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I. Introduction.

Investigation of recent jet transport aircraft accidents has indicated that inhalation of smoke is a significant factor in the incapacitation of passengers and their subsequent failure to evacuate the aircraft prior to its consumption by fire. Unfortunately, the immobilization and collapse of even one strategically-located passenger or crew member can have a very deleterious effect upon passenger evacuation flow. A recent study of United States air carrier accidents involving fire concludes that fire deaths and injuries can be reduced by aircraft crashworthiness design evacuation provisions and procedures, plus airport firefighting and rescue provisions.[6] Recent burn tests of obsolete instrumented aircraft, some

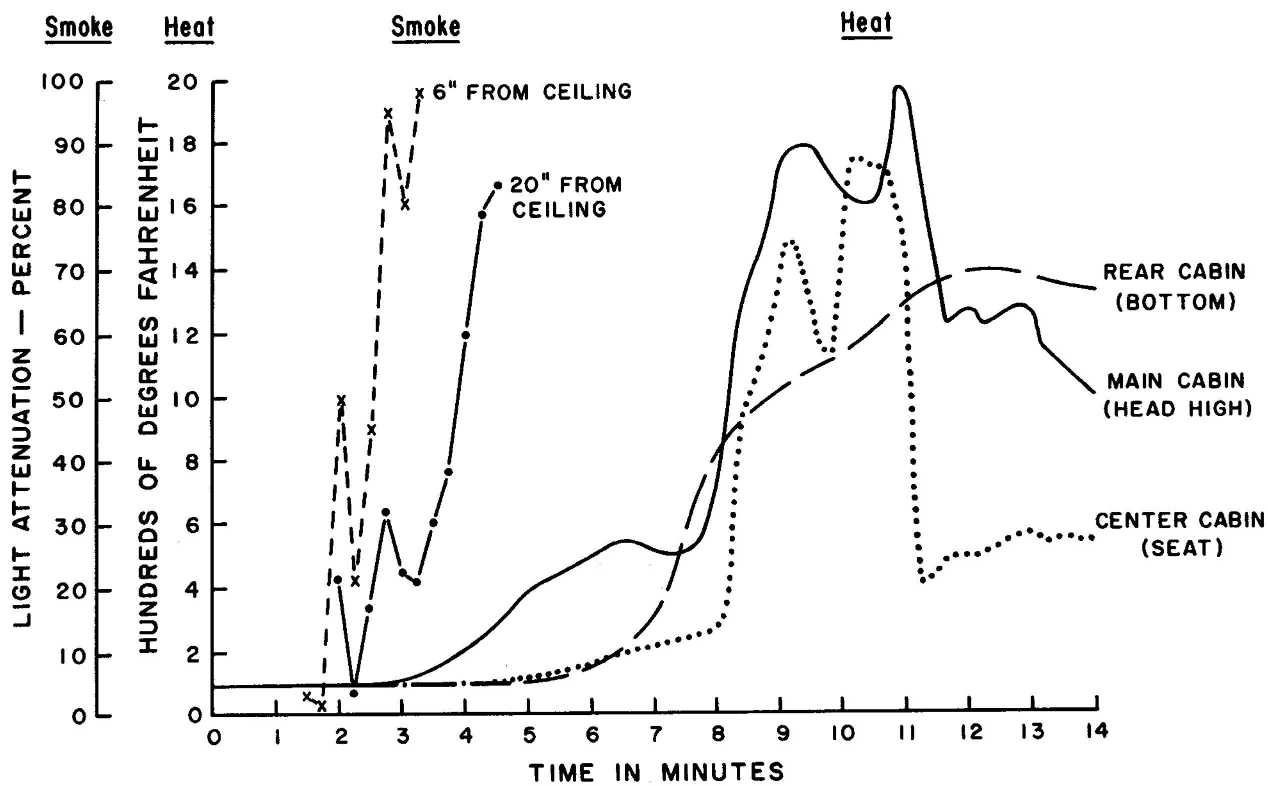

FIGURE 1.—Smoke and temperature data from Test Number 1 of the ALPA aircraft fire tests replotted on the same time base in order to demonstrate the sequential occurrence of smoke and heat.

