NAFEC TECHNICAL LETTER REPORT

NA-80-22-LR

PROJECT PLAN

EVALUATION OF A FIXED ONBOARD FOAM/WATER SPRINKLER SYSTEM FOR THE EXTINGUISHMENT OF AIRCRAFT CABIN FIRES BY THE CRASH FIRE RESCUE SERVICES

by

G. B. GEYER

February 1980

FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
Atlantic City, New Jersey 08405

TABLE OF CONTENTS

EVALUATION OF A FIXED ONBOARD FOAM/WATER SPRINKLER SYSTEM FOR THE EXTINGUISHMENT OF AIRCRAFT CABIN FIRES BY THE CRASH FIRE RESCUE SERVICES

Section 1 - OBJECTIVES

The principle objective of this investigation is to determine the fire extinguishing effectiveness of a fixed onboard, dry-pipe foam/water sprinkler system in terms of the solution discharge rate and application density, required to control and extinguish full-scale cabin fires involving seats, carpets, and the side/ceiling panels. Means will be developed for coupling the onboard foam/water sprinkler system to an adjacent crash-fire-rescue (CFR) foam truck through a permanent fixture mounted in the aircraft fuselage. Additionally, methods will be devised to utilize the potable onboard water supply in the system pending the arrival of the CFR services.

Section 2 - BACKGROUND

One of the principle objectives of the CFR services is to respond to aircraft accidents/incidents and extinguish all exterior fires to permit the safe self-evacuation of occupants. However, this limited scope objective is currently being reviewed by experts in the field. Accident reports are existent in which the CFR services accomplished their basic mission, but the aircraft was subsequently lost because of the uncontrollable interior cabin fires which had been ignited by external fuel-spill fires. One well-documented example (reference 1), illustrative of these conditions, is the United Airlines DC8 accident at Stapleton Airport, Denver, Colorado, which resulted in 17 fatalities, 16 of which were caused by carbon monoxide poisoning, and the subsequent loss of the aircraft.

From this and similar accident situations, it is apparent that the polymeric cabin furnishings which contain carbon, hydrogen, and halogen atoms in combination with lesser amounts of nitrogen, sulfur, etc., are potentially capable of high-temperature combustion and/or pyrolysis, thereby producing an extremely toxic aircraft cabin environment if the ignition source is of sufficient magnitude. That devastating thermal conditions develop very rapidly was demonstrated in reference 2 in which simulated aviation fuel-spill fires adjacent to an aircraft fuselage reached equilibrium burning conditions with flame temperatures between 1,500 and 1,700 degrees Fahrenheit (^{o}F) within 90 seconds causing a 0.125-inch-thick aluminum aircraft skin panel to fail (melt) within 53 seconds.

Therefore, serious consideration is being devoted to various means of providing the CFR services with new and more effective tools and equipment to combat complex three-dimensional class A fires as well as the external aviation fuel-spill fires. The principle concern of these efforts is to provide an increase in the safe passenger self-evacuation time and a potential reduction in property loss.

Prior to conducting the experimental portion of this project, an assessment was made of the potential availability of the CFR services at airports to respond and service the onboard foam/water sprinkler system from a suitable source of agent supply (foam truck(s)). The results of the accidents surveyed are summarized in table 1. From these data, it was apparent that a large majority of aircraft accidents occur within the airport perimeter and therefore they are reasonably accessible by the CFR services.

A second major parameter requiring delineation prior to implementing the project concerned the economic impact of the system in terms of cost and weight penalty. Accordingly, estimates of the weight and materials costs were developed and the results are summarized in table 2. These data tend to show that neither the projected material costs nor the weight penalty are excessive for this size aircraft. However, this information is not particularly meaningful unless a frame of reference is established which provides equal fire safety of passengers by some alternate means.

From a previous project effort entitled "State-of-the-Art Review of Ongoing Work and Developments in Aircraft Cabin Fire Safety and the Crash Fire Rescue Services," (reference 3) the economic impact of various fire safety concepts was derived in terms of a benefit/cost ratio. A portion of this information was extracted from the report and is presented in appendix 1. An assessment of these various fire safety concepts indicates that the one which most closely interfaces the onboard sprinkler system concerns various fundamental improvements in the flammability characteristics of the interior class A materials.

The benefit/cost ratios derived for both concepts, assuming equal improvements in the fire safety of passengers, is presented in table 3. These ratios show a significant benefit/cost advantage in favor of the foam/water sprinkler concept over the improved prototype cabin materials many of which are not in commercial production.

TABLE 1. ACCIDENTS IN WHICH THE CFR SERVICES WERE AVAILABLE

	PERCENT
USA	
IN IMMEDIATE VICINITY OF RUNWAY	75
IN APPROACH AREA	22
ENROUTE	3
GREAT BRITAIN (12 MONTHS ANALYSIS)	
ON AIRPORT	83

TABLE 2. ONBOARD DRY PIPE FOAM/WATER SPRINKLER SYSTEM FOR USE BY THE CFR SERVICES*

ESTIMATED MATERIALS COSTS AND WEIGHT PENALTY FOR THE DC7 AIRCRAFT

	WEIGHT POUNDS	COST DOLLARS
STAINLESS STEEL PRESSURE TUBING		
120 ft of 1 1/2 inch	65.6)	1,500
150 ft of 3/4 inch	38.4)	
QUICK DISCONNECT FITTINGS		
4 only 2 1/2 inch ($225 each)	30	900
FOAM/WATER SPRINKLER NOZZLES		
70 only ($5 each)	18	350
TUBING COUPLINGS		
250 only (various types)	20	534
TOTALS	172.0	3,284

*Utilization of the onboard potable water supply will be investigated

TABLE 3. BENEFIT/COST ANALYSIS ASSUMING EQUAL FIRE SAFETY IMPROVEMENTS (DC7 AIRCRAFT)

	ESTIMATED FACTOR
ON BOARD FOAM/WATER SPRINKLER SYSTEM MATERIALS ONLY	74.9
IMPROVED FLAMMABILITY OF INTERIOR KIT MATERIALS ONLY	2.2

BASIS OF ESTIMATE

83 to 97 PERCENT OF ALL ACCIDENTS OCCUR ON THE AIRPORT (CFR SERVICE AVAILABLE)

ONBOARD POTABLE WATER SUPPLY AVAILABLE FOR FIRE EXTINGUISHMENT WITHIN CABIN AND LAVATORIES AND THAT THE CFR SERVICES CAN PROVIDE AFFF SOLUTION TO THE ONBOARD SPRINKLER SYSTEM

From the preceding analysis, it was concluded that the onboard foam/ water sprinkler system was capable of providing both an economical and practicable means for improving passenger safety in fire emergencies involving aircraft cabin furnishings.

Section 3 - RELATED DOCUMENTATION/PROJECTS

There is no documentation known to the author in which aircraft cabin fire protection is achieved by providing an onboard dry pipe foam/water sprinkler system which is serviced principally by the CFR services from an external source of agent supply (foam truck(s)).

Tests of an onboard foam/water sprinkler system employing the potable water supply was evaluated in an Aerospace Industries Association of America, Inc. report entitled "Fire Suppression, and Smoke and Fume Protection" AIA CDP-2, July 1968. In this study pendant sprinkler heads of the type used in structural fire protection were deployed at ceiling level, down the center of both an 8-foot fuselage mockup and a 40-foot section of a DC8 aircraft. The experimental results demonstrated, in part, the well known wetting properties and fire extinguishing effectiveness of Aqueous-Film-Forming-Foam (AFFF). The foam/water sprinkler nozzles employed in this configuration provided limited coverage of the side panels and could seriously impair passenger visual acuity during evacuation. A system somewhat similar to this is employed during fabrication of the Boeing B747, B757, and B767 aircraft after which it is removed.

These facts, in general, tend to confirm the general acceptance of fixed foam/water sprinkler systems as one of the most effective means of extinguishing both class A and B materials fires.

The following additional studies are included in the AIA CDP-2 report:

1. Interior Materials With Improved Fire Resistance
   (ongoing at NAFEC and elsewhere)

2. Built-In Water-Fog Fire Suppression System
   (ongoing NAFEC project 081-431-170)

3. Built-In Freon 1301 Fire Suppression System
   (reevaluated by FAA/NAFEC)

4. Built-In High-Expansion-Foam Fire Suppression System
   (considered impracticable in AIA report)

5. Hand-Held Hose With Water-Fog or Foam Nozzle
   (considered impracticable in AIA report)

6. Escape Hoods and Masks
   (considered worthy for additional study in AIA report)

7. Compartmentation
   (considered worthy for additional study in AIA report - FAA/NAFEC completed additional studies)

8. Burn-Through Resistant Insulation
   (considered worthy for additional study in AIA report - NASA Ames Research Center developed entirely new system)

9. Fuselage Rupture-Closing Devices
   (considered heavy and impracticable in AIA report)

10. Fire-Stop Grilles
    (considered unnecessary in AIA report)

11. Cabin Fire Extinguishment by Dry Chemical Powder
    (considered impracticable in AIA report because of visibility problems during discharge).

Of the 11 projects considered in the AIA CDP-2 report, four of the most viable have been or are being evaluated by the FAA/NAFEC. Of the remaining projects, five were considered impracticable by the AIA for various reasons while two were considered to have good potential for improving passenger fire safety, namely improved burn-through resistant insulation and passenger's escape hoods and masks.

Section 4 - SYSTEM/ EQUIPMENT DESCRIPTION

DC7 AIRCRAFT FIRE TEST BED

The fire test bed is a DC7 aircraft from which the seats and galley equipment were removed. A 20-foot-long section within the cabin, between stations 530 and 770 (figure 1) was fire-hardened by means of ceramic fiber insulation and sheet steel. After the existing paneling had been removed, it was replaced with a 2-inch-thick layer of Kaowool®

(reference 4) which is supported over the formers by means of 20-gage, 1-inch mesh chicken wire. The ceramic insulation is supported by 2-inch-wide steel strips and covered with 24-gage cold rolled steel.

ANCILLARY FIRE PROTECTION SYSTEMS IN THE DC7 AIRCRAFT

To preclude the possibility of a catastrophic fire developing in those sections of the aircraft cabin which were not fire-hardened, three ancillary fire protection systems have been installed. The ceiling and sidewall panels are protected from possible ignition by a series of seven foam/water sprinkler heads installed at the stations indicated in figure 1. This system is capable of discharging a solution of AFFF at the rate of 90 gallons per minute through an external coupling to a foam firefighting vehicle.

In an attempt to inhibit or delay the development and propagation of an overhead flash fire during the tests, a series of seven flame barriers were constructed by suspending 30 mesh wire screens vertically from the ceiling at the stations indicated in figure 1. Although this conceptual means of controlling the propagation of flash fires in an aircraft is new and therefore unproven, the principle was proven to be eminently successful in preventing flaming, combustible gases from propagating through wire mesh grids of the proper size by Sir Humphry Davy in 1803. Prior to installing the flame barriers, laboratory experiments were conducted. The data from these experiments were utilized to obtain the proper mesh configuration to be employed during these tests.

DESCRIPTION OF THE FOAM/WATER DISPENSING SYSTEM

There are two basic concepts inherent in the use of a fixed foam/water sprinkler system installed on board an aircraft. The first concerns the utilization of the potable water supply to provide interim cabin fire protection by minimizing or preventing flame penetration of the fuselage, while the second involves means whereby the CFR services can continue the discharge of foam through the system from an external source of agent supply (i.e. foam/water trucks). Connection to the sprinkler system will be accomplished by means of quick-connect fittings in the front and rear as well as on both sides of the fuselage.

The fire extinguishing effectiveness of the AFFF solution will be demonstrated in a 13.3-foot-long section of the DC7 aircraft in which the side panels and ceiling have been fitted with flush-mounted sprinkler heads of the type shown in figures 2 and 3. A cross-sectional view through the test section is presented in figure 4 which shows the relative positions of three different types of foam nozzles. This test section comprises a "Kit" which was fabricated by Atlantic Aviation Corporation, Wilmington, Delaware, of current "State-of-the-Art" materials including dado panels, sidewalls, valance, racks, ceiling, and carpet all of which meet or exceed FAA 25.853 specifications. The physical properties and performance characteristics of "Lexan" F-6000 and Polyplastex United, Inc. are products which comprise the bulk of the kit and selected technical data are presented in appendix 2. The approximate dimensions of the installed kit are indicated in figure 5. Preliminary tests of the system will be conducted to determine the lowest operating pressure and minimum solution flow rate in terms of the maximum surface area covered (wetted) by the spray from each nozzle.

To more effectively utilize the limited potable water supply, the foam solution will only be discharged in the immediate vicinity of the fire whether it originates inside or has penetrated into the cabin. This will be accomplished in the DC7 aircraft by dividing the pressurized cabin section into approximately four equal fire zones as indicated in figure 6. Each zone will be provided with two heat sensors (thermocouples). The thermocouple inside the cabin will be activated (discharge foam/water) by a temperature rise of approximately 125^{o}F above ambient while the second will be imbeded in the aircraft skin and be activated by temperature of 600^{o}F and above.

<u>TEST SEQUENCE</u> Tests will be initiated by igniting methanol contained in a metal trough positioned adjacent to the lower dado panel (figure 4). Alcohol is employed as the class B ignition source since it can be readily ignited by means of a synchronized high-voltage spark and burns with a smokeless flame producing carbon dioxide and water as the only combustion products. The foam/water sprinkler system will be activated when either the ambient environmental temperature reaches 290^{o}F or the heat flux is 0.2 Btu/ft^{2}-sec or above, and the system will remain in operation until all flaming combustion ceases.

