Symposium Paper

AEROMEDICAL PROBLEMS OF HIGH SPEED LOW ALTITUDE FLYING

Heat Problems in High Speed Low Level Flight

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The Problem

HIGH speed low level flying during the summer in tropical areas results in cockpit temperatures of 50° C and above[12,14,20]. The heat load occurs due to aerodynamic heating of the boundary layer of the aircraft[21], solar radiations, avionics and the pilot's metabolic heat. Most of this heat load is due to the kinetic or aerodynamic heating in high performance aircraft[1]. Inflight cockpit temperatures recorded during two high speed low level (100 M AGL) missions and their effect on the observer's body temperatures are shown in Figs 1 & 2. The increase in cockpit temperatures of about 9-12° above the air temperature is similar to that reported by Nunnley and James[17]. It is therefore not difficult to conceive the degree of heat load in the cockpit when outside air temperatures are high.

Simulation of temperature and humidity conditions likely to be met with inflight have resulted in oral (TO), mean skin temperature (TSK) and mean body temperature (TB) of about 38.5°C, 38.7°C and 38.6° C respectively at the end of 30 minutes of heat exposure[18] in an environment where the Oxford Index (WD) was 44.9° C. In a more recent study in this laboratory with a WD of 38.7°C, the TO, TSK and TB reached 38.6°C, 37.9°C, and 38.5°C respectively.

Moderately large increase in body temperatures seen under inflight and simulated laboratory conditions is due to direct body heating. An attempt is immediately made by the body physiology to restrict an excessive body heat accumulation.

The increase in sweating which could be due to either a rise in core temperature[13,15] or skin temperature[11] is an important heat dissipating mechanism.

