Engineering Notes

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Personnel Thermoprotective Systems—II

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Introduction

IN a previous paper, presented at the Aero-Space Medical Association meeting in April 1967, the considerations involved in protecting aviators, wet-suit divers, and others against dangerous, unsafe environmental temperature extremes were delineated. Especially in the case of the aviator, it was pointed out that since the present state-of-the-art does not permit the design of an aviator's flight suit capable of keeping him cool under all cockpit operating conditions and warm on ejection into ocean waters, it appears that cooling and heating devices become necessary supplements. Possible simplifications of present air-conditioning systems, in conjunction with suit design, are suggested. Necessary temperature conditioning supplements must be mutually noninterfering. Whatever is done to cool the aviator during operation must not interfere with measures to protect him during emergencies when he finds himself afloat in the ocean. For personnel cooling during operations, present or supplemental cryogenic gas supplies can be adapted to furnish necessary cooling while simultaneously providing air for breathing. For heating while afloat in the ocean, the heat available in a chemical mixture with an exothermic heat of solution in water is a feasible heat source. Tests performed on such a mixture and results obtained are described in subsequent paragraphs.

Cooling and Breathing

In pursuing the idea of supplying breathable gases while simultaneously cooling aircraft interiors, occupants, and equipment, a cryo pack was located (marketed by Firewel Inc., Buffalo, N. Y.) which appears to offer much promise. This device is small and produces breathable air, not oxygen, by an ingenious placement of a cryogenic oxygen container, within a cryogenic nitrogen container, thereby constraining the gases to boil-off at the same temperature but different pressures. After passing through heat exchangers, the gases are forced to mix in the proper proportions prior to breathing.

According to Ref. 1, the aforementioned system is designed to provide 40 standard liters per minute of air with the oxygen absorbing 246 Btu/hr and the nitrogen absorbing 787 Btu/hr to convert the liquids to superheated gases at about 60°F when the temperature environment is 70°F. This total, 1033 Btu/hr, is sufficient to at least partially balance a body heat output which can vary from 70 to 700 kcal/hr (or from 278 to 2780 Btu/hr).[2]

According to Ref. 3, the work done in basal metabolism and during the muscle contraction of exercises can be equated with the amount of oxygen consumed by the body. A properly balanced system using a cryogenic cooling and breathing supply could then be expected to supply increased oxygen and cooling effect with increases in body heat output.

Such a system might resemble Fig. 1 which indicates schematically a double heat exchanger in which a liquid is cooled by a cryogenic heat sink and a gas (such as air) is cooled by cold exhaust gas from the cryogenic container. Preliminary calculations and results of tests performed in support of Hydra (a missile sea-launch project) indicate that such a design is feasible. The possible implications for the simplification of man-weapon systems cooling equipment and the added safety of air, rather than oxygen, breathing should be thoroughly investigated.

Heating

The previously described equipment would function as part of the aircraft. Upon ejection, the aviator will often find that his personal temperature problem has suddenly become reversed. He may, after successful ejection, find himself exposed to the extreme cold of freezing salt water and low air temperatures. Even much milder conditions may have serious consequences. For example, a recent TV program interviewing a pilot who had ejected in the ocean near Viet Nam brought out the following facts: 1) the pilot's physical condition was poor, since he had a broken neck and one arm was useless; 2) in climbing into his raft he punctured it and was therefore forced to reinflate every 20 min during the next 3 days and nights while awaiting rescue. When asked what his greatest difficulty during this period was, he replied, "I was cold." This was in relatively mild temperature conditions while suffering pain and hunger pangs.

In establishing the requirements for the downed aviator, it may be well to quote the following from Ref. 4:

> Conductive heat loss from the immersed nude body occurs at all water temperatures below body temperature. When the temperature difference between the body and the water amounts to 15°C, body heat loss threatens life within 24 hr. At tempera-

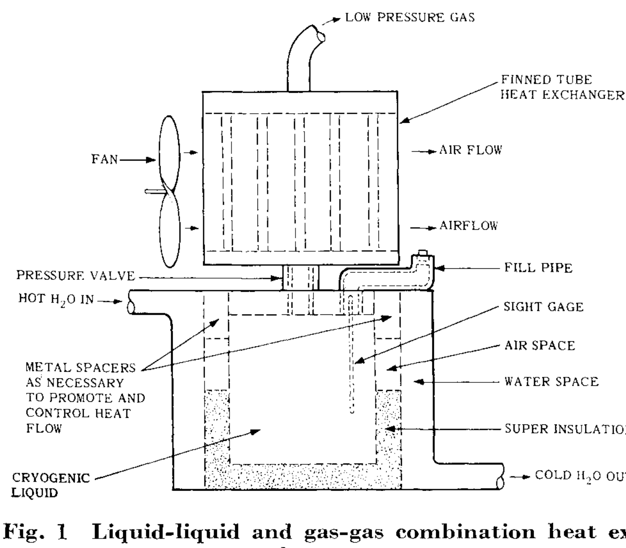

Fig. 1 Liquid-liquid and gas-gas combination heat exchangers.

