THE EFFECT OF THE AIRCREW CHEMICAL DEFENCE ASSEMBLY ON THERMAL STRAIN

Robert Thornton

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University of Edinburgh
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CONTENTS

ABSTRACT

A laboratory simulation has been undertaken of the thermal stress faced by military helicopter aircrew operating in central Europe whilst wearing chemical defence equipment. The first step was to measure the energy expenditure of aircrew flying Army and Royal Air Force helicopters in the field. That of the pilots was 50% higher than their resting rate. The crewmen's rate of energy expenditure in flight was up to 3 times that of their resting rate.

In order to determine the relationship between environmental climatic conditions and those in the cabin of helicopters, an investigation was carried out of the cockpit environment of the same aircraft types in Belize, at a time of the year when climatic conditions were similar to those of central Europe in mid-summer. The opportunity was also taken to record cockpit and metabolic data in the Harrier. The Harrier pilots demonstrated a significant degree of thermal strain.

The final stage was to utilise the energy expenditure and thermal results in a simulation of the effects of flying in the aircrew chemical defence assembly in summer in central Europe. The subjects worked at the appropriate rates for pilots and crewmen, while environmental conditions were controlled in the climatic chamber of the RAF Institute of Aviation Medicine.

The results show that while helicopter pilots are unlikely to suffer problems of thermal strain, crewmen, with their higher work rates are liable to experience an unacceptable rise in deep body temperature. It is recommended that personal thermal conditioning be adopted for helicopter crewmen. A review of the state of the art of personal thermal conditioning is also included.

ACKNOWLEDGEMENTS

I wish to record my appreciation to all those who have assisted with this study, in particular Dr Dick Alan, head of the Environmental Sciences Division at the Royal Air Force Institute of Aviation Medicine for his support and encouragement; Dr Graham Brown and Mr Colin Higenbottam, Higher Scientific Officers at the IAM, for their assistance with conducting the study, Mr. A. Belyavin for undertaking the statistical analyses, and finally the aircrew and other experimental subjects, for their patient co-operation.

DECLARATION

This study was carried out by a small team led by myself. All protocols and reports were written by me, and I am the sole author of this thesis.

R Thornton

INTRODUCTION

The Defence Staffs of the United Kingdom consider that there is a high probability that chemical warfare (CW) agents would be used against NATO. Airfields are considered to be a prime target for early and repeated chemical attack. The Staffs require that air operations shall continue unabated in the presence of the threat of, or actual, attacks with CW agents. Since there is no reliable means of providing early warning of a CW attack, since some CW agents act with great rapidity, since the performance of aircraft and ground support equipment is unaffected by CW agents, and since there is no cost effective method whereby the crew compartments of aircraft can be kept free of contamination with the agents, the primary defence against chemical warfare is individual personal protection.

It was recognised by the UK Staffs in 1967 that the NBC (nuclear, biological, chemical) personal equipment then being introduced to provide protection for ground personnel was not suitable for use by aircrew in flight. A requirement was therefore raised for personal equipment assemblies specifically to provide aircrew, both in flight and on the ground, with protection against chemical, bacteriological and nuclear toxic agents in vapour, aerosol, liquid and particulate forms.

The need to provide a very high level of protection to the respiratory tract and eyes to avoid the miotic effects of small doses of the nerve agents was recognised at an early stage of development.[12] This, together with the requirement that the equipment should be fully integrated with existing flying clothing, led to the development of the Aircrew Respirator NBC No 5 (AR5) which encloses the head and neck under the standard aircrew helmet, and is supplied with filtered pressurised air for breathing and for demisting the visor. The rest of the body is protected by a one-piece, charcoal impregnated suit and socks, and rubber gloves, all worn beneath the normal aircrew clothing. The assembly is described in more detail below.

A major disadvantage of the aircrew chemical defence (CD) assembly is that, unlike the ground forces equivalent, it cannot be donned quickly when the threat of a CW attack is thought imminent. Because of this, aircrew would have to wear the assembly routinely at a much lower threat level, perhaps even from the outbreak of hostilities. Accordingly, a very high level of expertise with the equipment must be acquired in peace time operations, by regular flying training under simulated NBC conditions.

The wearing of chemical protective clothing by aircrew increases the thermal stress imposed upon them during flight in hot weather conditions. It adds another layer to the aircrew equipment assembly (AEA), and restricts the ventilation of clothing by having sealed neck, wrists and ankles. Previous studies have suggested that the resulting degree of thermal strain may be unacceptable under the climatic conditions that may be encountered during the summer months in central Europe.[14,6,30,24]

The aim of this study was to conduct a thermal evaluation of the aircrew NBC assembly based upon a simulation of pre-flight and flying conditions that might be encountered by helicopter aircrew operating in Germany in mid-summer.

The main contributions to thermal strain for aircrew arise from two sources, metabolic and environmental.[15] In order to achieve maximum accuracy during the laboratory simulation, it was necessary to measure both these factors. The first phase of the study was therefore to measure the energy expenditure of helicopter aircrew in the field. The second phase was to determine the relationship between ambient meteorological conditions and those in the cockpit. The final phase utilised the results of the first two in a simulation in the climatic chamber of the Royal Air Force Institute of Aviation Medicine. The three separate phases are described individually in turn.

ENERGY EXPENDITURE

INTRODUCTION

A knowledge of energy expenditure in a variety of flying tasks is essential in assessing the effects of thermal stress on aircrew and in the design and development of aircraft and personal thermal conditioning systems. Laboratory experiments to assess thermal strain can simulate environmental conditions and physical workload, but the degree of workload must be based accurately on energy expenditure measured in flight if the results are to be valid. Climatic chamber studies of the thermal load imposed by NBC assemblies have emphasised the need for more information on the workloads faced by helicopter aircrew.[14,24]

There is considerable information regarding the energy cost of a wide variety of human activities,[40] but surprisingly little research has been performed on aircrew in flight. Sharp et al[45] in their review of the literature found only 3 studies on helicopter aircrew.[10,34,35] None were in UK helicopters. French et al[21] performed a limited study of 4 pilots flying Army Air Corps Scout helicopters. No work has been reported on the energy expenditure of helicopter crewmen.

The aim of this part of the study was therefore to measure the energy cost of flying helicopters in different phases of flight using 2 aircraft types, and that of working as a helicopter crewman. To obtain a basis for comparison, the energy expenditure of the subjects was also measured at rest and while walking to and from the aircraft.

METHODS

General Outline

The work was carried out in 2 separate stages, the pilots first, then the crewmen. Measurements of energy expenditure and heart rate were made on 2 groups of 6 helicopter pilots. 6 was the maximum number of pilots that could readily be made available. One group (Army Air Corps pilots) flew the Gazelle AH1, the other (Royal Air Force pilots) flew the Puma HC1. Details of the subjects are shown in Table 1. The 8 crewmen were all RAF and flew in the Puma. Their details are in Table 2.

The work was done at the instigation of the researchers, not the Air Staffs. It was therefore a condition of being given authority to do the experiments that the sorties flown were not to be altered in any way, which inevitably led to a number of limitations which had to be accepted. It was also necessary to minimise the inconvenience caused to the aircrew, who might otherwise be distracted from their flying task.

It was not possible to select or match subjects in any way. They were operational aircrew of varying age, size and experience, in the order that they were made available by the squadrons concerned. The only selection criteria were that they should be volunteers, and medically fit.

Similarly, the sorties flown were normal flying training or operational tasks, the appropriate phases being isolated for comparison. They were not flown solely for the purpose of the experiment, and the different phases were not flown in any particular order. The overall duration of flights varied between 1 and 4 hours.

The sorties in which the pilots were instrumented were flown during November to January. The 6 Gazelle sorties were flown before the Puma recordings began. Times of day varied, as did relation to meals and any recent exercise. Climatic conditions were also uncontrollable and aircrew equipment assemblies (AEA) were not standardised. The Puma crewman sorties were flown in March and April. Crewroom temperature was not controlled or recorded.

TABLE 1. SUBJECT DATA (PILOTS)

Subject	Age (yr)	Height (mm)	Weight (kg)	Surface Area (m^2)*	Ac Type	Flying Hours Total	Flying Hours On Type
P1	32	1773	77	1.92	Gaz	2400	1200
P2	27	1788	74	1.90	Gaz	920	800
P3	42	1831	83	2.08	Gaz	4500	900
P4	27	1734	72	1.86	Gaz	1400	1280
P5	28	1729	70	1.82	Gaz	645	525
P6	36	1841	83	2.08	Gaz	2500	1000
P7	30	1676	83	1.92	Puma	3200	600
P8	21	1834	88	2.14	Puma	2800	1600
P9	39	1801	82	2.02	Puma	4500	150
P10	29	1831	78	1.92	Puma	1200	120
P11	27	1752	70	1.84	Puma	900	150
P12	33	1910	90	2.20	Puma	2300	200

*Du Bois-Meeh[16]

TABLE 2. SUBJECT DATA (CREWMEN)

Subject	Age (yr)	Height (mm)	Weight (kg)	Surface Area (m^2)*	Flying Hours Total	Flying Hours On Type
C1	25	1836	80	2.02	420	340
C2	25	1750	63	1.76	310	310
C3	31	1800	77	1.96	400	350
C4	31	1648	77	1.82	2100	1400
C5	54	1810	81	2.02	11300	5400
C6	32	1821	69	1.88	3200	400
C7	23	1724	70	1.82	450	370
C8	24	1784	70	1.86	850	800

*Du Bois-Meeh[16]

Energy expenditure at rest in the crewroom for 10 minutes before the sortie was used as a baseline for comparison, though subjects had to be constantly reminded that they were meant to be resting, and not talking to their colleagues or preparing their maps. Activity immediately prior to the period of rest was not controlled. They were also monitored during their walk to the aircraft. Because of the geography of the various locations, the length of this walk varied. The speed of walking was not controlled or recorded, and they carried their normal amount of equipment.

Personal details, flying hours, height and weight were recorded immediately before the experiment began.

