U. S. NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE, PENNSYLVANIA

Aviation Medical Acceleration Laboratory

NADC-MA-6120 22 May 1961

Thermal Protection Capacity of Aviator's Textiles

Bureau of Naval Weapons
WepTask No. RAE 20J 020/2021/F012 10 008
Problem Assignment No. J44AE22-2

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SUMMARY

Since the advent of high-speed aircraft and nuclear warfare, the need for protection of personnel from thermal injury has been greatly emphasized. Among the more immediate aviation needs is that for fire-resistant anti-G clothing. With this specific need to the fore, an interim method has been devised for the selection and evaluation of textiles on the basis of their resistance to degradation by thermal irradiation of appropriate intensity and their protective capacity when in contact with living skin. At the present time, although field testing is not yet complete, a satisfactory thermally-resistant anti-G suit appears to have been achieved through this effort. This suit is fabricated of DuPont Experimental Fiber HT-1 in a twill weave and double-layer construction. On the basis of percentage of total body burns indicated by fuel flame exposures of clothed dummies, it has proven superior to a double-layer nylon suit and the regulation fire-retarded cotton coverall over the cutaway anti-G suit. The present method is being modified to yield surface temperature measurements during irradiation to provide for the ultimate goal of devising a thermal protection index based on previously established relationships between these temperatures and the tissue damage resulting from thermal irradiation.

ACKNOWLEDGMENT

The author acknowledges with much gratitude the excellent technical assistance of Mr. Lambert R. Munroe in all phases of this work; the courtesies and the fine cooperation of the DuPont Company representatives, particularly Dr. B. S. Farquhar, in providing expert technical advice and in making DuPont products available for this study; the material evaluations and technical advice provided by Miss Margaret B. Hays of the Naval Material Lab, NAMC, Philadelphia; the skilled work-room assistance made available by Mr. Frank Catroppa of the Air Crew Equipment Lab., NAMC; and last but by no means least, the enthusiastic cooperation of the Staff Instructors of the Fire Fighters School, Naval Damage Control Training Center, Philadelphia, in giving unstintingly of their time, facilities and unique abilities in the conduct of the flame exposure tests.

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INTRODUCTION

The need for thermal protection in aviator's textiles is too well-known to require any elaboration. The melt-drop hazard of nylon, and the irritation attributed to fire-retardant-treated fabrics are equally familiar to military aviators and flight personnel who must live in flight clothing while on duty. The present work was undertaken to eliminate both the hazard and the irritation. Its purpose is to provide, specifically, anti-G clothing that offers a significant measure of thermal protection and at the same time, strength sufficient to provide G-protection, comfort, washability and durability. Many fabrics fulfill the last four conditions but do not offer in addition the first and foremost asset, thermal protection. For this reason, thermal protection capacity was made the primary criterion of suitability.

APPARATUS AND METHODS

In setting up the laboratory procedure for fabric selection the maximum level of energy considered was that commensurate with exposure to thermal radiation from completely encircling fuel fires such as might be experienced in deck crashes. This level would be approximately 0.7 cal/cm^2 sec or 25,000 Kg cal/m^2 hr for flames of 2200°C with an emissivity of 0.5. Laboratory measurements of JP-4 fuel flames showed them to be at a temperature of 1200°C, well within the selected range. Assessment of the thermal protection afforded by the textiles was made by bioassay and by exposure of the fabric itself to the thermal radiation.

