FS50041

THE CLEVELAND AIRCRAFT FIRE TESTS

July 24 and 25, 1968

by

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SUMMARY

In Phase I of the Cleveland Fire Tests, June 30 and July 1, 1966, a control burn of an aircraft was done to determine the free burn characteristics of an average aircraft cabin interior. Full instrumentation and gas analysis was accomplished to give baseline data for comparison with future tests.

Also, in Phase I, a second aircraft burn was accomplished to determine whether high expansion foam could be used successfully to extend survival time in an aircraft cabin beyond previously known limits. This test was not successful since it was determined that ingestion of air contaminated with products of combustion/pyrolysis into the foam generator prevented formation of the foam. This has been further documented by research done by Williams and reported in Fire Journal (September 1968).

In both of the fire tests of Phase I, it was established beyond a reasonable doubt, that toxic products of combustion were the controlling factor in aircraft cabin fire survivability using presently available and commonly used materials. This is in sharp contrast to the previous theory that high temperature determined the survival limits before lethal concentration of toxic gasses was reached.

The obvious solution to the problem, though not easy to accomplish, was to utilize cabin interior materials which did not produce toxic products in the course of combustion/pyrolysis. An extensive research program sponsored by the Aerospace Industries Association using a full scale cabin mock-up was commenced in 1967 and concluded in 1968. As a result of this program, considerable progress was made in reducing flame spread and resulting toxic gasses.

The objective of Phase II, (July 24 and 25, 1968) of the Cleveland Fire Tests was to determine how far we could progress in reducing fire temperatures and toxic gasses in a so called ultimate cabin with the use of improved cabin finishing materials. Many of the materials are only available in pilot plant quantities and some can even be considered laboratory curiosities.

OBJECTIVE

Phase II of the Cleveland Fire Tests was conducted to determine if survival time in a post crash fire environment could be appreciably extended by the use of materials with improved fire resistant characteristics. A secondary objective was to determine the effect of a "fire barrier" installed between the skin of the aircraft and the occupied portion of the cabin to impede progression of the fire.

It was believed that by using interior furnishings and trim materials with the best fire resistant properties within the state of the art, and which could, with further development, be adapted, the elevation of temperatures and toxicity levels beyond the limit of human survival could be appreciably retarded.

It was also theorized that if a layer of material with exceptional fire resistant properties could be installed just inside the skin of the aircraft, it would act as a barrier to a fire that had already penetrated the outer skin.

As a secondary objective, a fire barrier was installed between the aircraft skin and the normal cabin insulation to determine whether flame penetration of the cabin could be forestalled for a finite period of time after the aircraft skin had failed due to flame exposure.

It is the opinion of the authors that both objectives were met as will be explained later in this paper, however, it must be borne in mind that neither technique is operationally feasible today and considerable more research and engineering must be done before they become a reality.

As in the case of the Phase I report, this paper is intended as a research tool only and cannot be considered as the final answer to the problem.

PROCEDURES

The aircraft was in a simulated all gear up landing configuration with wings level. All openings in the fuselage were closed with the exception of the port half of the cockpit windshield. This was opened to accommodate a Rockwood X-2 foam generator which was installed for the purpose of extinguishing the fire in the cabin at the conclusion of the test.

A pan measuring 3 feet wide, 5 feet long and 11 inches high was placed on the starboard side of the aircraft under the wing. The aft edge of the pan was approximately abeam of the aft cabin bulkhead with the long dimension of the pan against the fuselage. (See Fig. 1)

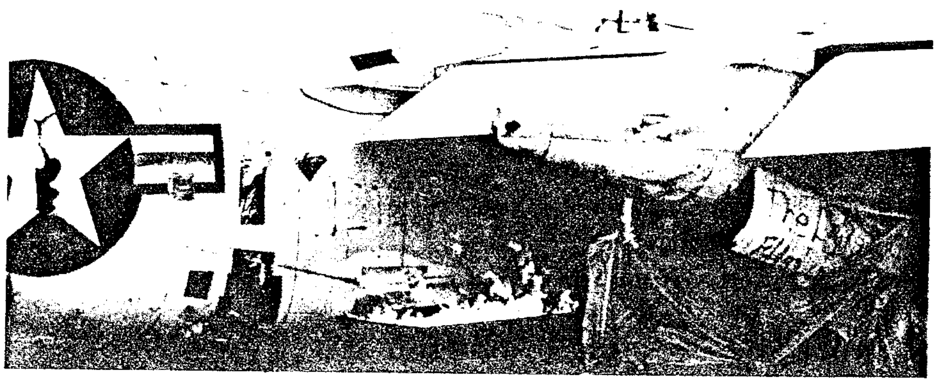


Fig. 1

The pan was fueled with approximately 30 gallons of clean kerosene on a water base and primed with about one pint of gasoline to aid ignition.

MOCK-UP

The aircraft used in Phase II was a North American AJ-1 which is basically the same type as was used in Phase I.

The center section (bomb bay) of the aircraft was fitted out to simulate a passenger cabin of a typical commercial aircraft. The cabin mock-up section measured approximately 5 feet wide, 5-1/2 feet high and 14-1/2 feet long.

The mock-up of the cabin consisted of a "fire barrier" material installed inside the skin of the aircraft extending from floor level to ceiling on the cabin sidewalls. Inside the fire barrier was a layer of insulation consisting of a fiber glass blanket impregnated with a melamine binder and encased in an orcon covering. Inside the insulating layer was a layer of Nomex* honeycomb covered with a sheet of 10 mil Nomex paper.

The port side and starboard side employed two different types of fire barrier materials. The one on the starboard side consisted of a number of layers of a coated, high temperature glass cloth while the port side fire barrier was a layer of modified Nomex paper 30 mils thick.

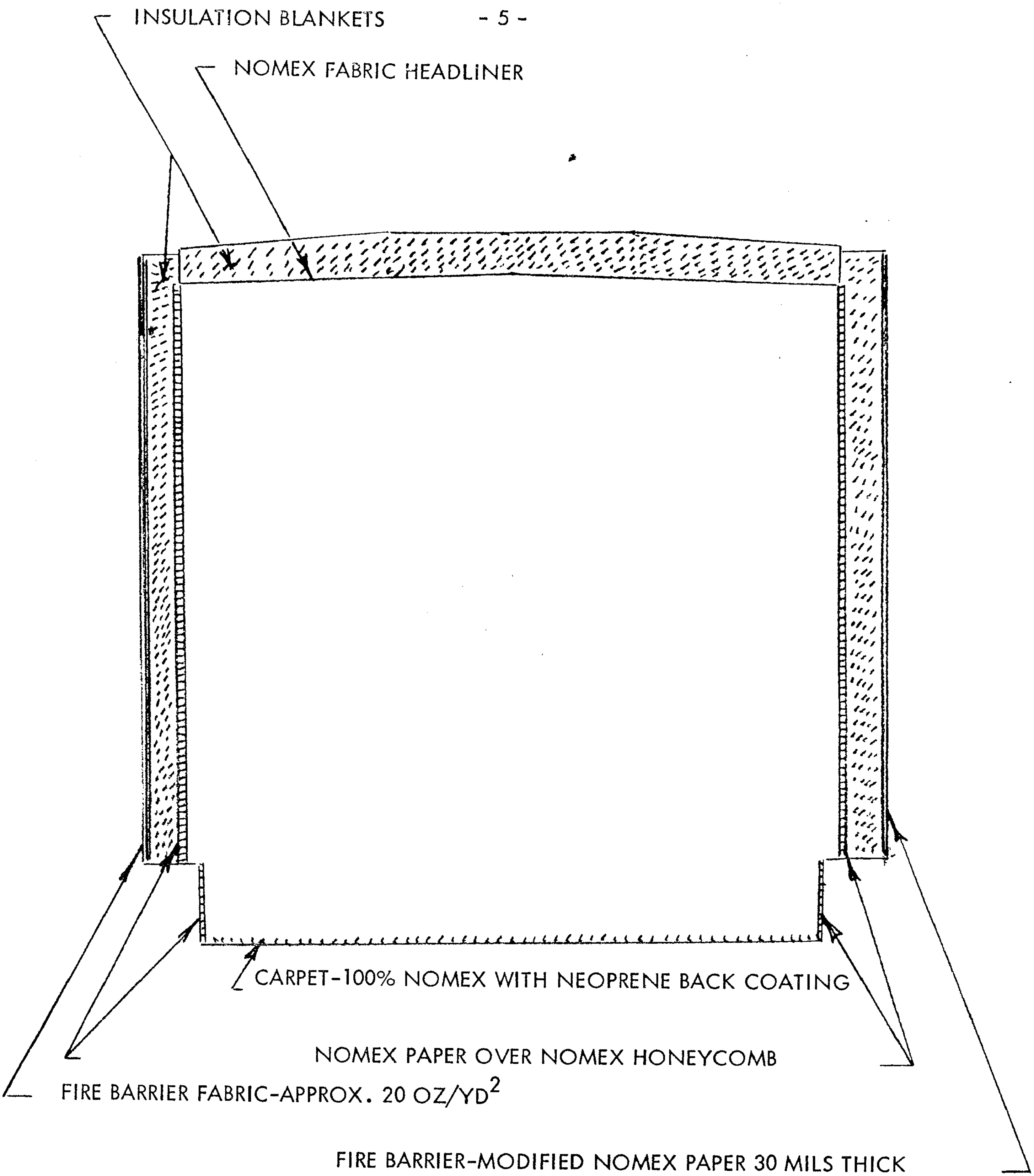
The ceiling was covered with the insulation and a Nomex fabric and the floor with a 100% Nomex carpet with a Neoprene coating on the back.