Measuring Techniques

Prevous studies have used cumbersome techniques involving Douglas Bags[10,34] or a Franz-Muller Gas Meter.[35] Measurements of energy expenditure in this study were made using the Oxylog (P K Morgan Ltd, Chatham, Kent).[33] (Figure 1).

The Oxylog has a number of distinct advantages. It is readily portable, measuring 18.5cm x 8.2cm x 21.5cm, and weighing 2610g; it provides continuous monitoring over an extended period, without the need to collect expirate for later analysis.

Inspiratory volume is measured by a turbine flowmeter. Oxygen sensors measure the pO_2 of inspired and expired air. Minute and cumulative values are presented on an LED display.

The instrument uses the following formula to calculate the volume of oxygen consumed:

$$\underset{\text{(NTP dry)}}{\underset{\text{Consumed}}{\text{Vol } O_2}} = \frac{(pO_2 \text{ insp air} - pO_2 \text{ exp air}) \times \text{Vol insp air}}{760}$$

This formula makes various assumptions which may introduce errors into the calculation.

1. The volume of inspired air has been corrected to $0^{o}C$ dry at the pressure of the experiment. This is achieved in the instrument by measuring the air temperature at the flowmeter with a thermistor, and correcting the volume accordingly. 50% relative humidity is assumed. The size of the error in this assumption varies with relative

humidity and temperature, and can be derived from curves supplied by the manufacturer. As an example, a relative humidity of 20% at a temperature of 12°C produces an error of -0.5%.

2. The pO_2 of both inspired and expired air is measured from dry samples of air. This is done by passing the air samples through anhydrous calcium sulphate drying tubes before analysis.

3. The volume of oxygen given by the formula is only correct if the respiratory exchange ratio (R) equals 1. In practice, R is not likely to equal 1, and may vary during the experiment. Changes in R will introduce small errors in the volume of oxygen indicated, as shown in Table 3.

TABLE 3. ERRORS IN VOLUME OF OXYGEN DUE TO VARIATIONS IN R

R	% error in volume
0.7	-5.3
0.8	-3.5
0.9	-1.8
1.0	0
1.1	+1.8

This error can be minimised if the volume is used to calculate energy expenditure, using the equation for the calorific value per litre of oxygen derived by Weir:[47]

$$K = 3.9 + 1.1R$$

(where K is in kilocalories per litre)

It can be shown that if a constant calorific value of oxygen of 5.0 kilocalories per litre is used to multiply the volume of oxygen as shown by the instrument, the error in the calorific value introduced by not taking account of R tends to compensate for the error in volume introduced by not taking account of R.

The error quoted by the manufacturer for a pO_2 of expired air of 134mm Hg at an atmospheric pressure of 760mm Hg is shown in Table 4, where the percentage error is for the calories obtained by multiplying the volume shown by the instrument by a fixed calorific value, relative to the calories obtained by multiplying the true volume by the true calorific value.

TABLE 4. ERRORS IN ENERGY EXPENDITURE DUE TO VARIATIONS IN R

R	% error in energy
0.7	+1.4
0.8	+0.9
0.9	+0.4
1.0	0
1.1	-0.4

4. The barometric pressure cancels out in the derivation of the formula, and so does not have to be measured by the instrument.

The soft oronasal mask supplied with the Oxylog has been shown to leak due to its unsatisfactory elastic suspension harness.[8] It was therefore replaced with a RAF P or Q mask, sized appropriately for the subjects, with the added advantage of having an in-built microphone to replace the subject's normal boom microphone, which could not be used.

The RAF masks were modified as follows:

1. The expiratory valve was removed, and the surrounding rubber moulding cut away to reveal the 30mm diameter expiratory port into which the expiratory valve of the Oxylog was securely located.

2. A length of standard non-kink oxygen hose was fitted to the inspiratory port, with the flowmeter secured to its free end. A clip was attached to enable it to be located on the aircraft seat harness for stability.

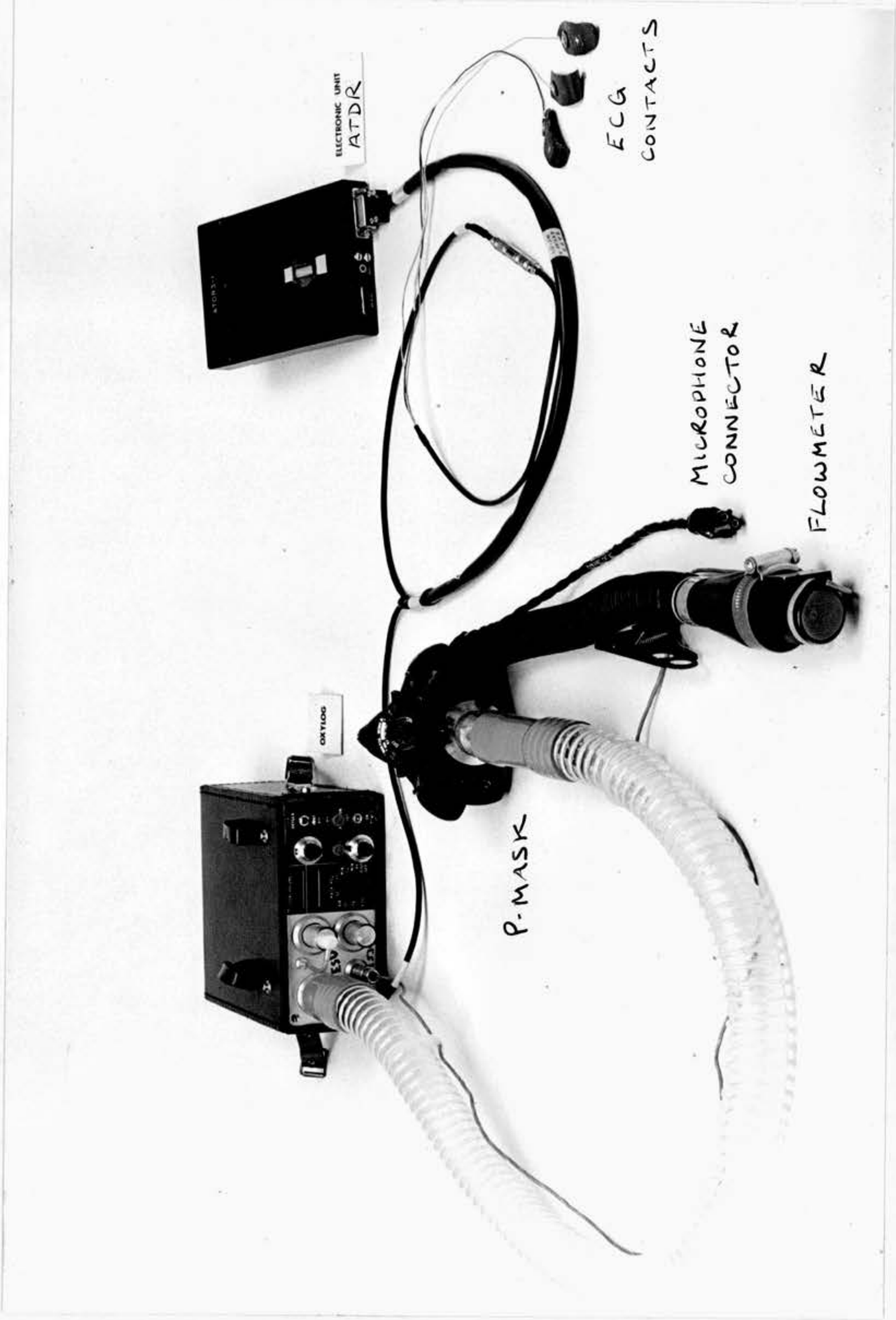


FIGURE 1. OXYLOG AND ATDR

The Oxygen sensors were set for zero pO_2 with oxygen-free nitrogen before the experiments started, and between each of the 3 phases. The instrument was calibrated for atmospheric pO_2 before each sortie, and if recording was interrupted during the longer trips, in accordance with the manufacturer's handbook.

Data Recording

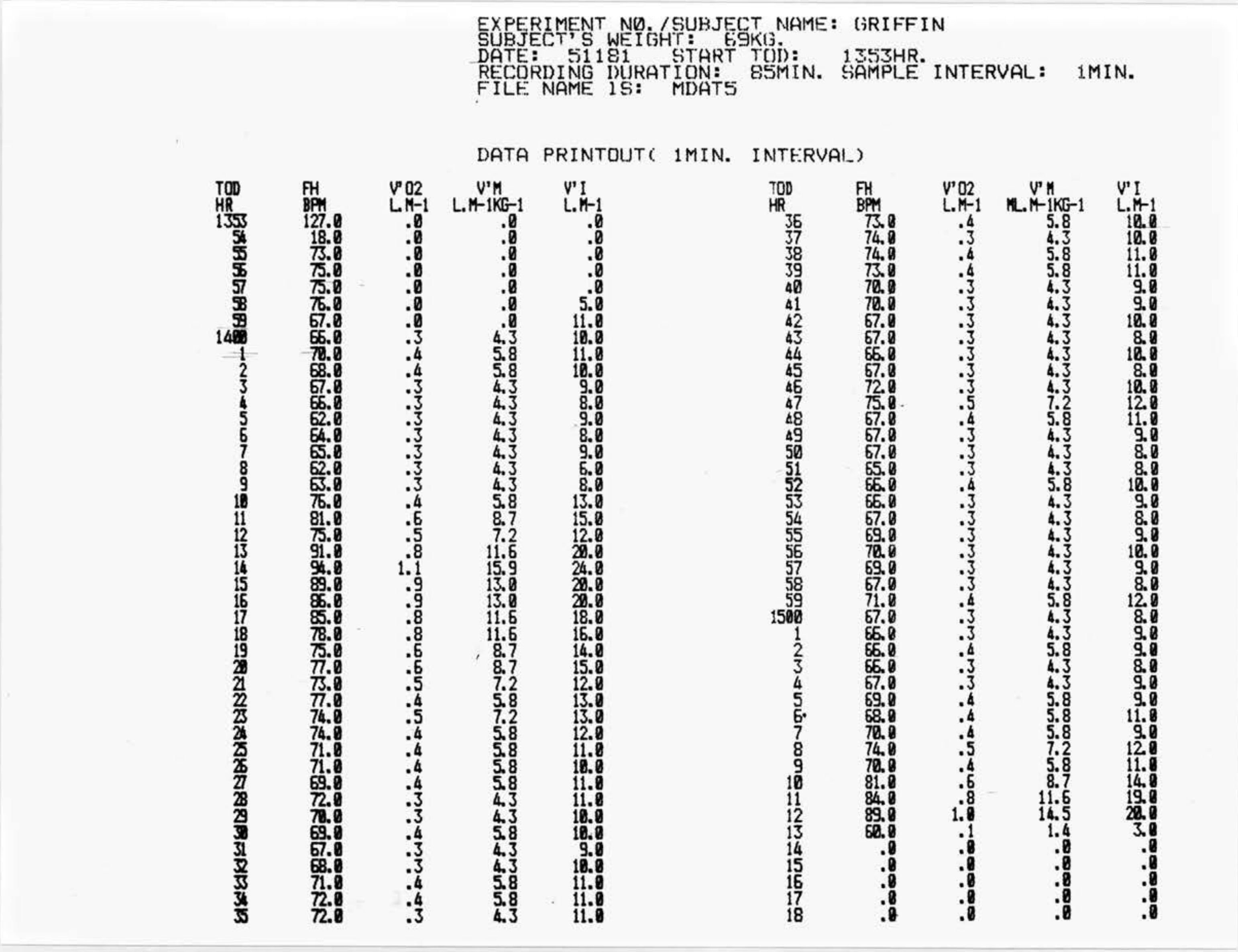
The digital LED displays of the Oxylog are totally impractical for use in flight, when the observer may not always be able to see them. An automatic data recording system (the ATDR) has therefore been developed and manufactured by the Royal Air Force Institute of Aviation Medicine[3,31] which records oxygen consumption and inspiratory volume at one minute intervals, together with heart rate.

