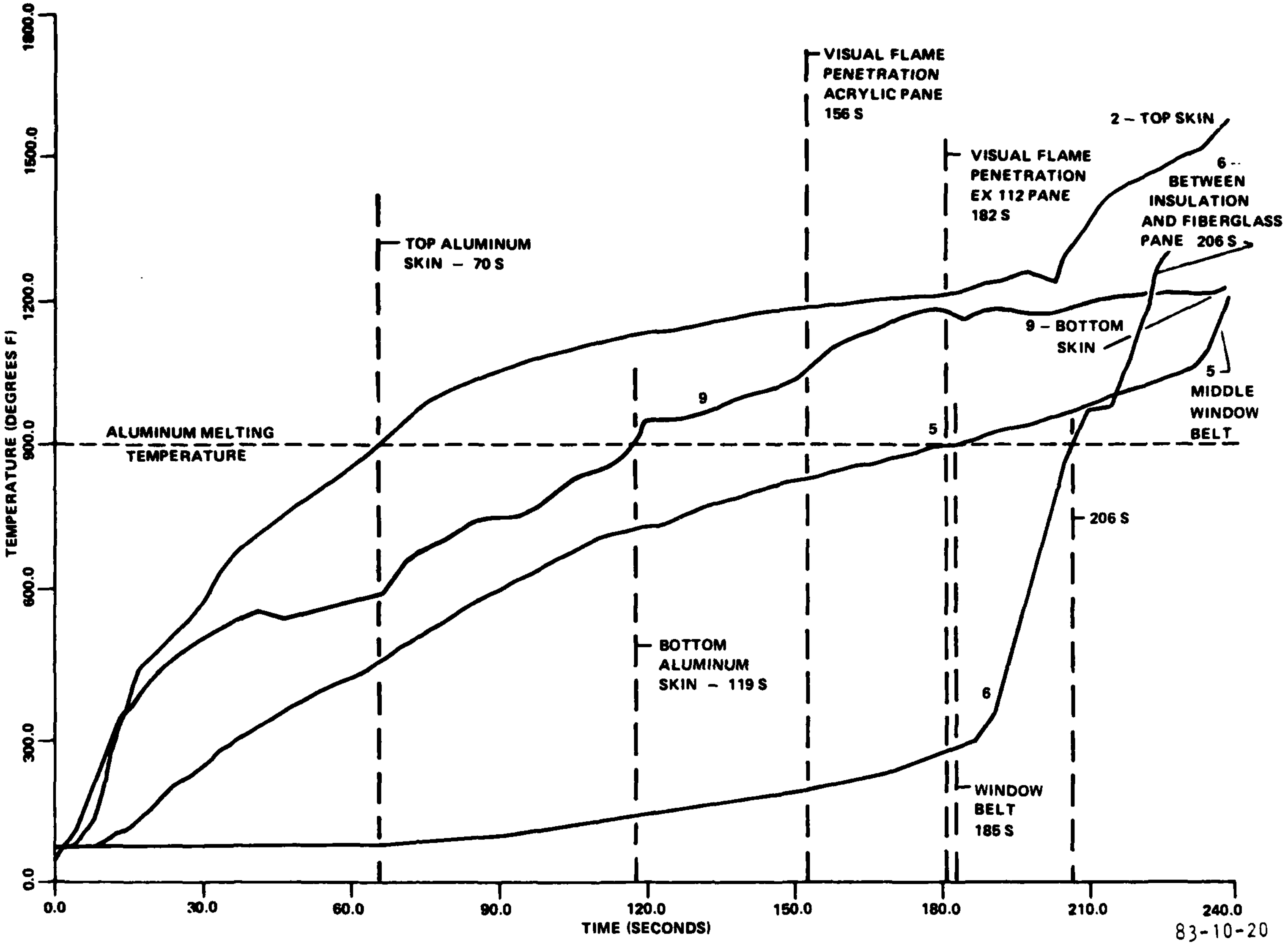


FIGURE 21. TEMPERATURE RISE OF THE *DC-10* SKIN, DOUBLER AND BELT DURING FIRE EXPOSURE (TEST 2)

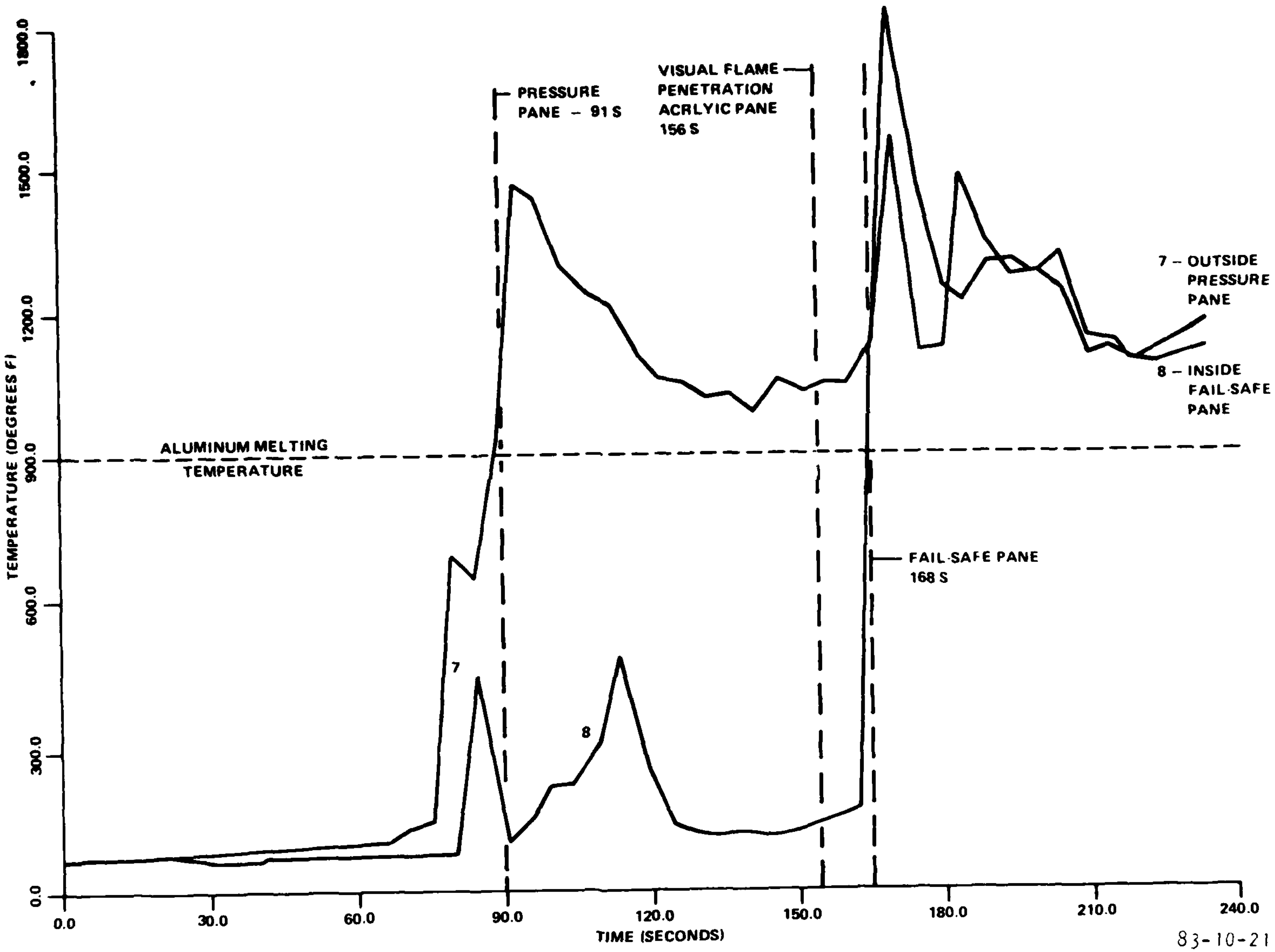


FIGURE 22. TEMPERATURE RISE OF THE STANDARD (ACRYLIC) WINDOW PANES DURING FIRE EXPOSURE (TEST 2)