A total of twelve seats were installed in the cabin. For details, see Figures 2 and 3. For details on cabin construction, see Figures 4 and 5.

INSTRUMENTATION

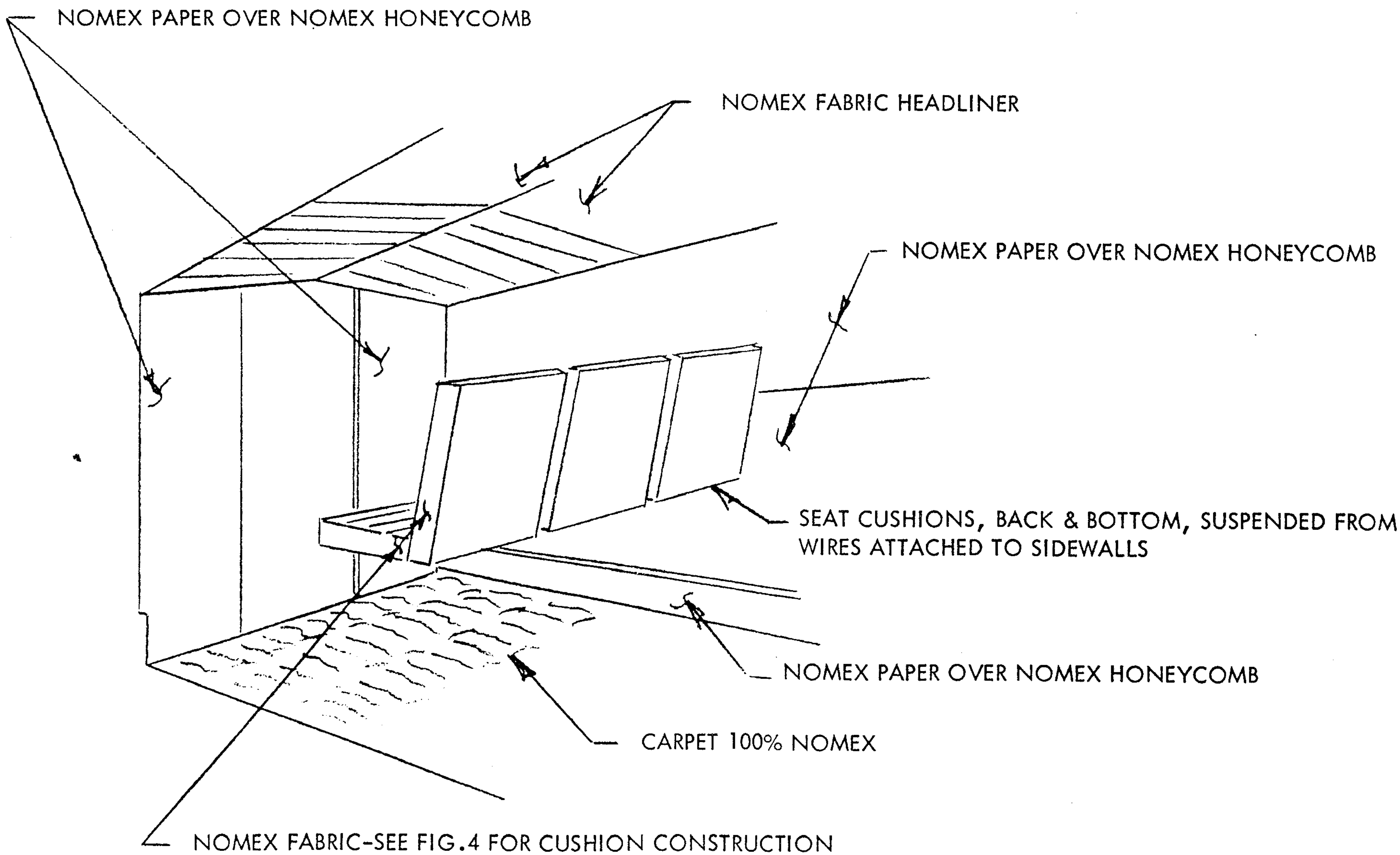
Twelve thermocouples were located in the cabin mock-up section and cockpit of each aircraft. There were located at floor level, seat back height, ceiling level, and at the high point of the aircraft beneath the cockpit canopy. (See Fig. 6) Eight thermocouples had simple metallic tubing shields and four were completely shielded in blackened copper spheres. (See Fig. 7) All thermocouples were connected to Honeywell recorders to provide a constant

*Reg. Tr. Mk. - E.I. DuPont De Nemours Co.



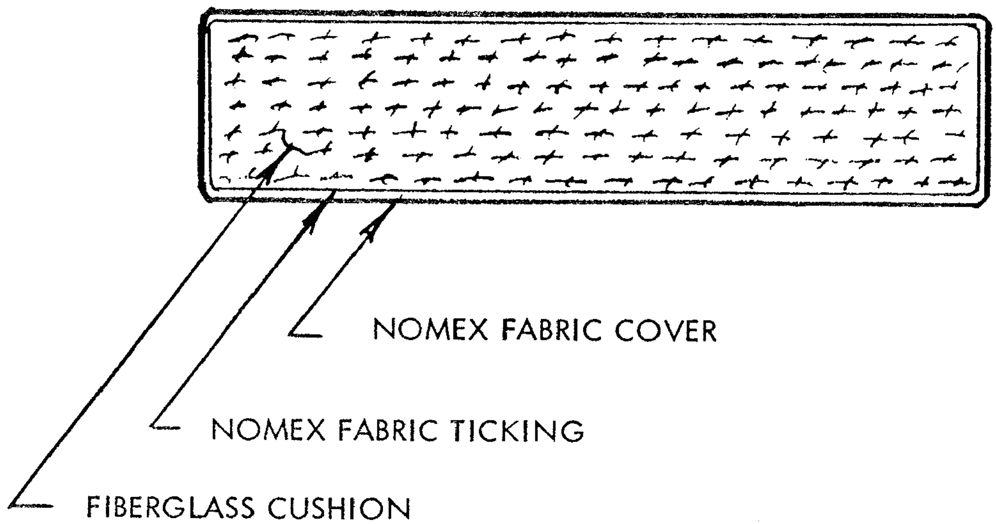
CABIN CROSS SECTION SHOWING
MATERIALS ONLY (NO STRUCTURE)

