

CHAPTER 5

PHYSIOLOGICAL EFFECTS OF HEAT AND COLD

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Introduction

1. Current British defence policy is centred in NATO, although overseas deployment and reinforcement may take place from time to time. Although aircraft operation is no longer generally on a world-wide basis, extremes of temperature may be encountered within Europe during operations in support of our NATO commitment. In hot countries an aircraft may take-off at a ground temperature of over 40°C and within minutes be at high altitude with an outside air temperature of about -55°C. As aircraft speeds increase, the climatic temperature variations will be further aggravated by the effect of kinetic heating of the aircraft skin causing an increase in cabin temperature above the ambient level.

2. In the following paragraphs the various factors associated with temperature variations will be examined and also the methods whereby aircrew are protected in order to maintain their efficiency.

Sources of Cold

3. The main source of cold from which aviators have to be protected constantly is the low temperature of the atmosphere at heights above 10,000 ft. The temperatures at various altitudes are shown in AP 3456A, Part 1, Sect 1, Chap 1, Fig 1, but briefly, the air temperature falls progressively in the troposphere to about -55°C at approximately 35,000 ft. In the stratosphere the temperature is constant at that figure to an altitude of about 80,000 ft. Above this height

there is a progressive increase in air temperature but the air is so thin that temperature in the ordinary sense begins to lose its meaning.

4. High altitude is not the only cold source however. Aircrew may be based in countries with a cold climate and in-flight emergencies in these areas may lead to a cold weather survival problem either on land or in the sea. But low water temperatures are not confined to polar seas; near freezing water temperatures are quite common in the North Sea and except for coastal waters, the sea temperature varies only slightly throughout the year. In a water temperature near freezing the survival time for an unprotected man can be measured in minutes.

Sources of Heat

5. Some staging posts on overseas deployment are located in hot climates. Aircraft may overfly different types of terrain so that aircrew are frequently exposed to the possibility of desert or jungle survival, even though they may not be based in such areas.

6. Due to the problem of possible exposure to very low temperature during long range flights, aircrew may have to be protected by warm, well-insulated clothing or even a garment impermeable to water to provide protection in the event of sea survival. These garments increase any heat load present in the cockpit during routine flight.

7. Kinetic heating has now become a significant source of heat in high-performance aircraft, particularly at low level. The temperature

increase is caused by the friction of the aircraft passing through the air and considerable rises in temperature can occur. The temperature rise due to kinetic heating is given by the formula:

$$T^{\circ}\text{C} = 0.85 \frac{V^2}{100}$$

where $T^{\circ}\text{C}$ = Temperature rise in degrees Centigrade

V = Indicated air speed in knots

Thus at 600kt, the temperature increase would be just over 30°C .

Physiological Classification of Thermal Environment

8. The components of the thermal environment which contribute to thermal stress are the ambient air temperature, air movement, humidity and solar radiation. In aircraft a significant contribution to the heat load is made by avionic equipment. Metabolic heat production by the body must be taken into account when clothing with a high thermal insulation is worn. Bearing these variables in mind, it is convenient to classify the environment according to the severity of the thermal stress imposed by that environment:

- a. *Very hot.* Environments in which a normal body temperature cannot be maintained without artificial cooling.
- b. *Warm.* Environments in which a normal body temperature can be maintained for long periods by natural physiological means, eg sweating and circulatory changes.
- c. *Comfortable.* Environments which provoke neither sweating, nor an increase in heat production by the body, above the minimum required for the task.
- d. *Cool.* Environments in which a normal body temperature can be maintained for long periods by natural physiological means, eg shivering and circulatory changes.
- e. *Very cold.* Environments in which a normal body temperature cannot be maintained without artificial heating.

Human Temperature Regulation

9. The human body acts as a thermostat maintaining thermal balance at a core temperature of 36.7°C . This temperature may fall to 36.0°C and rise to 38.5°C , depending on environmental condition and work load, without serious physiological effect. The performance of skilled tasks may, however, be impaired whenever there is a departure from thermal comfort.