of which were equipped with modern interiors, indicate that smoke density approaches saturation in two to two-and-one-half minutes.[3] Temperature rise approaching intolerable levels (480°F) occurred in these experiments at the fifth and sixth minutes followed characteristically by a flash fire with temperatures soaring to in excess of 1600°F in one or two minutes as shown in Figure 1. Smoke density and temperature measurements in other tests indicate stratification and localization, with flash fires reported to travel through the fuselage at a rate of 68 feet per minute.[4]

Current regulations require the airlines to demonstrate that all passengers can be evacuated in two minutes using one-half of the aircraft exits. In the Salt Lake City accident, fire broke out almost instantly after impact. Evacuation, however, could not be initiated until the aircraft came to rest, following a skid of some 2900 feet which consumed some forty seconds to one minute of the required evacuation time. Thus, the two-minute evacuation time was cut nearly in half. It is interesting to note that forty-three (43), or one-half of the eighty-five (85) passengers aboard, failed to evacuate the aircraft and became fatalities. If passengers in this type of accident could have been protected from the immobilizing and incapacitating effects of inhalation of smoke, toxic gases, and flame, for only one to two additional minutes of evacuation time prior to the development of intolerable temperatures, it is probable that a very significant increase in survival could have been attained.

II. Methods.

A number of approaches to providing passengers respiratory protection was considered. In this relation, the following primary and secondary design criteria were formulated.

Primary Design Criteria:

1. Simplicity in design and operation.
2. Omnidirectional visibility and donning.
3. Provide protection from smoke inhalation for a limited duration (2½ to 8 minutes).
4. Device should not melt or burst into flame when worn on face or head.
5. Light-weight and compact in size.

Secondary Design Criteria:

1. Prevent inhalation of flames and respiratory damage.
2. Protect the face and hair from direct contact with flames.
3. Esthetic considerations—prevention of disfiguring facial burns.
4. Extend passenger escape time by maintaining passenger mobility and continuation of evacuation.
5. Provide protection from convective and radiant heat.

Material Testing:

A bag or hood type of device was constructed of Kapton, a relatively new du Pont high temperature polyimide film. Normal volume of the hood was calculated to approximate 18.5 liters exclusive of the volume occupied by the wearer's head. Kapton was selected due to its non-melting character when exposed to extreme heat and because it is transparent and non-flammable. Kapton, reportedly, does not begin to char until temperatures exceed 1472°F. Other desirable features of polyimide film for this application include high tensile strength and folding endurance, low shrinkage, insolubility in organic solvents and inertness to fungi.

Since polyimide film has no melting point, experimental hoods cannot be fabricated by employing conventional heat-sealing techniques. Experimental transparent hoods were fabricated under contract by the G. T. Schjeldahl Company, utilizing special techniques and high temperature adhesives. A second group of experimental hoods was fabricated by the same company employing a reflective but transparent metalizing coating. Twenty-one samples of polyimide film were successively coated with varying thicknesses of gold, silver and aluminum, with and without a protective coating over the metal. These samples were evaluated for infra-red reflectance and emissivity plus heat and optical transmission. Infra-red emissivity was measured by a Lion Emissometer and infra-red reflectance by a Perkin Elmer Spectrophotometer at wave lengths from three to fifteen microns. Optical transmission was measured on a Beckman DKZA Spectrophotometer over the wave length range from 3500 to 7000 Angstroms. Thermal transmission was measured by locating thermocouples equidistant (approximately 1/16″) from both sides and measuring air temperatures using a common infra-red lamp as the emitting heat source.

Specially-charged, high-pressure, disposable, compressed air cylinders were fired under water in a protective steel chamber in order to obtain flow curves and volumes as well as to test the integrity of the actuating mechanism. High-speed motion picture photography was used to record any leakage or any failure of the assembly. These types of cylinders are being evaluated for use in purging and ventilating the hoods in order to extend their useful duration.

Human Testing:

The feasibility of utilizing rebreathing techniques, for short durations, was demonstrated by use of an LB–1 infra-red CO_2 analyzer and by continuously monitoring carbon dioxide accumulation of subjects wearing various size plastic hoods during rest and maximal work. The infra-red protective capability of the clear and metalized hood was evaluated by exposing human subjects wearing the hoods to infra-red radiation and measuring skin and interior and exterior hood temperatures. These tests were carried out with the subject's protected head exposed to radiation from four 250-watt industrial infra-red lamps located at various distances from the face. Voltage to the lamps was controlled by a variac and monitored by watt meters to assure operation at the lamp rating.