The ATDR measures 18.5cm x 12.0cm x 2.4cm and weighs 600g, dimensions chosen to fit into an aircrew coverall leg pocket. Recessed power and mode selection switches are provided, together with connectors for attachment to external sensors, and for data replay and system checkout, and a battery low warning LED. A photograph of the unit is shown in Figure 1. Power is supplied by 2 rechargeable 9V 160mA silver-zinc batteries. Switches on the memory card allow selection of the scan interval over the range 0.5 seconds to 126 minutes, while the number of channels accessed may be selected to be 1, 2, 4, 8 or 16. By this means, the scan interval and recording time can be optimised for the particular data to be recorded, limited only by the maximum memory capacity of 2 kilobytes. The useable recording time can be up to 34 hours. Recording time in the field can be prolonged by the use of a 'pause' switch to halt recording, when appropriate. The memory is volatile, so power must be maintained to the circuits until data have been read out. Battery operating life is 40 hours.

A 'metabolic signal board' has been designed which receives the pulsatile signal from the Oxylog record output and converts and stores the minute volumes, along with heart rate derived from chest electrodes. One pulse from the Oxylog represents a fixed increment of 1l of inspired air, or 0.1l of oxygen consumption. These pulses are accumulated in 8 bit counters, and at 1 minute intervals the counter outputs are sequentially switched into the digital data base and stored in memory, after which the counters are reset. For the ECG a similar R-wave counting and storage process occurs.

A ground monitor unit plugs into the replay connector of the electronic unit and is used for the checking of sensors before recording starts.

Data recovery is accomplished using a Powerhouse 2 48K microcomputer (Powerhouse Microprocessors Ltd, Hemel Hempstead) and an OKI Microline 80 printer (OKI Electric Industry Ltd, Tokyo). The Powerhouse 2 is a Z80 based computer, with ROM-resident DOS and Basic. It contains a microcassette programme and data storage unit and video display. A specially constructed adaptor into which the ATDR is plugged allows its external memory to be 'mapped' into an internally undecoded 2K portion of the Z80's memory space. The recorder memory is automatically selected into a 'read' mode, and its contents may be transferred, via Basic Exam (Peek) instructions, into Basic variables, stored on microcassette, and finally converted to appropriate units for data printout and plotting on the printer. The computer also allows a degree of data manipulation, and calculates oxygen consumption per kilogram body weight of the subject. The form of the tabular data printout is shown in Figure 2, the graphical printout in Figure 3.



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EXPERIMENT NO./SUBJECT NAME: GRIFFIN
SUBJECT'S WEIGHT:  69KG.
DATE:  51181   START TOD:   1353HR.
RECORDING DURATION:  85MIN. SAMPLE INTERVAL:  1MIN.
FILE NAME IS:  MDAT5


DATA PRINTOUT( 1MIN. INTERVAL)

TOD     FH       V'O2         V'M      V'I            TOD     FH       V'O2          V'M       V'I
HR      BPM      L.M-1  L.M-1KG-1    L.M-1          HR      BPM      L.M-1   ML.M-1KG-1    L.M-1
1353    127.0       .0           .0       .0            36     73.0       .4           5.8     10.0
  54     18.0       .0           .0       .0            37     74.0       .3           4.3     10.0
  55     73.0       .0           .0       .0            38     74.0       .4           5.8     11.0
  56     75.0       .0           .0       .0            39     73.0       .4           5.8     11.0
  57     75.0       .0           .0       .0            40     70.0       .3           4.3      9.0
  58     76.0       .0           .0      5.0            41     70.0       .3           4.3      9.0
  59     67.0       .0           .0     11.0            42     67.0       .3           4.3     10.0
1400     66.0       .3          4.3     10.0            43     67.0       .3           4.3      8.0
   1     70.0       .4          5.8     11.0            44     66.0       .3           4.3     10.0
   2     68.0       .4          5.8     10.0            45     67.0       .3           4.3      8.0
   3     67.0       .3          4.3      9.0            46     72.0       .3           4.3     10.0
   4     66.0       .3          4.3      8.0            47     75.0       .5           7.2     12.0
   5     62.0       .3          4.3      9.0            48     67.0       .4           5.8     11.0
   6     64.0       .3          4.3      8.0            49     67.0       .3           4.3      9.0
   7     65.0       .3          4.3      9.0            50     67.0       .3           4.3      8.0
   8     62.0       .3          4.3      6.0            51     65.0       .3           4.3      8.0
   9     63.0       .3          4.3      8.0            52     66.0       .4           5.8     10.0
  10     76.0       .4          5.8     13.0            53     66.0       .3           4.3      9.0
  11     81.0       .6          8.7     15.0            54     67.0       .3           4.3      8.0
  12     75.0       .5          7.2     12.0            55     69.0       .3           4.3      9.0
  13     91.0       .8         11.6     20.0            56     70.0       .3           4.3     10.0
  14     94.0      1.1         15.9     24.0            57     69.0       .3           4.3      9.0
  15     89.0       .9         13.0     20.0            58     67.0       .3           4.3      8.0
  16     86.0       .9         13.0     20.0            59     71.0       .4           5.8     12.0
  17     85.0       .8         11.6     18.0          1500     67.0       .3           4.3      8.0
  18     78.0       .8         11.6     16.0             1     66.0       .3           4.3      9.0
  19     75.0       .6          8.7     14.0             2     66.0       .4           5.8      9.0
  20     77.0       .6          8.7     15.0             3     66.0       .3           4.3      8.0
  21     73.0       .5          7.2     12.0             4     67.0       .3           4.3      9.0
  22     77.0       .4          5.8     13.0             5     69.0       .4           5.8      9.0
  23     74.0       .5          7.2     13.0             6     68.0       .4           5.8     11.0
  24     74.0       .4          5.8     12.0             7     70.0       .4           5.8      9.0
  25     71.0       .4          5.8     11.0             8     74.0       .5           7.2     12.0
  26     71.0       .4          5.8     10.0             9     70.0       .4           5.8     11.0
  27     69.0       .4          5.8     11.0            10     81.0       .6           8.7     14.0
  28     72.0       .3          4.3     11.0            11     84.0       .8          11.6     19.0
  29     70.0       .3          4.3     10.0            12     89.0      1.0          14.5     20.0
  30     69.0       .4          5.8     10.0            13     60.0       .1           1.4      3.0
  31     67.0       .3          4.3      9.0            14       .0       .0            .0       .0
  32     68.0       .3          4.3     10.0            15       .0       .0            .0       .0
  33     71.0       .4          5.8     11.0            16       .0       .0            .0       .0
  34     72.0       .4          5.8     11.0            17       .0       .0            .0       .0
  35     72.0       .3          4.3     11.0            18       .0       .0            .0       .0
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FIGURE 2. TABULAR COMPUTER PRINTOUT

Time of Day (TOD) (hr)
Heart rate (FH) (beats per min)
Oxygen consumption (VO_2) (lmin^{-1})
Oxygen consumption per kg body mass (VM) (lmin^{-1})
Inspiratory volume (VI) (lmin^{-1})