A zone of thermal comfort may be defined as a core temperature of $36.5^{\circ}\text{C} - 37.5^{\circ}\text{C}$ and a mean skin temperature of $33^{\circ}\text{C} - 34^{\circ}\text{C}$, when in the resting state. The human body is continuously producing its own heat internally by metabolism of foodstuff, although metabolic heat production is not an important factor in thermoregulation.

10. The mechanism by which body temperature is regulated may be compared to a control system. Thermal information from the skin, and possibly elsewhere, passes to the temperature regulating area of the brain. This information may initiate, or inhibit, various thermoregulatory responses.

11. The normal mechanism of temperature control of the body is by means of an adjustment of the blood flow to the skin. The four main responses to exposure to heat and cold are:

- a. In cold conditions the blood vessels on the surface of the skin constrict to reduce the amount of heat loss.
- b. In warm conditions, the opposite effect occurs and the surface vessels dilate to increase the heat loss from the skin.
- c. If the cold conditions get worse, a further response occurs later than that described above at sub-para a. This takes the form of progressive muscular activity starting as an increase in muscle tension and leading to involuntary shivering and also voluntary limb movements, such as stamping or arm swinging. This increases the heat production of the body.
- d. Sweating is another major response to changes in ambient temperature. There is some water loss at all times from the body surface, but as the temperature rises the sweat glands come into action and provide evaporative cooling.

12. The lungs are not involved in temperature regulation in humans. Heat loss from the lungs becomes increasingly important, however, as ambient air temperature decreases and at low humidities.

Effects of Heat

13. Thermoregulation in a hot environment is achieved predominantly by the evaporative cooling of sweat produced at the skin surface. If this evaporation is impaired or prevented—eg by clothing—overheating (hyperthermia) will result. The dangers of overheating are:

- a. Impairment of mental efficiency.

- b. Restlessness, headache, nausea, faintness and unconsciousness.
- c. Fatigue.

Fatigue will also lead to an impairment of mental function if a number of sorties are carried out in the same day.

14. Another danger associated with exposure to high temperatures is concerned with the loss of salt in sweat. A person who is sweating profusely must ensure an adequate intake of salt as well as water, otherwise he may feel weak and faint from salt deficiency.

Acclimatization to Heat

15. When exposed to hot climates the body adapts itself to the new conditions. After some two weeks in the new environment the body acclimatizes by means of changes in the temperature regulating mechanism. Firstly, the normal sweating response is made more efficient as a means of cooling the body. This is done not only by the increased production of sweat, but more particularly by the fact that it takes place more readily and also occurs over a larger area of the body. This overall improvement helps to maintain a lower skin temperature for a given ambient temperature. Secondly, there are circulatory changes which result in an improved ability to perform work effectively, and without fatigue, in the heat.

16. In order that heat acclimatization can be of practical benefit to the individual it follows that conditions must be such as to permit the evaporation of sweat. In most areas, this is true on the ground when wearing ordinary clothing. An individual feels more comfortable when he is heat acclimatized and he will feel cooler when he enters his aircraft in hot climates than will someone who is not so adapted.

17. Acclimatization may be achieved artificially by maintaining a core temperature above 38°C for 1-2 hours each day for 2 weeks. This may be accomplished by immersion in hot baths, by exposure to a hot environment in a climatic chamber, or by exercise wearing clothing with a high thermal insulation.

Effects of Cold

18. As the temperature of the environment falls below levels at which the maximum possible closing down of the surface blood vessels is achieved (as classified in para 8e), the temperature of the body falls. As the intensity or duration of exposure is increased, so the

severity of the effects will increase. Shivering gives way to muscular rigidity and as the body temperature falls further, unconsciousness supervenes.

Frostbite

19. If a part of the body is exposed to very low temperatures, frostbite may occur. The closing down of the surface vessels is so complete that it stops circulation altogether and the skin of the chilled extremities goes white, the flesh feels hard and the part feels numb. Finally all the tissues freeze hard and the affected area becomes stiff and rock-like.

20. The current treatment for frostbite, whilst the tissues are still frozen, is rapid rewarming. This can best be done in warm water at a temperature between 42°C and 45°C. At this temperature, water feels hot to the normal hand but not too hot for prolonged immersion. In the absence of heated water, the next best thing is to put the frozen part against the armpit or groin.