Three full-scale fire modeling experiments are scheduled. The first will employ a plywood mockup to establish instrumentation and ancillary systems integrity. The second will involve fire in the floor, side panels, and ceiling of the installed kit while the third will include the paneling as well as two rows of seats. The parametric measurements for each test are indicated by the test matrix in table 4.

TABLE 4. TEST DATA MATRIX

			Heat Flux			DC7 Cabin Atmosphere			
Test No.*	Fire Class	Temperature	Radiometer	Calorimeter	Smoke	CO_2	CO	O_2	HF
1	A	X	X						
2	A	X	X	X	X	X	X	X	X
3	A	X	X	X	X	X	X	X	X

*1. Plywood mockup
2. Paneling only
3. Paneling and seats

Section 5 - DATA COLLECTION

INSTRUMENTATION

General. The thermal effects of the fires on the interior environment of the aircraft will be monitored principally by means of thermocouples, radiometers, calorimeters, and smoke meters positioned strategically within the cabin (figure 7). Additional instrumentation will include a video tape camera, instrumentation cameras, and gas sampling apparatus. The position of each of these elements is identified in figure 8.

Thermocouple Positions. Nineteen thermocouples (chromel-alumel) will be strategically distributed throughout the aircraft cabin in various arrays and at different elevations above floor level as indicated in figure 7. One of the principle uses of the thermocouples is to monitor the cabin environment in terms of human survival during the fire buildup period. Unsurvivable conditions are considered to exist from 1/4 to 1/3 of the cabin atmosphere rises to temperatures between 290° to 300°F. To maintain uniform test conditions, insofar as practicable, the AFFF fire extinguisher will be energized when any one of the thermocouples at stations T4, T_5, or T_6 reaches 290°F.

The flame spread rate over the side paneling, hatracks and ceiling panels of the installed kit will be monitored by a grid of microthermocouples (23) embeded in the surface and spaced on 12- to 14-inch centers as indicated in figure 9. These data will be recorded remotely in the instrumentation trailer positioned adjacent to the DC7 aircraft.

Thermal Radiation. Four radiometers will be positioned on either side of the fire-hardened section of the test bed at stations 581 and 645. This location is 25 inches above floor level and approximately 77 inches from the center of the paneling. Additional thermal data will be obtained from two calorimeters positioned along the centerline of the fuselage, 67 inches above floor level at stations 562 and 780. The calorimeters will be used principally as backup instrumentation for assessing human tolerance, if required.

In addition to the thermocouples, the radiometers will also be employed to monitor the aircraft cabin in terms of passenger survival during evacuation. A practical estimation of the intensity of thermal radiation may be made by considering the fact that approximately 0.10 Btu/ft^2-sec is delivered by the sun, at sea level, during the summer months in the temperate zone. Also, exposure to 0.2 Btu/ft^2-sec for periods in excess of 30 seconds will cause severe pain in humans.

Accordingly, 0.2 Btu/ft^2-sec is established as the radiation level capable of contributing significantly to prolonging passenger self-evacuation. Fire extinguishment will therefore be initiated when either the air temperature reaches a minimum of 290°F or the radiation is 0.2 Btu/ft^2-sec or above when measured within the fire-hardened section.

Determination of Smoke Density. Two methods will be employed to assess the relative visual obscuration of the aircraft cabin interior by smoke as the fire progressed. Four photoelectric cell, smoke-density meters will be installed along the centerline of the aircraft cabin 68 inches above floor level at the stations indicated in figure 7. These instruments along with two pen recorders will be used to sense and continuously record the reduction in light transmission over a 1-foot distance for the duration of each test.

To assess the relative visual obscuration of the cabin interior by smoke, two illuminated EXIT signs will be established at stations 526 and 780, 74 inches above floor level within the optical range of two thermally insulated cameras located at stations 359 and 935 (figure 8). Each camera installation will contain one instrumentation motion picture camera exposing 16-millimeter (mm) color film at 24 frames per second and one 35-mm, time-sequenced still camera which will record at 2-second intervals. The camera lens will be positioned 30 inches above floor level forming an angle between the floor and the EXIT signs of approximately 15°. This provides a direct line of sight of approximately 15 feet forward and approximately 13 feet to the rear of the fire.

ENVIRONMENTAL GAS SAMPLING APPARATUS. Samples of the cabin atmosphere will be collected and analyzed for carbon monoxide (CO), carbon dioxide (CO_2), hydrogen fluoride (HF), and oxygen (O_2). A test data matrix is presented in table 4.

Sampler Design. Twelve sampling stations have been designed and constructed for gathering atmospheric samples. Each station comprised two sampling points: one for CO, CO_2, O_2, the other for HF (figure 8).

The HF sampler consists of a glass "midget bubbler" containing 0.1 normal (N) sodium hydroxide solution. The body of the bubbler is a Pyrex® test tube fitted with a two-hole rubber stopper. A Teflon® tube is inserted through the stopper and into the collection medium. The portion of the Teflon tube in the solution is fitted to allow for optimum mixing, while the other end is connected to a Milipore® filter to keep solid particles from being collected in the solution. A second Teflon tube is inserted through the rubber stopper, but not permitted to come in contact with the collection medium. The outside end of this tube is connected to a calibrated orifice which is subsequently connected to a vacuum source. By this means the volume of gas passing through the collection solution will be accurately measured.

The other sampling device will consist of two evacuated test tubes held in place by a wooden bracket. An electric solenoid containing two hypodermic needles is placed below the test tubes. By manually closing the electrical circuit, the solenoid is made to push the syringe needles into the evacuated test tubes for sample collection.

Sampler Locations. Four sampler "trees" (figure 10) each containing three sampling stations will be placed inside the aircraft fuselage (figure 8). One station designated "A" will be located in the "aisle" at an elevation of 64 inches to approximate the position of a person standing. Samplers "B" and "C" will be positioned at a height of 42 inches to simulate the respiratory level of a person seated in the aircraft.

The sampling trees will be spaced two on each side of the fire-hardened area in order to obtain a distribution profile of the toxic gases HF and CO.

Sampling Sequence. The HF samplers will be run continuously during the fire suppression tests. The evacuated test tube samplers will be activated at 30-second intervals during each experiment. Prior to each test, samples will be taken in order to obtain background readings within the aircraft fuselage.

Analytical Procedure For CO_2. A Varian model 3700 gas chromatograph will be used to determine CO_2. A 12-foot, Porapak QS, 1/8-inch-diameter column will be utilized for separation and a thermal conductivity detector employed for quantitation. Helium will be used as the carrier gas.

Analytical Procedure For O_2. Oxygen will also be determined by gas chromatography using a thermal conductivity detector. The separation will be performed using a molecular sieve, 5A, 6-foot 1/4-inch column at $100^{\circ}C$.

Analytical Procedure For CO. Since the concentration of CO is expected to be low and since each sample is only 15 milliliters (ml), a procedure using Drager tubes will be adapted to determine the CO content. In order to obtain sufficient sample volume, 10 ml will be drawn from each sampler that was activated within the same time period. For example, all A samples (4 sampling stations with 2 tubes/ station) will be tested with one Drager tube.

Analytical Procedure For HF. National Institute for Occupational Safety and Health (NIOSH) Analytical Methods, Set L, dated January 1976, will be used to determine hydrogen fluoride. The procedure in this set is numbered S176. This technique is based on the work of Elfers and Decker entitled "Determination of Fluoride in Air and Stack Gas Samples by Use of an Ion Specific Electrode," Analytical Chemistry, 40 (11), pg. 1,658, 1968.

The general procedure is as follows:

1. A known volume of air is drawn through a midget bubbler 10 ml of 0.1 n sodium hydroxide to trap HF.

2. The resulting solution is made up to 25 ml using 0.1 n sodium hydroxide.

3. Twenty-five milliliters of buffer are added.

4. The diluted samples are then analyzed using a fluoride specific ion electrode.

Section 6 - DATA REDUCTION AND ANALYSIS

ENVIRONMENTAL THERMAL DATA

Variations in the ambient air temperature will be presented as indicated in figure 11 for each of the fire monitoring stations. These data will be analyzed in terms of passenger impairment during evacuation within the established 90-second time frame required for aircraft certification.

During the fire modeling experiment(s), the radiation levels developed for each of the radiometers at stations 581 and 695 will be presented as indicated in figure 12. This information will provide baseline data concerning the thermal energy released from burning state-of-the-art materials and the effectiveness of AFFF to control and extinguish a specific fire area. The impact of the heat flux upon passenger safe self-evacuation procedures will be assessed in terms of human tolerance levels previously defined.

The rate at which flames spread over the surface of the side panels after fuel ignition will be determined from the temperature rise of

23 microthermocouples imbeded in the panel surface. From this information, isotherms will be constructed at 1-minute intervals and the data presented as indicated in figure 9.

ANALYSIS OF THE CABIN ATMOSPHERE

The chemical analytical results of the gaseous components within the DC7 cabin during each fire test will be presented as illustrated in figure 13. These data will also be depicted as indicated in figure 14 to detect any trends involving gaseous or thermal stratification of components.

Section 7 - INSTRUMENTATION AND FACILITIES

ELECTRONIC FIRE-MONITORING EQUIPMENT

The instrumentation to be employed for the required parametric measurements will consist of radiometers and thermocouples. Thermal data will be recorded on a Speed Servo 11, two-channel crossover potentiometer analog recorder, model L 1102S, manufactured by the Esterline Angus Instrument Corporation which is equipped with an event marker that may be manually activated when foam is discharged. The heat flux transducers were manufactured by Heat Technology Laboratory Inc., Model GRW 20-64D-SP, and will be mounted as indicated in figure 7. These radiometers measure the radiant heat flux and are rated at 10 $\pm$1.5 millivolts (mV) at 15 Btu/ft^2-sec. The angle of view is 120°. Each unit is provided with a calibration curve by the manufacturer.

PHOTOGRAPHIC TEST PLAN

Each full-scale fire-modeling experiment will be monitored by two 16-mm Lo Cam motion picture instrumentation cameras, both equipped with a 15-mm lens exposing Ektachrome commercial color film, type 7252, at 24 frames per second operated by one photographer each from fixed positions strategically located around the interior paneling. An elapsed-time clock, graduated in minutes and seconds, will be within the line of sight of each camera. The experiments require the instrumentation cameras to start operating 0.5 minutes prior to panel ignition and to continue running till the end of foam agent discharge.

Documentation coverage of the fire tests will be provided from a 16-mm Arriflex motion picture camera equipped with a 12-mm to 120-mm Angenieux zoom lens exposing Ektachrome Commercial color film, type 7252, at 24 frames per second. This camera will be operated by one photographer from various positions around the fire test bed selected at his discretion.

One still photographer will shoot a minimum of six different exposures marking critical events before, during, and after each full-scale fire-modeling experiment using a 120-mm Mamiya RB-67 camera equipped with a 90-mm Mamiya/Sekor lens exposing Vari-Color II (VPS) roll film. The exposures will provide a 8- by 10-inch glossy color prints, 2- by 2-inch color slides, and 8- by 10-inch color viewgraphs of each full-scale fire-modeling experiment.

Section 8 - COORDINATION AND AREAS OF RESPONSIBILITY

The principal cost centers interfacing this project are the Photographic Laboratory, ANA-63 and the Fire/Crash Rescue, ANA-620B. Additional support will be obtained from the Supporting Services Branch, ANA-53, Reports Processing Section, ANA-63C, and the Fire Safety Branch, ANA-350.