FIGURE 3.—Subject wearing the coated, silver, metalized smoke hood emerges from a smoke-filled fuselage into a gas-fed flame directed at his face.

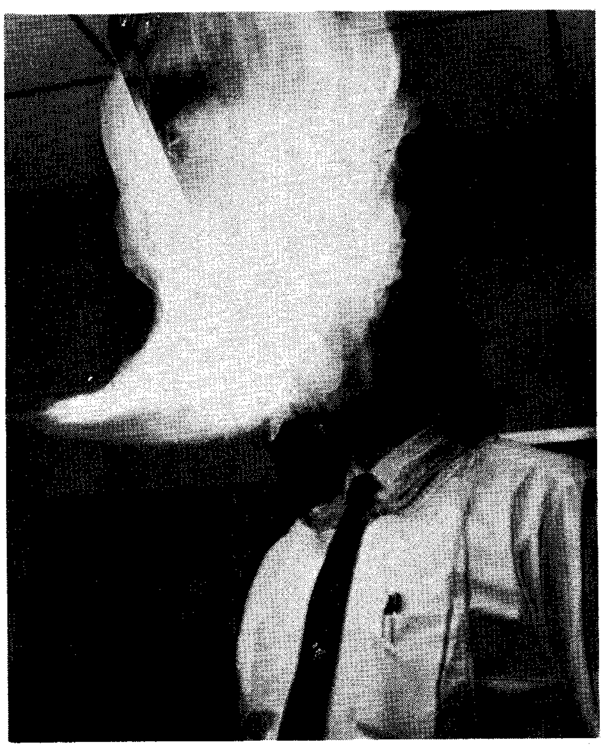

FIGURE 2.—Subject wearing the clear, polyimide, smoke hood is exposed to a natural gas flame.

Thirty-six gauge copper constantan type thermocouples with an ice bath reference junction were taped to the forehead, cheek, interior and exterior of the hood. Skin and hood temperatures were recorded on a Leeds and Northrop Speedimax W Recorder calibrated to a range of 80 to 280°F. A thermocouple stepping relay allowed recording of each of the four temperature positions at 7.5-second intervals.

Subjective evaluations of the hood have been made by human subjects inserting their hood-protected heads into natural gas flames as shown in Figure 2. In addition, several tests have been carried out in an obsolete Constellation aircraft fuselage of 3,000 cubic feet volume in which 168,000-cubic-foot volume irritant smoke grenades were fired. The subject donned the hood after the grenade was fired and remained in this environment for two to three minutes, then located the exit and emerged to the exterior through a sheet of flame directed at his head and face, as shown in Figure 3. In order to assure mobility, these subjects were not instrumented. Tests were conducted to determine the reduction of visibility induced by wearing the coated and uncoated hoods under low level emergency lighting. Six random numbers of varying contrast with their backgrounds were viewed by subjects at the current interior emergency lighting standard level of .05 foot candles. The numbers were chosen with contrast ratios such that some numbers were not perceived and/or were barely perceived by the unobstructed eye at the .05 foot candle levels of illumination. The clear, amber-colored, polyimide hood was donned and the illumination increased to a point where the subject perceived the same group of numbers as observed at the .05 foot candles illumination level without the hood. This was repeated with the metallic coated hood. Between each test subjects were re-adapted to illumination levels approximating standard cabin lighting levels. All measurements and light settings were made using a Photo Research Spectra Milli-Candela Photometer.

III. Results.

Material:

Emissivity values for the twenty-one metalized samples of polyimide film were as follows: coated gold—0.020–0.033; coated aluminum—0.033–0.120; coated silver—0.008–0.025. The thinner thicknesses of metal have the higher emissivity values. The infra-red reflectance of non-metalized polyimide film is approximately 25%. In these experiments with metalized polyimide films, the IR reflectances were as follows: coated gold—82.4 to 90.4%; coated aluminum—76.2 to 90.2% and 90.3 to 90.9% for coated silver.