Fig. 2



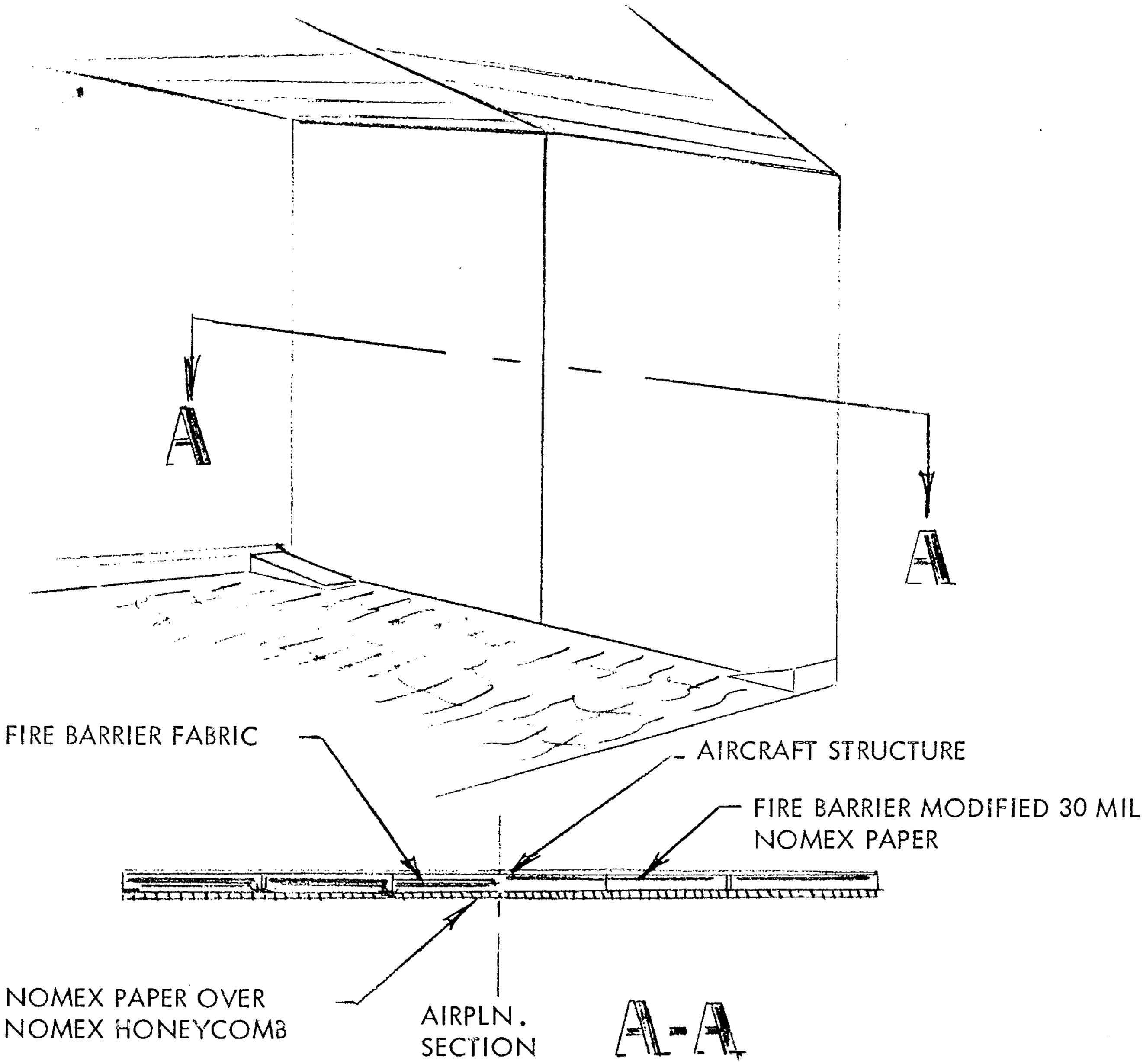
VIEW OF CABIN, RIGHT SIDE, LOOKING FWD. & OUTBOARD
TYPICAL FOR LEFT SIDE

Fig. 3



TYPICAL CROSS SECTION
OF BACK & BOTTOM SEAT CUSHIONS

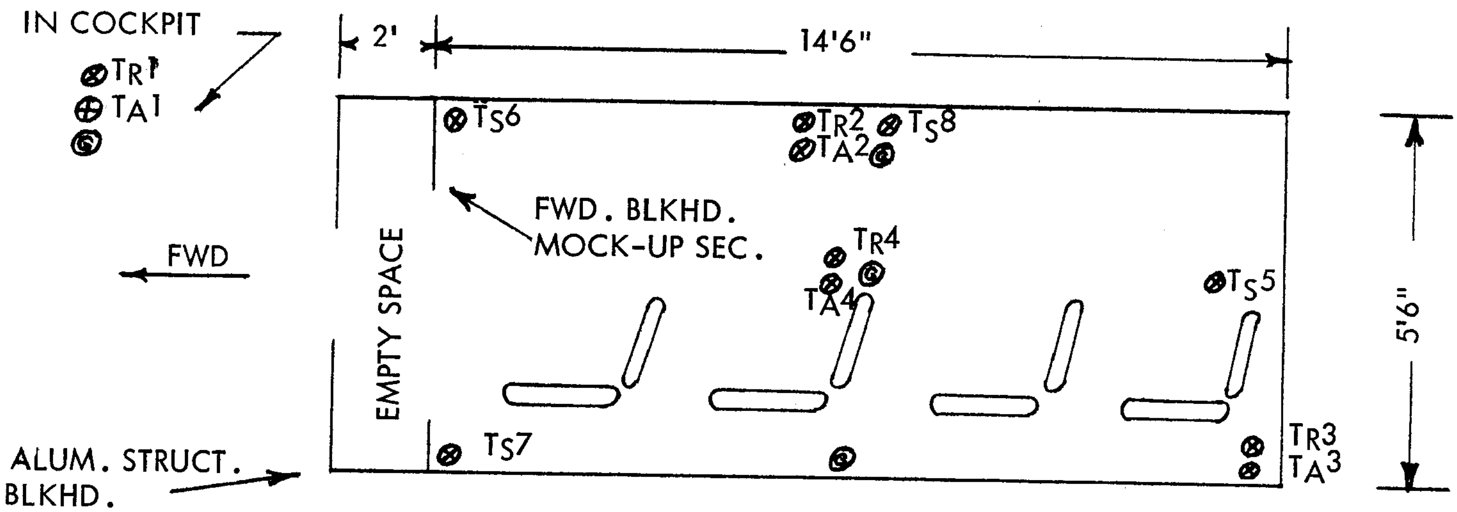
Fig. 4



AFT. CABIN BULKHEAD CONSTRUCTION

Fig. 5

THERMOCOUPLE AND GAS SAMPLE LOCATIONS



NO SCALE

$T_R1 + T_A1$ - COCKPIT PILOTS HEAD.

$T_R2 + T_A2$ - CENTER CABIN, 3" BELOW CEILING, CENTERLINE.

$T_R3 + T_A3$ - REAR OF CABIN, 3" ABOVE FLOOR, PORT SIDE.

$T_R4 + T_A4$ - CENTER CABIN HEAD HIGH SITTING, CENTERLINE.

T_S5 - CENTER SEAT, 4TH ROW, HEAD HIGH SITTING, CENTERLINE.

T_S6 - FWD. BULKHEAD, 6" BELOW CEILING, PORT SIDE 1' INBOARD.