The apparatus used is shown diagrammatically in Figure 1. It consists of a bank of six 500 watt infrared quartz bulbs mounted in front of an exposure plate through which the specimen or animal is irradiated. The shutter mechanism for regulating the exposure time consists of a double guillotine device mounted on the exposure plate in front of an aperture 2 cm in diameter. The device is operated by means of two solenoids so that, with the aperture shielded from the radiation initially, on actuation of the first solenoid a shutter snaps into place permitting radiation to fall on the aperture and on actuation of the second solenoid a second shutter snaps into place cutting off the irradiation. Each shutter moves completely across the aperture in about 0.01 sec. Since no exposure time less than 3 seconds was used, the shutter operation times were negligible and a virtually square wave pulse was achieved. The intensity of the source was controlled by means of a variac, and sub-surface temperatures were measured by thermocouples in conjunction with a recording oscillograph. Surface temperatures which require radiometric measurement were not possible with this apparatus. The color temperature and irradiance of the source at a

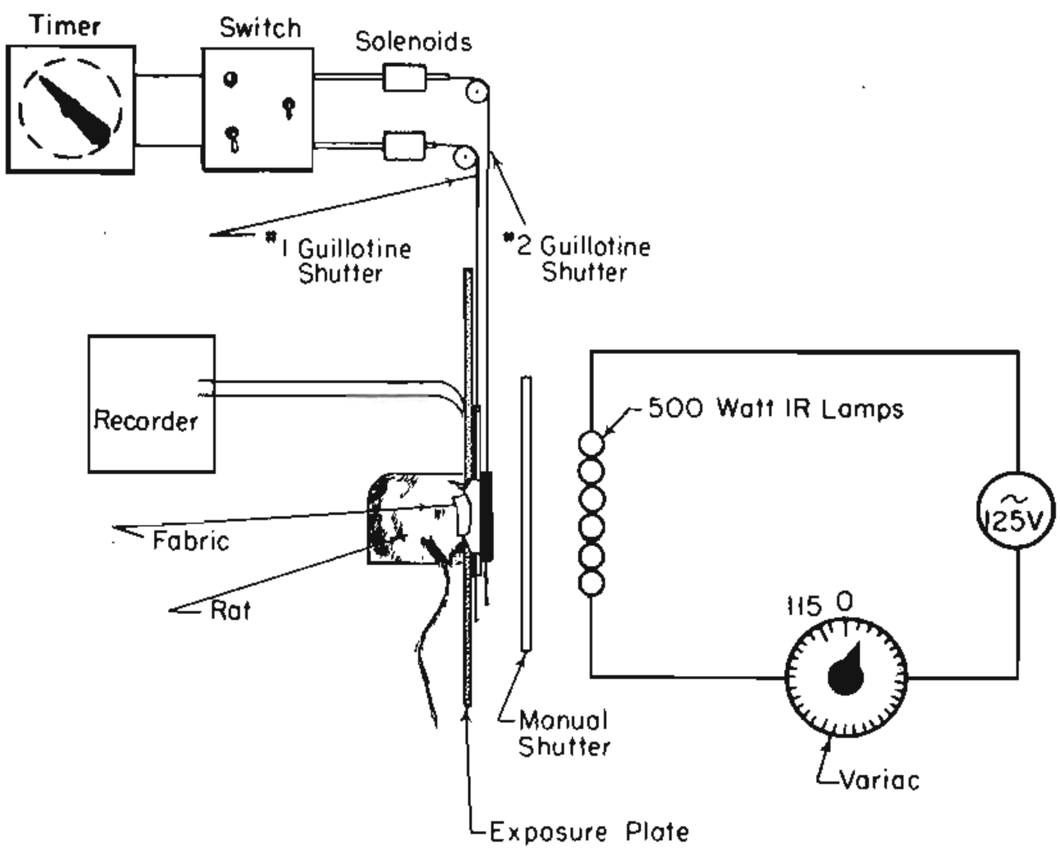

Figure 1. Thermal irradiation apparatus.

distance of 12 cm is shown in Figure 2. The maximum irradiance at this distance was 715 mc/cm^2 sec. From these measured values the wavelength of the radiation was determined and is shown in Figure 3. It is seen that throughout the operable range of the source, the bulk of the radiation falls in the near infrared region which corresponds to the wavelengths of the energy from which protection is sought.