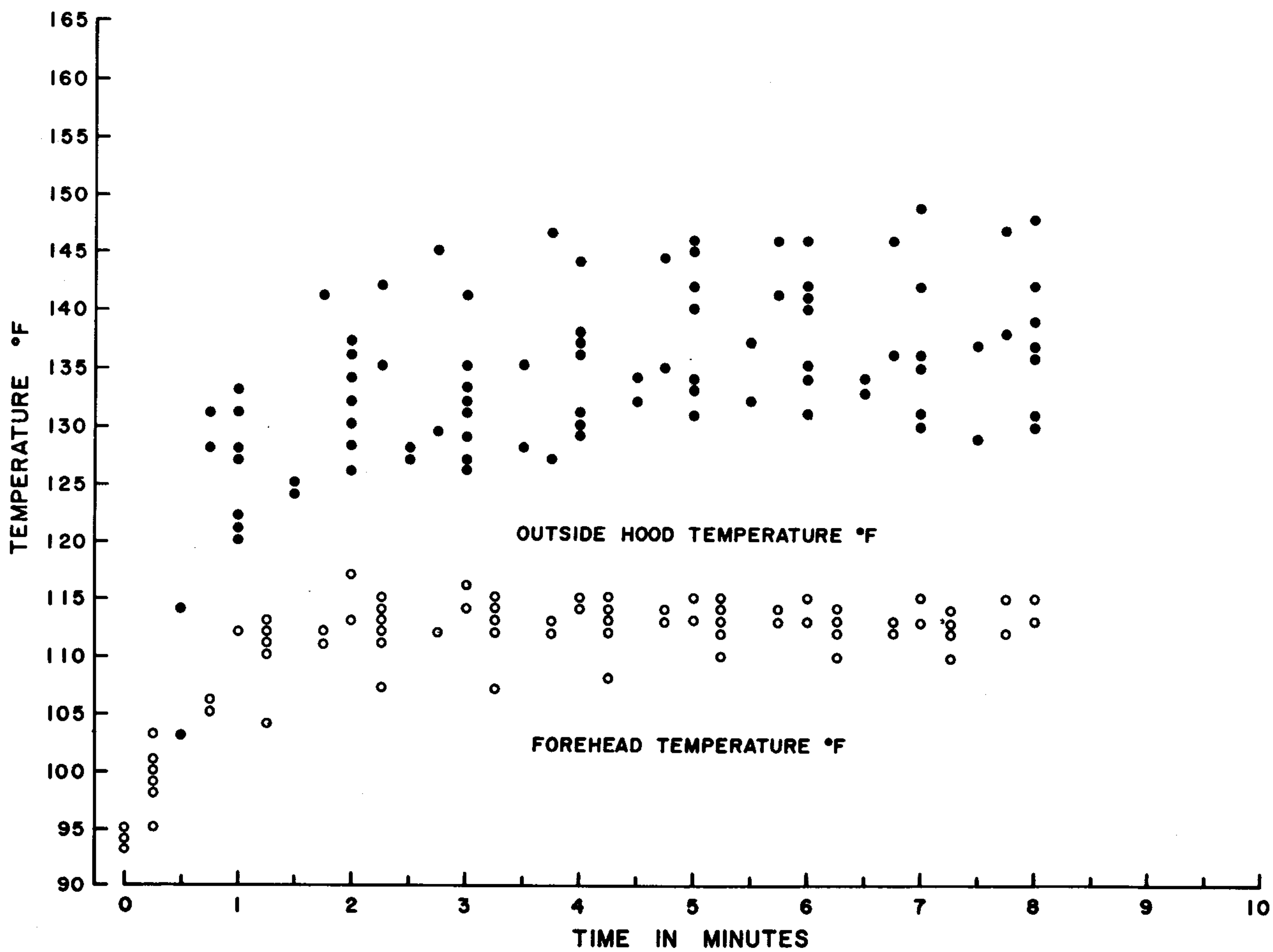

FIGURE 4.—Hood and skin temperatures of subjects wearing the clear, polyimide hood and exposed to four infra-red sources positioned twenty-two inches from the front surface of the hood. N = 12.

Optical transmission as measured by the Beck-nan spectrophotometer is not representative of he human visibility capabilities of the hoods, ›ut is, however, useful for comparison of metaliz-ng systems. Thermal transmission measure-nents indicated that the coated silver film had ignificant superiority to the other coatings in ıeat reflectivity. After ten minutes exposure of , silver metalizing system, the thermal differen-ial measurements indicated a 92°F temperature ⁄16 of an inch from the inside or non-coated side vith a 225°F temperature measured at a similar listance from the exterior or coated side.