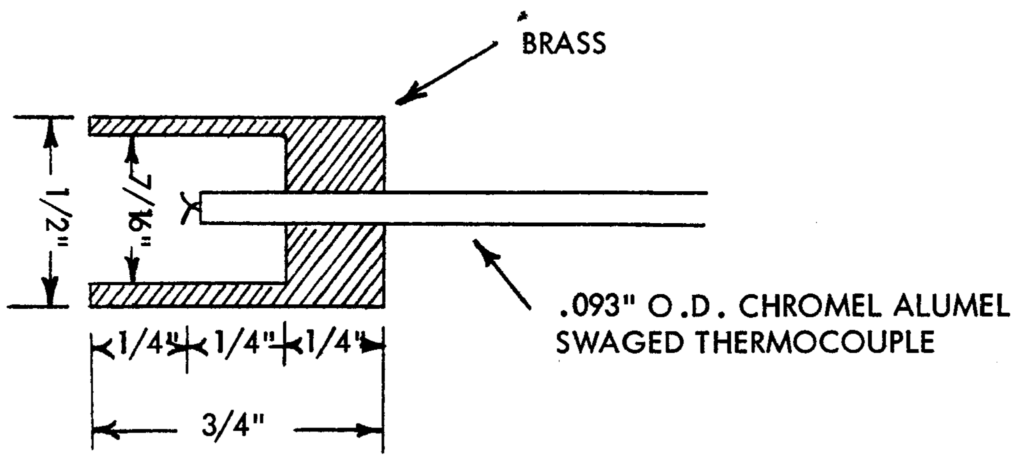
T_S7 - FWD. BULKHEAD, 3" ABOVE FLOOR, PORT SIDE 1' INBOARD.

T_S8 - CENTER CABIN, 2" BELOW CEILING, CENTERLINE.

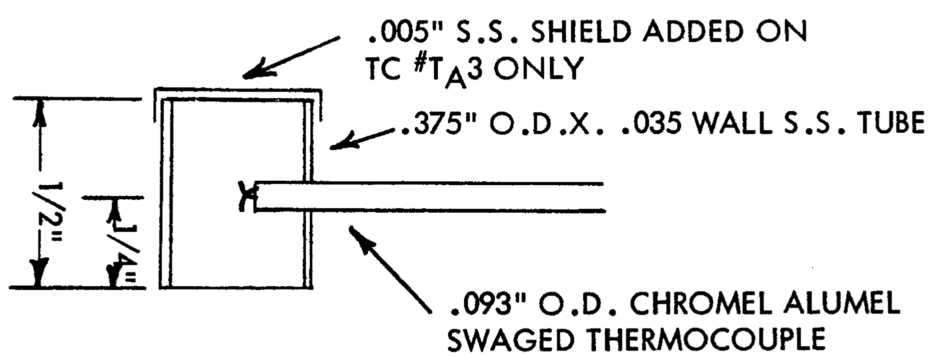
G - GAS SAMPLING POINTS

Fig. 6

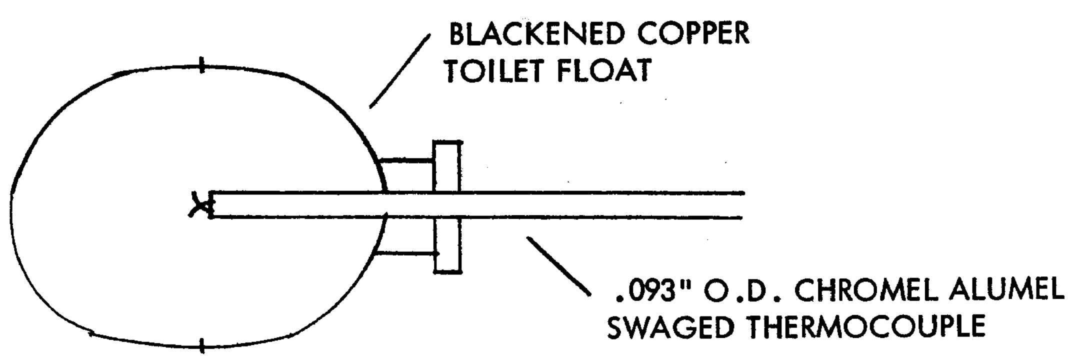
THERMOCOUPLE DETAILS



TYPICAL OF T_S SERIES



TYPICAL OF T_A SERIES



TYPICAL OF T_R SERIES

Fig. 7

temperature record throughout the test period. Six alternating channels were assigned to each thermocouple to provide closely spaced recording points. (See Fig.8)

Fig. 8

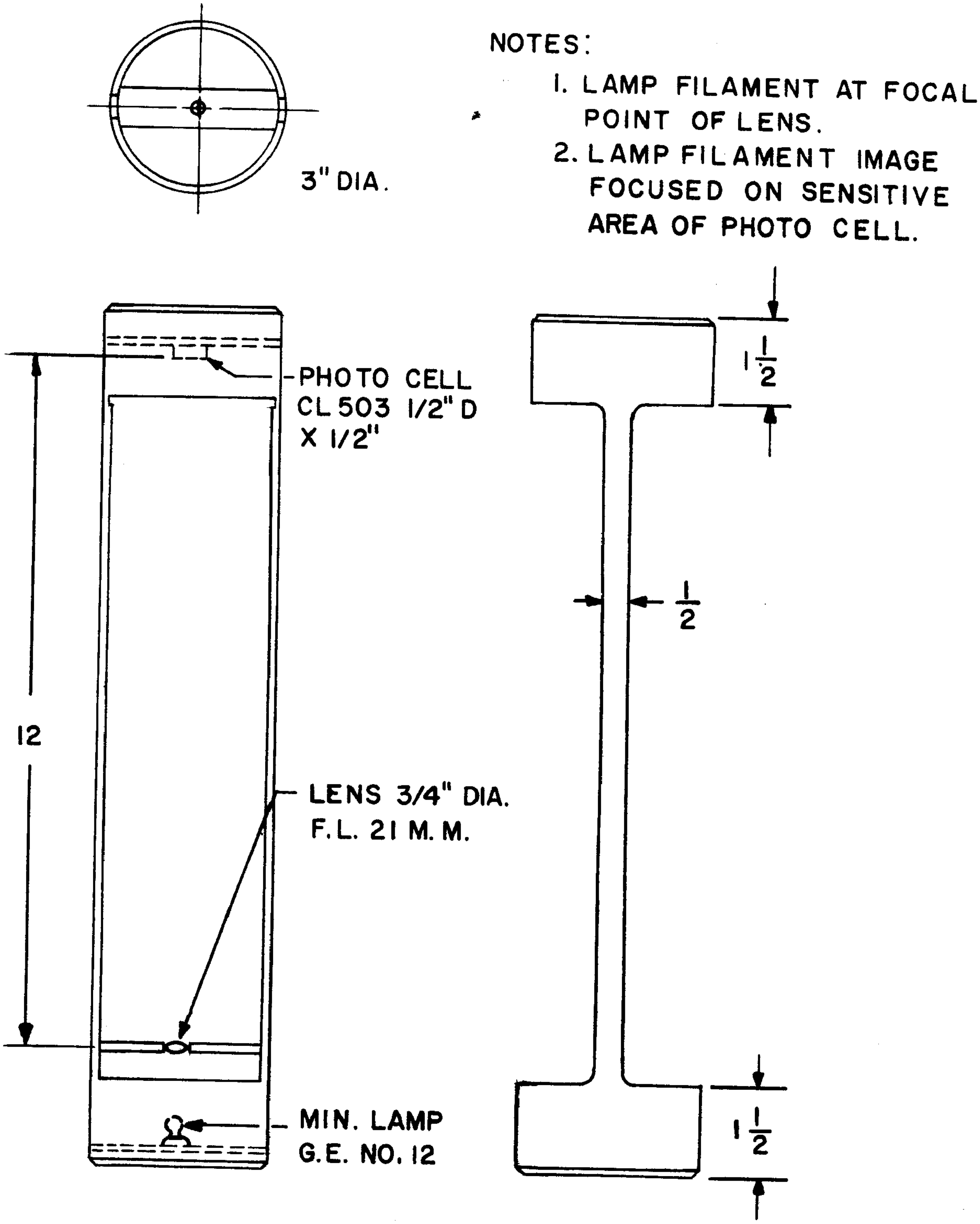
Smoke density was measured in the cabin area as a function of time. Two detectors were used in the aircraft for this purpose. One detector was suspended about six inches from the ceiling, and the other about twenty inches from the ceiling. The suspension point was at the second row of seats, and on the longitudinal centerline.

Each smoke detector consisted of a light source, lens, and photo cell, all mounted in a suitable frame as shown in Figure 9. A shroud was provided at installation to eliminate stray or ambient light from reaching the photo cells, as shown in Figure 10.