The radiant energy distribution was such that the intensity over the entire field lay within ±2.3% of the average intensity while that over an area 1 cm in diameter about the center lay within 1.3% of the average.

The bioassay procedure consisted of determining the exposure time required to produce a white burn about 1 cm in diameter on the bare depilated skin of an anaesthetized albino rat and on the fabric-covered skin on another site of the same animal at each of four irradiance levels.

Routinely, the fabric itself is evaluated on the basis of its ability to withstand an irradiance of 715 mc/cm^2 sec for 280 seconds. The fabric was mounted in a holder which permits continuous observation of changes occurring during exposure. Separation of the effects due to reflectance and transmittance was achieved by backing the fabrics with black and with white materials.

RESULTS

Some of the more significant results elicited by these methods are shown in Table I. In the first group appear two cotton twills exactly alike except for color. The orange reflects more energy and therefore offers greater protection, the latter is expressed here in terms of the ratio of the exposure time for production of the standard burn in the fabric-covered skin to that in the bare skin, T_f/T_b; thus, the larger the number, the greater the protection. On exposure of the fabrics alone, both charred without glowing or flaming, and disintegrated on touch. The treated wool-gabardine, almost three times as heavy as the cottons, offers considerably more protection but shares the same fate on exposure to the relatively high irradiance.

The second group consists of untreated cottons, a heavy black one, compared with a light-weight white. Despite the thickness of the black fabric, due to its high absorptance it actually reduces the time to burning, and itself burns on exposure to the higher irradiance. The light-weight white, by virtue of its high reflectance offers good protection against skin burns and is only browned and weakened under circumstances which destroyed the black fabric.

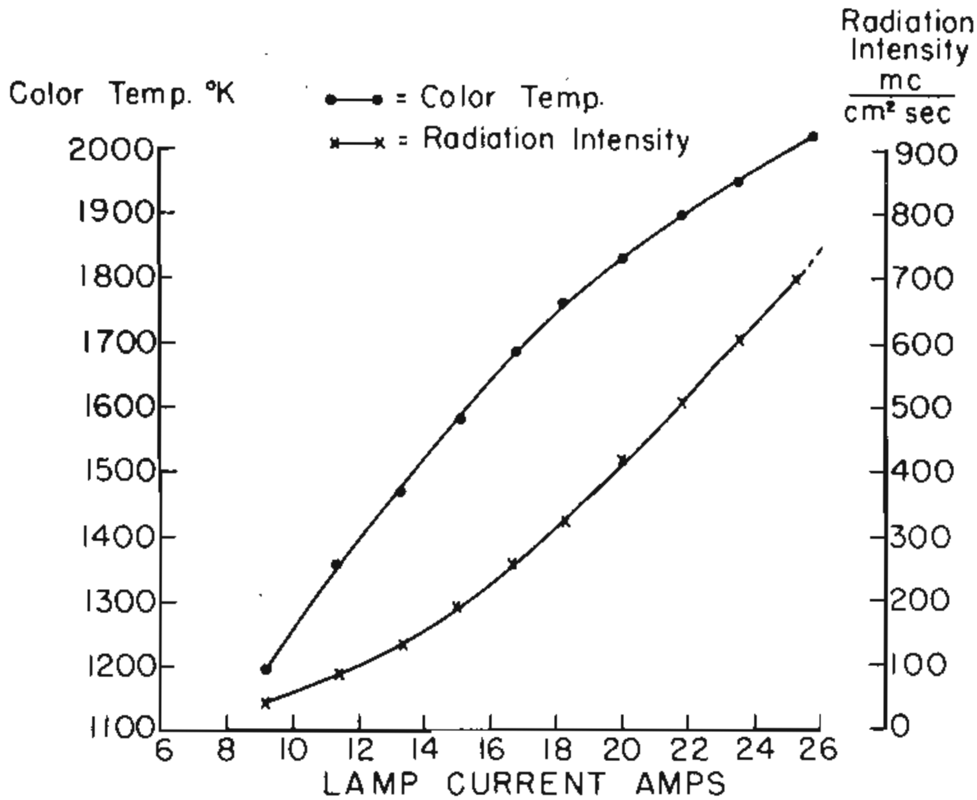

Figure 2. Color temperature and irradiance of infrared quartz lamp source.