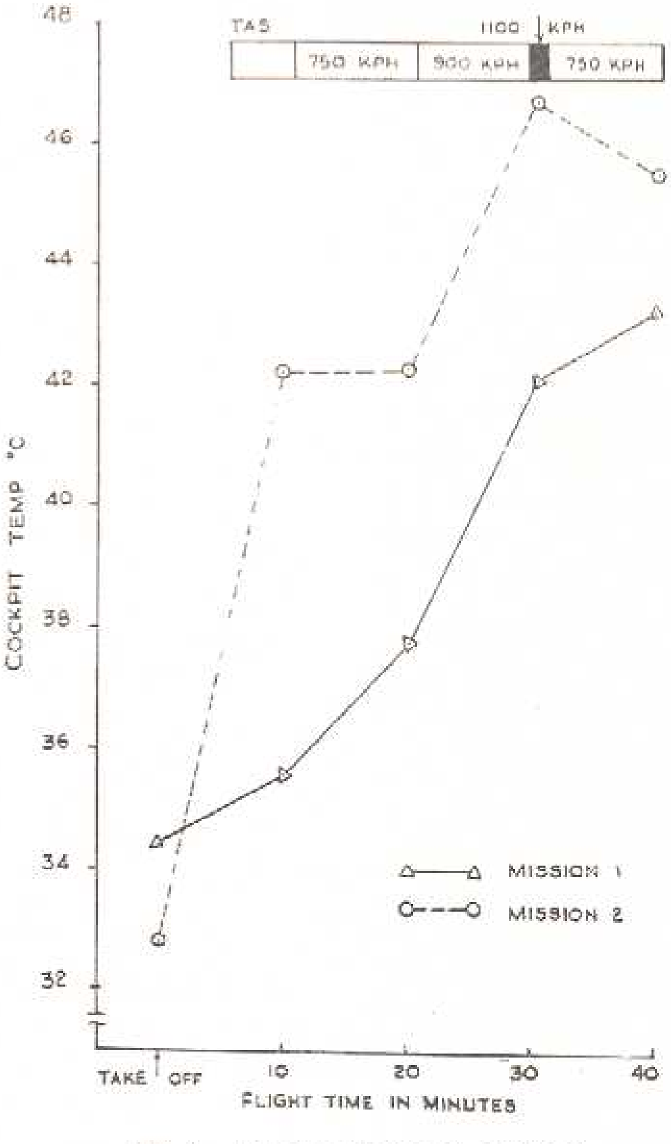

FIG. 1 IN FLIGHT HEAT STRESS

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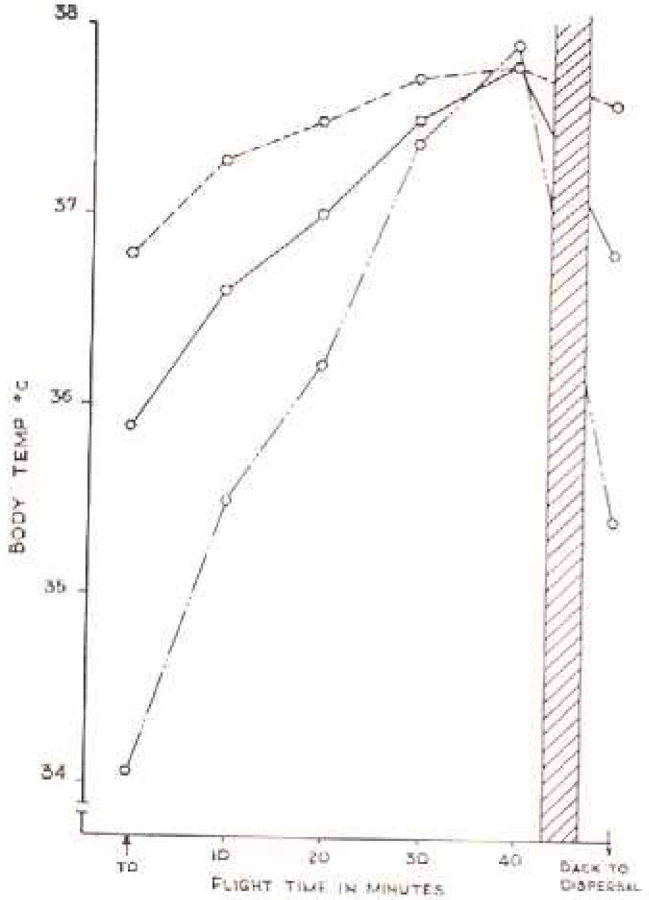

FIG 2 IN FLIGHT BODY TEMP

Cooling by sweat evaporation is by far the most effective method of heat dissipation as other routine measures such as convection, conduction and radiation are rendered ineffective due to the very high environmental temperature. In fact these options contribute to the heat gain by body surface when environmental temperature is excessive. Exposure to such heat stress results in a sweat loss of about 0.7 kgs/hour[7] at a WD index of 37°C which amounts to about 1% of total body weight.

The cardiovascular system bears the brunt of heat stress and responds by an increase in heart rate, cardiac output and a reduction in peripheral vascular resistance. This mechanism in conjunction with the high heat conductivity of blood[16] helps to dissipate the accumulating heat.

In spite of the compensatory mechanisms, the body temperature keeps on rising and ultimately at about a core temperature of 39—40°C and a hea
rate of around 180 beats/min the collapse point
tolerance to heat stress in reached[6]. Tolerance ti
is best related to body heat storage and at a he
storage level of about 77 Kilocals/m^2, the end poi
to heat tolerance is said to have been reache
However, a pilot flying a high performance aircra
will have forefeited his flying efficiency long belo
such an end point. Blockley et al[4] have suggest-
that performance decrement occurs significantly at
body heat storage level which is about 70% of that
tolerance time. For well acclimatized tropical su
jects the level of heat storage at tolerance point,
calculated from Sinha and Verghese (1969)[18],
about 110 Kilocals/m^2 and at performance decr
ment, about 70—80 Kilocals/m^2 will be accumulate
This is borne out by our experiments (Fig 3) wherei
at the end of 50 minutes of heat exposure at a sim
lated WD index of 38.7°C, the heat accumulation
about 88 Kilocals/m^2.

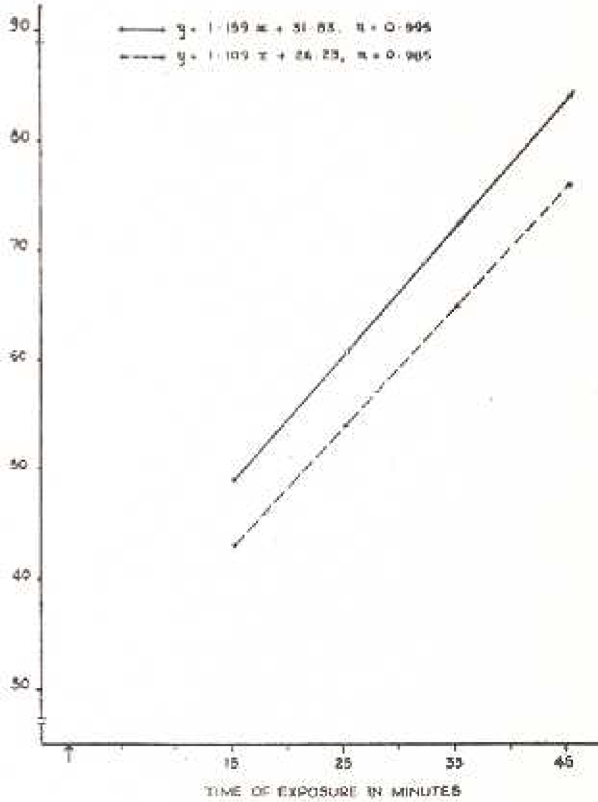

FIG 3 BODY HEAT STORAGE (KILO CALS/M^2) IS PLOTTED
AGAINST TIME OF EXPOSURE IN MINTS. (•——•) AIR
BREATHING (•- - -•) O^2 BREATHING EXPERIMENTS
THE EQUATIONS ARE REGRESSION EQUATIONS