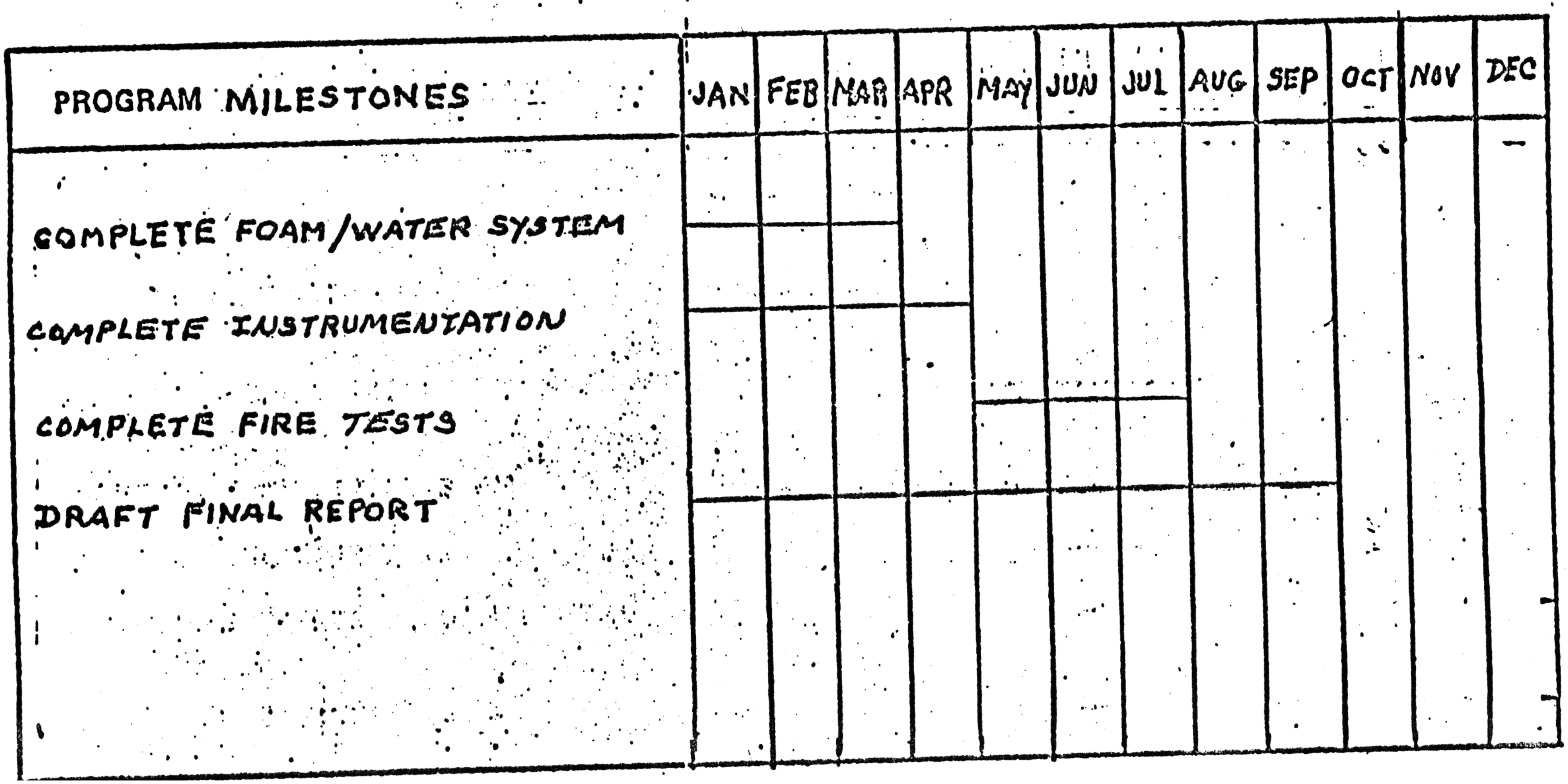
The photographic section will provide instrumentation/documentary motion picture coverage as well as still and time lapse photographs of each test conducted in the DC7 aircraft.

The NAFEC CFR services will provide and activate the foam-water solution required for extinguishing the internal cabin fires by means of the onboard sprinkler system through a quick disconnect coupling in the side of the DC7 fuselage. They will also provide backup support in the unlikely event of a runaway fire developing in the aircraft cabin.

Additional support of the effort is being provided through a contract with the Atlantic Research Corporation (reference 5) to conduct an analysis of the toxic gaseous components of the cabin atmosphere during each fire test.

CRASH FIRE RESCUE

PROJECT SCHEDULE



REFERENCES

1. Hasbrook, H. A., Garner, J. D., and Snow, C. C., Evacuation Pattern Analysis of a Survivable Commercial Aircraft Crash, Federal Aviation Agency, Oklahoma City, Oklahoma, FAA Report 62-9, May 1962.

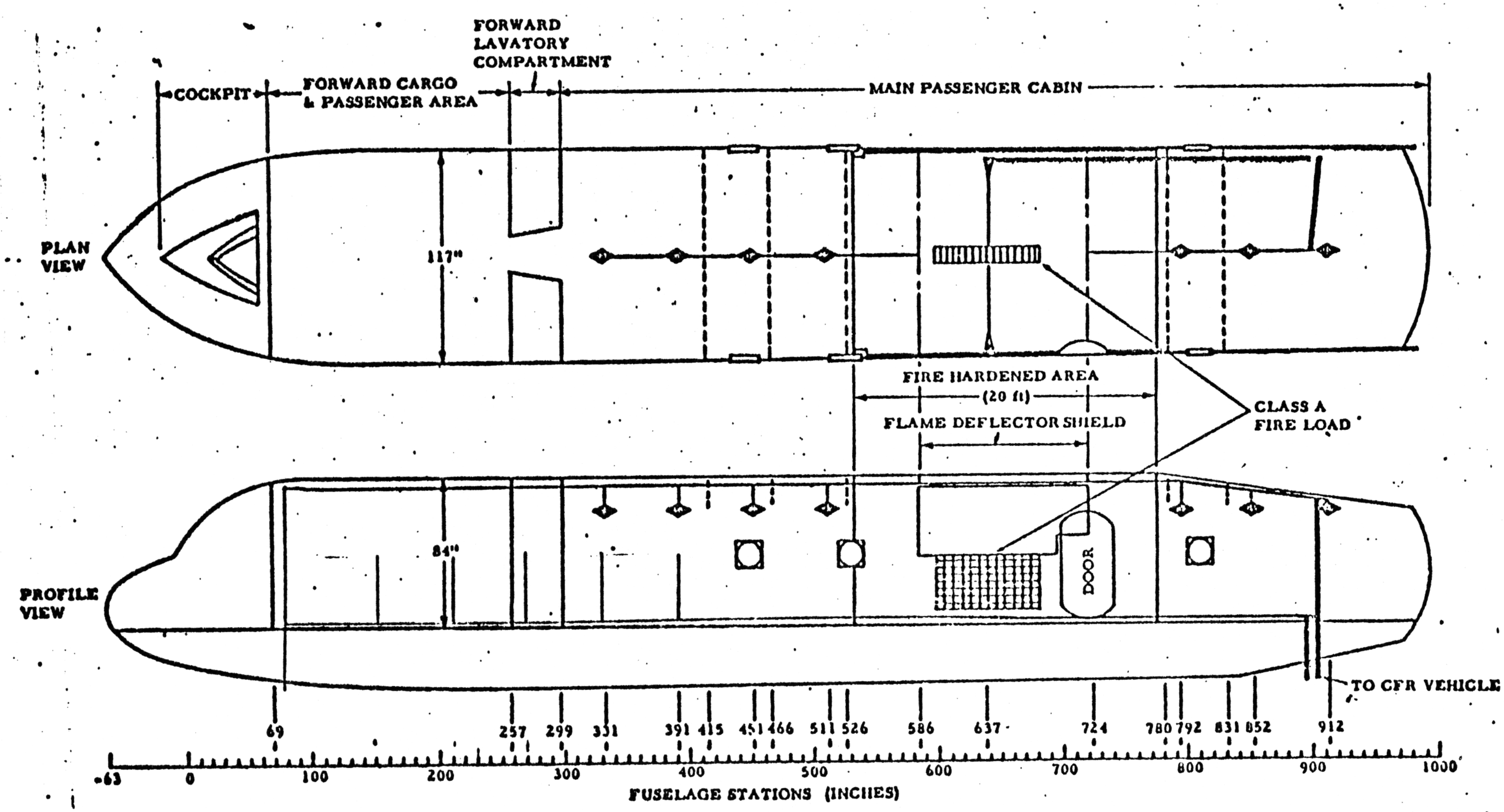
2. Geyer, G. B., Effect of Ground Crash Fire on Aircraft Integrity, FAA Report No. NA-69-37 (RD-69-46), December 1969.

3. Geyer, G. B., Neri, L. M., and O'Neill, J. H., State-of-the-Art Review of Ongoing Work and Developments in Aircraft Cabin Fire Safety and the Crash-Fire-Rescue Services, June 17, 1976.

4. B & W Kaowool Ceramic Fiber, Babcock & Wilson

5. Atlantic Research Corporation, 5390 Cherokee Ave., Alexandria, Virginia 22314.

6. Lucha, G. V., Robertson, M. A., and Schooley, F. A., An Analysis of Aircraft Accidents Involving Fires, NASA CR 137690, Stanford Research Institute, Menlo Park, California.



ONBOARD AFFF OVERHEAD SPRINKLERS (7 each)		AFFF FOAM WATER NOZZLES (2 each)		FLASH FIRE BARRIERS (7 each)	
FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)	FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)	FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
331	72	637	44	415	75
391	72	637	44	466	75
451	72			526	75
511	72			586	80
792	72			724	80
852	72			780	75
912	72			831	75