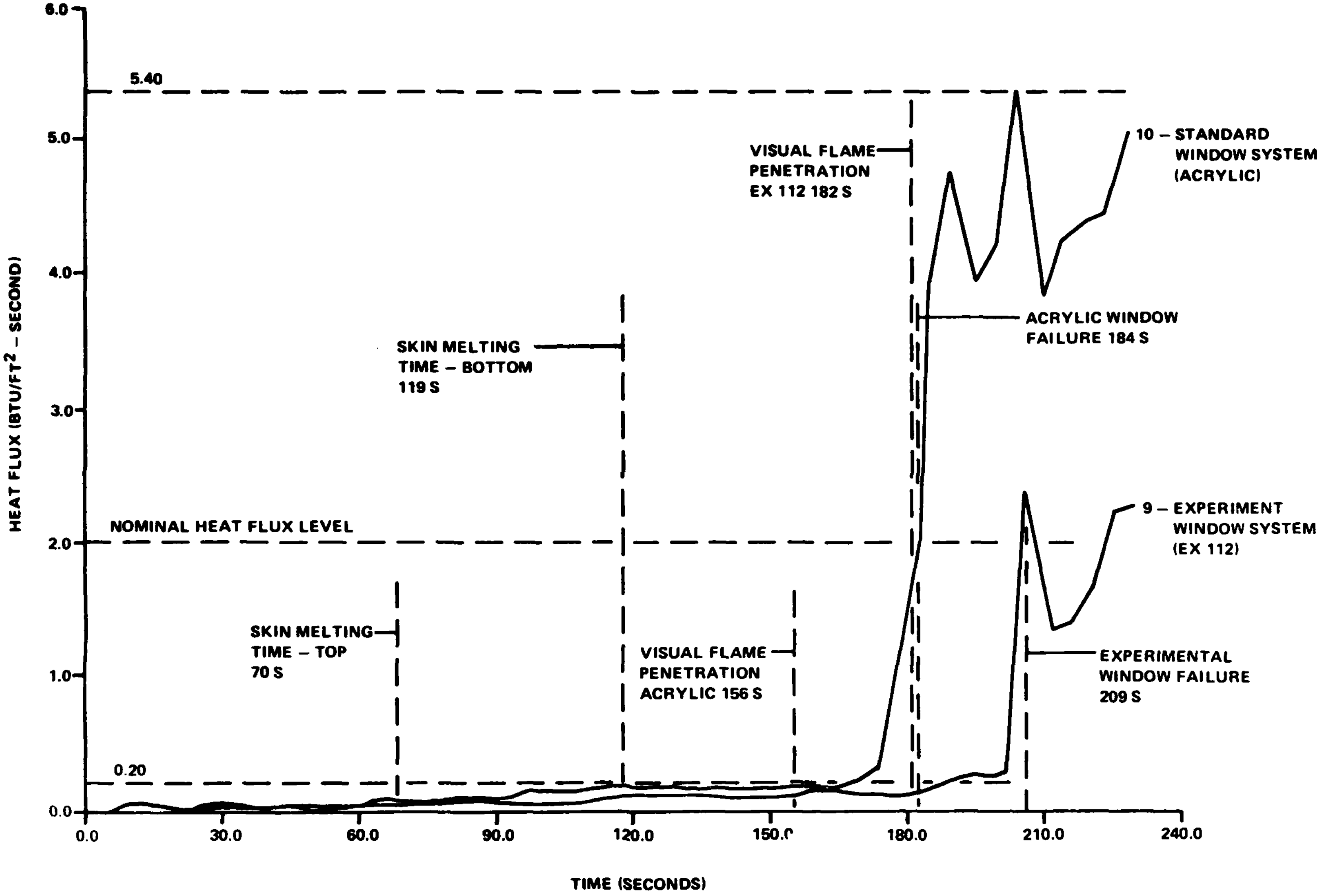


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FIGURE 23. HEAT FLUX THROUGH THE STANDARD (ACRYLIC) AND THERMALLY IMPROVED (EX 112) WINDOWS DURING FIRE EXPOSURE (TEST 2)

FIGURE 24. FIRE DAMAGE TO THE STANDARD (ACRYLIC) AND IMPROVED (EXIT 112) WINDOWS (TEST 2)

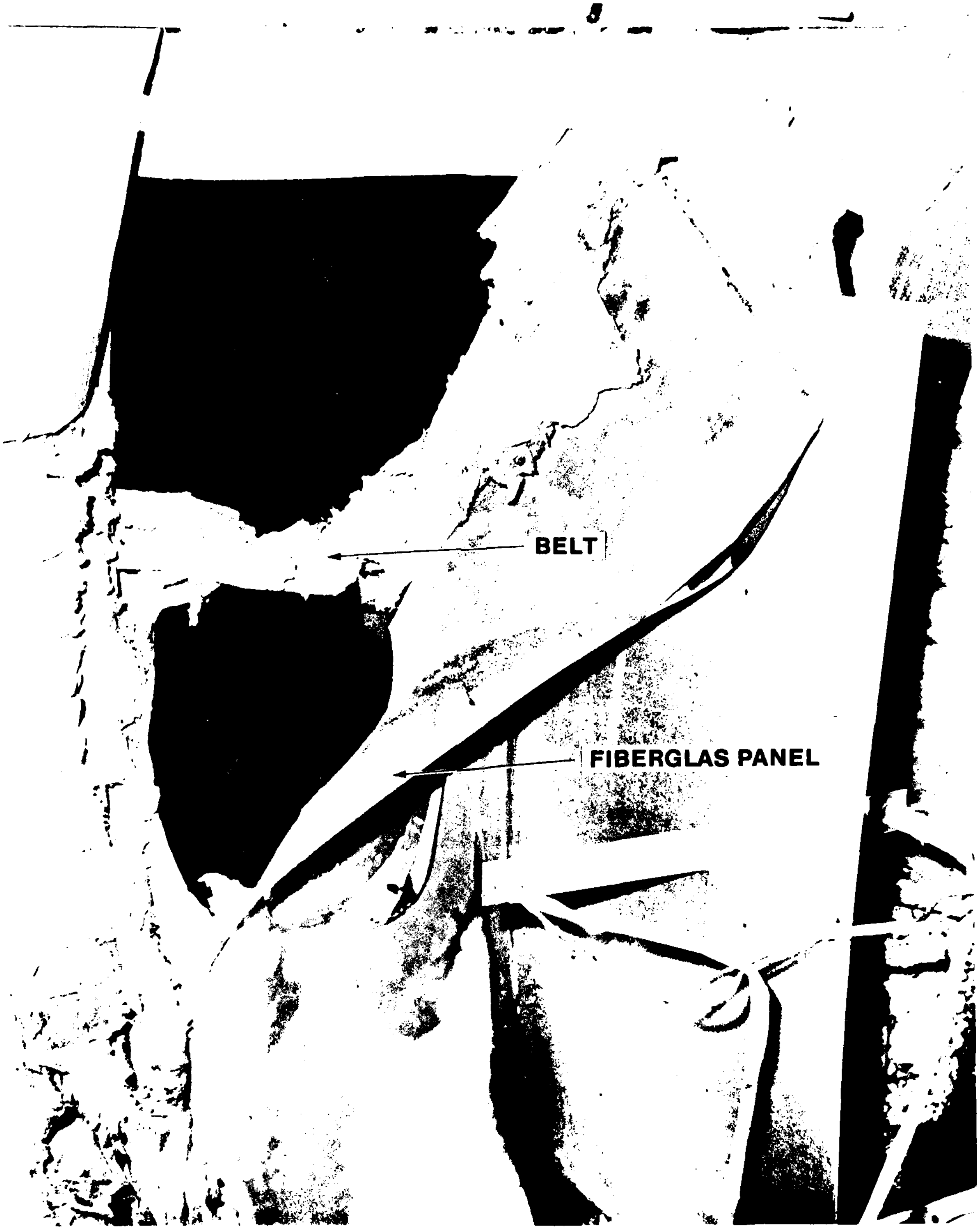

FIGURE 25. CLOSE-UP VIEW OF THE FIRE DAMAGE TO THE IMPROVED (EX 112) WINDOW SYSTEM (TEST 2)