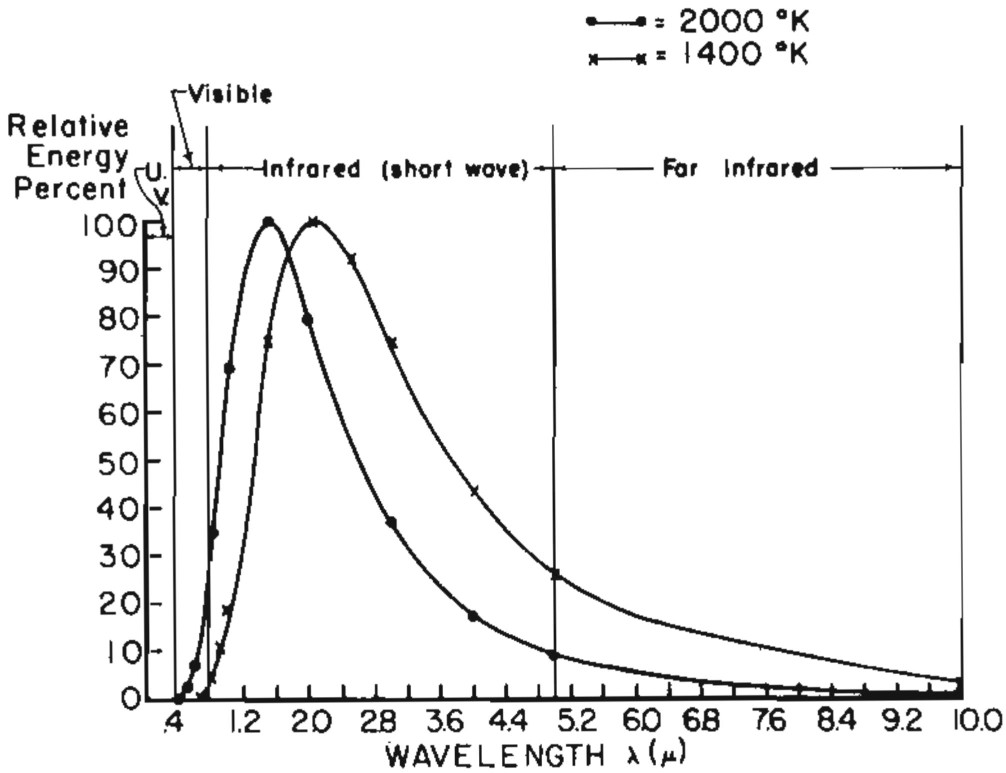

Figure 3. Spectral distribution of source energy.

TABLE I

BIOASSAY OF THERMAL PROTECTION CAPACITY, AND PHYSICAL EFFECTS IN FABRICS DETERMINED BY EXPOSURE TO THERMAL IRRADIATION

Fabric	Treatment	Color	Weight (approx.) oz/yd^2	Time to burn*(sec)	Ratio $\frac{T_f}{T_b}$	Effect of fabric exposure**
cotton twill	fire retarded	tan	5+	21.8	1.72	Charred, no flame, no glow, disintegrated on touch.
cotton twill	fire retarded	orange	5+	23.6	1.86	Charred, no flame, no glow, disintegrated on touch.
wool gabardine	fire retarded	white	14	27.8	2.19	Charred, no flame, no glow, disintegrated on touch.
cotton sateen	none	black	9	11.6	0.91	Burned with glowing.
cotton sheeting	none	white	2.5	28.0	2.21	Browned, weakened.
nylon taffeta	none	dark gray	3	19.0	1.49	Melted.
nylon-cotton oxford	none	dark gray	> 5	19.9	1.57	Partially melted, stuck to backing, disintegrated on touch.
HT-1 exp. fiber twill	none	egg shell	3	33.1	2.61	None.
HT-1 exp. fiber twill	none	egg shell	4	34.5	2.72	None.