Calibration of these devices was accomplished by use of Kodak Wratten Neutral Density Filters in 10% increments, thus providing attenuation, or opacity, from zero to 90%. Plots of the calibration runs for each of the two detectors are shown in Appendix A.

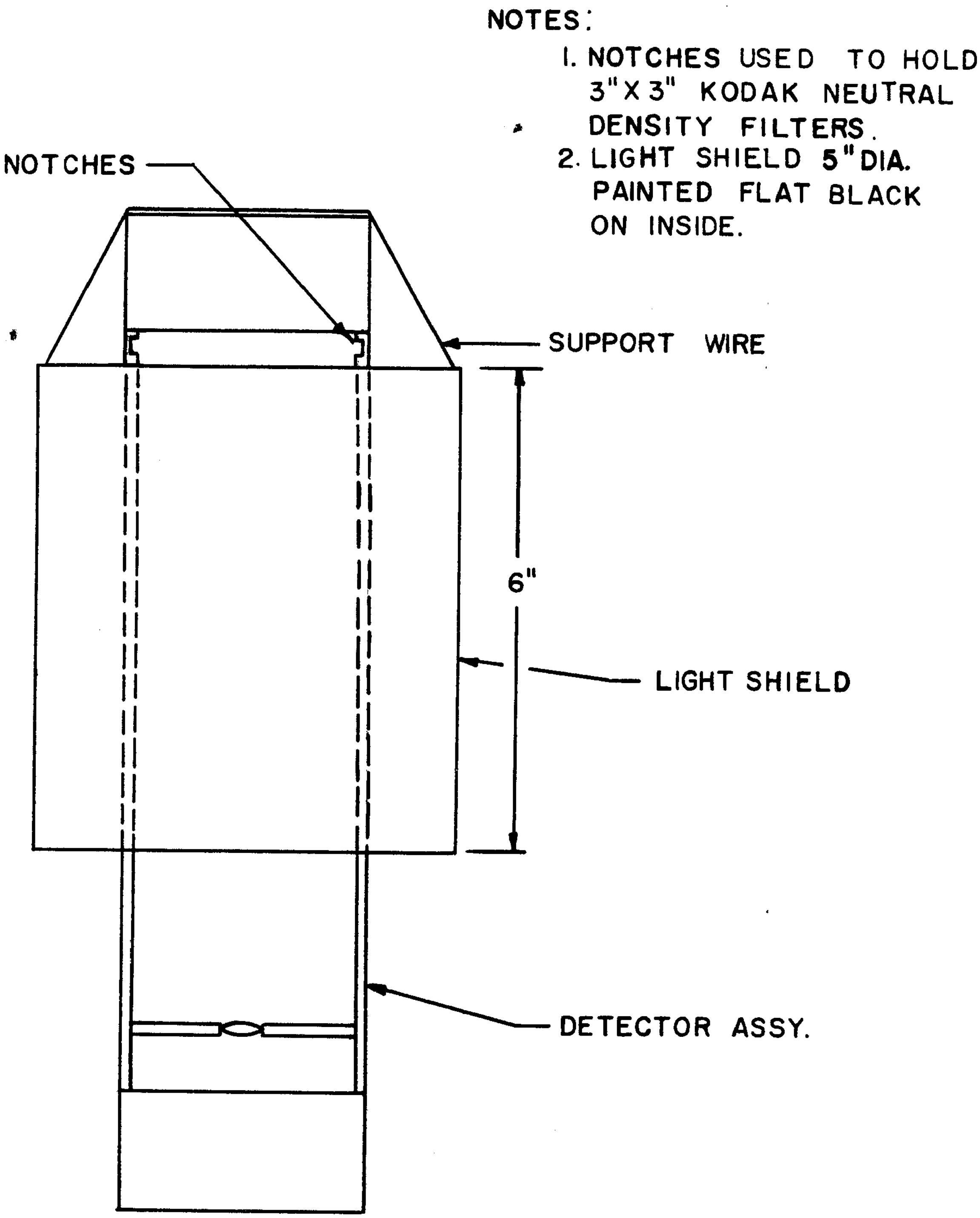
Plots of the smoke density as per cent attenuation of light are shown in Figure 11.

Data on smoke density was recorded on a Honeywell 906 Visicorder; the detectors were powered by a Hewlett-Packard regulated power supply.



SMOKE DETECTOR INSTRUMENTATION

Fig. 9



DETECTOR & SHIELD INSTRUMENTATION

Fig. 10

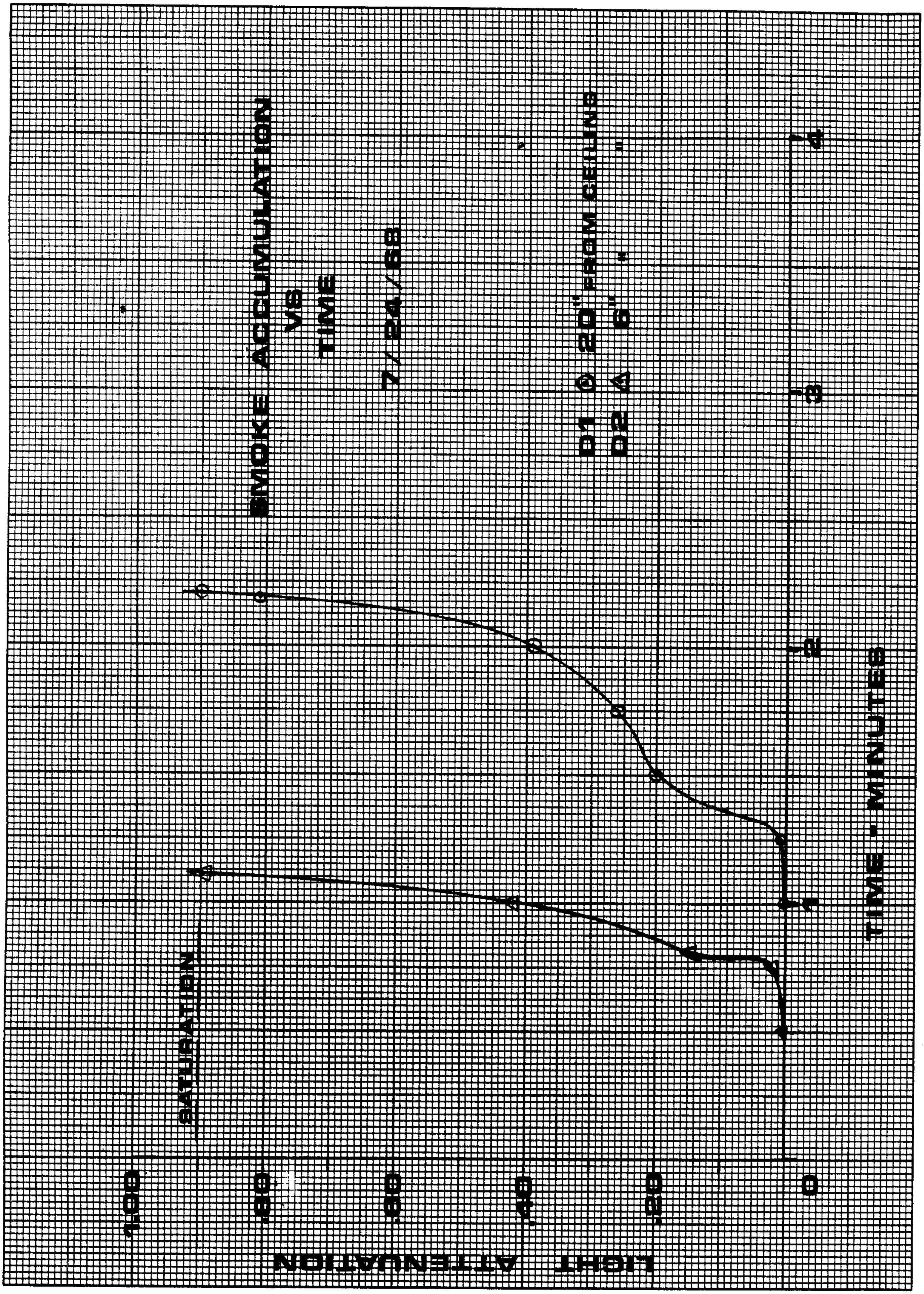

SMOKE ACCUMULATION
VS
TIME
7/24/68
D1 ⊙ 20" FROM CEILING
D2 △ 6" "
SATURATION
LIGHT ATTENUATION
1.00
.80
.60
.40
.20
0
1
2
3
4
TIME - MINUTES

Fig. 11

Samples of the atmosphere during the test fire were obtained from four separate locations within the aircraft. Stainless steel tubing sample leads were used for this purpose connected to banks of 500 cc glass flasks. An electrically driven vacuum pump located down line from the flasks provided a sample velocity through the leads calculated at 10.3 fps. Each flask was individually valved at intake and outlet to provide selectivity. (See Figs. 12 and 13) Simulaneous samples from all locations were taken at one minute intervals.