FIGURE 1 DC7 AIRCRAFT CABIN ANCILLARY FIRE PROTECTION SYSTEM

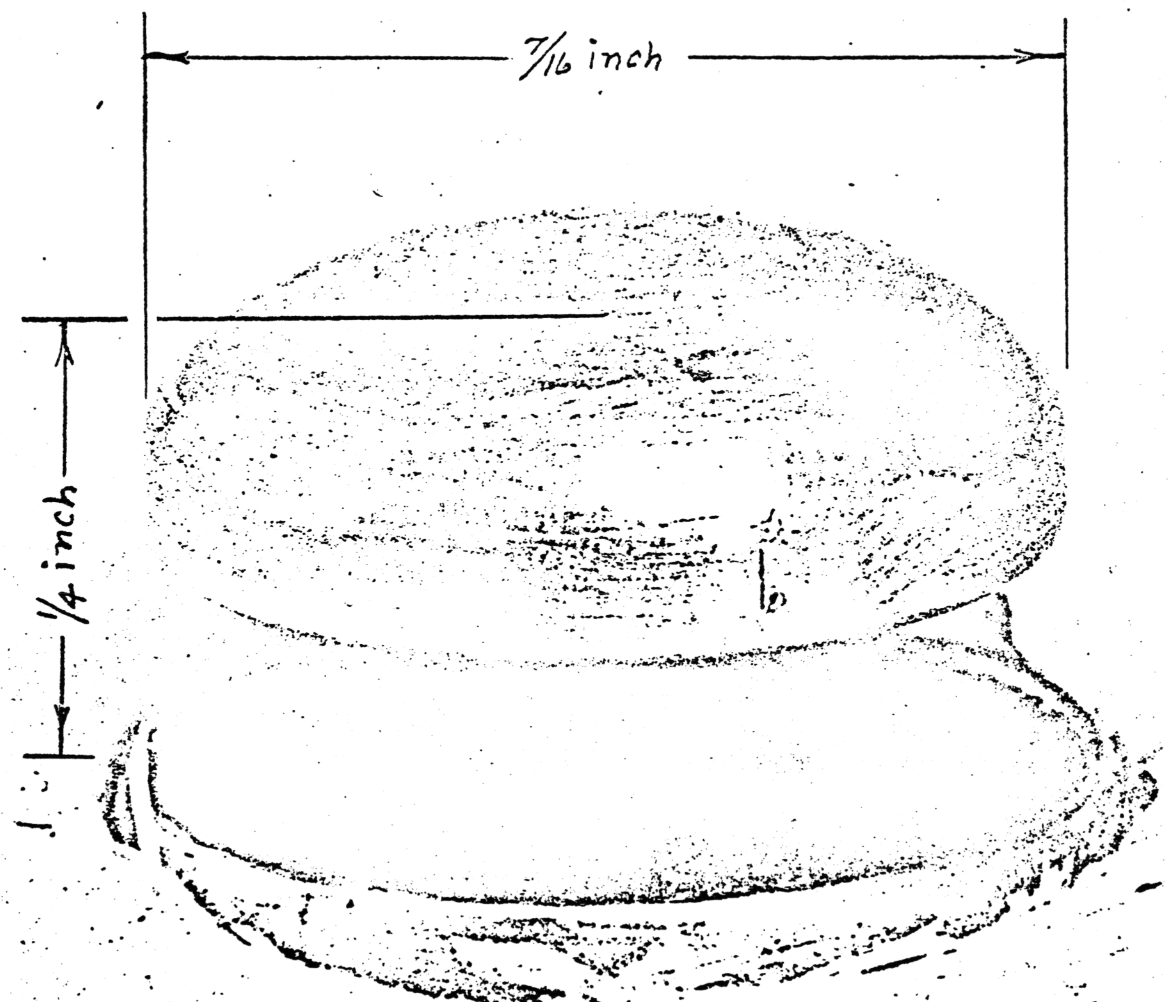


FIGURE 2. FLUSH-MOUNTED 360° FOAM/WATER SPRINKLER NOZZLE

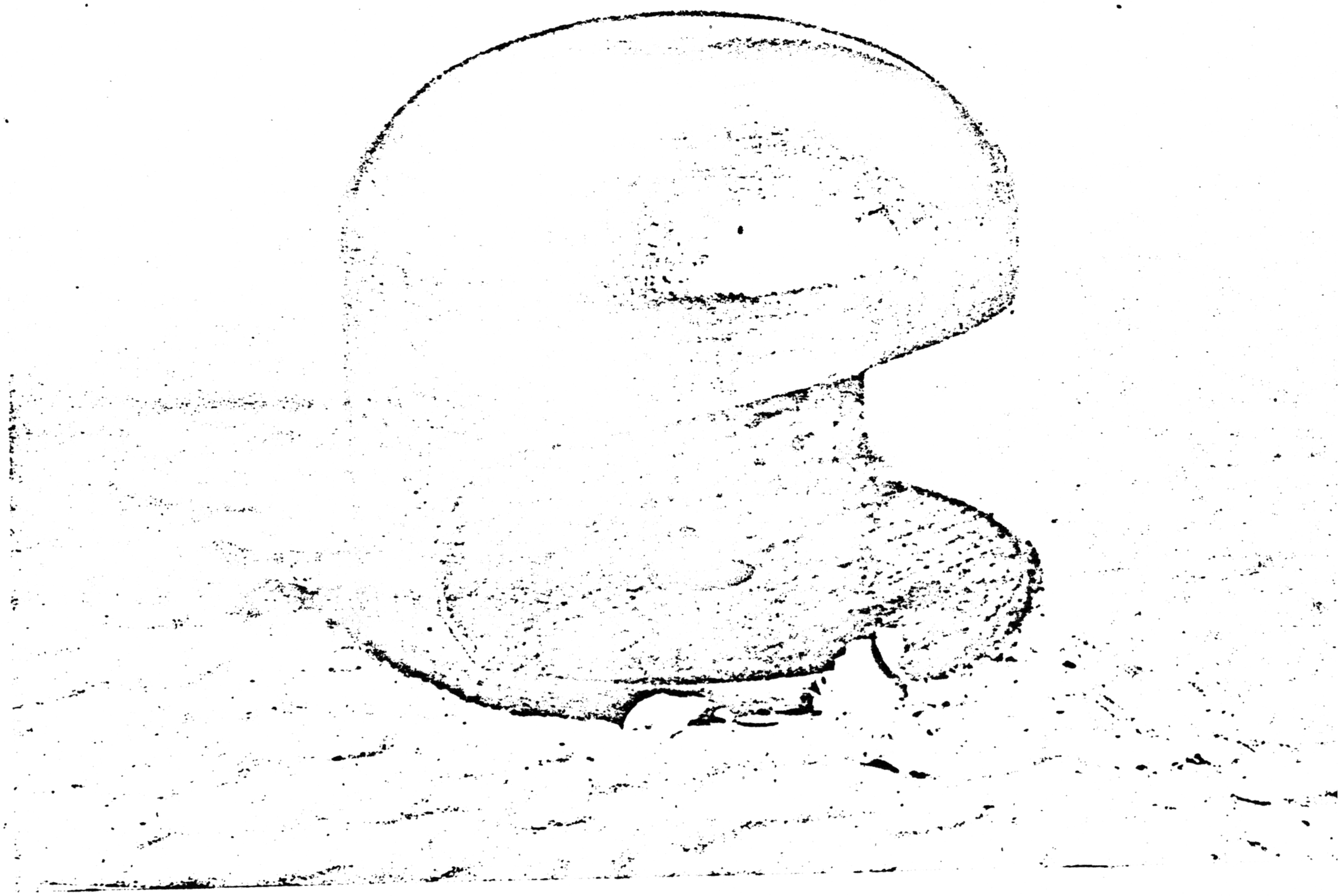


FIGURE 3. FLUSH-MOUNTED 180° FOAM/WATER SPRINKLER NOZZLE

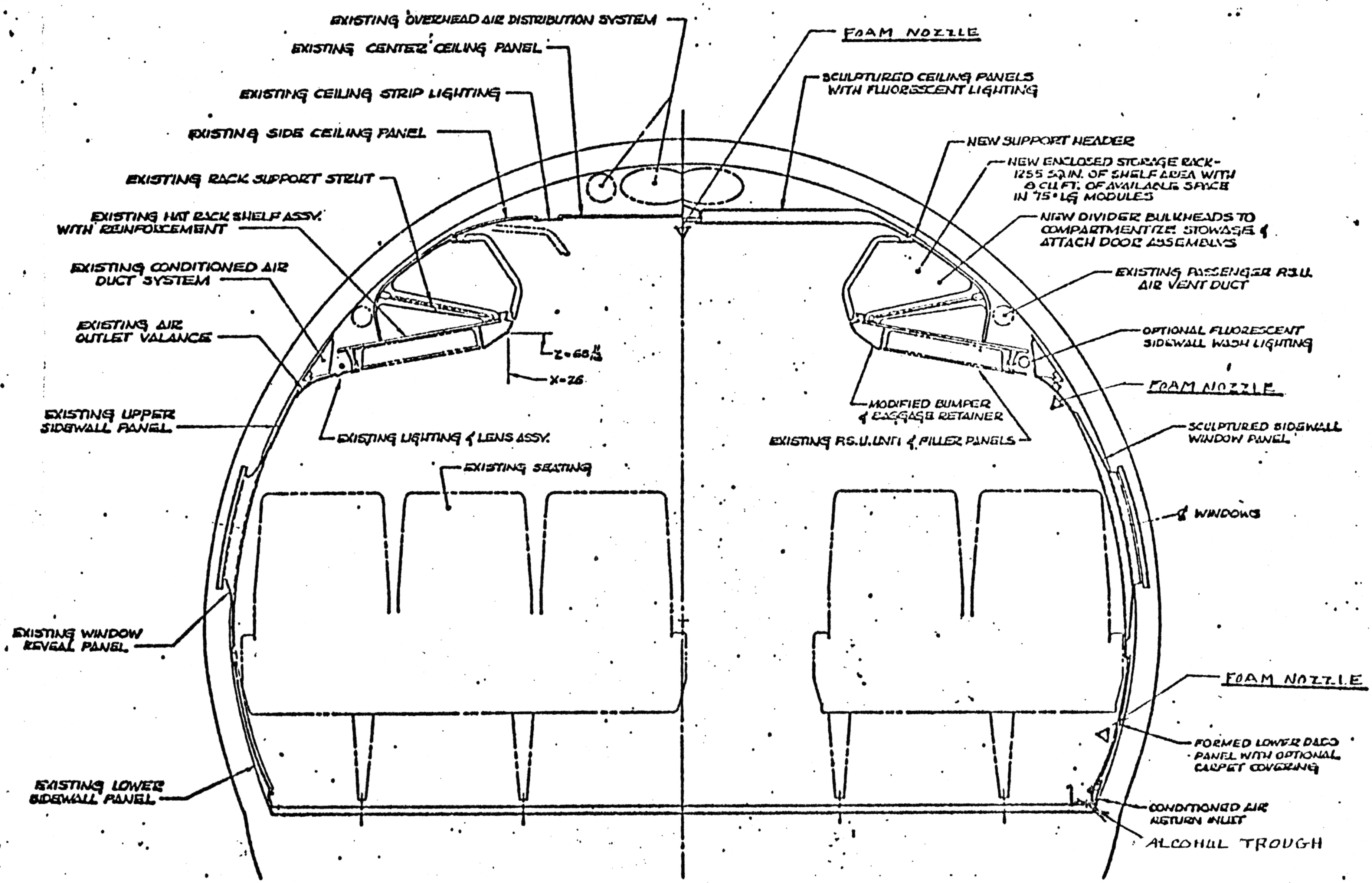


FIGURE 4 RELATIVE POSITIONS OF THE FOAM-WATER SPRINKLER NOZZLES WITHIN THE DC7 AIRCRAFT CABIN

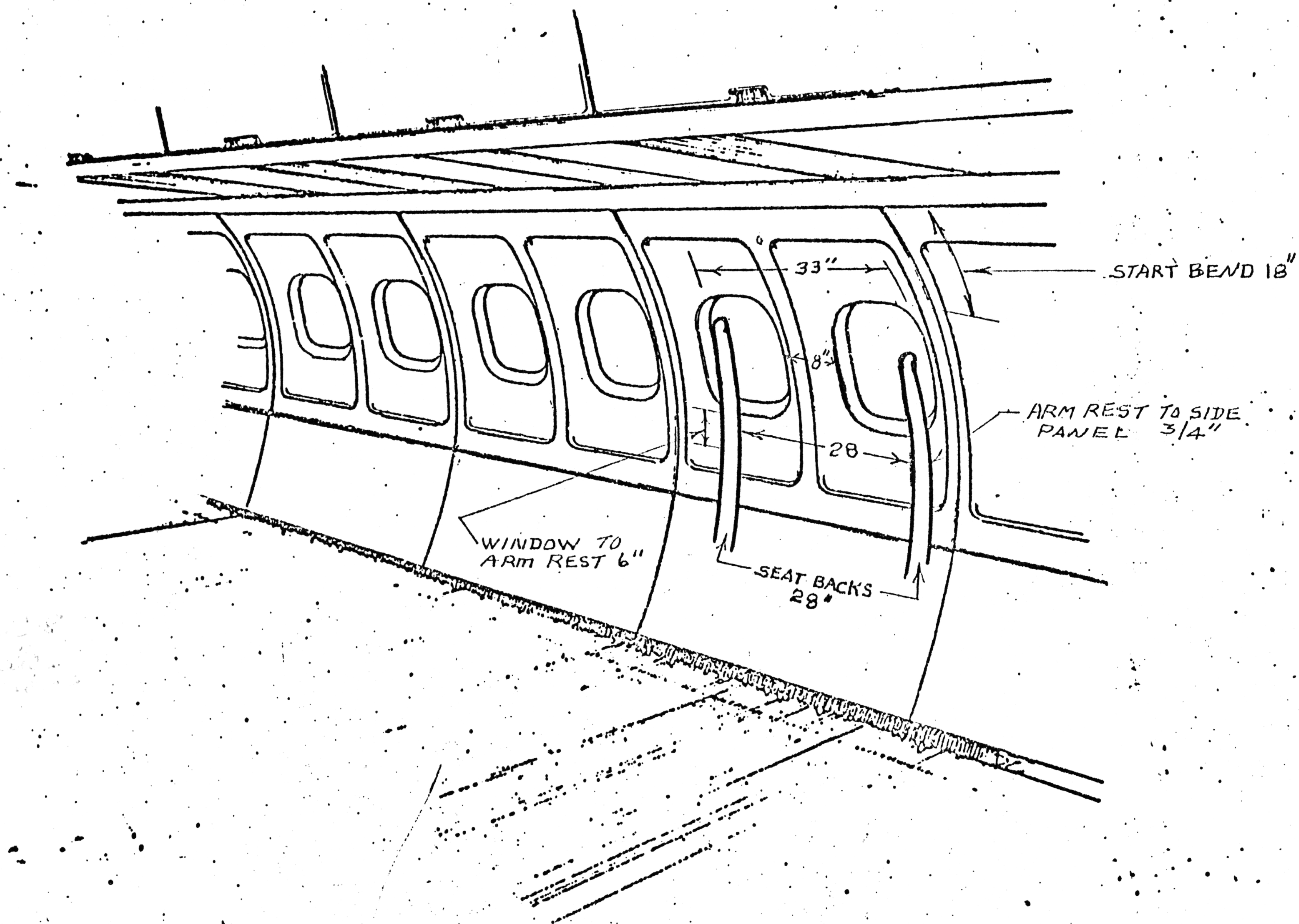


FIGURE 5 APPROXIMATE DIMENSIONS OF THE KIT INSTALLED IN THE DC7 AIRCRAFT

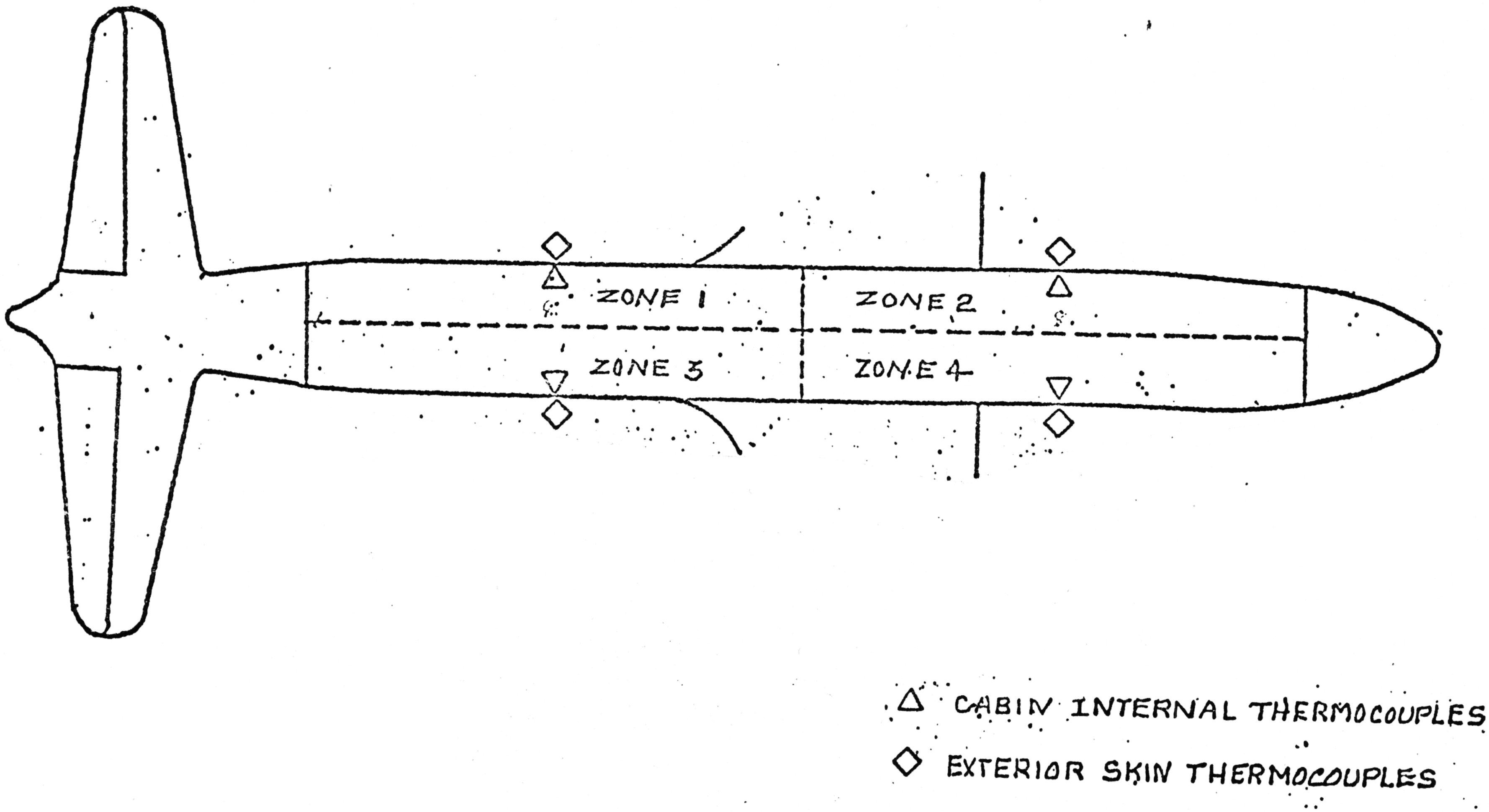
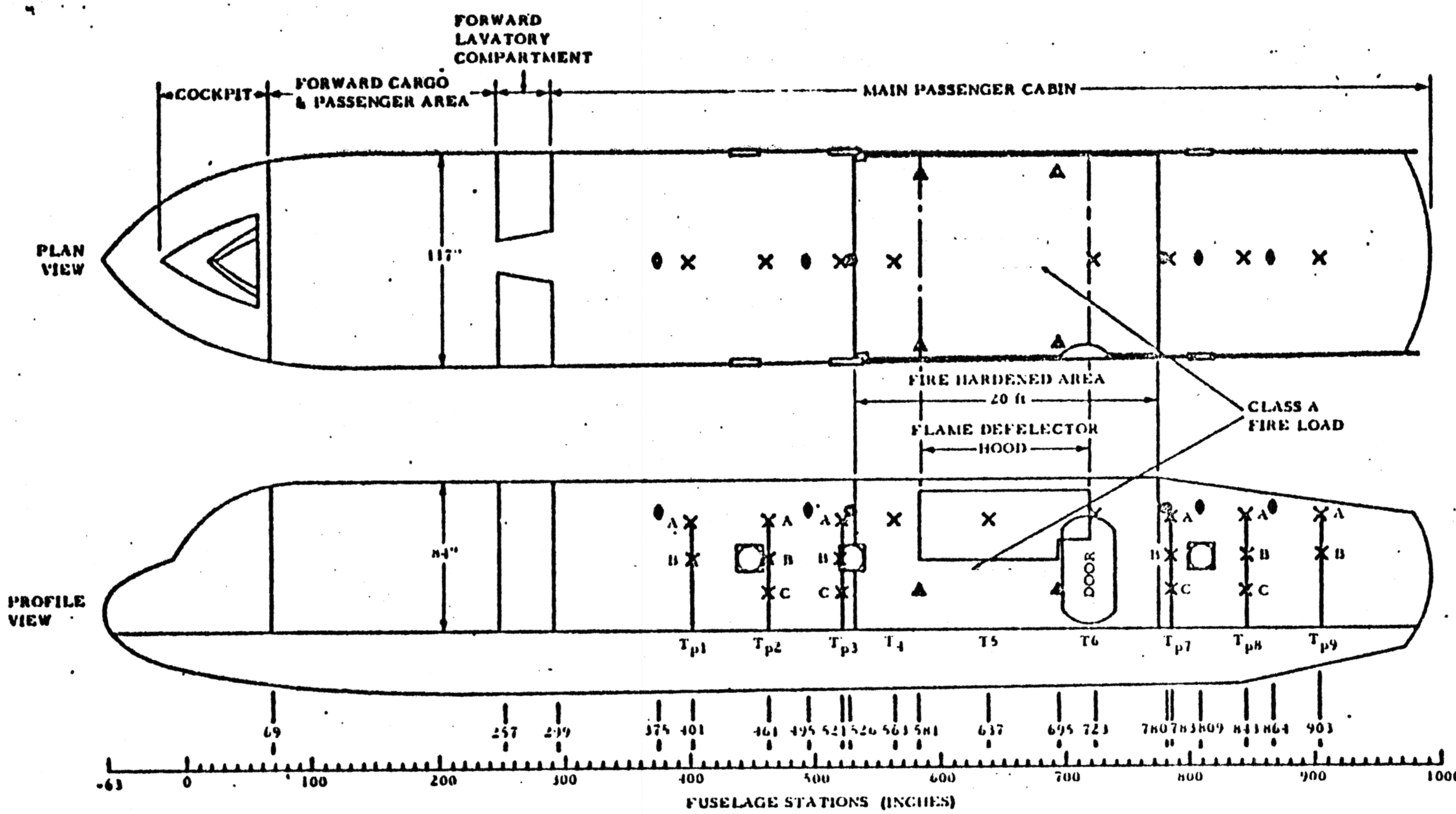


FIGURE 6 POSITION OF THE HEAT SENSORS IN THE DC7 AIRCRAFT FOR LOCALIZING THE DISCHARG OF THE FIRE EXTINGUISHING AGENT



● SMOKE METERS (4 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
375	68
495	68
809	68
864	68