Disposable gas cylinders 4½ x 1½ inches were :harged to 2000 psi with compressed air. Test iring of these cylinders through very small fixed ›rifices produced a very high initial flow curve :ollowed by a reduced flow as the pressure was ·educed. This type of curve is desirable since .he initial high flow would tend to purge the hood and the subsequent lower flow provide supplementary ventilation. In these initial tests, the approximate nine liters total volume of the cylinder was released in one minute. Attempts are being made to increase both the volume and flow duration of a hood ventilating system, and at the same time minimize size and weight.

Human Testing:

Preliminary monitoring of the CO_2 accumulation indicated an accumulation and plateau of 6–8% CO_2 after eight minutes of rebreathing at rest. The shape of the curve indicated that the seal around the neck began to develop significant leakage in 4–6 minutes in response to the elevated tidal and minute volumes of hyperventilation. This was reduced to 2½ to 3 minutes by maximal work on a bicycle ergometer. The 2 mil. polyimide film has sufficient rigidity so that it does not exhibit a tendency to be drawn up against

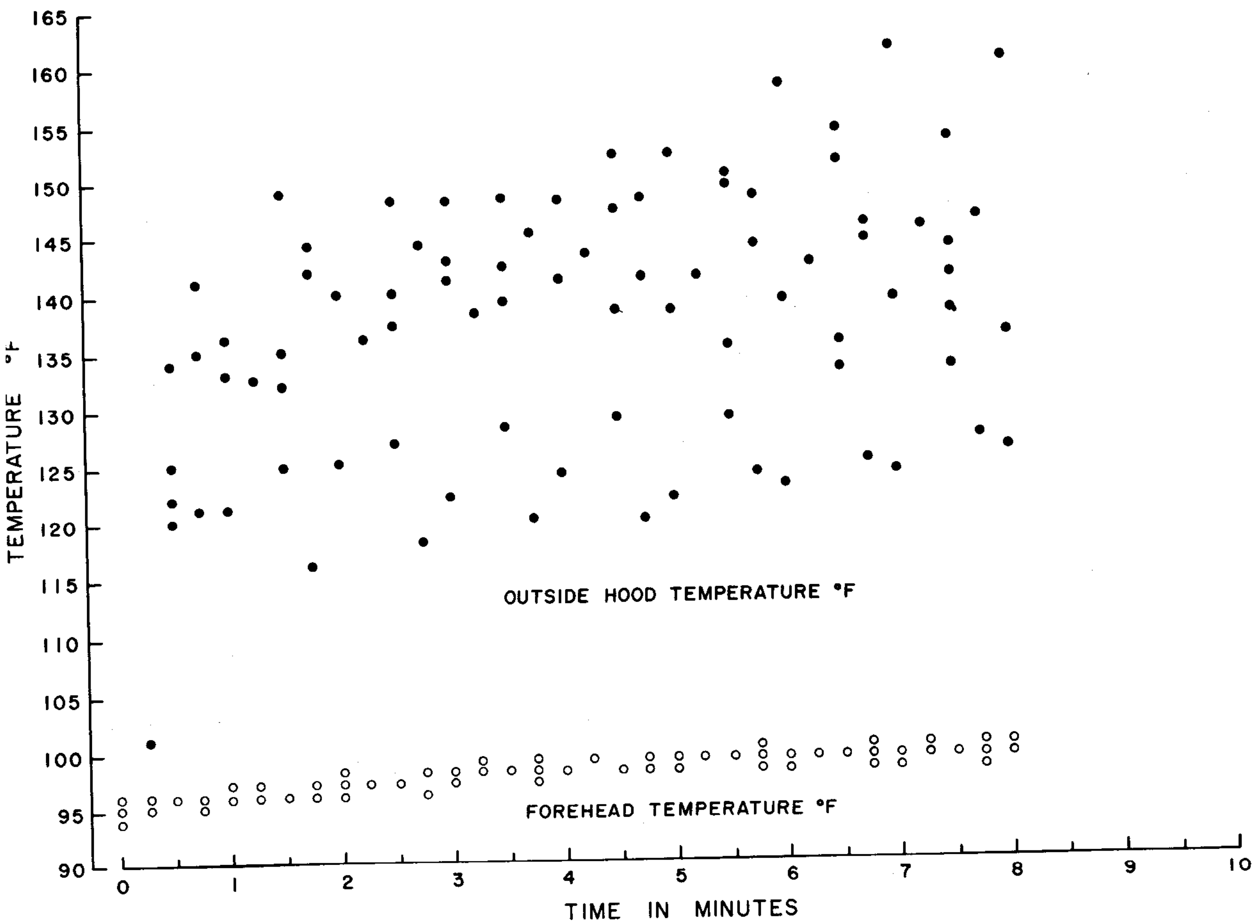

FIGURE 5.—Hood and skin temperatures of subjects wearing the silver metalized polyimide hood and exposed to four infra-red sources positioned twenty-two inches from the front surface of the hood. N = 11.