C-133 TEST BED (TEST 3)

FIGURE 26. INTERIOR VIEW OF THE DC-10 WINDOWS INSTALLED IN THE C-133 TEST BED (TEST 3)

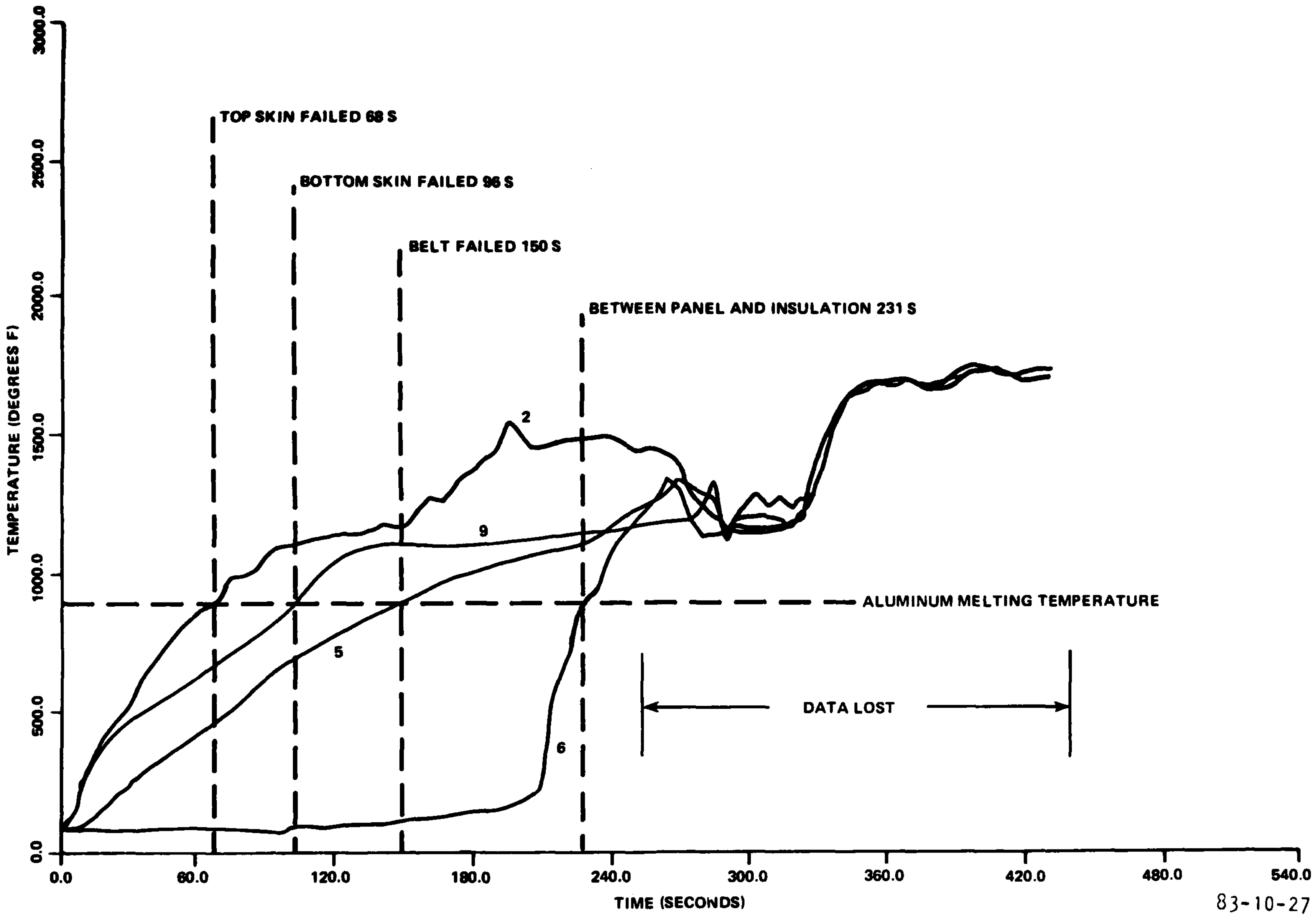

FIGURE 27. TEMPERATURE RISE OF THE DC-10 SKIN, BELT AND THE INTERFACE BETWEEN THE INTERIOR PANEL AND INSULATION BATT (TEST 3)