X THERMOCOUPLES (19 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES) A	B	C
401	66	40	
461	66	40	20
521	66	40	20
563	66		
637	66		
723	66		
783	66	40	20
843	66	40	20
903	66	40	

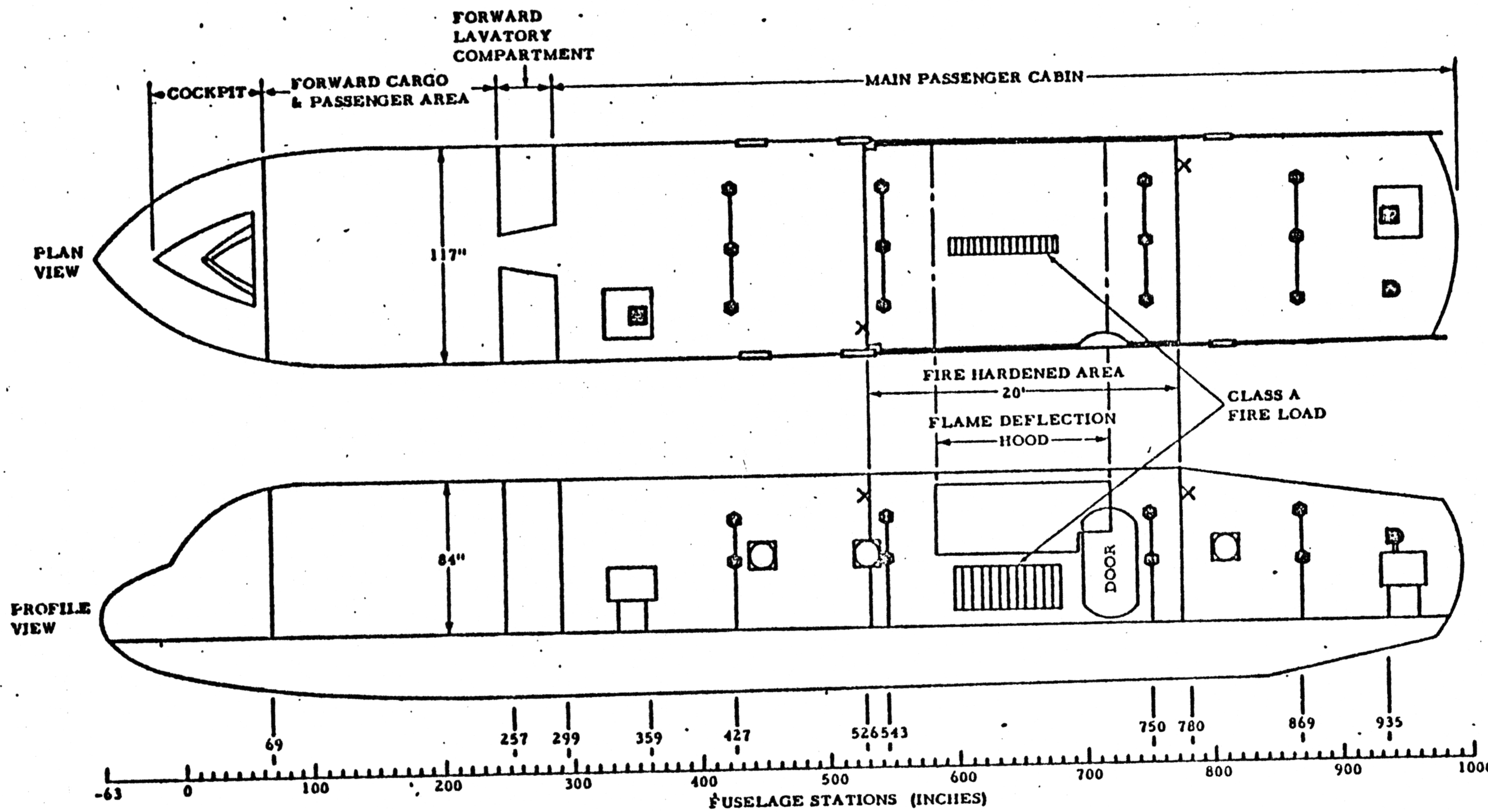
▲ RADIOMETERS (4 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
581	25
581	25
695	25
695	25

● CALORIMETERS (2 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
526	67
780	67

FIGURE 7. SMOKE METER AND THERMAL INSTRUMENTATION FUSELAGE STATIONS



INSTRUMENTATION CAMERAS

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
359	30
935	30

VIDEO TAPE CAMERA

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
935	66

X EXIT SIGNS

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
526	74
780	74

CHEMICAL SAMPLER LOCATIONS

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
427	66, 42, 42
543	66, 42, 42
750	66, 42, 42
869	66, 42, 42