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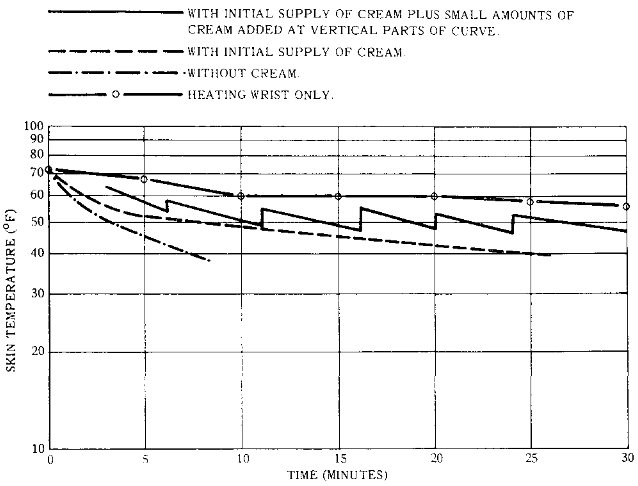

Fig. 2 Test results—hand heating.

ture differences greater than this, failure of body thermal balance may become critical in a matter of hours or even minutes if the immersion is in freezing sea water.

Even though the downed aviator is not nude and may not be immersed, he does have the problem of excessive body heat loss, as evidenced by the foregoing TV interview and by the results of tests performed at Naval Missile Center.[5] Any supplemental heat devices will of necessity be on his person or in his raft. These devices must also satisfy the previously stated requirement of posing no interference with cooling aids on the aircraft.

In considering solutions to the downed aviator's body heat loss problem, it is wise to make use of any available material or substance to provide heat. Since he has an unlimited supply of water, it would be reasonable to supply him with a substance which when mixed with water generates heat. This thought, upon implementation at Naval Missile Center, led to the development of "Thermal Cream."

Chemical Approach

Thermal Cream is a chemical product, which, upon mixing in water with agitation, produces heat due to an exothermal heat of solution of its main constituent in water. This product consists of a mixture of calcium chloride buffered by inert materials. An unclassified technical report describing this product has been prepared and is available for unlimited distribution.[6]

Handling safety of the product on a short-term basis is quite satisfactory. Its long-term effects are under investigation. The questions that become uppermost after the above statements are: (1) how long will thermal cream heat last?

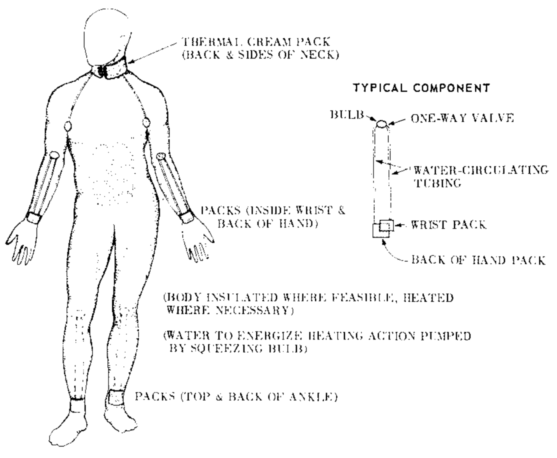

Fig. 3 Thermal cream heating system.

Table 1 Probable preferred distribution of skin temperature and heat loss for unacclimatized subjects (about 90% of the heat is lost as sensible heat, the remainder by evaporation)

Region	Area, m²	Temperature, °C	Heat loss k cal/hr	Heat loss k cal/m²hr
Head	0.20	34.6	8	41
Trunk	0.70	34.6	29	41
Thighs	0.33	33.0	12	36
Calves	0.20	30.8	15	75
Feet	0.12	28.6	10	83
Arms	0.10	33.0	8	80
Forearms	0.08	30.8	9	113
Hands	0.07	28.6	8	114
Total	1.80		99	

and (2) how much is required? Neither question can be answered until certain variables are established. For example, we must decide what areas of the body to heat, and what water temperature to design for.

Heat Loss Distribution

In deciding what areas of the body to heat, Table 1[3] appears useful. The extremities suffer the greatest heat losses per unit areas as indicated in Table 1. Since these extremities, especially the hands, are also the most difficult to insulate, it appears that supplementary heating is required in at least some areas of the body.