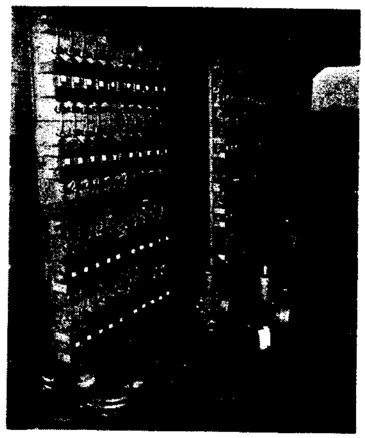


Fig. 12

Lead #1 was located in the cockpit of the aircraft at the approximate position of the pilot's headrest. Lead #2 was located in the cabin mock-up section approximately 3 inches below the ceiling on the longitudinal and lateral centerlines. Lead #3 was located directly below lead #2 and at the height of the passenger seat headrest. Lead #4 was located directly below lead #3 approximately 3 inches off of the floor. (See Fig. 6)

Figure 14 shows cabin mock-up section with thermocouples and smoke detectors installed.

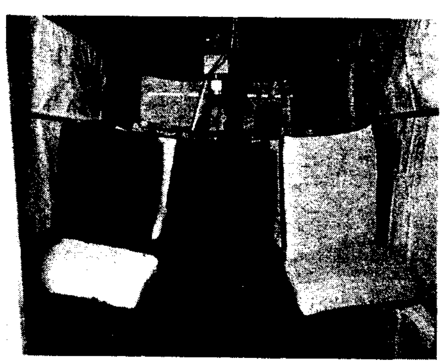
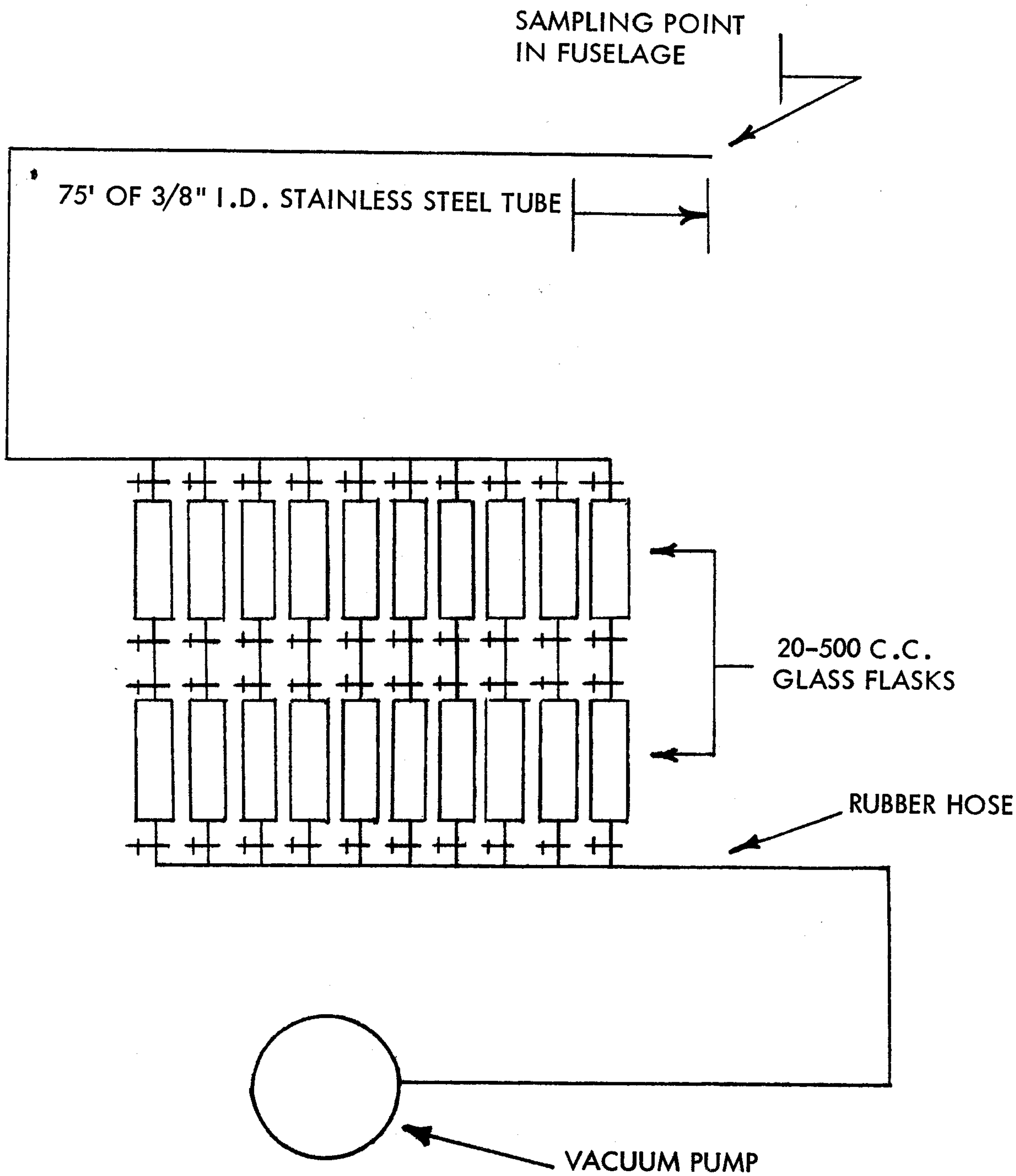


Fig. 14

GAS SAMPLING SCHEMATIC



NO SCALE

Fig. 13

The complete report on the atmospheric sampling is included in this report as Appendix B.

An ionization type combustion detector was installed on the cabin centerline at the ceiling. This detector was wired to a bell to sound an alarm when initial flame penetration of the cabin occurred.

NARRATIVE

Wind direction variable but generally just aft of starboard wing. Velocity 5 kts. with occasional gusts to 14 kts.

Initial burn through the aircraft skin (.035 aluminum alloy) occurred and was detected visually at 35 seconds after ignition.

Visible smoke was detected approximately 40 seconds after ignition on D-1 with total saturation on this same detector at 1 minute 10 seconds. D-2 registered visible smoke at 1 minute 15 seconds with total saturation at approximately 2 minutes 15 seconds. (See Fig. 11)

It is significant to note that actual combustion products were not signaled by the ionization detector until 2 minutes 10 seconds after ignition signifying that flame had not yet made its initial penetration into the cabin.

At 2 minutes 45 seconds after ignition, a sharp temperature rise was detected on the temperature recorders which rapidly rose to the point where it was beyond human tolerance. (See Figs. 15, 16, and 17) Observation of real time motion pictures of the test confirm massive failure of the fire barrier at this point.