* Time to produce standard (1 cm diameter white) burn on albino rat skin covered by single layer of fabric at an irradiance of 300 mc/cm^2sec at which level standard burn occurs on bare skin on exposure for 12.7 sec.

** Fabric exposed at an irradiance of 715 mc/cm^2sec as single layer backed by single layer of white cotton sheeting (2.5 oz/yd^2).

The last group represents 2 synthetics and one mixture. The 3 oz. nylon is seen to offer little protection and to melt at the higher irradiance. The nylon-cotton fabric, though heavier in weight is not much better under these conditions. The last two fabrics listed are obviously the best of all those shown. These are fabrics made of DuPont experimental fiber, HT-1, so-named for its resistance to degradation by high temperatures. In the same weight fabric as the nylon it offers far greater protection to the skin and is totally unaffected by the radiation which melts the nylon. Heavier fabric offers more protection. Just how far this relationship of increased protection with increased weight can be carried profitably has not yet been determined. Investigation is underway to determine the optimal weight and construction. Some of the efficiency of the HT-1 material in resisting irradiation is due to its high reflectivity and may be expected to be reduced by soiling. However, the surface is slick and quite soil-resistant. Furthermore, the material may be washed as frequently as necessary and is a drip-dry fabric. At the present time no practical method for dyeing the fiber exists but efforts to do so are going on at DuPont and past experience would indicate that these efforts will be successful.

In any event, on the basis of the laboratory tests HT-1 fabric was selected as the best available for the purpose of fire-resistant anti-G suits. Accordingly, experimental suits were fabricated and subjected to contact with fuel flames in a manner calculated to simulate a crash fire. The system employed was simple. A store manikin was covered with leather to provide a pliable surface, the heating characteristics of which could be determined and readily related to those of living skin. For instance, the heating rate of the leather was found to be three times that of living skin; it was possible, therefore, to relate a given temperature attained on the leather surface with that which would have been attained on the skin under the same circumstances. At 20 points on this surface calibrated detector paper and precise melting point indicators were placed. The dummy was then dressed in regulation Navy underwear under the experimental anti-G suits. The hands were encased in asbestos gloves, and the feet in regulation flight deck shoes. A cable was strung across a 100-foot fuel pit and the dummy was suspended from the cable by a shackle. Another cable was attached to the shackle, led around a post beyond the far end of the pit and grasped by a runner. Fifty gallons of fuel were spread across 25-30 feet in the center of the pit to simulate one half of a circle of flame about an aircraft in a deck crash. The fuel was ignited by tossing a torch into the pit and the runner raced away from the pit at his best speed, pulling the dummy through the flames. An observer timed the flame-contact with a stop watch. The suits were examined after the run and the temperatures indicated at the 20 sites were noted. Previously obtained temperature-time data on skin burns (1) permit the evaluation of these temperatures in terms of burns in living skin, while the placement of the detection sites permits the determination of the proportion of surface affected (2).

Comparisons could then be made between the severity and extent of surface damage under different anti-G suit assemblies. The experimental results are shown in Table II. The fabric of choice was a 2/2 twill woven from 100 denier HT-1 yarn, and weighing 3 oz/yd^2, a weight equivalent to that of the standard nylon anti-G suit fabric. The assemblies tested were flight coveralls over the Z-3 model cutaway anti-G suit and the integrated anti-G suit-coverall, or Z-2 model. The time in contact with the flames varied from 3 to 4 seconds. The burn effects were evaluated in terms of the percentage of the total body surface area affected and categorized as "none" where temperatures were indicated to be less than 45°C at all times; "slight" where temperatures exceeded 45 but did not exceed 60°C; and "severe" where temperatures exceeded 60°C at any time. Thus, "severe" refers to any burn which would be characterized by blistering and classified as second degree or worse.