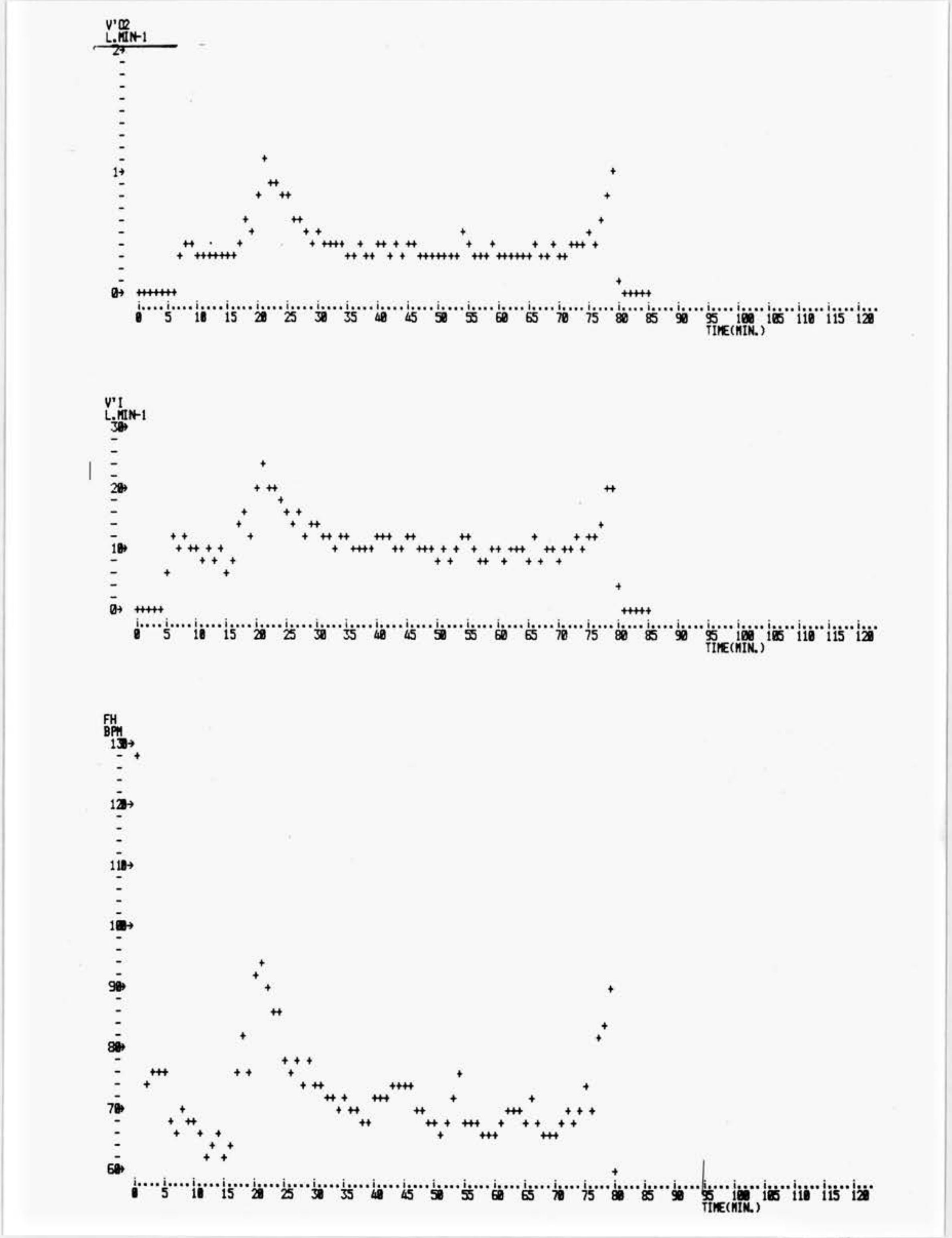


FIGURE 3. GRAPHICAL COMPUTER PRINTOUT

Oxygen consumption (VO$_2$) (lmin^{-1})
Inspiratory volume (VI) (lmin^{-1})
Heart rate (FH) (beats per min)
All plotted against lapsed time (min)

Oxylog Evaluations

The accuracy and reliability of the Oxylog's readings have been compared with standard measuring techniques in a study undertaken at the RAF Institute of Aviation Medicine by Belyavin et al.[8] They used a Parkinson Cowan dry gas meter, calibrated with an 8l syringe, to measure expiratory volume, and a Centronics Quadrupole mass spectrometer to measure oxygen consumption. Readings were recorded simultaneously by the Oxylog, while subjects exercised on a bicycle ergometer at rates varying from 30 to 150W, for periods ranging from 3 to 10 minutes, at a constant pedalling rate of 50rpm.

Subjects inspired through the turbine flowmeter of the Oxylog, and expired through the Oxylog and into a 2.175l mixing box, and then to the the dry gas meter. The mass spectrometer analysed fractional concentrations of expired oxygen and carbon dioxide. Measurements of inspiratory volume and oxygen consumption from the Oxylog, and of expiratory volume, oxygen consumption, carbon dioxide production and respiratory exchange ratio (R) from the standard system were made at one minute intervals, but only once the pen recorder trace from the mass spectrometer indicated that a respiratory steady state had been achieved, normally about 30 sec after increasing the workload.

For each subject, values for respiratory volume and oxygen consumption from the 2 systems were averaged over each work period. The mean values were then used to derive 2 new variables, representing the percentage errors in the 2 sets of values. The error terms were subjected to analysis of variance for differences between the work periods, and for values of the means different from zero. In addition, values for oxygen consumption obtained from the Oxylog were regressed against work rate, and compared with equivalent values from the standard system.

Three different series of measurements were undertaken using different combinations of work rate, and experimenting with different mask and mouthpiece arrangements.

Averaging the mean differences between oxygen consumption measured with the Oxylog and the standard system revealed a statistically non-significant underestimate of 1.5%. This is approximately the size of the underestimate predicted from Table 3 for an R value of 0.9 (the mean value of R during the experiments was 0.91). The underestimate tended to increase with higher work rates. Averaging the mean differences between volumes gave an underestimate for the Oxylog of 1.2% (again, not statistically significant).

A second study at the IAM[43] addressed the problem of using the Oxylog at different altitudes, and the effect that might have on measured volume. This was achieved by comparing Oxylog volumes with those measured by a calibrated dry gas meter, a Beaver Respirator being used to simulate the breathing cycle at a variety of minute volumes ranging from 17.0 to 33.56l. Simultaneous recordings of 4 minute volumes were carried out at 3 Beaver settings in a decompression chamber at ground level, 10,000 feet, 20,000 feet and 30,000 feet (3048m, 6096m and 9144m).

The percentage difference between the means for the 2 instruments was calculated, and the percentage error of the Oxylog flowmeter thus obtained, and analysis of covariance undertaken.

At ground level, the Oxylog produced a non-statistically significant underestimate of 0.75%. At 10,000 feet the mean Oxylog value was 2.79% less than the dry gas meter ($p<0.01$), at 20,000 feet 2.91% ($p<0.001$) and at 30,000 feet 7.21% ($p<0.001$). This decreasing accuracy at high altitude is likely to be due to the nature of the construction of the Oxylog flowmeter, which consists of a light vane which is sensitive to changes in air density. On the basis of this study, it was decided to restrict the recordings to the lowest altitude at which the proposed phases of flight could reasonably be undertaken, which was

1500 feet (457m) above mean sea level (AMSL).

In the light of the proven accuracy of the Oxylog, as shown by the 2 reports, the same Oxylog equipment being used in those and the present study, it was felt that it could be used with confidence in the field. It was appreciated, however, that the experiments had been undertaken in the laboratory, and that previously unrecognised problems might occur when the equipment was used in field conditions.

Although the Oxylog is easily portable, its weight and bulk, and the number of wires and hoses, still present a hindrance to the crewman in carrying out his duties, less so to the pilot. Due to the strenuous nature of some activities, damage was caused to the equipment, despite modification to it as the study proceeded, to reduce the size of the on/off switch to prevent accidental switching off, and to restrain the wires more effectively with the extensive use of masking tape.

Equipment checks were generally difficult during experiments, and data storage in the ATDR could not be monitored, leading to complete loss of data from 3 additional crewmen.

The extra energy expenditure entailed in carrying the Oxylog was assumed to be similar to that of carrying the NBC portable ventilator, being similar in weight. (Oxylog and ATDR 3.21kg, portable ventilator 4.32kg).

Energy Expenditure

Energy expenditure was calculated from the ATDR printout of oxygen consumption and oxygen consumption per kilogram body mass. The tabulated data were divided into groups according to phase of flight. The first reading in each group was discarded to remove the effect of lag in the Oxylog; the rest were used to calculate a mean value. The heart rates were treated in a similar manner. The overall mean was then calculated, for each phase of flight and each aircraft type.

The mean oxygen consumption values were each multiplied by the constant calorific value of 5.0, and converted to Watts. Watts were used as the appropriate SI unit, as specified by the Air Standardisation Co-ordinating Committee standard, to which the United Kingdom Armed Services subscribe.[1]

Statistical Methods

Analysis of variance (ANOVA) was employed to investigate the variation of energy expenditure (W/kg) for the pilots. The experimental design may be described by 3 factors:

1. Conditions (C)
2. Group (G) (Gazelle or Puma)
3. Pilots (P)

C and G are 'fixed' effects, while P is a random effect, the pilots being a random sample from a large population crossed with C and nested under G.

A preliminary analysis was undertaken for each variate to decide whether a transformation would be required, to ensure that the assumptions of ANOVA were reasonably well satisfied, and it was decide that a logarithmic transformation would be appropriate.

ANOVA was used to compare the energy expenditure values for each phase of flight with level flight for the pilots of each aircraft type. A second analysis was then undertaken to compare the effect of aircraft type for the different phases of flight.

For the crewmen data, ANOVA was used to compare the various phases of flight with transit flying. ANOVA was also used to test for the significance of differences in heart rate.

The Aircraft

The Gazelle AH1 is a light observation helicopter, with a maximum all-up weight (MAW) of 1800kg (Figure 4). It is normally flown by a pilot and aircrewman and can carry up to 3 passengers. The flying controls are hydraulically operated, but there is no autopilot or stabilising system fitted.

The Puma HC1 is a medium battlefield support helicopter (MAW 7000kg) (Figure 5). It is normally crewed by a pilot and a crewman and can carry up to 16 passengers. The flying controls are hydraulically operated and there is an autopilot providing full stability in pitch, yaw and roll, and height hold.

FIGURE 4. GAZELLE AH1

FIGURE 5. PUMA HC1

Conduct of the Experiment

The subjects donned their normal winter AEA. Their chests were shaved if necessary, cleaned with alcohol, abraded with ECG jelly and gauze swabs, then dried. Three NDM Silvon silver/silver chloride electrodes (NDM Corp, Dayton, Ohio) were applied to the chest. They then donned their flying helmet and were fitted with the appropriate size of oxygen mask. (The RAF P/Q mask comes in 2 sizes, determined by trial and error). The hose of the Oxylog was connected to the adaptor in the expiratory port of the mask. The Oxylog flowmeter was attached to the end of the oxygen hose fitted to the inspiratory port of the mask (Figure 6). The electrical connections between the flowmeter and the Oxylog, the Oxylog and the ATDR, and the chest electrodes and the ATDR were made. The integrity of the system was finally checked using the ATDR's ground monitor unit, and any necessary adjustments made. The subjects then rested in a chair for 10 minutes. Recording commenced at the beginning of this rest period.