Fire extinguishing commenced at 4 minutes 0 seconds using hand portable extinguishers and the installed high expansion foam generator. Again difficulty was encountered in developing effective foam since the generator was ingesting smoke and other products of combustion. It

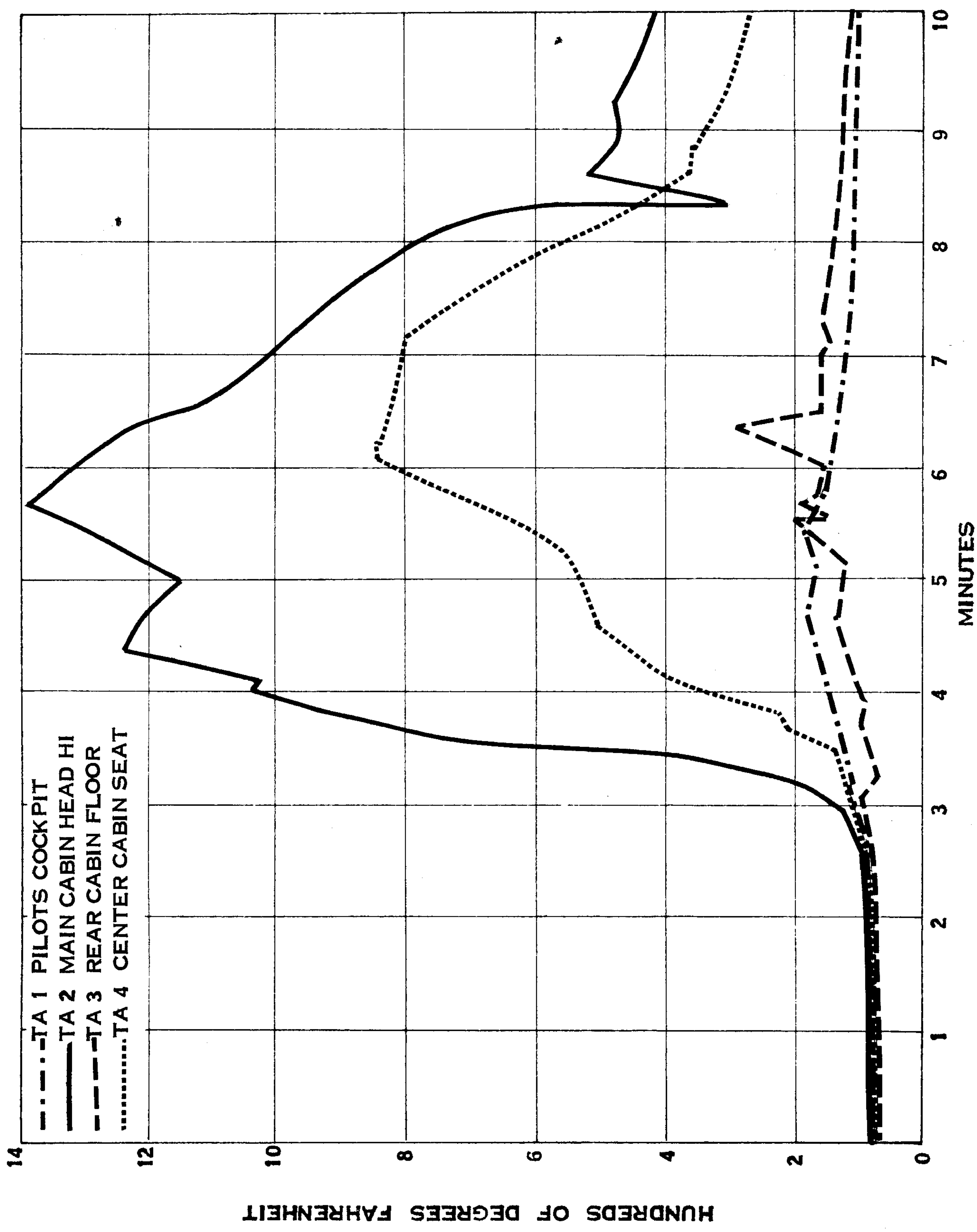

TA 1 PILOTS COCKPIT
TA 2 MAIN CABIN HEAD HI
TA 3 REAR CABIN FLOOR
TA 4 CENTER CABIN SEAT
HUNDREDS OF DEGREES FAHRENHEIT
MINUTES
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10

Fig. 15

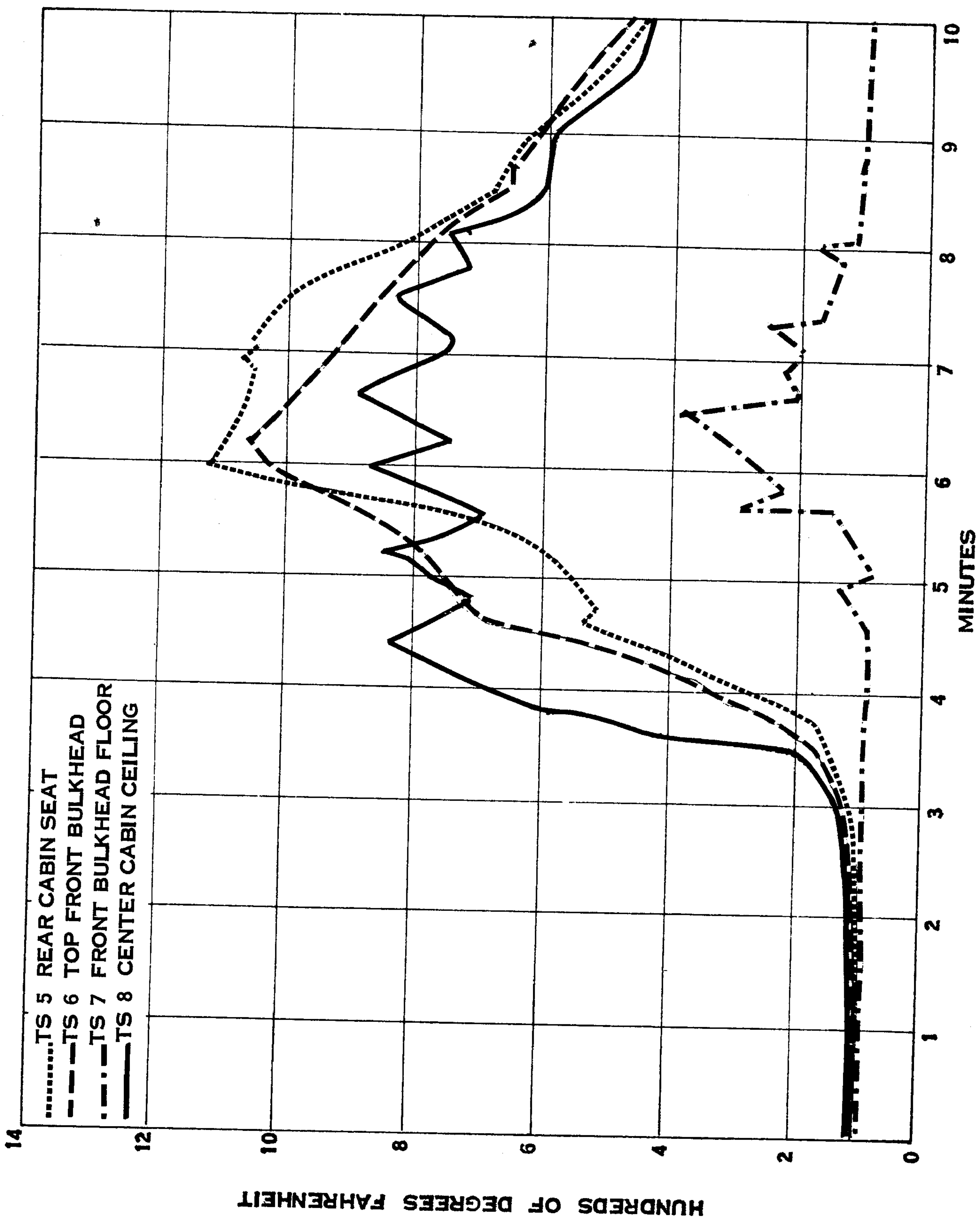

TS 5 REAR CABIN SEAT
TS 6 TOP FRONT BULKHEAD
TS 7 FRONT BULKHEAD FLOOR
TS 8 CENTER CABIN CEILING
HUNDREDS OF DEGREES FAHRENHEIT
0
2
4
6
8
10
12
14
MINUTES
1
2
3
4
5
6
7
8
9
10

