AIR TEMPERATURES REQUIRED FOR COMFORT IN FIGHTER AIRCRAFT

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INTRODUCTION

Modern fighter aircraft capable oflow-level, highspeed night can produce severe thermal loads on aircrew. In addition, the protective clothing worn by aircrew is both highly insulative and relatively impermeable to water vapour with the result that dissipation of metabolic k a t is difficult. Thermal comfon is known lo affect aircrew performance (1.2) and therefore it is necessary lo specify the cockpit temperature at which comfon will be maintained. This poster describes a melhod of determining the required cockpit temperature, the results of experiments to validate this model, and discusses the effects on conifon oftemperatures in excess of the required temperature for comfort.

METHOD

The Subjective Temperature (T_{sub}) (3) required for thermal conifon can be predicted using an empirical equation derived by Mclntyre (4), based on the work of Fanger (5), and is a function of clothing insulation and metabolic rate. Subjective conifon has traditionally been assessed using a 7 point scale (Figure 1) where the comfort range is generally taken as the centre 3 points on the scale. The T_{sub} for a neutral comfort vote can be shown to be 25.6^{o}C which, using the Mclntyre equation, will be required for a metabolic rate of 55.5W.m^{-2} and clothing with an insulation of 0.6clo. Similarly. it can be shown that at a T_{sub} of 30^{o}C, 50% of subjects will vote greater than 5 on the scale in Figure 1 and thus will be uncomfortably warm (5). This upper limit of comfort can be predicted by simple modification of the equation. In addition, if T_{sub} is redefined in terms of ambient and radiant temperatures (T_{rad}) and air velocity, the effects of radiant heat loads and cockpit air movement can be included in the equation (4). Finally, the equation can be extended to calculate the likely T_{rad} for various climatic conditions and to include the effect of aerodynamic heating during high speed flight. The model developed in this way was used to predict the temperatures required for thermal conifon (T_{comf}) and for the upper limit of thermal comfort, for aircrew wearing flying clothing of different insulations, at a range of ambient temperatures, during different phases of flight and with varying solar radiation intensities.

The temperatures predicted by this model were validated in a series of experiments conducted in a climatic chamber capable of accurate simulation of the thermal conditions in an aircraft cockpit. Two different clothing assemblies were worn (2.45clo and 3.02clo) by 4 subjects who were exposed for 2 hours to the comfort temperature (T_{comf}) and 5^{o}C above T_{comf} for the clothing worn. The values lor clothing insulation were obtained using a thermal manikin. Io a second experiment a further 4 subjects were exposed to 10^{o}C arid 15^{o}C above comfort temperature wearing clothing of 2.45clo insulation. Rectal (T_{re}) and skin temperatures (T_{sk}) at 4 sites were measured throughout each exposure and sweat loss estimated by nude weighing before and after the experiments. During the exposures subjects repeated a cycle of 5 minutes rest followed by 10 minutes lower limb exercise which consisted of raising and lowering a 10kg mass every 2s. Metabolic rate was measured by indirect calorimetry during the last 5 minutes of the exercise periods. At the end of each of the 8 exercise periods subjects were asked to record their impressions of thermal sensation on the seven point scale shown in Figure I. These conifon votes were compared with the predicted mean vote (PMV) calculated using the equation derived by Fanger (5).

RESULTS

The required air temperatures for comfort ranged from as low as -1.0^{o}C for aircrew wearing summer chemical defence flying clothing operating at low level Mach 0.9 on a summer day with bright sunshine. to 11"C whilst taxying on a cool day wearing the same clothing. Required temperatures for the upper limit of comfort were approximately 4^{o}C higher.

The data from the validation experiments showed that in all cases subjects' T_{re} rose by no more than 0.3^{o}C from the starting value. Mean T_{sk} was between 34.1^{o}C and 34.8^{o}C at T_{comf}, between 35^{o}C and 35.5^{o}C at 5^{o}C above T_{comf} and rose to a maximum of 35.7^{o}C at the 2 highest temperatures. Mean subject weight loss over the 2 hour exposures ranged from 027% to 0.97% of body weight.