Heating Methods

In attempting to answer the previous questions of how much and how long, with respect to thermal cream, two approaches were taken: 1) the heating medium was trapped and circulated about the extremity, the hand, within a glove closed at the wrist; 2) the heating medium was enclosed in a pack secured around the wrist, warming the blood at this point and allowing the gloved hand to be warmed by heated blood transport. In these fairly crude preliminary tests, the second approach proved superior, as can be seen in Fig. 2, in which approximately equal amounts of cream applied as described previously produced quite different results.

All of these tests were performed using a $\frac{1}{32}$-in.-thick glove to cover the hand, thrusting same into a bucket of ice water, and determining a temperature-time curve by reading from a thermocouple inserted into a callus on the hand. Taking the curves in order, beginning with the largest temperature drop rate, is a curve showing a drop from 70°F to 40°F in 7 min with a dry glove and no cream. Next, 140 g of cream were placed in the palm of the hand, ice water was allowed to enter the glove and the glove was secured at the wrist. The hand was opened and closed to achieve agitation, and a drop from 72°F to 40°F occurred in 25 min. This test was repeated adding small amounts of cream from time to time, maintaining a temperature of 46°F or higher for 30 min using 200 g of cream. Finally, the wrist was covered with a pack containing about 190 g of thermal cream and was fitted with a squeeze bulb for injecting and agitating water. In order to achieve a slow and fairly even temperature drop from 70°F to 55°F over a period of 30 min the squeeze bulb was agitated for 2 min and then released for 2 min.

Errors are introduced into these results due to the fact that only a part of the body is immersed in the ice water bath. These errors should be consistent in comparing results between tests. Quoting Ref. 2,

Below this temperature, 50°F, there was a striking increase in hand blood flow, which was frequently as large as at a water temperature of 95°F. If, except for the hand, the subject was comfortably warm, alternating vasodilation and vasoconstriction occured ("hunting"). If the subject was chilled, the degree of increased blood flow was reduced. If the subject was uncomfortably warm, the blood flow in the hand remained high even in water at 10°C (50°F). Therefore, it would seem that the general body heat balance must be maintained before the local vasodilation of the fingers can be mobilized to provide heat to the fingers.

This suggests that heating of the extremities plus adequate insulation of other body parts is the proper method of attack.

It is anticipated that with a suit providing voluntary closure of wrist, ankle, and neck openings these would be secured and heating packs as shown in Fig. 3 would be applied to these points. The bulbs shown would be filled with water and the water agitated by bending the limbs or squeezing arms together in the case of the neck. Alternatively bulbs could be squeezed by hand. Placement of the bulbs may vary from that shown. This arrangement allows wearing of close fitting gloves and other clothing. Although the downed aviator might still be cold, this arrangement would tend to alleviate his discomfort and prevent serious consequences from immersion.

Applications

Given body core temperature drops, and applying the recommended body specific heat of 0.83 Btu/lb/°F[3,7] and a thermal cream heating value of 380 Btu/lb,[6] calculations can be made to determine the total amount of cream required to replace body heat losses, as follows:

$$\text{cream consumption} = \frac{\text{heat loss}}{\text{heat of reaction}} =$$

$$\frac{(\text{body core temp drop})\ (\text{body wt})\ (\text{body specific heat})}{\text{heat of reaction}}$$

For the following values[5]:

$$\text{body core temperature drop} = 1.03°\text{F/hr}$$

$$\text{body weight} = 192 \text{ lb}$$

we obtain cream consumption = 0.432 lb/hr. The distribution of this material should be in proportion to the heat losses as given in Table 1:

$$\text{hands } 0.133 \text{ lb/hr} + \text{feet } 0.166 \text{ lb/hr} + \text{neck } 0.133 \text{ lb/hr} = 0.432 \text{ lb/hr}$$

If this source of heat is utilized, it should be pointed out that storage in plastic bags is feasible, including storage under water. Laboratory tests have demonstrated that a properly designed bag will allow the cream to be ejected under water with only slight surface spoilage. In using this or other heat sources, the preliminary tests described herein suggest that heating wrists, ankles, and neck, and insulating other body parts will provide heat that will then be distributed and conserved throughout the body, with a minimum of body heat losses. The success of applying heat to wrists, ankles, and neck for whole-body heating might lead to a similar cooling method providing comfort by a properly designed suit together with cooling of wrists, ankles, and neck.

Conclusions

It is apparent that solutions to aircraft personnel temperature problems involve man-weapons systems, materials, supplementary temperature conditioners, and the interactions of many operational and environmental variables. Extensive analysis of available data, research in new methods and materials and a great deal of careful work by physicians, physiologists, engineers, and others using an integrated systems approach will be required before completely satisfactory designs for all conditions are achieved. However, the goal is worth the effort and the fallout in the areas of ocean and polar exploration should prove to be extremely valuable.

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