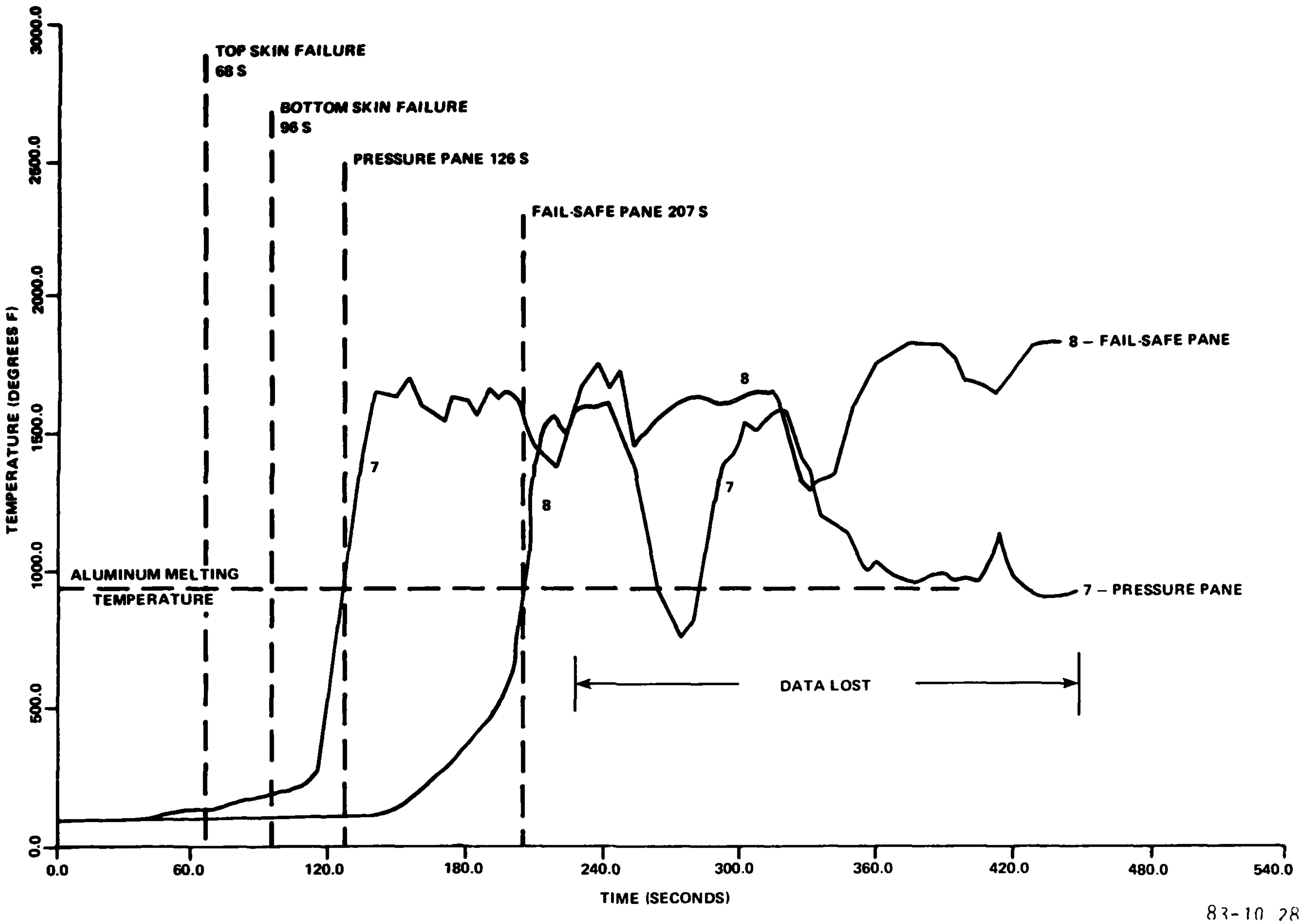

FIGURE 28. TEMPERATURE RISE OF THE STANDARD (ACRYLIC) WINDOW PANES (TEST 3)

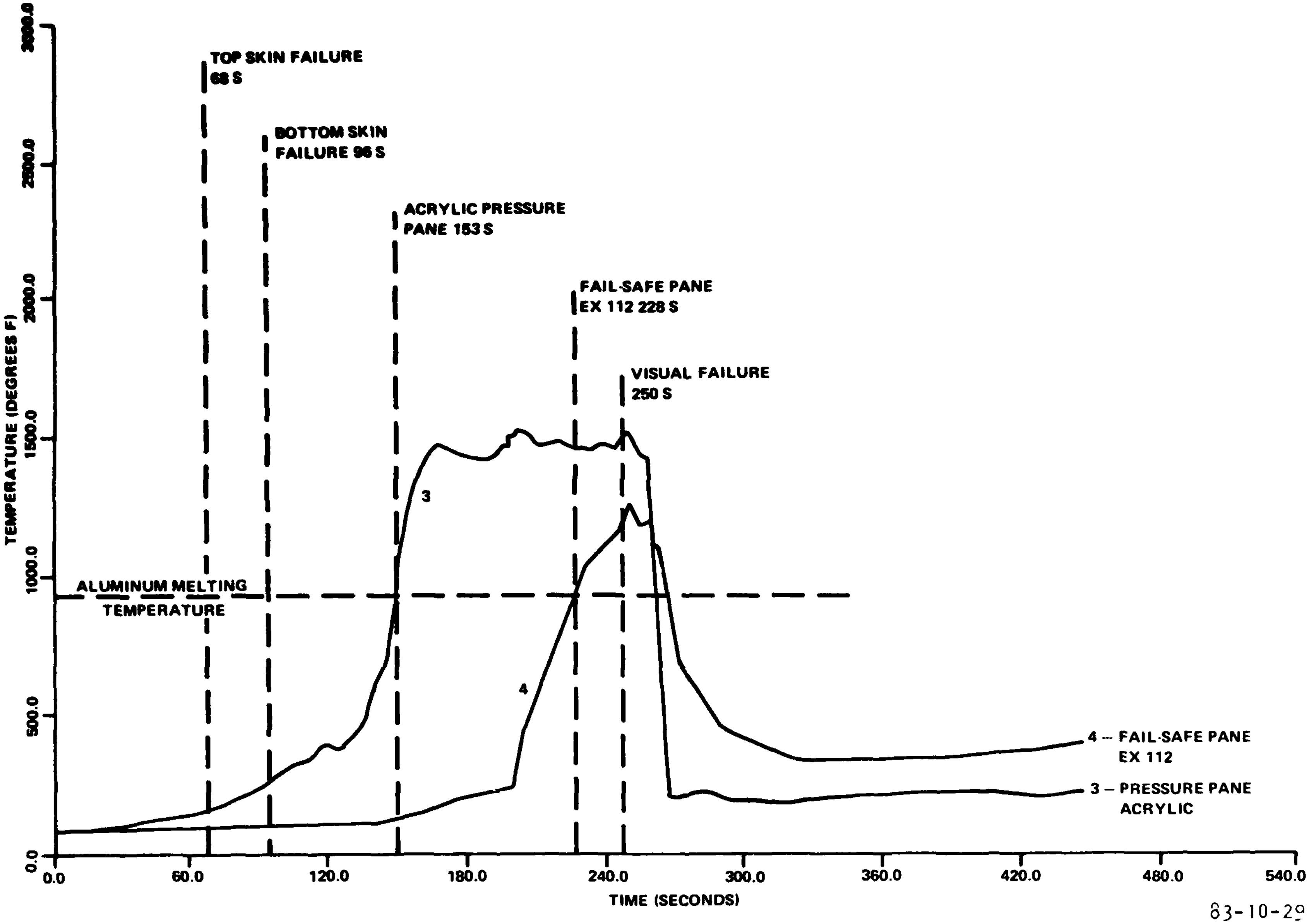

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FIGURE 29. TEMPERATURE RISE OF THE THERMALLY IMPROVED (EX 112) FAIL-SAFE WINDOW PANE AND STANDARD (ACRYLIC) PRESSURE PANE DURING FIRE EXPOSURE (TEST 3)