NOTE:
EACH CAMERA BOX CONTAINED ONE MOTION PICTURE AND ONE 35mm CAMERA

FIGURE 8. PHOTOGRAPHIC AND CHEMICAL SAMPLING EQUIPMENT FUSELAGE STATIONS

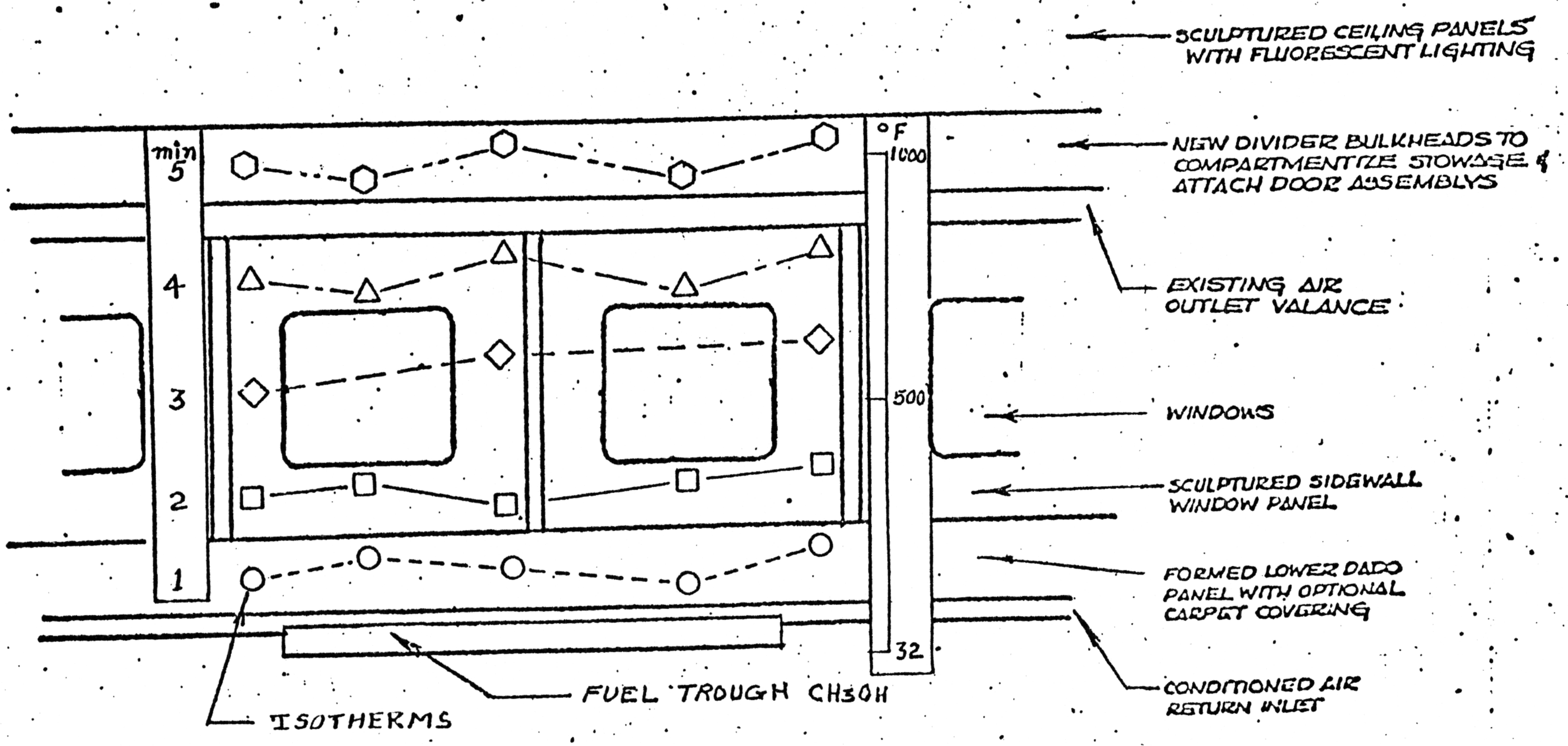


FIGURE 9 SEMI-MICRO THERMALCOUPLE LOCATIONS ILLUSTRATING POSSIBLE ISOTHERMS AT ONE MINUTE INTERVALS AFTER FUEL IGNITION

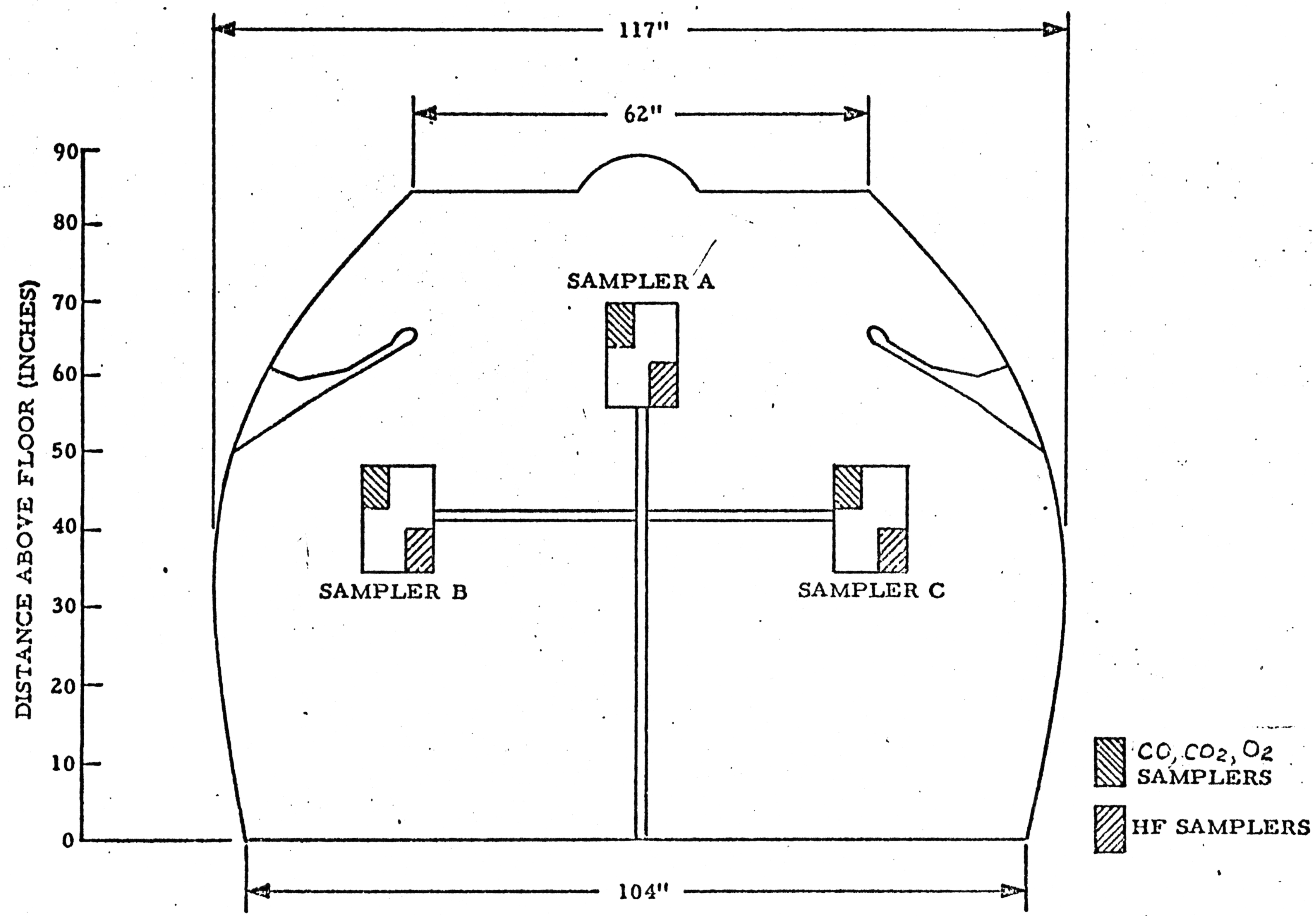


FIGURE 10. GAS SAMPLER LOCATIONS VIEWED FROM THE DC7 COCKPIT

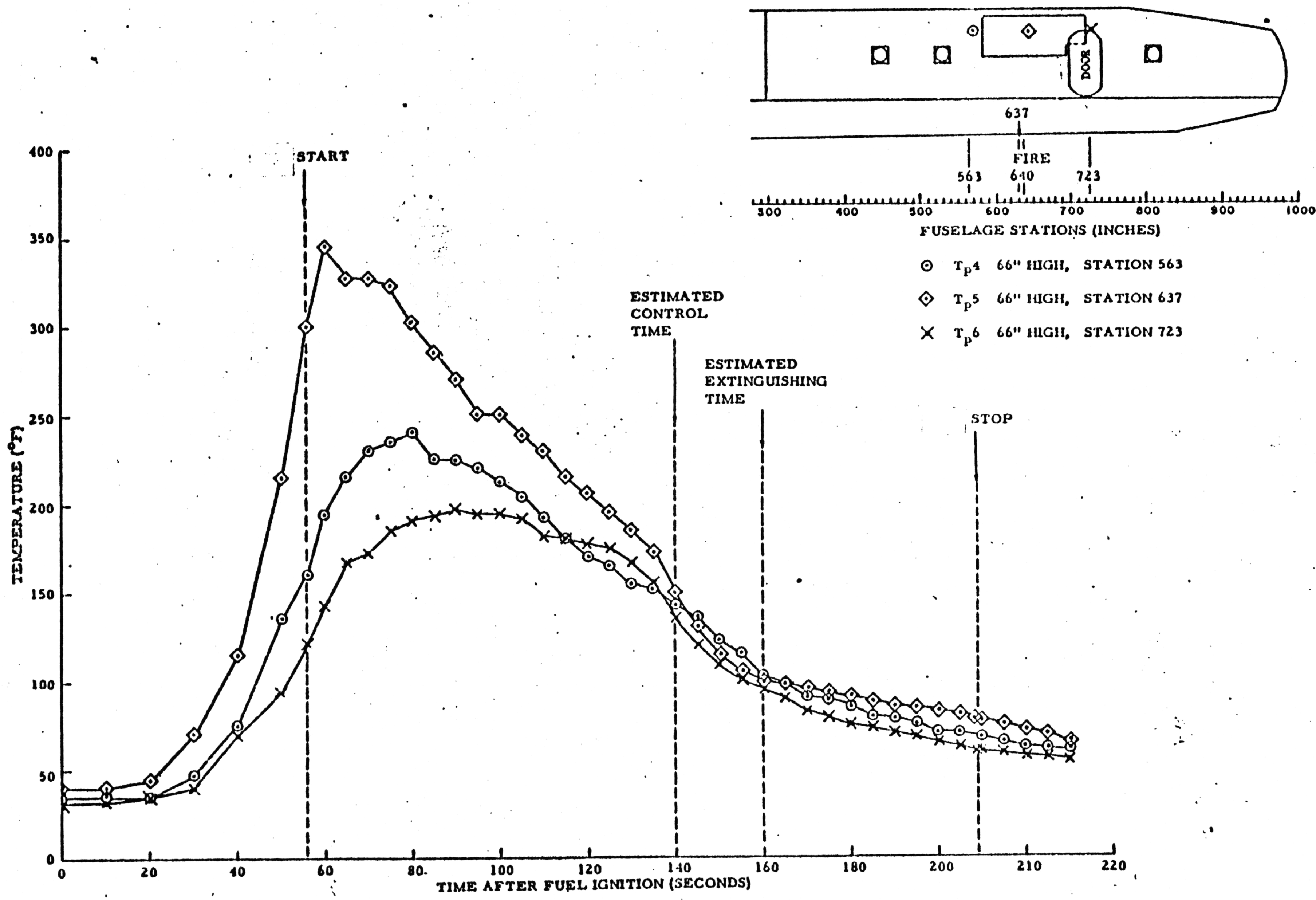


FIGURE 11 TEST 1 —AMBIENT AIR TEMPERATURES WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

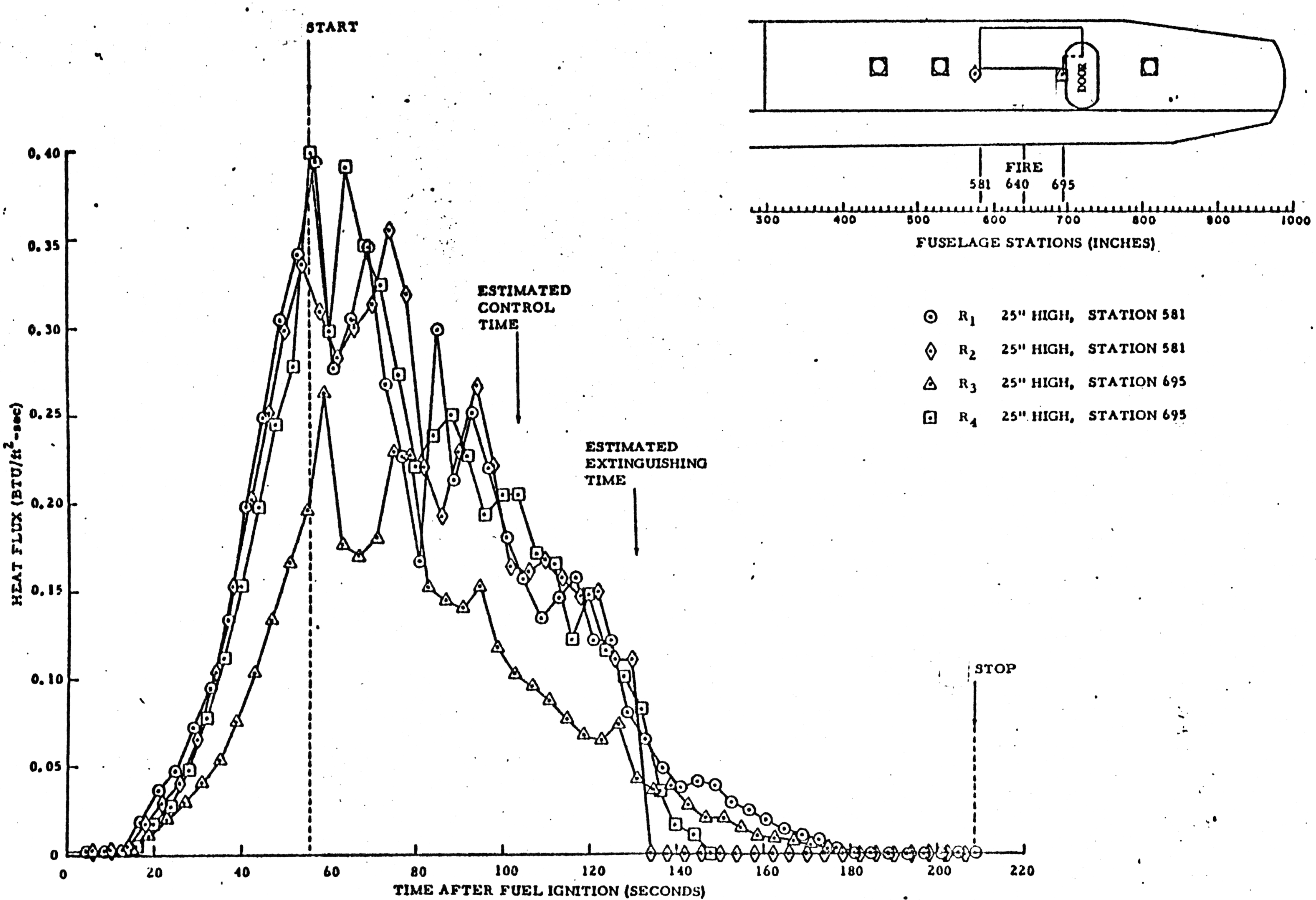


FIGURE 12 TEST 1—THERMAL RADIATION LEVELS WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