Conditions in the Crew Compartment

21. It is desirable to maintain aircrew within the comfort zone (as defined at para 8c) in the crew compartment but this is frequently impossible and the individual's ability to cool himself by the evaporation of sweat is often relied upon. This could lead to considerable discomfort unless it is possible for the sweat to evaporate as efficiently as possible by permitting an adequate airflow over the skin surface. At the other end of the scale, a certain amount of cooling may have to be accepted towards the end of a long flight but it must never be such as to provoke shivering.

22. Normal cockpit temperatures should be controlled between -5°C and +25°C. At low ambient temperatures the conditioning system should be able to maintain at least -5°C and at the other end of the scale it must be able to keep it below +25°C, except for short periods of time when, due to kinetic heating, the temperature may rise to +33°C.

23. Cockpit temperatures will be affected by a variety of factors such as ambient air temperature, solar radiation, colour and surface finish of the aircraft, internal sun blinds and kinetic heating effects. On the ground in hot climates the use of cockpit covers and ground cooling trolleys will keep the internal temperature down between flights.

24. In flight, certain emergencies may have significant effects on the cabin temperatures. The loss of a canopy for example, will lower the cockpit temperature close to that of the outside air. On the other hand, small holes in the pressure cabin may, in some aircraft, initiate flood flow to maintain pressure, thereby creating resultant cockpit temperatures as high as +60C to +100°C.

Protective Measures

25. There are a number of protective measures available to aircrew whereby the problems of thermal stress may be reduced:

a. *Protection of Crew Compartment on the Ground.* In hot countries, the problem of keeping crew compartments cool on the ground between flights is important. This has been done by three methods; either by the use of ground cooling trolleys or by means of a large wheeled sunshade covering the aircraft canopy or, alternatively, a "thermal blanket". The thermal blanket is made up of three layers of fibreglass sandwiched between outer skins of reversed and aluminized dinghy fabric and can be made large enough to cover the entire crew compartment of an aircraft. Used in conjunction with a cold air source supplying cooling air to the cockpit it can be particularly effective.

b. *Cabin Conditioning.* The availability of air conditioning in aircraft cabins is very valuable, particularly in modern high-performance aircraft. Gas turbine engines are able to supply relatively large volumes of air for this purpose. As aircraft speeds become greater, so the problem of cooling the cabin is intensified until a limit is reached at which further cooling cannot be achieved without impairment of aircraft performance. At this stage, the weight of refrigeration equipment would be a limiting factor.

c. *Flying Clothing.* The value of a many-layered clothing assembly and clothing with

a high insulative quality is of great value as a protection against cold. It does, however, present problems at other stages of flight when cockpit temperatures may be high. This has led to the development of a ventilating garment as part of the flying clothing assembly. This is particularly useful in cases where aircrew wear immersion suits as protective garments in case of sea survival.

d. *Air Ventilated Suits (AVS).* The function of the air ventilated suit is to blow cool dry air beneath clothing and thereby keep the wearer cool although the environment may be very hot. When supplied with air of the correct temperature and humidity, the air ventilated suit performs this function well. Ideally the suit should be functional from the moment the flying clothing is put on. This could be achieved by having an AVS supply available at all points between the changing room and the aircraft.

e. *Liquid Cooled Suits (LCS).* Liquid cooled suits operate on the same principle as the AVS system, with the advantage that liquids have a much higher thermal capacity than air. More cooling may therefore be provided with less fluid. By using warm liquid, the suit may be adapted to provide thermal protection from cold. The LCS is ideal for situations where no AVS supply is available—eg in helicopters.

f. *Electrically-Heated Clothing.* The latest type of electrically-heated clothing has the heating element knitted into the material. This ensures more uniform distribution of heat than did the old system which relied on relatively few wires. The new garments are made up as vests, long pants, socks and gloves. The socks and gloves may be particularly useful since it is often difficult to keep the hands and feet warm. This is particularly so in the case of the hands as the heating must be achieved without impairing manual dexterity.

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