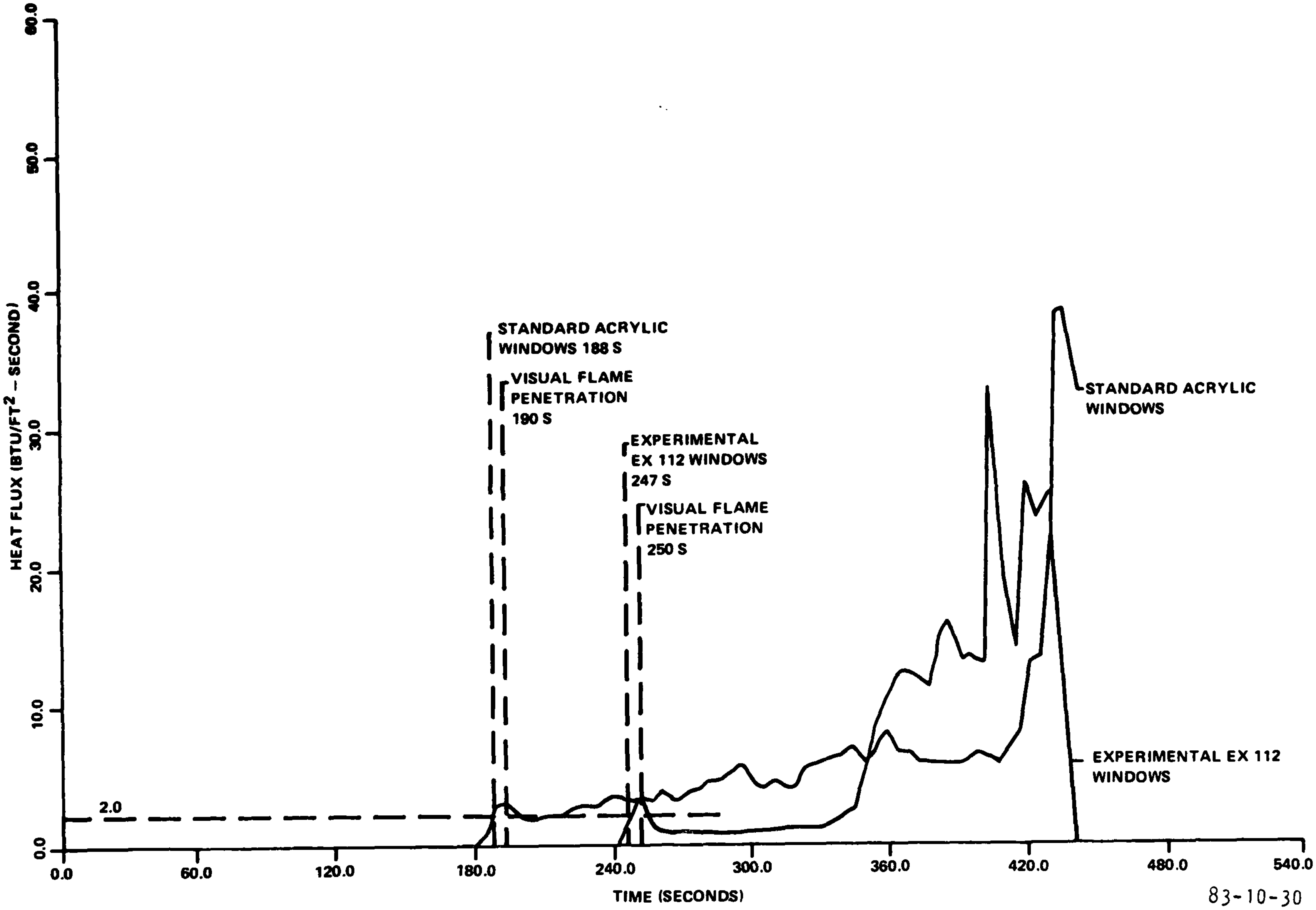

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FIGURE 30. HEAT FLUX THROUGH THE STANDARD (ACRYLIC) AND THERMALLY IMPROVED (EX 112) WINDOWS DURING FIRE EXPOSURE (TEST 3)

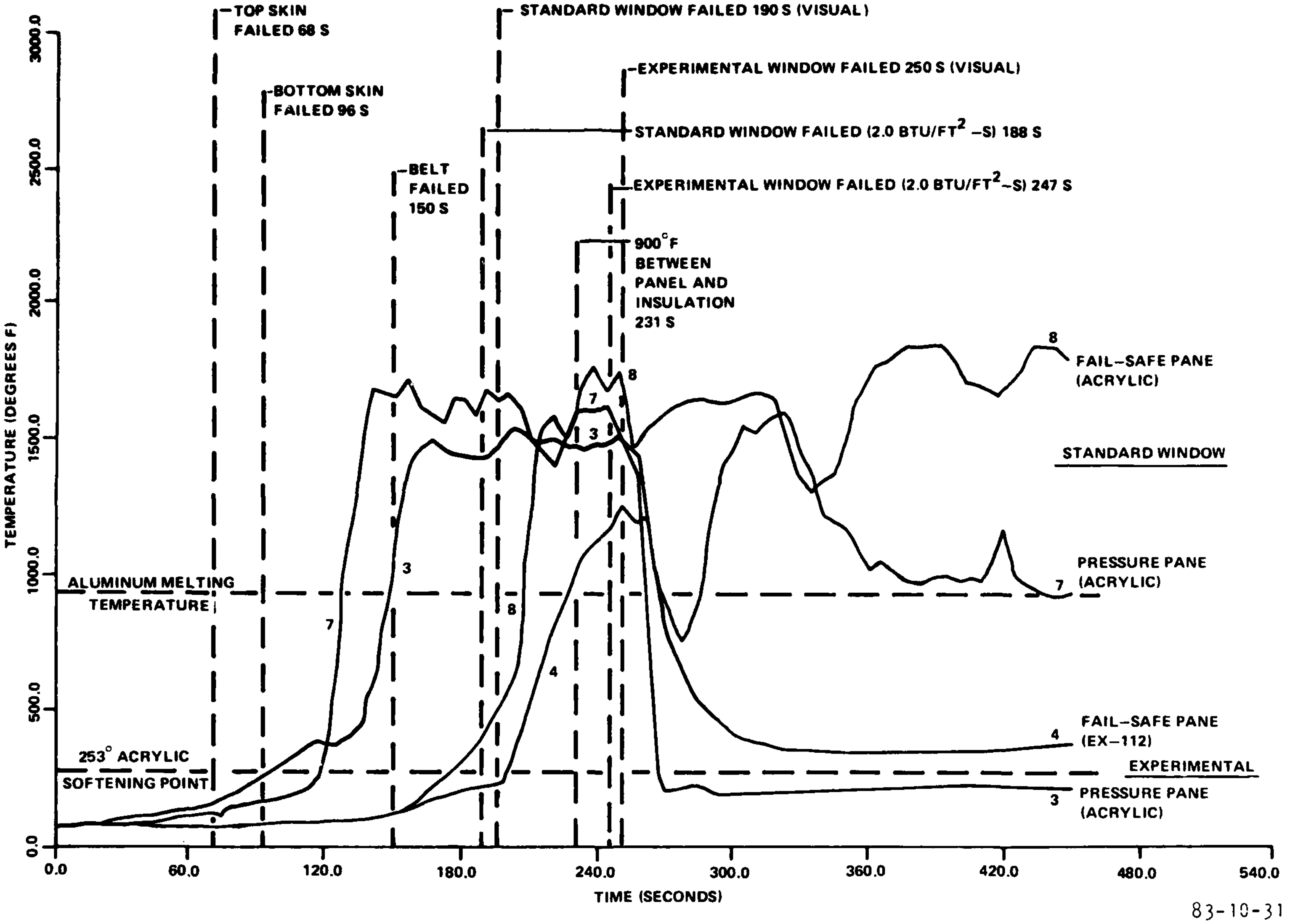

FIGURE 31. SUMMARY OF EXPERIMENTAL DATA OBTAINED FROM TEST 3 EMPLOYING THE STANDARD AND THERMALLY IMPROVED WINDOW SYSTEM WITH THE DC-10 INTERIOR HONEYCOMB PANEL CONFIGURATION