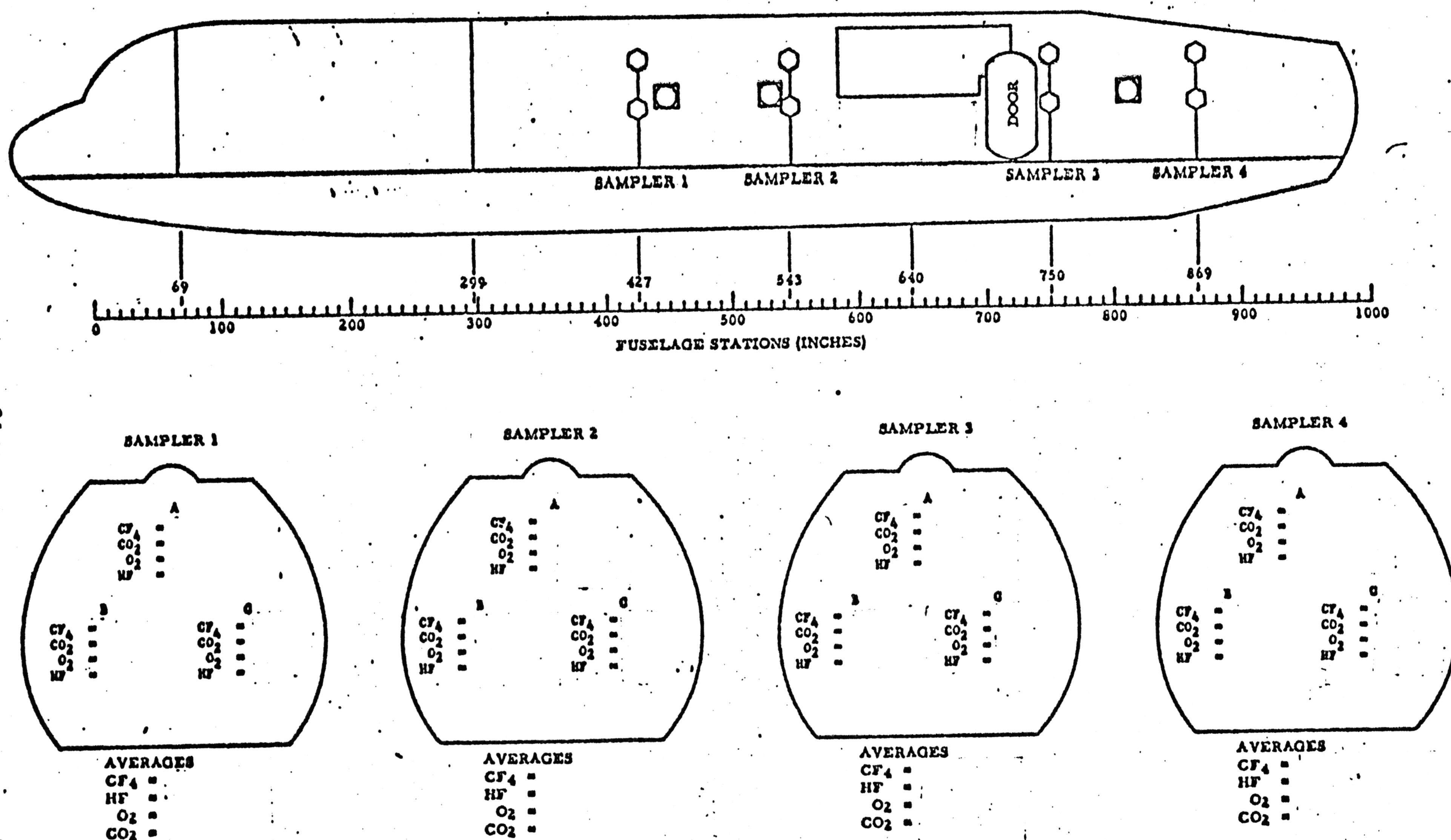


FIGURE 13 TEST 1 -COMPOSITION OF THE DC7 CABIN ATMOSPHERE (CLASS A FIRE)

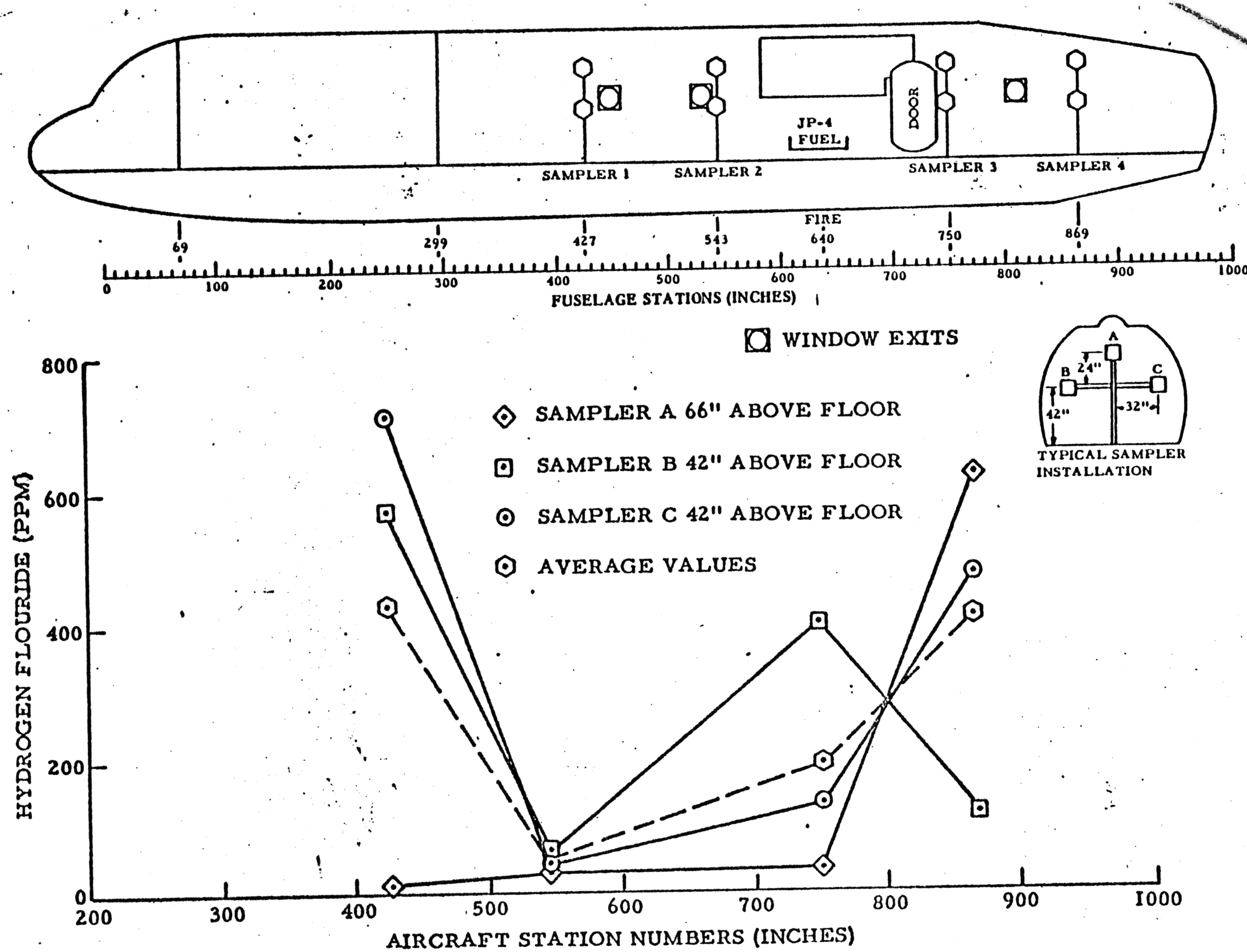


FIGURE 14. TEST 1.—HYDROGEN FLUORIDE CONCENTRATIONS AT FOUR SAMPLER LOCATIONS

APPENDIX A

ECONOMIC IMPACT OF FIRE SAFETY CONCEPTS

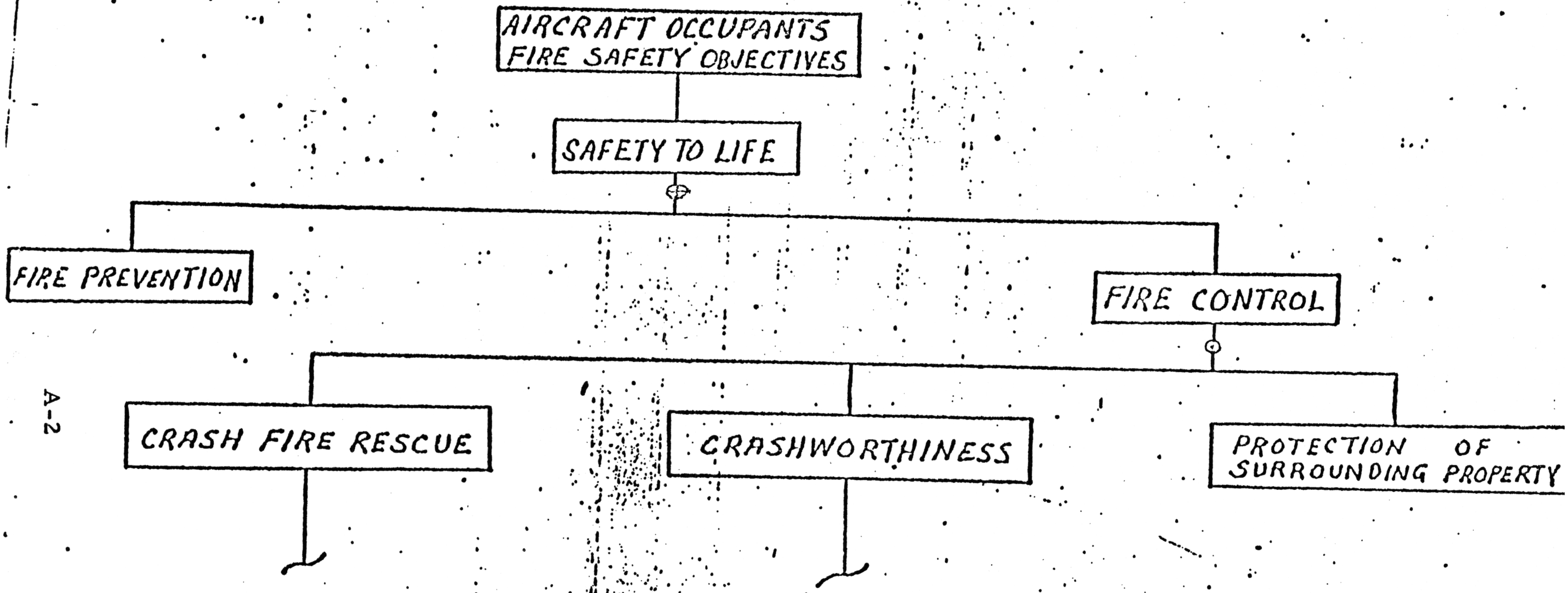
The interface between aircraft crashworthiness and the crash-fire-rescue mission is difficult to define effectively in terms of improved safety. The problem of choosing the best level of fire protection for aircraft occupants and reducing the loss of property is foremost to effective improvements planning. Whatever the advances in basic fire technology may be, one question remains; how much fire protection is enough. Increased fire protection is always desirable from the standpoint of protecting lives and minimizing property damage. However, very large capital investments may be required initially as well as substantial annual operating costs. Accordingly, there is conceptually a tradeoff between the cost of improved protection and the actual value of the protection realized.

The determination of the best level of fire protection is conceptually simple; money would be spent on additional fire protection until the additional cost of more protection is just greater than the value of the extra protection received. However, in practice, this criteria is difficult to apply. It is difficult to evaluate the cost of each of a number of potential improvements in aircraft crashworthiness and the CFR mission when there is so much uncertainty about whether a fire will occur and how large it might be.

It is also difficult to determine precisely the value of preventing a fire. In general, the value of preventing a catastrophic aircraft fire may be greater than the monetary loss when there is a serious disruption of services. Any choice of fire protection involves some risk of fire loss which can occur in a variety of ways ranging from small fires to total losses. The risk of loss of any particular level of severity depends on the level of physical protection.

To establish the relationship between the various parameters associated with aircraft accidents involving fire, a decision analysis procedure was applied for choosing levels of protection that could provide improved levels of protection for aircraft occupants. Collectively, a large number of alternative protection stategies exist. The possible decisions can be conveniently represented in a "decision tree" shown in figure A-1. This is a convenient technique for sytematically organizing complex alternatives.

Figure A-1 shows the two major areas concerned with improving the safety of aircraft occupants in survivable accidents. While fire prevention is the ultimate objective, fire control or fire management is of major concern and will probably reamin so in the foreseeable future.



⊙ "AND" GATE, ALL NECESSARY

⊕ "OR" GATE, ALL ACCEPTABLE BUT NOT NECESSARY

FIGURE A1 FIRE SAFETY OBJECTIVES

BENEFIT/COST CRASHWORTHINESS ANALYSIS

To assess the relative significance of aircraft intrafuselage and systems conceptual improvements, a benefit/cost analysis was conducted. To accomplish this objective in a meaningful manner, it was expedient to assess the benefit to be derived from each potential area of improvement and the cost of effecting the improvement within the entire United States jet aircraft fleet. The classification and type of U. S. air carrier services are indicated in figure A-2. Only those impact survivable accidents involving fire to U. S. certificated route and supplemental air carrier aircraft were included in the benefit/cost analysis.

The most significant areas of concern in the benefit/cost analysis were those involving aircraft occupant fatalities and/or serious injuries and the monetary damage to the aircraft. The additional loss of revenue based on the curtailment of aircraft operations was found to vary widely and difficult to assess; therefore, it was excluded from the calculation of gross loss.

The estimated settlement cost for passenger fatalities and serious injuries as well as the aircraft loss in impact survivable fire related aircraft accidents between 1970 through 1979 is presented in table A-1. The aircraft fatalities, serious injuries, and aircraft damage from 1970 through 1974 were extracted from reference 6. It was then speculated that an equal number of similar aircraft accidents could be anticipated from 1975 through 1979.