Figure 1 shows the mean votes for the 4 subjects over the second hour of exposure PI each temperature for the 2 clothing assemblies. The mean vote at 5^{o}C, T_{comf} for a 2.45clo assembly, was not significantly different from a neutral conifon vote. 5^{o}C above T_{comf} produced a mean vote of 5 which may be considered to be the upper limit of comfort. Temperatures higher than this produced votes indicating thermal discomfort, although there was no significant difference between the votes at 15^{o}C and those at 20°C. When the subjects wore the more insulative clothing assembly, the mean votes during the second hour of exposure at both the predicted T_{comf} and 5°C higher

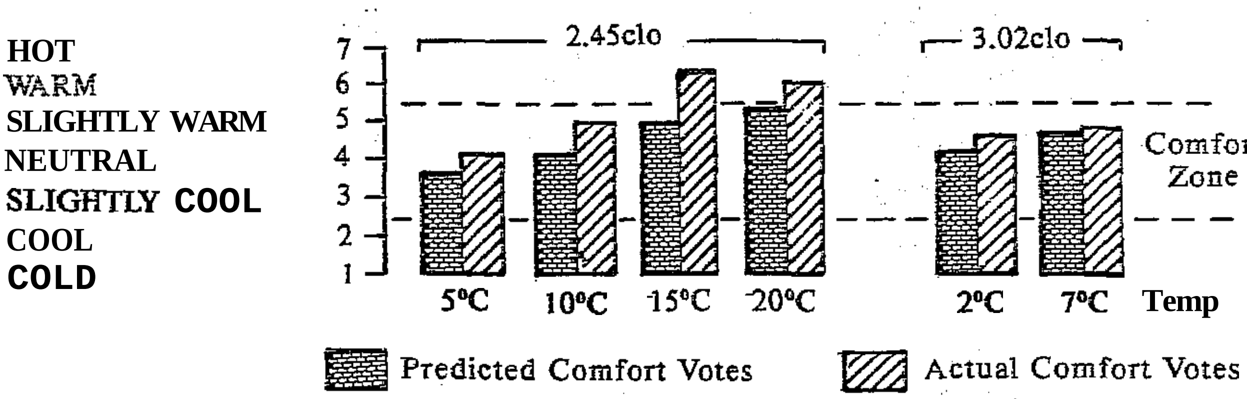

FIGURE 1

were within the upper limit of thermal comfort. The mean vote lor each subject showed no correlation with nude weight loss, mean T_{sk}, or chmge in T_{re}. There was, however, a correlation between metabolic rate and comfort vote during exposures at the 2 highest temperatures (r^2=0.56; $p<0.05$). The PMV calculated for the conditions employed in the validation was not well correlated with the actual comfort votes cast by the subjects: in every case the PMV underestimated the actual vote although the difference was generally less than one point on the scale of comfort (Figure 1).

DISCUSSION

The climatic chamber experiments show that, even at the highest temperature in this study, there was no evidence of serious physiological thermal strain. Nevertheless, at temperatures 10 °C or more above T_{comf} the subjects were suffering thermal discomfort. There was no correlation between the subjective impression of comfort and any of the physiological measures except metabolic rate which was positively correlated with comfort vote. This is, perhaps, not surprising since given the highly insulative clothing which was worn, the discomfort is principally due to the rate of internal heat production.

The data show that the simple model predicts T_{comf} and the temperature for the upper limit of comfort reliably. However, it is not capable of giving any indication ofsubjective comfort beyond that limit. Prediction of comfon using the PMV equation derived by Fanger would be one method of assessing tbe effects of cockpit temperature in excess of those required for comfort although the equation as originally developed only dealt with clothing insulations up to 1.5clo. PMVs calculated for the conditions employed in this study tended to underestimate the actual votes probably because of the high level of insulation being wom and the effect on Sweat evaporation of the impermeable nature of *the* clothing.

This study confirms that highly insulative and impermeable flying clothing will require cockpit temperatures which cannot readily be achieved in current military aircraft. Conditioning systems could only provide these temperatures at the expense of engine power, range and payload. A more efficient method of ensuring aircrew comfort would be to condition the micro-environment under the llying clothing.

CONCLUSIONS

The model predicts values for T_{comf} which are valid. The cockpit temperatures required are lower than those which can be achieved in most military aircraft and, therefore, micro-environment conditioning will be necessary to maintain comfort and performance.

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