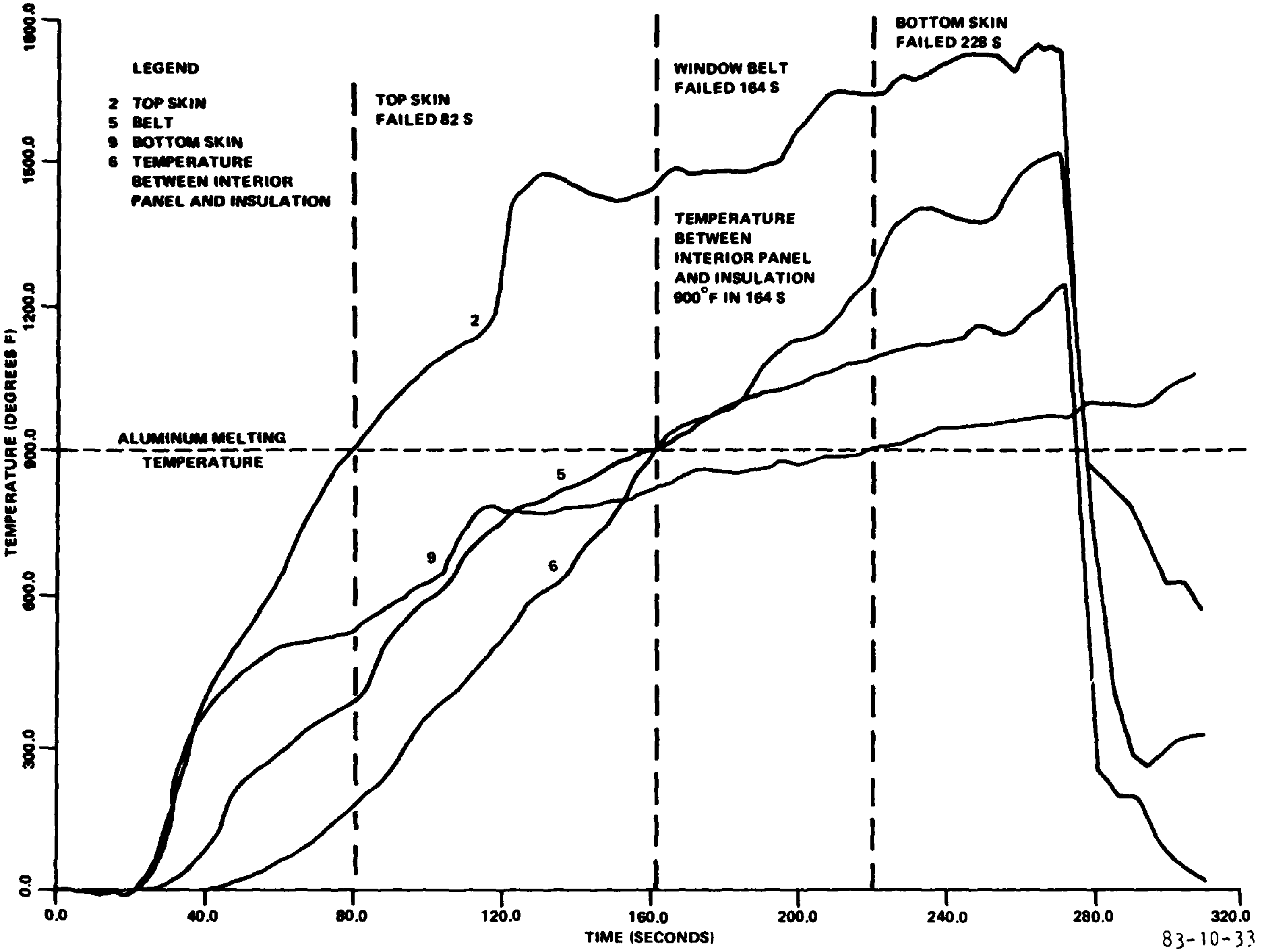

FIGURE 32. TEMPERATURE RISE OF THE DC-10 SKIN, BELT AND THE INTERFACE BETWEEN THE INTERIOR PANEL AND INSULATION BATT (TEST 4)

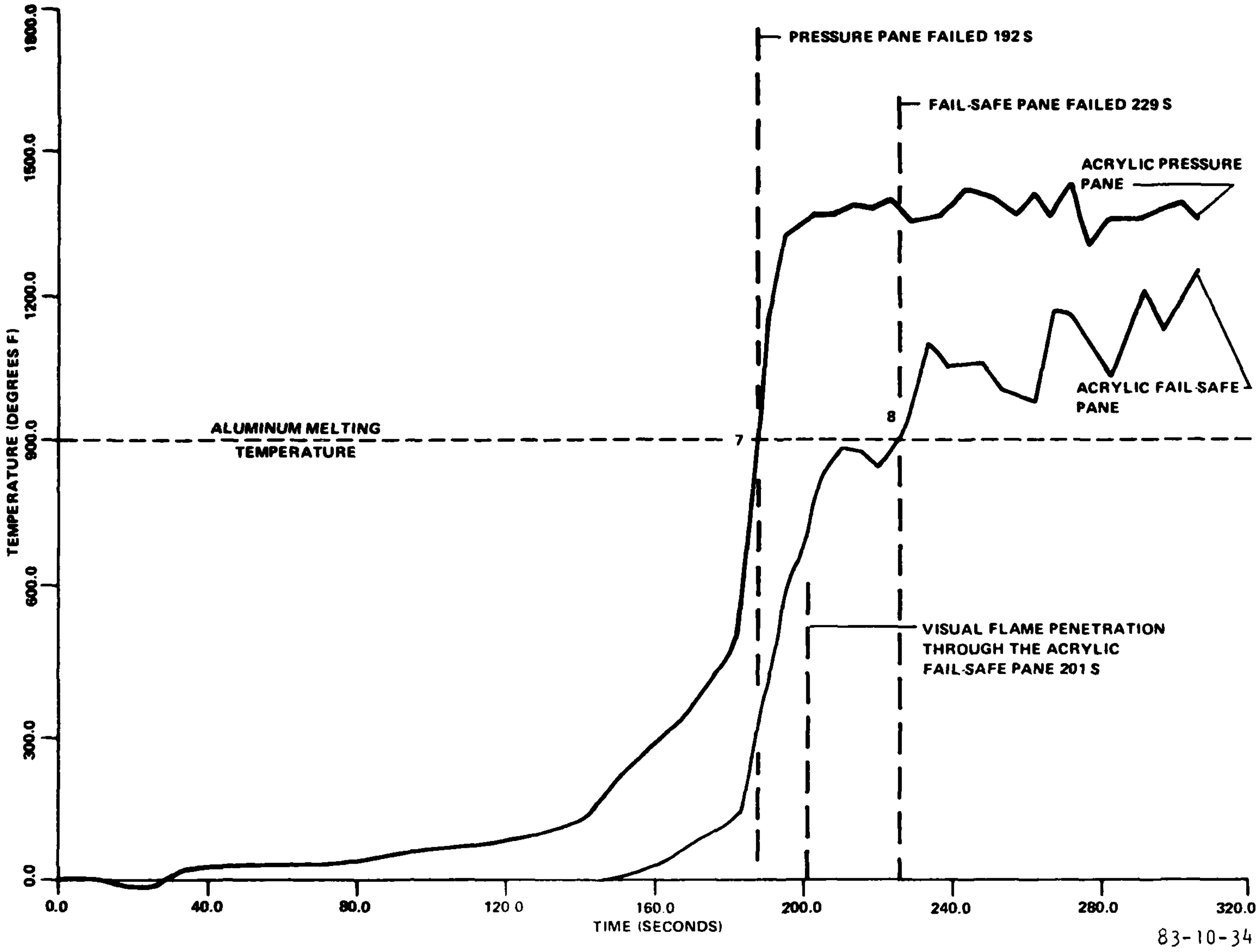

FIGURE 33. TEMPERATURE RISE OF THE STANDARD (ACRYLIC) WINDOW PANES DURING FIRE EXPOSURE (TEST 4)