FIGURE 6. SUBJECT WEARING RECORDING APPARATUS

Having completed any last minute preparation, the subject then walked to the aircraft and did his external pre-flight checks before strapping in. The Oxylog was carried over his shoulder by its strap, and secured to his waist by a belt, and the ATDR carried in a lower leg pocket of his flying coverall. Inside the aircraft, the Oxylog was held by the experimenter seated on the rear seat in the Gazelle or the crewman's jump-seat in the Puma, for the pilots. The crewman carried it himself throughout the flight. When the subject was a pilot, a safety pilot was carried to cover any potential lookout problems caused by limitation of head movement or visual fields produced by the oxygen mask.

The pilots then flew a normal training sortie, or the crewmen flew a normal task, while the experimenter monitored the function of the Oxylog and manually recorded the time at which different stages of flight were begun and ended.

At the end of the sortie, the subject again carried the Oxylog to the crewroom, where recording was stopped and the data retrieved from the ATDR.

RESULTS

General

Table 5 gives the energy expenditure results for the pilots, Table 6 for the crewmen. The heart rates are shown in Tables 7 and 8.

The phases of flight considered for the pilots were the hover, level flight at 1000 feet (305m) above mean sea level (AMSL), low level flight at 100 - 200 feet (30.5 - 60.0m) above ground level (AGL), instrument flying, and a circuit with the hydraulics selected out. The instrument flying phase represents the period when the aircraft was under positive air traffic control while conducting an instrument approach to an airfield. In the majority of cases instrument flying conditions were simulated.

The phases considered for the crewmen were preparation for flight, transit flying, trooping, underslung loads, and refuelling in the field.

In preparation for flight, the crewman has to stow his equipment and tools in the aircraft, check the interior of the rear cabin, then inspect the outside of the aircraft. This involves getting in and out of the cabin several times, and climbing up the outside to inspect the main rotor hub. During transit flying he sits in the 'jump' seat and has little physical work to do. He changes radio frequencies and navigational instrument settings, and helps the pilot with map reading.

When trooping, the crewman must help soldiers in and out of the aircraft, stow their weapons and equipment and ensure that they are all strapped into their seats. Monitoring underslung loads involves moving between the 2 doors and floor hatch to check the safety of the load as it hangs from its strop, and to direct the pilot into the correct position for lifting and depositing it.

Refuelling in the field entails getting out of the aircraft and manouvering drums of fuel into a suitable position. He must then check the fuel for water contamination, and use the portable electric pump to refuel the aircraft. The empty barrels must finally be rolled clear, and the pump returned to the cabin.

Some of the sorties from which the data were obtained did not include all the phases of flight considered in the tables. In Table 7, heart rates are not shown for subjects P7 - P10 due to recording problems, usually due to the electrical contact of the chest electrodes becoming completely detached, or wiring faults between the electrodes and the ATDR. Similarly in Table 8 for subjects C6 - C8.

Energy Expenditure (Tables 5 and 6)

To minimise the effects of weight difference between subjects, all results shown in Tables 5 and 6 are expressed as Watts (W) and W/kg.

Gazelle Pilots. (Subjects P1 - P6). (Table 5). There was no significant difference between the energy cost of flying the Gazelle in level flight (mean 1.7 W/kg, range 1.4 - 2.0), and at low level (1.5 W/kg) or while instrument flying (1.5 W/kg). In the hover and flying without the hydraulics, the mean value was greater at 1.9 W/kg in each case ($p<0.01$). The mean value at rest was 1.2 W/kg (range 0.9 - 1.5) and while walking to the aircraft 3.6 W/kg (range 2.4 - 4.5). All forms of flight had values significantly higher than resting ($p<0.001$).

Puma Pilots. (Subjects P7 - P12). (Table 5). The energy expended by the Puma pilots was consistently higher than the Gazelle pilots in all forms of activity ($p<0.05$). In level flight, 2.5 W/kg was the mean result (range 1.6 - 4.5). Again, flying at low level and on instruments had similar values of 2.5 and 2.8 W/kg respectively. Hovering required a significantly greater energy expenditure at 3.1 W/kg (range 2.1 - 5.0) ($p<0.01$), as in the Gazelle. Similarly, the result for flying in manual was greater at 2.2 W/kg than that for level flight at 1.9 W/kg in the 3 subjects for whom direct comparison could be made ($p<0.01$). The results for resting and walking were both significantly higher than for the Gazelle pilots at 1.5 W/kg and 5.18 W/kg respectively ($p<0.05$). All forms of flight had values significantly higher than resting ($p<0.001$).

Puma Crewmen. (Subjects C1 - C8). (Table 6). There is considerable variation between the energy cost of transit flying (mean 2.2 W/kg, range 1.8 - 2.7) and trooping (mean 4.6 W/kg, range 3.5 - 5.5), or monitoring underslung loads (mean 4.5 W/kg, range 3.9 - 5.0). No flying activity was higher than preparing for flight (mean 5.1 W/kg, range 3.0 - 7.0) or refuelling (mean 5.5 W/kg, range 4.8 - 6.1). The mean value for walking was 6.7 W/kg (range 5.5 - 8.2) and for sitting at rest 1.7 W/kg (range 1.3 - 2.0). All other phases of flight were significantly higher than transit flying ($p<0.001$).

TABLE 5. ENERGY EXPENDITURE (PILOTS)

Subjects divided into Gazelle pilots (P1-6) and Puma pilots (P7-12) for each stage of flight.

vO_2 = oxygen consumption (l/min)
W = total rate of energy expenditure (W)
W/kg = rate of energy consumption per kg body mass (W/kg)
n = number of values used in calculating mean

Subject	Rest				Walking				Hover			
	vO2	W	W/kg	n	vO2	W	W/kg	n	vO2	W	W/kg	n
P1	0.3	105	1.4	8	0.7	244	3.2	6	0.4	139	1.8	5
P2	0.2	70	0.9	7	0.8	279	3.6	7	0.4	139	1.9	4
P3	0.3	105	1.3	9	0.9	314	3.8	7	0.4	139	1.7	5
P4	0.2	70	1.0	9	0.5	174	2.4	6	0.4	139	1.9	5
P5	0.3	105	1.5	9	0.9	314	4.5	5	0.4	139	2.0	4
P6	0.3	105	1.3	9	0.9	314	3.8	6	0.5	174	2.1	9
mean	0.27	93	1.23		0.78	273	3.55		0.42	145	1.90	
standard deviation	0.05	18	0.23		0.16	56	0.70		0.04	14	0.14	
P7	0.3	105	1.3	8	1.2	418	5.1	11	0.5	174	2.1	4
P8	0.3	105	1.2	7	1.3	453	5.2	5		–		
P9	0.3	105	1.3	5	1.1	383	4.7	10	0.5	174	2.1	3
P10	0.3	105	1.3	5	1.0	349	4.5	10		–		
P11	0.4	139	2.0	7	1.3	453	6.5	10	1.0	349	5.0	3
P12	0.5	174	1.9	4	1.3	453	5.1	3		–		
mean	0.35	122	1.50		1.20	418	5.18		0.66	232	3.07	
standard deviation	0.08	29	0.35		0.13	44	0.70		0.29	101	1.7	

TABLE 5. ENERGY EXPENDITURE (PILOTS) (CONTD)

Subjects divided into Gazelle pilots (P1-6) and
Puma pilots (P7-12) for each stage of flight.

vO_2 = oxygen consumption (l/min)
W = total rate of energy expenditure (W)
W/kg = rate of energy consumption per kg body mass (W/kg)
n = number of values used in calculating mean

Subject	Level Flight				Low Level				Instrument Flying			
	vO2	W	W/kg	n	vO2	W	W/kg	n	vO2	W	W/kg	n
P1	0.3	105	1.4	8	0.3	105	1.4	10	0.3	105	1.4	7
P2	0.4	139	1.9	18	0.3	105	1.3	5	0.3	105	1.4	4
P3	0.4	139	1.7	13	0.4	139	1.7	8	0.4	139	1.7	5
P4	0.3	105	1.5	16	0.3	105	1.5	11	0.3	105	1.5	4
P5	0.4	139	2.0	11	0.3	105	1.5	12	0.3	105	1.5	4
P6	0.4	139	1.7	11	0.4	139	1.7	12	0.4	139	1.7	4
mean	0.37	128	1.70		0.33	116	1.52		0.33	116	1.53	
standard deviation	0.05	18	0.23		0.05	18	0.16		0.05	18	0.14	
P7	0.4	139	1.7	5	0.4	139	1.7	10		-		
P8	0.4	139	1.6	11	0.4	139	1.6	6		-		
P9	0.4	139	1.7	7		-			0.4	139	1.7	14
P10	0.7	244	3.2	5	0.6	209	2.7	5	0.6	209	2.7	9
P11	0.9	314	4.5	3	0.8	279	4.0	7	0.8	279	4.0	4
P12	0.6	209	2.3	27		-			0.7	244	2.7	19
mean	0.57	197	2.50		0.55	192	2.50		0.63	217	2.78	
standard deviation	0.21	72	1.15		0.19	67	1.12		0.17	60	0.94	

Manual

	vO_2	W	W/kg	n		vO_2	W	W/kg	n
P1	0.4	139	1.8	4	P7	0.5	174	2.1	5
P2	0.3	105	1.4	7	P8		-		
P3	0.5	175	2.4	6	P9	0.4	139	1.7	5
P4	0.4	139	1.9	5	P10		-		
P5	0.4	139	2.0	4	P11		-		
P6	0.4	139	1.7	4	P12	0.7	244	2.7	9
mean	0.40	139	1.87			0.53	186	2.16	
standard deviation	0.06	22	0.33			0.15	54	0.50	