Fig. 16

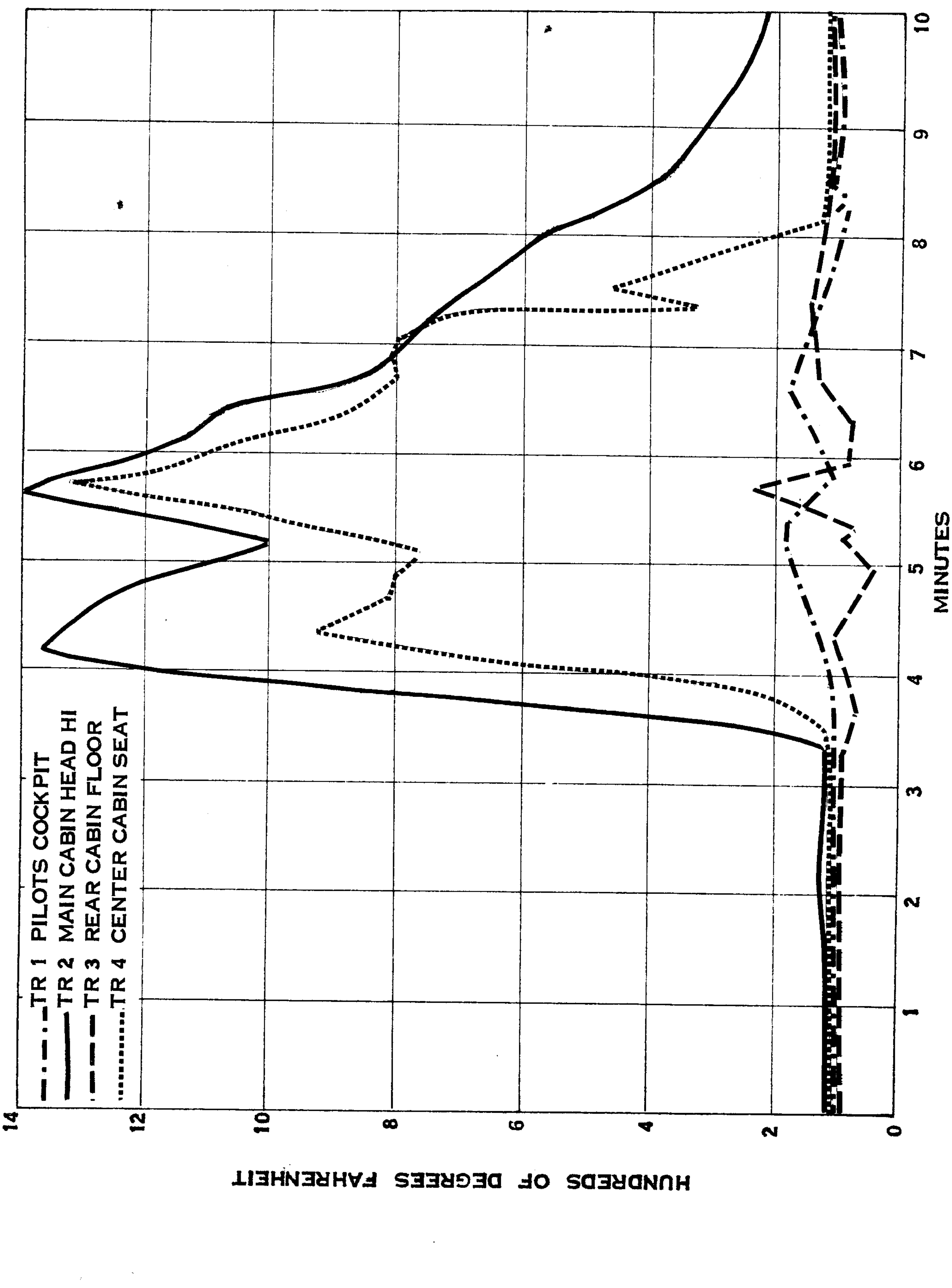

TR 1 PILOTS COCKPIT
TR 2 MAIN CABIN HEAD HI
TR 3 REAR CABIN FLOOR
TR 4 CENTER CABIN SEAT
HUNDREDS OF DEGREES FAHRENHEIT
0
2
4
6
8
10
12
14
MINUTES
1
2
3
4
5
6
7
8
9
10

Fig. 17

was not until the foam generator was successful in reversing the air flow in the cabin, thus making an uncontaminated air supply available, did the foam become effective in controlling the fire.

CONCLUSIONS

The fire barrier was successful in preventing significant flame penetration into the cabin for 2 minutes 10 seconds after failure of the aircraft skin. Examination of the evidence showed that no thermal failure of the fire barrier had occurred. However, it did show that a failure of the aircraft structure supporting the barrier had allowed it to drop out of place and thereby negating its effectiveness. (See Figs. 18 and 19)

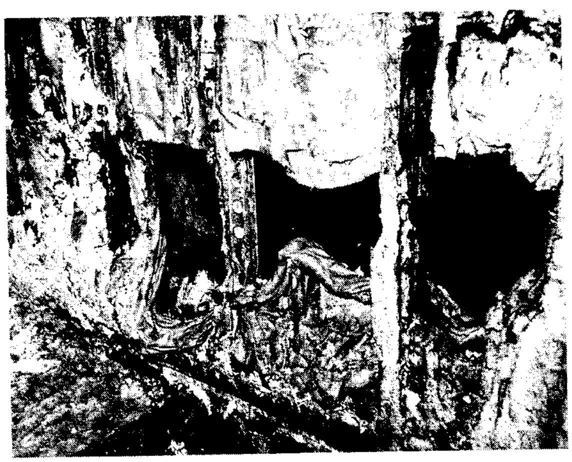


Fig. 18

Fig. 19

While the ionization detector would indicate that there was some structural deformation at 2 minutes 10 seconds after ignition, the massive structural failure did not occur until 35 seconds later.

Toxicity levels were significantly reduced from those detected in Phase I using ordinary cabin materials. (Appendix C) In Phase II temperatures proved to be the limiting factor to survivability. This may not have been true had there been no structural failure of the fire barrier. While toxicity levels were greatly reduced, they were still above acceptable levels indicating a need for continuing research in this area.

Physical examination of the Phase II post fire cabin mock-up indicated that the materials used exhibited a high degree of fire resistance as compared to those materials used in the Phase I tests. Seat cushions and carpeting were recovered virtually intact indicating that they contributed nothing to the flamability of the cabin interior.

The insulation used in Phase II, which is presently incorporated in the design of certain production aircraft, also showed a high degree of resistance to fire attack and thermal degradation. (See Fig. 20)

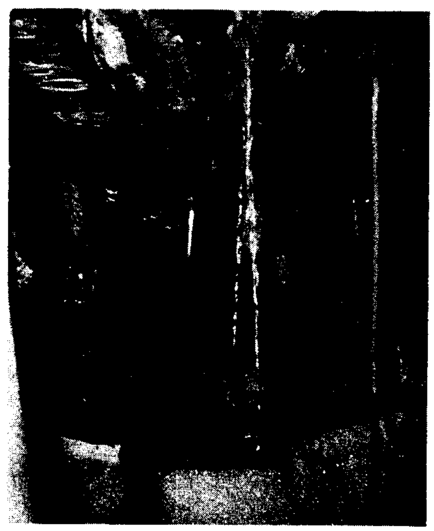


Fig. 20

ACKNOWLEDGEMENTS

Organizations participating in the tests were the Air Line Pilots Association, United Air Lines, National Aeronautics and Space Administration, Cleveland Hopkins Airport Fire Department, E.I. Dupont de Nemours Co. Inc., Owens Corning Fiberglas, the Boeing Company, E.W. Bliss Co., Bliss Rockwood Corporation, Pyrotronics, Inc. Crobaugh Laboratories and Central Scientific Company.

The assistance and contributions of these organizations is sincerely appreciated.