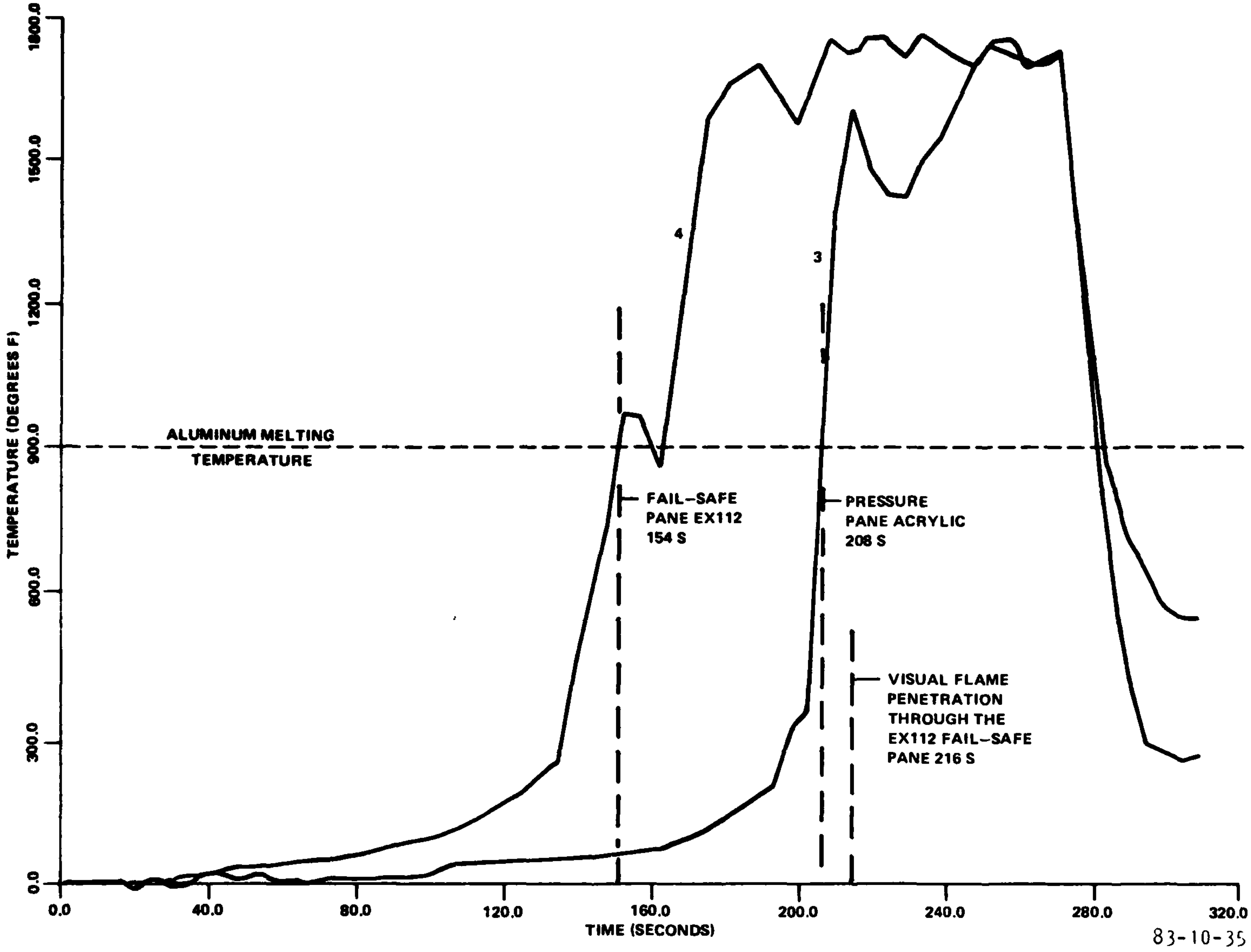

FIGURE 34. TEMPERATURE RISE OF THE THERMALLY IMPROVED (EX 112) WINDOW PANE AND STANDARD (ACRYLIC) PRESSURE PANE DURING FIRE EXPOSURE (TEST 4)

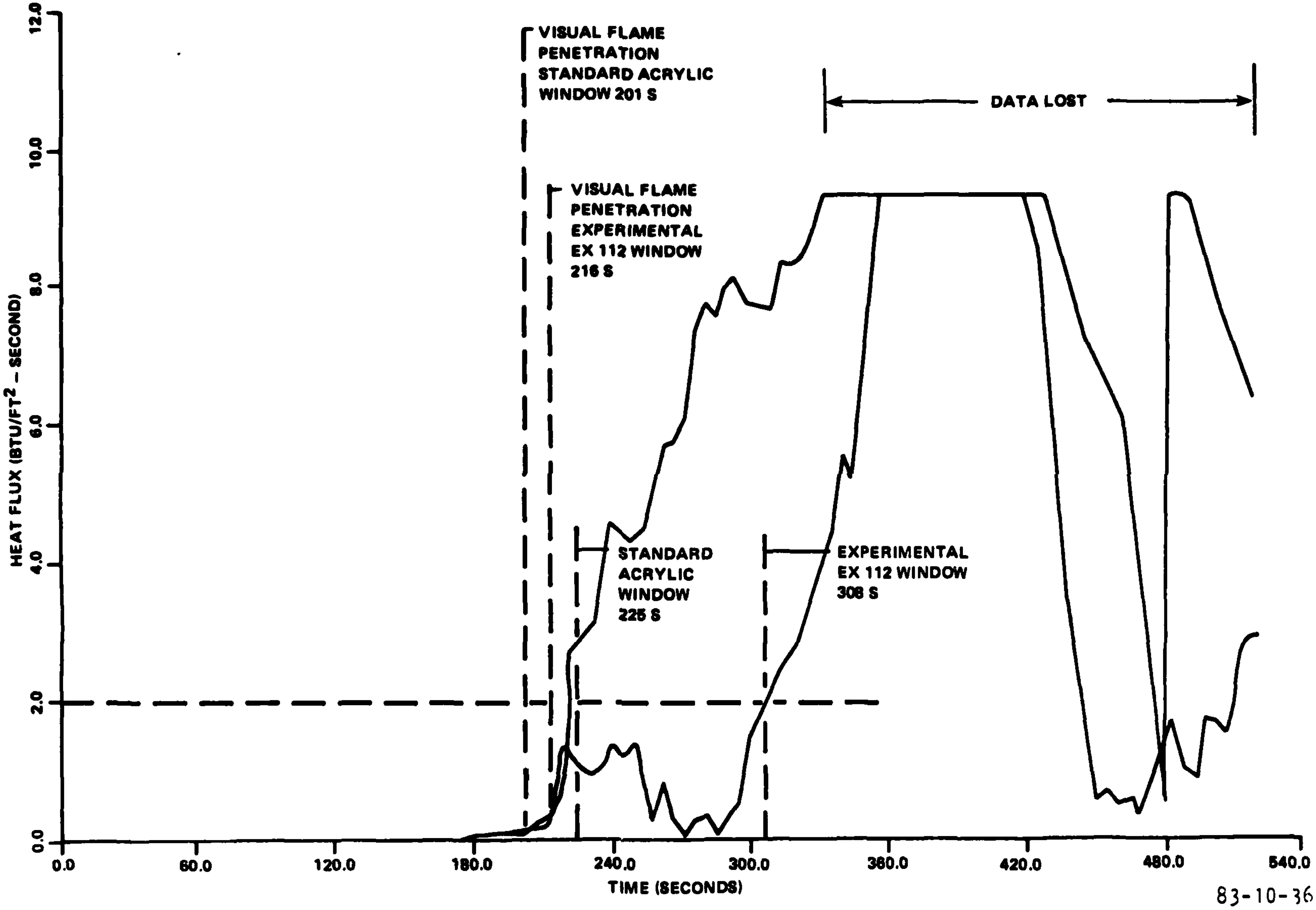

FIGURE 35. HEAT FLUX THROUGH THE STANDARD (ACRYLIC) AND THERMALLY IMPROVED (EX 112) WINDOWS DURING FIRE EXPOSURE (TEST 4)

APPENDIX A

SCHEMATIC DRAWING SHOWING THE RELATIVE POSITIONS OF THE THERMOCOUPLES AND RADIOMETERS WHEN VIEWED FROM OUTSIDE THE C-133 TEST BED (NOT TO SCALE)