TABLE 6. ENERGY EXPENDITURE OF PUMA CREWMEN

vO_2 = oxygen consumption (l/min)
W = total rate of energy expenditure (W)
W/kg = rate of energy consumption per kg body mass (W/kg)
n = number of values used in calculating mean

Subject	Rest				Walking				Flight Preparation			
	vO_2	W	W/kg	n	vO_2	W	W/kg	n	vO_2	W	W/kg	n
1	0.3	105	1.3	7	1.4	492	6.1	9	0.7	246	3.0	10
2	0.3	105	1.7	9	1.0	351	5.9	7	0.8	279	4.4	12
3		-			1.2	422	5.5	7		-		
4	0.3	105	1.4	4	1.8	633	8.2	6	1.2	422	5.5	7
5		-			1.3	457	5.6	7	1.2	422	5.2	6
6	0.4	140	2.0	12	1.6	563	8.2	10	1.1	387	5.6	14
7	0.3	105	1.5	13	1.4	492	7.0	11	1.4	492	7.0	7
8	0.4	140	2.0	6	1.5	528	7.5	8	1.0	352	5.0	10
mean	0.33	117	1.65		1.40	492	6.75		1.06	371	5.10	
standard deviation	0.05	18	0.30		0.24	86	1.12		0.24	86	1.22	

TABLE 6. ENERGY EXPENDITURE OF PUMA CREWMEN (CONTD)

vO_2 = oxygen consumption (l/min)
W = total rate of energy expenditure (W)
W/kg = rate of energy consumption per kg body mass (W/kg)
n = number of values used in calculating mean

Subject	Trooping				Underslung Loads				Refuelling			
	vO_2	W	W/kg	n	vO_2	W	W/kg	n	vO_2	W	W/kg	n
1		-			0.9	316	3.9	46		-		
2	1.0	352	5.5	27		-			1.1	387	6.1	12
3	1.1	387	5.0	17		-				-		
4		-				-				-		
5	0.8	281	3.5	32		-			1.1	387	4.8	23
6	1.0	352	5.1	18	0.9	316	4.6	46		-		
7	0.8	281	4.0	72		-			1.1	387	5.5	56
8		-			1.0	352	5.0	31		-		
mean	0.9	330	4.6		0.9	328	4.5		1.1	387	5.5	
standard deviation	0.13	47	0.83		0.05	21	0.56		0	0	0.65	

	Transit Flying			
	vO_2	W	W/kg	n
1	0.4	141	1.8	17
2	0.4	141	2.2	37
3	0.4	141	1.8	23
4	0.6	211	2.7	10
5	0.5	176	2.2	15
6	0.5	176	2.5	13
7	0.4	141	2.0	2
8	0.5	176	2.5	5
mean	0.46	163	2.21	
standard deviation	0.07	26	0.34	

Heart Rate (Tables 7 and 8)

Because of the technical difficulties already described in recording heart rate, results were retrieved for only 2 of the Puma pilots. These are therefore not considered further. Considering the mean of the Gazelle pilots' results (Table 7), there is no significant difference between heart rate at rest and for any phase of flight. Examining individual results, the variation appears to be because subject P2 had a particularly high resting heart rate at 97 beats per minute (bpm); higher indeed than while walking, possibly due to apprehension. The values for the individual subjects show no particular trend, other than the fact that heart rate increased slightly over rest with the various forms of flight, the increase ranging from 0 - 18 bpm. The increase is not statistically significant. The mean heart rate rises from 75 bpm at rest to 92 bpm on walking ($p<0.001$).

The results for the Puma crewmen carrying out monitoring of underslung loads and refuelling are too few for consideration. The means of the remaining results (Table 8) show a tendency to follow those for energy expenditure, except that the mean for trooping (99 bpm, range 87 - 112) is now higher than for flight preparation (96 bpm, range 79 - 117), though the difference is not significant. All are significantly higher than the mean resting rate of 68 bpm ($p<0.001$), and rates during flight preparation and trooping are significantly higher than during transit flying ($p<0.001$). There is a large increase in heart rate on walking to 116 bpm (range 109 - 125) compared to rest, 68 bpm (range 62-73) $p<0.001$.

TABLE 7. PILOTS' HEART RATE (BEATS PER MINUTE)

Subjects divided into Gazelle (P1-6) pilots and Puma (P11-12) pilots for each stage of flight.

Flight Phase Subject	Rest	Walking	Hover	Level Flight	Low Level	Instrument Flying	Manual
P1	63	85	73	69	70	67	70
P2	97	88	71	70	72	69	67
P3	76	105	85	87	92	94	91
P4	66	78	70	68	70	66	74
P5	74	96	85	83	81	76	88
P6	73	95	83	85	87	78	81
mean	75	92	78	77	79	75	79
standard deviation	12	9	7	9	9	11	10
P11	90	115	91	92	90	85	--
P12	108	143	--	111	--	110	109

TABLE 8. CREWMEN'S HEART RATE (BEATS PER MINUTE)

Flight Phase Subject	Rest	Walking	Flight Prep	Transit	Trooping	Underslung Loads	Refuelling
C1	62	118	90	80	--	108	--
C2	73	119	117	84	112	--	--
C3	--	125	--	85	98	--	--
C4	69	111	79	83	--	--	--
C5	--	109	96	77	87	--	--
mean	68	116	96	82	99	--	--
standard deviation	6	6	16	3	13	--	--

DISCUSSION

Pilots

The results for mean energy expenditure for pilots of both aircraft types show that the energy cost of level flight is approximately 50% higher than that of sitting at rest, and that of hovering is significantly higher than level flight ($p<0.01$). In the hover, changes in the position of the flight controls are continuously required due to variations in the wind, particularly as the aircraft is in close proximity to the ground.

When instrument flying the mental workload rises as the aircraft must be controlled within much more precise limits in terms of height, airspeed and heading, than is generally the case in transit flying. This might reasonably be expected to be accompanied by an increase in physical workload as more frequent control adjustments must be made to achieve this degree of accuracy. The results presented, however, show no such increase.

Flying at low level also requires an increase in mental effort. Lookout must be more thorough to pick up wires, birds and other obstacles, and map reading is more difficult close to the ground because of the lower perspective. Again, more use of the controls is required because of the frequent changes of height and heading to avoid obstacles, built-up areas and livestock. However, in this study there was no significant difference between level flight and flying at low level.

Each of the Gazelle pilots flew a circuit with the hydraulics selected out, leaving a purely mechanical linkage between the flying controls and the rotors. The control forces which must be applied simply to maintain straight and level flight are considerable, and rise even higher during the approach to landing. This was reflected by a significant increase in mean energy expenditure over normal level flight from 1.7 to 1.9 W/kg ($p<0.01$). The Puma pilots also showed an increase in manual from 1.9 to 2.2 W/kg for the three subjects from whom data were obtained.

When comparing the results of Gazelle pilots with those of Puma pilots, it appears that for all the activities considered, the Puma pilots expended significantly more energy whether resting, walking or flying ($p<0.05$). No attempt was made to match pilots in both groups for age, weight or experience, though the energy expenditure calculated in W/kg should at least take account of weight differences, though not differences in body density.

Resting conditions were not controlled in any way other than instructing subjects to sit in a chair and rest. The occasional subject was observed to take the opportunity to do some of his flight planning, and energy was expended at times in replying to the comments of passing colleagues. It may be that the Puma pilots indulged more in this activity, which would involve a small increase in energy expenditure through writing and folding maps. All values are in any case within the range quoted by Durnin and Passmore[17] for seated subjects.

Walking to the aircraft was again not controlled in any way. The Puma pilots had farther to walk than the Gazelle pilots as can seen from the generally higher values for n in Table 5. They tended to carry more in the way of equipment than the Gazelle pilots and their walk was over grass, and in some cases snow, rather than asphalt.

The difference in energy expenditure in the various forms of flight is less easy to explain. Littell and Joy[35] found no such difference between helicopters of different size (Table 10). The Gazelle has particularly light controls, especially in the version flown by the Army, which lacks any stability aids. Conversely, it would be expected that few control adjustments would be required when flying the Puma, by virtue of its autopilot system.

To find out whether the difference between the rest values could explain the overall difference, in the sense that if the resting value was high then the remaining values would also be high, the rest value was treated as a covariate and the other 6 conditions analysed by analysis of covariance. In this case the effect of helicopter type is dramatically reduced and is no longer significant. A summary of the statistics is shown in Table 9.

TABLE 9 ANALYSIS OF VARIANCE FOR ENERGY EXPENDITURE OF PILOTS (W/KG)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Sig
Gazelle/Puma	2.3166	1	2.3166	7.056	$p<0.05$
Conditions	8.65354	6	1.4422	78.465	$p<0.001$
Conditions x Group	0.113819	6	0.02303	1.253	NS

Crewmen

The results show that mean energy expenditure of Puma crewmen for transit flying is 34% higher than that of sitting at rest in the crewroom and is slightly less than that of flying the Puma under the same conditions. Transit flying is spent sitting in the jump-seat with little physical work to do other than change radio frequencies, update the avionics and map read.

The crewmen's work rate rises considerably when trooping, to almost 3 times their resting rate. They have to help soldiers into their seats, help stow their equipment and check that they are strapped in, then close both doors. During the exercises in which these experiments were conducted, the soldiers were carrying relatively light scales of equipment. In practice they would frequently be carrying large packs and Bergen rucksacks which are stowed by the crewmen and markedly increase their workload. The troop lifts were all short, rarely exceeding 5 minutes of transit flying. Each sortie contained several troop lifts, hence the higher values for n (17-72) in Table 6. On longer flights, the overall workload would be correspondingly less.

The workload of carrying underslung loads is not significantly different from that of trooping. As expected, working on the ground, out of the aircraft, the crewman's workload rises even higher; in preparing for flight, to over 3 times his resting rate, and when re-fuelling in the field to 3.3 times his resting, 82% of his walking rate, based on overall means.