Performance under Heat Stress

Flying is a complex psychomotor activity requi
ing a high degree of alertness, mental function an

muscular co-ordination and is more subjected to deterioration under adverse conditions[8]. In their study on a flight simulator, these authors concluded that there was a significant decrement in performance measured in terms of deviations from a set flight path when the cockpit temperature was raised to 60°C with a RH of 11%(WD index of 35°C) which was lesser than the simulated WD of 38.7°C in our experiments. Furthermore, the core temperature in their subjects did not exceed 37.5°C at 50 mts while the skin temperatures increased to about 38.5°C. The mean body temperature was about 38.5°C as against 38.8°C in our study. It is also of interest to note that the performance decrement was not always related to time of exposure to heat stress and did not have any clear cut relationship with physiological changes induced by the heat. This ambiguous situation is explained by the fact that the complexity of the psychomotor task may influence performance[8]. This study also established that routine psychomotor tasks could be performed without any significant deterioration in performance while the more complex tasks were adversely affected due to the heat stress. On the other hand, Wing[23] has commented that the upper thermal limit for unimpaired mental performance is dependent upon time of exposure to heat. Also, the physiological tolerance limits are well above the temperature duration curve for mental performance. This was further highlighted by Grether[4] who mentioned in his review that performance decrement occurs rapidly as environmental temperatures exceed an effective temperature of 85°F. However, in the initial phase of heat stress there is probably greater arousal and performance may increase.

In the cockpit of a high speed fighter aircraft, the heat stress reached induces a body heat storage level of about 70-80 kilocals. which even by the standards of well acclimatized subjects, impinges upon the levels of performance deterioration. Keeping in view the earlier discussed observations that the deterioration of peformance in a highly complex task may occur independently of strain, one has to consider that such a situation can occur often during low level high speed flights and hence some measures need to be adopted to relieve the heat load as far as possible.

Alleviation of Cockpit Heat Stress

Cabin air conditioning: The most obvious solution to solving the problem of acute thermal stress in the cockpit is the provision of an adequate cockpit airconditioning system. However, to date in most of the high performance military aircraft, this facility is still very variable and considerations such as strategic utility, payload and aircraft design prevent the evolution of an ideal system. Other modes have thus to be resorted to.

Precooling

Body cooling can extend heat tolerance[18,19]. The body is like a tank of water which can get heated to a certain temperature. If the tank can be cooled prior to heat exposure, it will take longer to reach peak temperatures[21]. With this analogy, Veghte & Webb[19] used precooling to increase the tolerance time of their subjects. Sinha and Verghese[18] showed that the time taken to reach the body heat storage levels at tolerance limit was delayed by 8-10 mts. They quote Veghte & Webb and explain this extension of tolerance by saying that this is the time taken in restoring body heat storage level to control values. It is also possible that precooling initiates sweating at a much lower core temperature. However it was observed that total sweat output remains the same with precooling as compared to non precooling experiments and therefore it is possible that the sweat rate is different in the two conditions[18].

Precooling for 60 minutes was carried out on their subjects by these authors at a temperature of 17°C DB and 13°C WB. Such a feasibility exists at squadron levels where aircrew can be pre-cooled in airconditioned crew rooms for about 45-60 mts prior to undertaking a mission.

Air Ventilated Suits

Air ventilated suits may be used to create a microclimate around the body and remove excess heat[9]. Cold air can be pumped through the AVS to produce convective and evaporative cooling. Such an air supply is obtained from the engine air passed through a system of heat exchangers. The inlet air temperature depends inversely upon the cockpit air temperature and during high speed low level flight with cockpit temperatures ranging upto 60°C, the inlet temperature will have to be very low in order to achieve an optimum heat loss from the body and maintain the skin temperature around 33°C. The aircraft heat exchanger system is inadequate to meet such stringent requirements during low level high speed flight in the summer and therefore this method of producing a comfortable microclimate around the body is not very effective.

A less demanding AVS system as used in the IAF consists of the suit connected to a venturi outside the cockpit. The pressure drop created between the suit and the venturi during high air speeds sucks out the air of the micro environment around the body and provides evaporative cooling by removing some amount of saturated air immediately surrounding the sweating skin. The method may not be subjectively effective as felt by a number of our pilots but objectively within a certain range of cockpit temperatures, it is of some value in alleviating heat stress. It has also been suggested that the AVS could be connected to an oxygen supply in the aircraft and short burst cooling towards the end of the mission could be used to reduce the heat stress[20]. Laboratory experiments have shown that such a procedure delays the rise of MBT to intolerable levels.