the respiratory passages and occlude breathing. However, at the same time, it is flexible enough to be responsive to changes in volume imposed by inspiration and expiration.

Subjects wearing the clear, uncoated, amber-colored, polyimide hoods and the coated silver polyimide hood were exposed to eight minutes of infra-red radiation with the filament of the infra-red lamps located 22 inches from the front surface of the hood. Forehead skin temperatures and exterior hood temperatures are shown in Figures 4 and 5. Using the clear hood, skin temperatures of 115–117°F approached the limits of voluntary tolerance. Skin temperatures of subjects wearing the coated silver hood and exposed to the same heat flux as the clear hood, exhibited maximum skin temperature of 100°F. The heat sources were moved to a point where the filaments of the lamps were 6.5 inches from the front surface of the hood. This places the lamp lens within one or two inches of contacting the front surface of the hood. Although exterio surface temperatures occasionally exceeded re corder calibration temperatures, the forehea skin temperature averaged approximately 106°F Figure 6. Infra-red sources providing highe levels of heat flux will be required to exten these evaluations of tolerance.

Reduction in visibility induced by the clea and metalized hoods at low levels of illuminatio is shown in Table 1.

TABLE 1. Increase in illumination required to make se lected targets equivalent in conspicuity while wear ing the clear and metalized hoods as when viewe by the unobscured eye at .05 foot candles of illumi nation. N = 11

	FOOT CANDLES OF ILLUMINATION		
	Unobscured Eye	Amber Clear Hood	Silver Metalized Hood
RANGE	0.05–0.05	.063–.100	.60–4.30
MEAN	0.05	.076	2.02