Comparison with other Studies (Table 10 and 11)

In order to compare results for the pilots with those of other authors in the field, all values considered have been converted to express energy expenditure in terms of Watts per square metre of body area (Wm^{-2}), the only common denominator available. Table 10 shows the results in their original units, Table 11 in Wm^{-2}.

The results for the Gazelle pilots in this study compare very closely with those of other authors, while those for the Puma pilots are somewhat higher. The only reasons postulated for this difference are those already discussed for that between Puma and Gazelle pilots.

There is no comparable work in the literature for helicopter crewmen.

TABLE 10. COMPARISON WITH OTHER STUDIES

(ORIGINAL UNITS)

Source	Aircraft Type	Mean and range ($Kcal/m^2/hr$) of energy expended during		
		Rest	Level flight	Hover
Littell and Joy (1969)[35]	OH-6A (light)	53 (48-58)	49 (47-51)	67 (63-71)
	UH-1D (medium)	50 (46-54)	49 (47-51)	55 (50-60)
	CH47A (heavy)	48 (42-54)	52 (50-54)	62 (60-64)
Kaufman et al (1970)[34]	J-CH3 (heavy)	53 (50-56)	52 (49-55)	--
French et al (1973)[21]	Scout (light)	42 (39-44)	50 (40-61)	56 (54-59)
		Mean and range (l/min STPD) of oxygen consumption during		
		Rest	Level flight	Hover
Billings et al (1979)[10]	UH-12E (light)	0.31 (0.27-0.33)	0.46 (0.43-0.51)	0.53 (0.43-0.63)

TABLE 11. COMPARISON WITH OTHER STUDIES

(SI UNITS)

Source	Aircraft Type	Mean and range (Wm^{-2}) of energy expended during Rest	Level flight	Hover
Littell and Joy (1969)[35]	OH-6A (light)	62 (56-67)	57 (55-59)	78 (73-83)
	UH-1D (medium)	58 (53-63)	57 (55-59)	64 (58-70)
	CH47A (heavy)	56 (49-63)	60 (58-63)	72 (70-74)
Kaufman et al (1970)[34]	J-CH3 (heavy)	62 (58-65)	60 (57-64)	--
French et al (1973)[21]	Scout (light)	49 (45-51)	58 (46-71)	65 (63-69)
Billings et al (1979)[10]	UH-12E (light)	56 (51-59)	85 (74-93)	113 (99-128)
Present Study	Gazelle (light)	48 (32-54)	66 (54-72)	75 (72-90)
	Puma (medium)	61 (52-87)	98 (69-156)	116 (87-173)

ENVIRONMENTAL CONDITIONS

INTRODUCTION

It is axiomatic that attempts to measure cockpit thermal stress in Europe result in a rapid deterioration in local weather conditions. It was decided therefore to select an area where hot conditions could be more or less guaranteed at a particular season, and undertake the measurements at a time of the year when dry bulb temperatures would approximate those in Central Europe at mid summer.

Belize, in Central America, was the location selected, satisfying the climatic criteria and having permanent detachments of the appropriate helicopter types. At the request of the Air Staffs, the Harriers in Belize were also included in the investigation.

The air element of British Forces Belize consists of a flight of 4 Harriers, a detachment of 4 Pumas, and an Army Air Corps flight of 4 Gazelles. They operate throughout the year in a part of the world where the mean monthly maximum temperature varies between 29 and 32°C. Airport Camp, from where the aircraft operate, is located at 17°31'N, 88°11'W (well within the tropics), at sea level.

The relative humidity recorded at 0700 and 1900 remains at around 90% all year.[37]

METHODS

Aircraft Operations

The 3 aircraft types were all flown on normal operational or training sorties. There were 4 low level, high speed Harrier sorties, cockpit time varying from 48 to 80 minutes. Recordings were successfully obtained from the pilot on 3 Puma sorties, and from the crewman on 4, sortie times varying from 1hr 27min to 7hr 50min. Flying was mainly low-level (500ft (152m) agl) transit flying and trooping, or carrying stores, both of which involved the crewman in hard physical work, loading and unloading equipment. Only 2 Gazelle sorties were instrumented. One consisted of 2hr 50min of liaison flying, mainly at low-level, the other 1hr 50min of carrying free-fall parachutists, alternately climbing and descending between ground level and 8000ft (2438m) with the doors removed. Some aircrew flew 2 instrumented sorties.

Measurements

1. **Airfield Climatic Conditions.** The following recordings were made at half-hourly intervals during the sorties.

a. Dry bulb temperature (T_{db}) and ventilated wet bulb temperature (T_{wb}) were measured using a Hygrophil psychrometer. (Ultrakust-Geratebau, Ruhmannsfelden, W. Germany).

b. Globe temperature (T_{bgs}) was measured using a 50mm black globe and a Grantmeter (Grant Instruments, Toft, Cambridge).

c. Wind speed (V_w) was measured using a vane anemometer.

2. **Aircraft Temperatures.** Aircraft T_{db}, T_{bgs} and relative humidity (rh) were measured using an environmental sensor unit as described by Higenbottam[31] (Figure 7). Wet bulb globe temperature (WBGT) was calculated using the programme in the ATDR's microcomputer by the equation:

$$WBGT = 0.7\ T_{wb} + 0.3\ T_{bgs}{}^{50}.$$

The unit was mounted on the starboard side of the ejection seat in the Harrier, on the bulkhead behind the pilot's head or on the side of the rear cabin above the rear port window in the Puma, and on the back of the pilot's seat in the Gazelle.

3. Physiological Measurements.

a. Deep body temperature (T_{gi}) was measured using a radio pill in the gastrointestinal tract.[32,25] The radio pill was used because it is the only method of deep body temperature measurement that is both aesthetically acceptable to aircrew, and does not present a flight safety hazard by causing distraction.

b. Skin temperatures were measured at 4 sites (chest, upper arm, inner thigh and outer calf) using thermistors accurate to within 0.25°C (Edale Instruments (Cambridge) Ltd) as described by Allan et al.[3] Mean skin temperature ($\bar{T}_{sk}$) was calculated in the manner of Ramanathan.[42]

c. Body weight loss was measured from nude weighings of the aircrew before flight and after landing. An attempt was made to estimate the dehydration of the helicopter aircrew by weighing all food, and measuring volumes of fluid drunk and urine produced. This proved impractical in the wide variety of conditions encountered on their very long sorties, and was soon abandoned.

4. **Subjective Fatigue.** The development of fatigue was assessed subjectively by asking the aircrew to complete a 'fatigue checklist' before and after each sortie. Details of the checklist and instructions are given in Annex A. The technique used is an anglicised version of that described by Pearson and Byars[41] as used by Allan et al.[5]

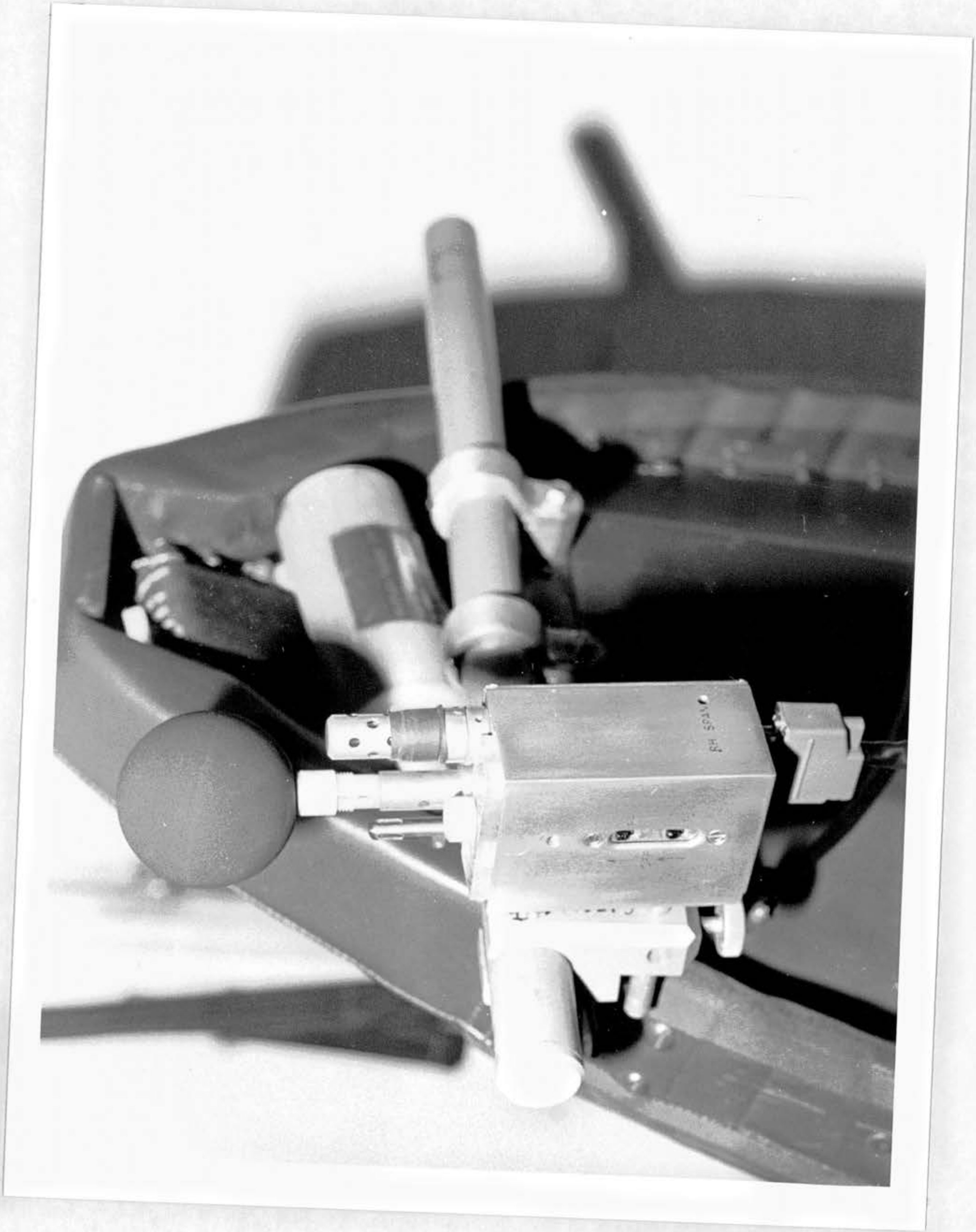


FIGURE 7. AIRCRAFT ENVIRONMENTAL SENSOR

Data Collection

Each subject was asked to report to the trial team 20 minutes before flying. He swallowed the radio pill, and was weighed. The subject was then fitted with the skin thermistor harness and radio pill aerial before dressing. The electronic unit for recording the data (ADTR), and for the radio pill, were fitted and the sensors checked. The system was connected to the aircraft sensors during strapping in. At the end of the sortie, the aircrew reported to the trial team for retrieval of the equipment and re-weighing. The data were recovered as already described for the Oxylog, though an Osborne microcomputer (Future Management, Milton Keynes) was used in place of the Powerhouse, being more easily portable.