Liquid Cooled Suits and Systems

Water has a higher conductivity than air and if subjects are immersed in water at about 16°C for 60–90 mts their tolerance time is extended more as compared to exposure to cool air at 7.2°C[19]. Circulating cold water around the body has also been shown to be an effective method of attenuating body heat storage [17]. This method comes of use especially under conditions where evaporative cooling on which air ventilation suit method depends, is limited due to very high humidity conditions or when the subject wears insulated clothing. Shvartz and Beno
introduced a liquid cooled garment which cover
92% of the body surface area while water conducti
tubes in the garment covered 15% of the total bo
surface. With this implement they reported marke
reduced heat strain in all their subjects, the sign
cance being at the 1% level[17]. This was achieved
a DB temperature of 50°C.

It has been shown at IAM that there is a mark
reduction in physiological strain of subjects weari
a liquid cooled garment through which was circulat
a 50% glycol in water solution cooled by a Fre
cooling system[2]. The flow rate of the liquid w
about 1.75 L/min and inlet temperature ranged fr
18°C after 1 mt of starting the circulation to abo
26°C at the end of 30 mts. In an extend
study of a similar nature where the circulati
glycol water mixture was cooled by passing
through a small portable ice pack, the he
strain in a moderately severe hot environment w
effectively reduced even after 60 mts of exposu
(Table I). Further trials were conducted by givi
bursts of liquid cooling for periods of 3 mts or so
intervals of 7 mts. This conserved the melting ice
the pack as well the power used. It is not necessa
to eliminate heat stress completely [17] nor will it
practical to do so. However a method of protecti
which will delay the onset of performance deteri
ration and thus increase tolerance to heat stress f
the duration of a high speed low level mission w
serve the purpose. The system just described
expected to achieve this aim and further experimen

TABLE I

Changes in physiological parameters after 60 mts of heat exposure
(modified from extension of work by Baner jee etal[2])

		Mean skin temp.		Oral temp.		Heart rate		Sweat loss in Gm	
		Without LCS	With LCS	Without LCS	With LCS	Without LCS	With LCS	Without LCS	Wit LC
1.	Control	33.7	34.8	37.1	37.2	82	82		
	60 mts.	36.9	34.9	37.8	37.3	103	80	792	34
2.	Control	34.9	34.7	36.9	36.8	88	84		
	60 mts.	36.6	35.1	37.3	37.1	104	76	566	31
3.	Control	34.5	34.1	36.7	36,7	76	68		
	60 mts.	37.2	35.5	37.5	37.2	104	72	453	17

to make such a system available in the aircraft are in progress.

Liquid Cooling of the Head

Isolated head cooling has been advocated as a means of reducing heat strain [4,10,22]. The procedure reduced sweating and core temperature during heat exposure. This could be attributed to a high concentration of thermoreceptors in the face and head region or a presence of a counter cooling exchanger system in the same area [10]. The water cooled cap used by Fonseca [4] removed from a heated manikin, heat storage which amounted to about 33% of the total metabolic heat production in a seated person. Sweating, which is by far the most important mechanism of dissipating excess body heat, is under control of hypothalamic heat sensitive neurons [11]. A fall in hypothalamic temperatures by head cooling may reduce the degree of sweating needed to alleviate heat strain and in fact escalate the heat effects by promoting a rapid heat accumulation. In view of this isolated head cooling may be viewed with suspicion even though successful experiments have been reported[10].

Use of 100% O_2 in Low Level High Speed Flight

A recent series of experiments in this laboratory have indicated that breathing 100% oxygen during heat exposure in a simulated environmental temperature of 57°C DB with a RH of 25% significantly reduces heat storage at the end of 50 mts., as compared to air breathing under similar conditions (Fig. 3). The extension of tolerance time is about 8–9 mts as the body heat storage of 79 Kilocals m^2 at the end of 50 mts of exposure with 100% oxygen, occurs at about 41 mts of breathing ordinary air. Air breathing for the same period results in a heat gain of about 88 Kilocalslm^2. The beneficial effect is in all probabilities due to the dryness of the breathing oxygen.

Conclusion

None of the methods of alleviating heat stress are yet fool proof. However it is not necessary to totally eliminate heat induced physiological strain and an adequate extension of tolerance time as indicated by a delay in acquisition of heat storage levels at which performance is expected to deteriorate, should be aimed for. The liquid cooled suit system should cater adequately for the type of requirement in hand. Other, though less effective, means such as precooling, airventilated suits with oxygen burst cooling and 100% oxygen breathing are also advisable.

With the introduction of deep penetration strike aircraft which would be expected to fly low, fast and for prolonged periods, the heat problems must be looked at from a new point of view and enthusiastic measures as suggested would have to be implemented to make such flights more tolerable.

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