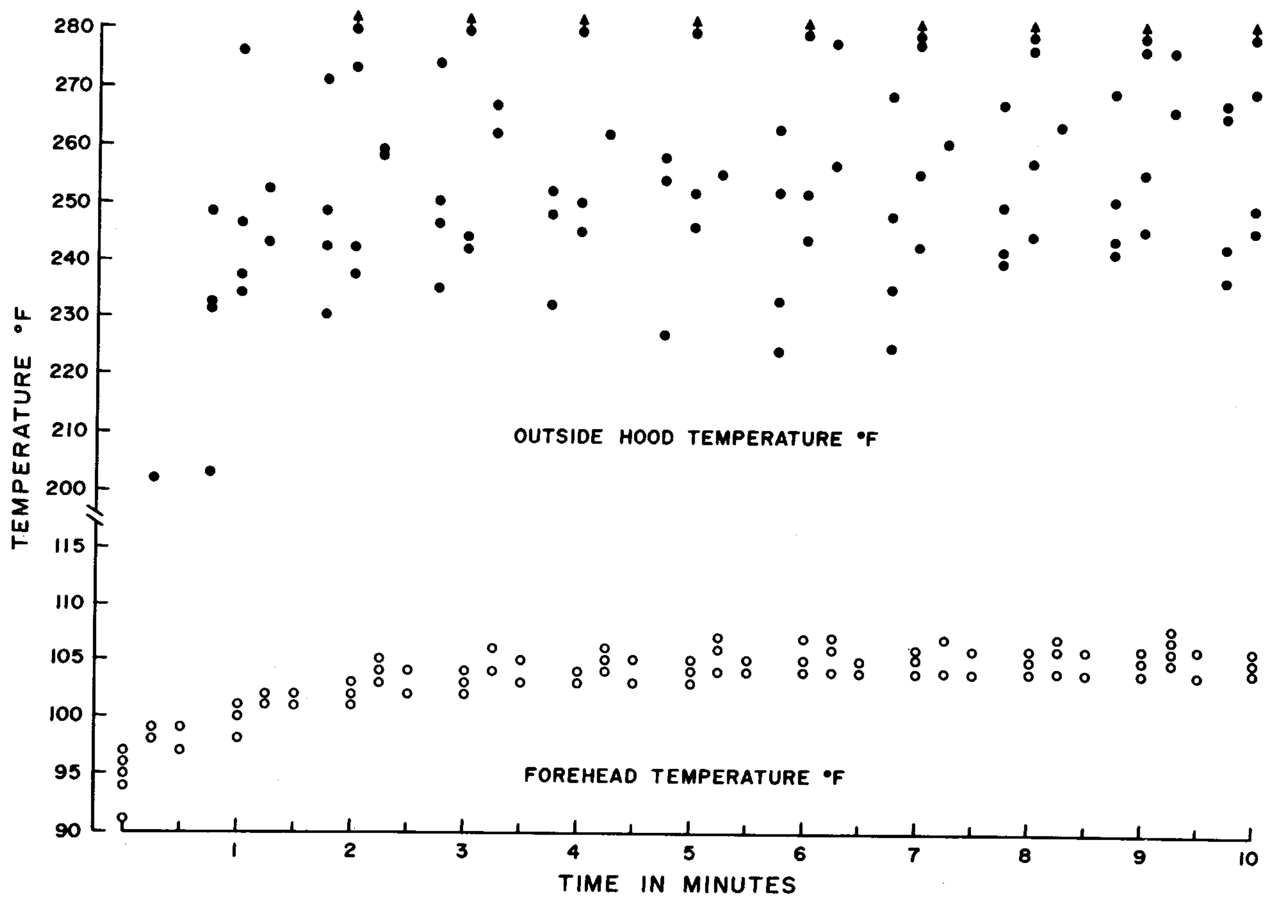

FIGURE 6.—Hood and skin temperatures of subjects wearing the same hood as shown in Figure 5 but with the infra-red sources positioned 6.5 inches from the front surface of the hood. N = 11.

V. Discussion.

Phillips and Cope[5] made a study of 1,140 consecutive burn case hospital admissions with 106 fatal cases and were surprised to find that shock accounted for only 20% of the deaths. Respiratory tract damage, with or without superimposed respiratory tract infection, was responsible for nearly half of the burn fatalities. Where facial burns were incurred, 78% developed respiratory difficulties due to inhalation of flame. According to Connell[2], if the lower respiratory tree is burned; i.e., trachea, main bronchi, and secondary bronchi, death is almost inevitable.

The hoods do not provide protection from burns to the body. Clothing, however, provides some degree of protection to high radiant temperatures for a few minutes depending upon the characteristics of the weave and orientation of the fibers.[1] As the temperature increases, there is, however, danger of ignition. Survivors of the Salt Lake City accident related that they pulled suit coats, top coats and even shirts up over their heads to provide protection from high radiant heat levels. One survivor, using this method but standing with his back to the fire focus and awaiting his chance to evacuate, received burns to one ear which protruded from under his coat. Exclusive of burns to the head and neck, male survivors of this accident most frequently received severe burns to the hands and area between the trouser cuff and shoes. These are areas to which clothing provides little or no protection from the effects of exposure to radiant, convective and conductive heat.

Although full-body protection of passengers has been considered, it does not appear to be practical since the time required for donning such a protective garment would probably delay evacuation to such an extent as to be more detrimental than no protection whatsoever. In addition, the added complexity, passenger training requirements and storage make this proposal even less plausible.

The very light and compact polyimide hood may prove to have potential usage for short duration emergency protection in home, forestry and industrial fires. However, additional testing and design refinements should be carried out with regard to each specified proposed application.

Prior to any specification for operational use in aircraft, further studies are necessary. The FAA is actively pursuing these avenues.

V. Summary.

1. Development of a polyimide smoke hood designed to provide short duration protection from the effects of inhalation of smoke, toxic gases and flame is described. Additional protection is afforded the eyes from the temporary blinding effect of irritant smoke.
2. The hood provides a barrier to direct flame contact with the exposed face and head.
3. A system for metalizing polyimide film with a thin transparent layer of metal capable of up to 90% infra-red reflectance was developed.
4. Duration of the usefulness of the hood may be extended by a self-contained supply of uncontaminated breathing air in order to purge and provide supplementary ventilation of the hood.
5. Prior to any specification for operational use in aircraft, further studies are necessary. The FAA is actively pursuing these avenues.

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