The average estimated domestic (non-Warsaw) death recoveries and settlement costs for each passenger prior to 1968 were less than $90, 000; while in the 1970's, the compensation rose to almost $300, 000 per casualty. For passenger accidents involving serious infury, the claims rose to $170, 000 in recent years. The recorded aircraft loss and damage between 1970 through 1974 was $133, 444, 000 which was projected to remain the same from 1975 through 1979. Therefore the total loss from impact survivable fire related accidents from 1970 through 1979 was estimated to be $705, 968, 000 (table A-1). To calculate an approximate relative benefit/cost factor for each basic concept indicated it was necessary to estimate, insofar as possible, the cost of equipping the entire U.S. certificated route and supplemental air carrier turbine-powered fleet comprising approximately 2, 444 aircraft with each of the indicated conceptual improvements in fire safety. These benefit/cost ratios are provided in table A-2 and presented graphically in figure A-2. These data are necessarily very crude since the majority of the concepts presented are still in the experimental or formative stages while others have been calculated solely on a theoretical basis.

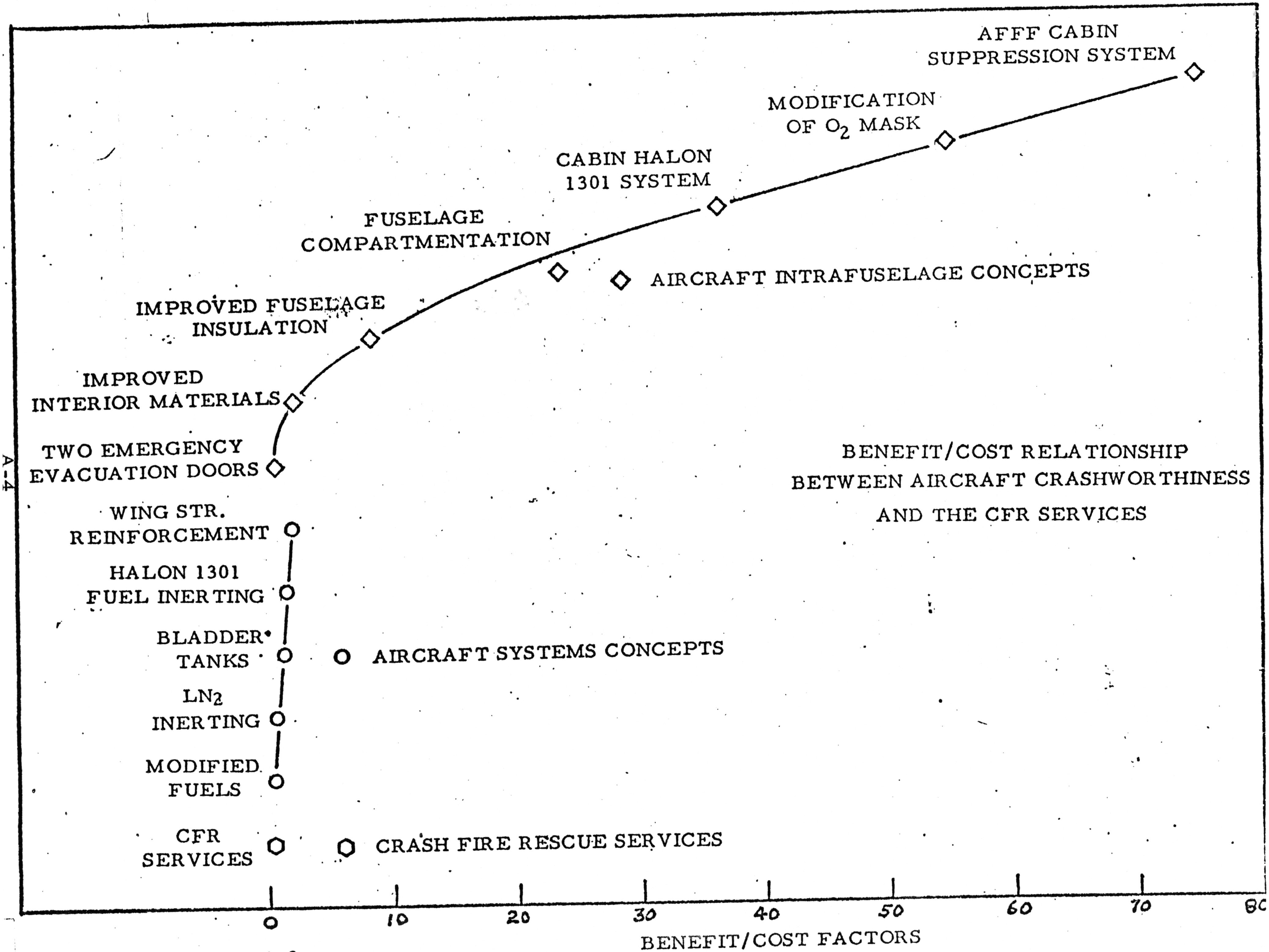

AFFF CABIN SUPPRESSION SYSTEM
MODIFICATION OF O_2 MASK
CABIN HALON 1301 SYSTEM
FUSELAGE COMPARTMENTATION
AIRCRAFT INTRAFUSELAGE CONCEPTS
IMPROVED FUSELAGE INSULATION
IMPROVED INTERIOR MATERIALS
TWO EMERGENCY EVACUATION DOORS
BENEFIT/COST RELATIONSHIP BETWEEN AIRCRAFT CRASHWORTHINESS AND THE CFR SERVICES
WING STR. REINFORCEMENT
HALON 1301 FUEL INERTING
BLADDER TANKS
AIRCRAFT SYSTEMS CONCEPTS
LN_2 INERTING
MODIFIED FUELS
CFR SERVICES
CRASH FIRE RESCUE SERVICES
0
10
20
30
40
50
60
70
80
BENEFIT/COST FACTORS

TABLE A-1 ESTIMATED SETTLEMENT COST FOR PASSENGER FATALITIES AND SERIOUS INJURIES, AND AIRCRAFT LOSS IN IMPACT SURVIVABLE - FIRE RELATED ACCIDENTS 1970 - 1979

Passenger Fatalities	
Average Estimated Settlement Cost/Passenger Fatality $300,000	
Passenger Fatalities (Recorded) 1970 - 74	606
Passenger Fatalities (Projected) 1975 - 79	606
Total Fatalities 1970 - 79	1212
Total Fatalities Settlement Cost 1970 - 79	$363,600,000
Serious Injuries	
Average Estimated Settlement Cost/Passenger Serious Injury $170,000	
Serious Injuries (Recorded) 1970 - 74	222
Serious Injuries (Projected) 1975 - 79	222
Total Serious Injuries 1970 - 79	444
Total Serious Injuries Settlement Cost 1970 - 79	$ 75,480,000
Aircraft Loss	
Aircraft Loss (Recorded) 1970 - 74	$ 133,444,000
Aircraft Loss (Projected) 1975 - 79	$ 133,444,000
TOTAL Aircraft Loss 1970 - 79	$ 266,888,000

Grand Total Loss $ 705,968,000

TABLE A-2. BENEFIT/COST SUMMARY OF CRASHWORTHINESS CONCEPTS

AIRCRAFT			INTRAFUSELAGE CONCEPTS							SYSTEMS CONCEPTS				
Turbine Powered Aircraft Categories	Average Number of Aircraft (1970-1974)	Maximum Average Number of Seats (1970-1974)	Two Additional Emergency Evacuation Doors ($)	Compartmentation Concept Two Per Aircraft ($)	Improved Thermal Insulation Cost 25% Over Present ($)	Respiratory Device Modified O_2 Mask ($)	Improved Interior Cabin Materials-Cost 25% Over Present ($)	Cabin Fire Suppression System Halon 1301 ($)	Cabin Fire Suppression System AFFF ($)	Fuel Containment Structural Reinforcement ($)	Fuel Containment Bladder Tanks ($)	Fuel Tank Inerting LN_2 ($)	Systems Halon 1301 ($)	Modified Fuels ($)
Four-Engined Turbojet (707/DC8)	302	129,184	208,741,104	9,799,920	27,097,200	2,513,680	103,720,500	6,500,520	3,134,430	NOTE 1	NOTE 2	NOTE 3	166,710,960	NOTE 4
Three-Engined Turbojet (727)	697	111,584	207,254,344	9,033,120	18,784,150	2,231,680	71,094,000	4,955,670	2,415,105				107,909,340	
Twin-Engined Turbojet (BAC-111) (737/DC9/BAC)	541	60,145	160,867,432	5,328,360	16,946,825	1,202,900	51,800,750	3,143,210	1,541,850				70,871,000	
Three-Engined Turbojet Wide-Bodied (DC10/L1011)	81	31,236	24,085,512	1,373,760	4,074,300	624,720	19,017,990	1,167,210	556,470				14,188,770	
Four-Engined Turbojet Wide-Bodied (747)	101	53,400	30,032,552	2,116,960	9,759,125	1,004,000	43,050,750	2,015,960	956,672				40,344,995	
Turboprops	322	17,486	95,747,344	2,241,120	6,858,600	349,720	21,010,500	1,661,520	816,270				30,107,000	
Totals	2444	400,035	726,728,288	29,953,240	83,520,200	8,000,700	314,694,490	19,444,090	9,420,797	353,083,653	571,181,582	1,155,000,000	430,132,225	1,800,600,000
Benefits			439,080,000	705,968,000	705,968,000	439,080,000	705,968,000	705,968,000	705,968,000	705,968,000	705,468,000	705,968,000	705,968,000	705,968,000
Benefit/Cost			0.60	23.6	8.5	54.9	2.2	36.3	74.9	2.0	1.2	0.61	1.6	0.39

Notes: Reference 6

These benefit/cost values do tend, however, to indicate that those concepts associated with the aircraft systems have a lower benefit/cost ratio than those concerned with intrafuselage improvements. However, this trend does not necessarily imply that intrafuselage innovations provide the greater fire safety advantages, since it is evident that if the aircraft fuel spill did not ignite as a result of fuel improvements, the overall aircraft fire hazard would be minimal and preclude the need for most other safety measures even though the benefit/cost ratio is low (0.39).

All of the benefit/cost ratios shown in table A-2 were speculated to derive from the complete protection of both passengers and aircraft from fire damage with the exception of providing two additional evacuation doors and the modification to the oxygen mask. It was assumed that these two safety measures would provide improved fire protection and survival solely for the passengers. Therefore, the benefit/cost ratios calculated for these concepts are based on the death recoveries and settlement costs shown in table A-1.

APPENDIX B

PHYSICAL/CHEMICAL PROPERTIES OF THE CONSTRUCTION MATERIALS EMPLOYED IN THE FABRICATION OF THE DC7 CABIN KIT

The following data are typical for F-6000 LEXAN Sheet (Polycarbonate)

	PROPERTY	VALUE	ASTM TEST
PHYSICAL PROPERTIES	Specific Gravity	1.21	D 792
	Water Absorption, % Equilibrium @ 73°F.	0.25	D 570
	Mold Shrinkage, in./in.	0.005-0.007	D 955
THERMAL PROPERTIES	Heat Deflection Temp., °F.		D 648
	@ 66 PSI	280	
	@ 264 PSI	270	
	Thermal Conductivity Btu/hr/ft^2/°F/in.	1.35	
	Coeff. of Thermal Expansion, in/in/°F.	3.75×10^{-5}	D 696
ELECTRICAL PROPERTIES	Dielectric Strength, v/mil Short time, 1/8"	380	D 149
	Dielectric Constant		D 150
	60 Hz	3.17	
	10^6 Hz	2.96	
	Power Factor		D 150
	60 Hz	0.009	
	10^6 Hz	0.010	
	Volume Resistivity, ohm-cm @ 73°, dry	10^{16}	D 15[illegible]
	Arc Resistance, sec.		D 49[illegible]
	Stainless Steel Electrodes	10	
	Tungsten Electrodes	120	
MECHANICAL PROPERTIES	Tensile Strength, PSI @ Yield	9000	D 63[illegible]
	Elongation, %	95	D 63[illegible]
	Tensile Modulus, PSI	325,000	D 63[illegible]
	Flexural Strength, PSI	13,200	D 79[illegible]
	Flexural Modulus, PSI	325,000	D 79[illegible]
	Compressive Strength, PSI	12,500	D 69[illegible]
	Compressive Modulus, PSI	325,000	D 69[illegible]
	Izod Impact Strength, ft-lbs/in.		D 25[illegible]
	Notched, 1/8" Thick	12.0	
	Unnotched, 1/8" Thick	60	
	Falling Dart Impact Strength ft-lbs, 1/8" Thick, 1/2" radius dart	125	--
	Rockwell Hardness		D 78[illegible]
	R	118	
	Taber Abrasion Resistance, mg. weight loss/100 cycles	10	D 10[illegible]

FLAMMABILITY PROPERTIES

LEXAN F-6000 offers the most advanced flammability technology in polycarbonate sheet. In addition to improved flame resistance, the material gives less smoke emission than previous flame retardant polycarbonate sheet. These results have been substantiated by both small and large scale testing. Information on large scale flammability testing is available upon request.

FLAMMABILITY CLASSIFICATIONS*

LEXAN F-6000 has been evaluated in our laboratories and in independent laboratories. For the flammability tests and classifications, the indicated ratings can be obtained.

FAR 25.853 a

.030" .... Passes
.060" .... Passes
.125" .... Passes
.250" .... Passes

NBS Smoke Density Chamber - D_s @ 4 Minutes

.030" 33
.125" 59

U.L. Bulletin 94

.060" and greater.......... V-O

ASTM D 2863 Oxygen Index....... 35

*Results from small scale flammability tests are not intended to reflect hazards presented by this or any other material under actual fire conditions.