The "severe" category is the most significant figure in estimating incapacitation. As an experimental criterion, 40% was chosen as the maximum permissible area of severe burns from which survival and functional recovery might be expected. Since the area observed excluded the head and hands, it amounted to 88% of the total and, assuming the worst possible situation, the additional 12% of the body not observed could be included in the severely-burned area, therefore, the final figure for indication of adequate protection became a maximum of 28% in the "severe" category.

From the table of results (Table II), it is seen that the burned area with the single layer of 3 oz HT-1 fabric in contact with the flames for 4 seconds far exceeded this limit. However, inspection revealed that in areas where the fabric formed a double layer, as in pockets or over the anti-G suit, no burns were indicated. In the areas where burns were indicated most of these would have been severe.

The coveralls, therefore, were made of a double layer of the same fabric and the test was repeated. This assembly achieved the desired effect: the outside layer acted as a sacrificial cover and the underlying layer was unaffected. Only 8% of the body surface was indicated as severely burned, about 24% slightly burned, and almost half of the body completely unaffected.

For comparison, the regulation single layer, fire-retarded orange cotton coverall over the Z-3 was exposed for an equal time. Although it did not flame or glow, it did char, the underwear burned through in a number of areas, and 67%, or almost all of the surface beneath this assembly was indicated as severely burned. In addition, voluminous flames poured out, and dye and tarry residues were deposited on the underlying surface.

TABLE II

THERMAL PROTECTION CAPACITY OF ANTI-G ASSEMBLIES DETERMINED BY ESTIMATE OF SKIN BURNS PRODUCED BY ENVELOPMENT IN FUEL FIRE FLAMES

Fabric	Weight oz/yd^2	Assembly	Time in flames (sec)	Skin burn effect (% surface area)		
				None	Slight	Severe
HT-1	3	Single layer coverall over HT-1 Z-3 and cotton underwear.	4	32.6	3.5	45.5
HT-1	3	Double layer coverall over HT-1 Z-3 and cotton underwear.	4	48.7	24.2	8.0
Cotton	5+	Standard fire-retarded orange-colored coverall over nylon Z-3 and cotton underwear.	4	7.0	6.5	67.5
Nylon	3	Standard Z-2 over cotton underwear.	3	20.5	3.5	57.0
HT-1	3	Double layer HT-1 Z-2 over cotton underwear.	3	51.5	27.8	1.6

In tests on the combination coverall-anti-G suit, the standard nylon Z-2 suit in a 3-second exposure gave almost as poor protection with 57% of the area falling in the "severe burn" category.

In striking contrast, a double layer HT-1 Z-2 suit in a similar 3-second exposure showed less than 2% of the surface severely burned. This difference between the HT-1 clothing and the standard assemblies may mean to the airman the difference between discomfort and almost certain death following such an exposure. In the face of this evidence there can be no question of the efficacy and superiority of the HT-1 suit. It clearly indicates that with the face and hands protected the wearer could sustain with only minimal injury contact with fuel flames of 1200°C for about 3 seconds, or sufficient time for an uninjured man to break out of a 50-60 foot circle of flame.

In conclusion, it should be noted that the HT-1 fabric is not intended to supplant asbestos fire-fighters suits, nor to be the answer to all thermal protection problems. It is anticipated that for energies of nuclear detonation magnitude and characteristics, quite different fabrics will prove to be more suitable. However, for the immediate problem of fire-resistant flight clothing, the HT-1 fabric offers comfort, durability, washability, more than adequate strength, and a good measure of positive thermal protection over and above freedom from the hazard of melt-drop burns.

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