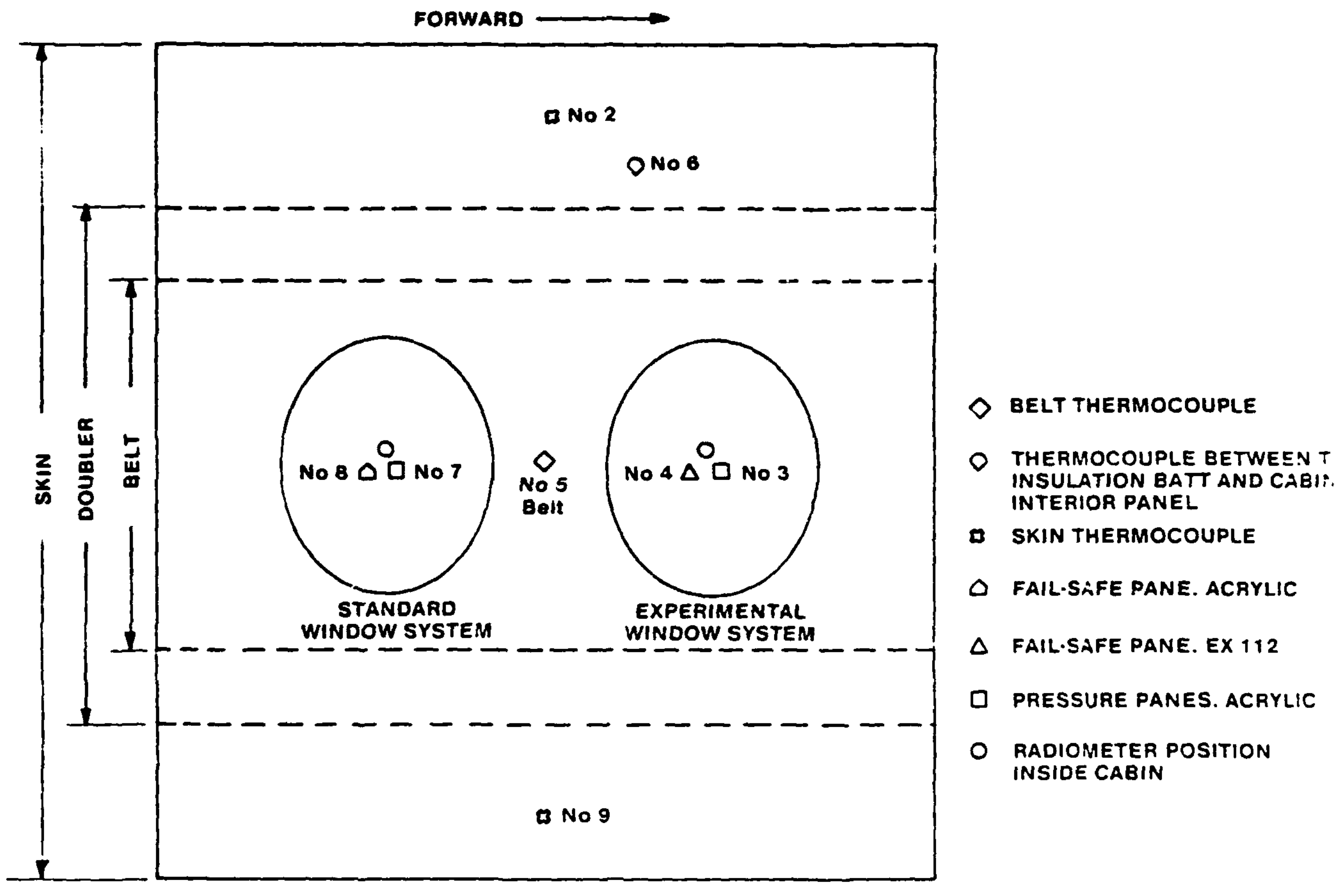

FIGURE A-1. SCHEMATIC DRAWING SHOWING THE RELATIVE POSITIONS OF THE THERMOCOUPLES AND RADIOMETERS WHEN VIEWED FROM OUTSIDE THE C-133 TEST BED (NOT TO SCALE)

APPENDIX B

FLAME PLUME TEMPERATURE OF A FREE BURNING AVIATION FUEL FIRE SUPERIMPOSED OVER A DC-10 FULELAGE WINDOW TEST SEGMENT IN THE C-133 TEST BED

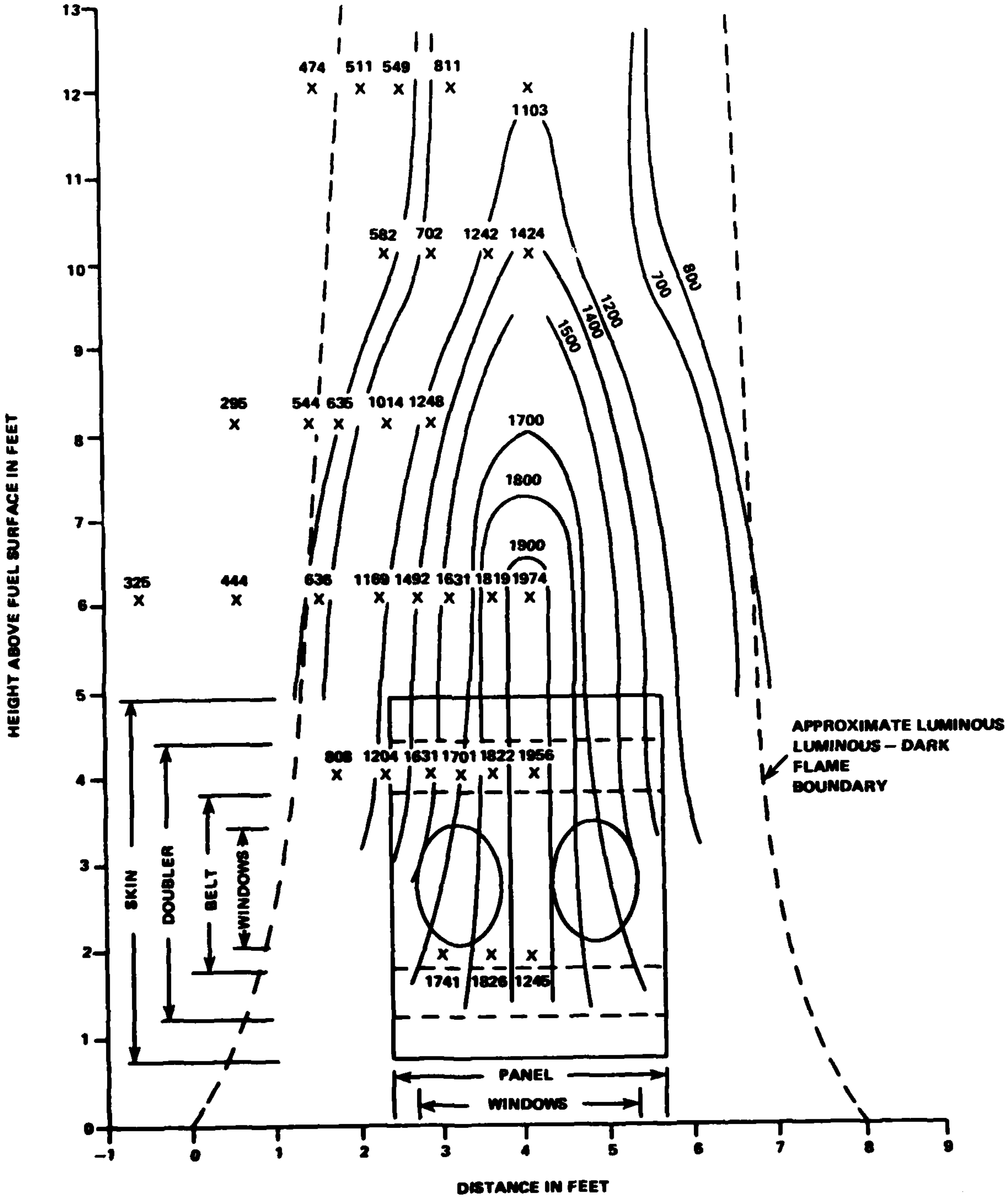

FIGURE B-1. FLAME PLUME TEMPERATURE PROFILES OF A FREE BURNING AVIATION FUEL FIRE SUPERIMPOSED OVER A DC-10 FUSELAGE WINDOW TEST SEGMENT IN THE C-133 TEST BED