Aircrew Clothing

1. Harrier.

   a. Personal briefs.
   b. Socks, Terry loop, olive drab.
   c. Coverall, aircrew, Mk 14A.
   d. Boots, aircrew, lightweight.
   e. Gloves, S/R, olive drab.
   f. Trousers, anti-G, external, Mk 2.
   g. Life preserver, Mk 27.
   h. Garters, leg restraint.
   i. Helmet, aircrew protective, Mk 3C or 4B.
   j. Mask, oxygen, Type P/Q.
   k. Treescape.
   l. Torso harness.

2. Puma.

   a. Personal briefs.
   b. Socks, Terry loop, olive drab.
   c. Personal T-shirt (in some cases).
   d. Coverall, aircrew, Mk 14A or 11.
   e. Boots, aircrew, 1965 pattern or lightweight.
   f. Gloves, S/R, olive drab.
   g. Helmet, aircrew protective, Mk 3C or 4A.

3. Gazelle.

a. Personal briefs.
b. Socks, Terry loop, olive drab.
c. Tropical combat shirt.
d. Tropical combat trousers.
e. Boots, aircrew, 1965 pattern.
f. Gloves, S/R, olive drab.
g. Helmet, aircrew protective, Mk 3C.

RESULTS

The measurements made on each sortie are presented graphically in Figures 8 to 20. The figures are arranged in pairs so that the first page gives details of the sortie, the airfield climatic conditions, and whether the subject was acclimatised or a new arrival (less than one week before the start of the trial), weight, and weight loss. The length of the sortie is calculated as time of take off to time of landing. The second shows cockpit temperatures and the physiological data. T_{bgs} is the black globe temperature, T_{db} the dry bulb temperature, T_{wg} is the calculated WBGT, and T_{wb} the wet bulb temperature. $\bar{T}_{sk}$ is the mean skin temperature, and T_{gi} the deep body (gastrointestinal tract) temperature.

The figures are annotated to show time of take-off (T/O), landing (L) and drinking (D). Figures 8 to 11 show data for the Harrier pilots, Figures 12 to 14 Puma pilots, Figures 15 to 18 Puma crewmen, and Figures 19 and 20 Gazelle pilots. Airfield climatic conditions are recorded as mean T_{db}, T_{bgs}, rh, absolute humidity and WBGT, and their ranges during the sortie. Windspeed is shown as the range.

Harrier

The highest mean airfield temperature was recorded during sortie H4 (WBGT 31.2°C, range 31.0-31.4). The highest cockpit temperatures were recorded, paradoxically, on sortie H3 with a maximum WBGT of 35.7°C, (Figure 10). In all cases, the cockpit temperatures rose on closing the canopy, and fell again on starting the engine, due to the operation of the cabin conditioning system. The cockpit T_{wb} fell correspondingly, reflecting the low relative humidity with cabin conditioning in operation (rh 18% by the end of the sortie). *

T_{gi} was not recorded on sorties H1 and H3 due to the radio pill being out of range of the aerial. The highest T_{gi} recorded was 38.2°C on sortie H4, a rise of 1.3°C (Figure 11). The largest weight loss was on sortie H2, at 1.5% per hour. The highest mean skin temperature was seen at the start of sortie H2, at 37.8°C (Figure 9). Skin temperatures generally fell as the sortie progressed, to as low as 33.6°C on sortie H1 (Figure 8).

* The T_{wg} and T_{wb} fell during flight on both sorties H1 and H2, whereas on H3 and H4, after an initial slight fall they rose during flight, to fall again when the aircraft canopy was opened after landing. The photographic reconnaissance sorties (H3 and H4) were conducted at an overall lower altitude than the range sorties (H1 and H2). This would result in a higher cabin conditioning system inlet temperature and more thermodynamic heating of the aircraft skin at the lower, hotter and denser levels at which H3 and H4 were flown.

There are no heat limitations defined for UK aircrew. The United States Air Force (USAF) has a system developed by Stribley and Nunneley[46] designed to assist their commanders in minimising the adverse effects of heat stress on aircrew during hot-weather operations. This system, the Fighter Index of Thermal Stress (FITS), was developed from the WBGT and produces a single value representing effective heat stress, based on 3 weighted variables: air temperature, humidity and radiant heating. Exposure limits are divided into 'normal', 'caution' and 'danger' zones. (The FITS table is reproduced at Annex C). The caution zone (FITS 32-38°C) includes conditions that should be physiologically compensable when adequate hydration is maintained. Commanders are advised to be aware of heat stress, limit the ground period (preflight and ground standby) to 90 minutes, and allow a minimum of 2 hours recovery period between flights. The first 3 Harrier sorties fell in this zone with FITS of 36-37°C. The danger zone (FITS greater than 38°C) produces progressive heat storage, with adverse effects on performance and on tolerance to other stresses such as acceleration and hypoxia. Commanders are advised to cancel low-level flights (below 3000' AGL), limit the ground period to 45 minutes, and allow a minimum recovery period of 2 hours. The fourth Harrier flight was well within the danger zone, with a FITS of 39-40°C.

The physiological data from this trial suggest that the USAF FITS is perhaps rather too cautious, though 'ground' times were short, as were the sorties themselves.

The FITS calculations are shown in Table 13.

TABLE 13. FIGHTER INDEX OF THERMAL STRESS (FITS)

Sortie	RH	Mean Temperature ($^{\circ}$C)			Zone
		Dry Bulb	Dewpoint	FITS	
H1	62	30.6	22.5	36-37	Caution
H2	63	30.5	23.3	36-37	Caution
H3	61	31.2	23.8	36-37	Caution
H4	63	31.4	25.5	39-40	Danger

SORTIE DETAILS

Sortie number: H1

Date: 120483

Time of take-off: 0937

Length of sortie: 36 min

Type of sortie: Range

Aircrew: Harrier Pilot 1

New arrival

Weight: 83.8 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 30.47°C Range: 30.4 - 30.8°C

T_{bgs}: 35.33°C Range: 31.8 - 38.7°C

RH: 62% Range: 61 - 64%

Absolute humidity: 20.3 torr Range: 20.1 - 20.4 torr

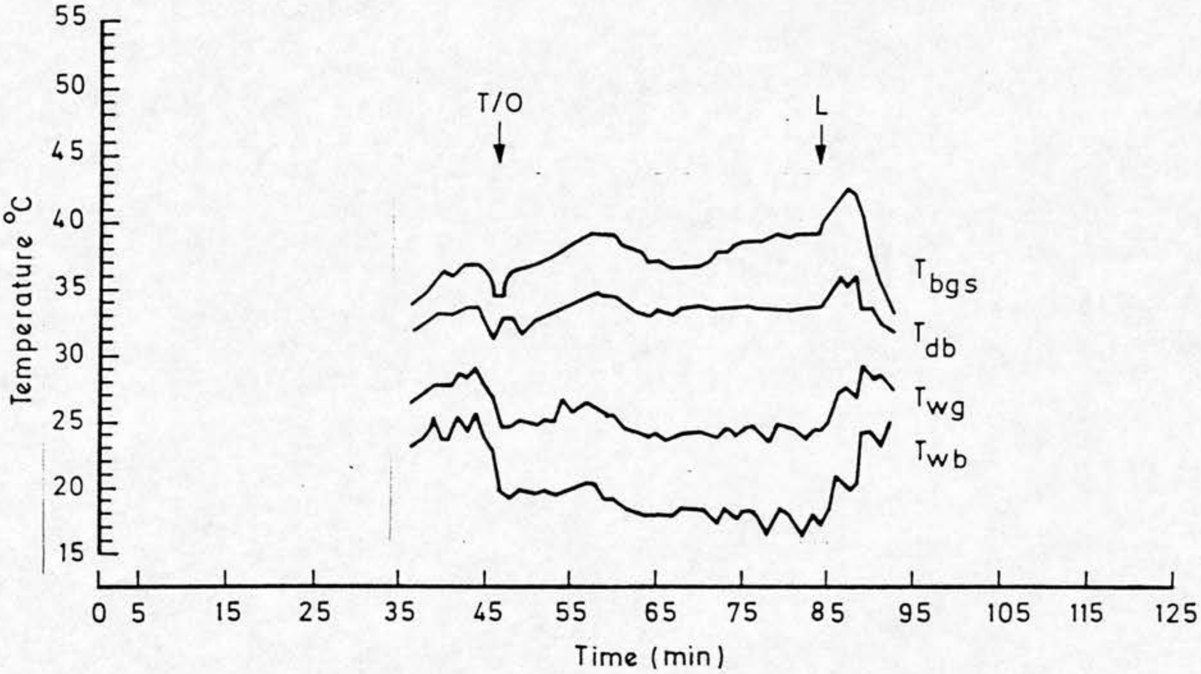
Windspeed: 1.8 - 3.6 ms^{-1}

WBGT: 27.91°C Range: 26.6 - 29.2°C

Weight loss: 0.54 kg

% body weight loss per hour: 0.96

FIGURE 8



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Temperature °C
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T_{db}
T_{wg}
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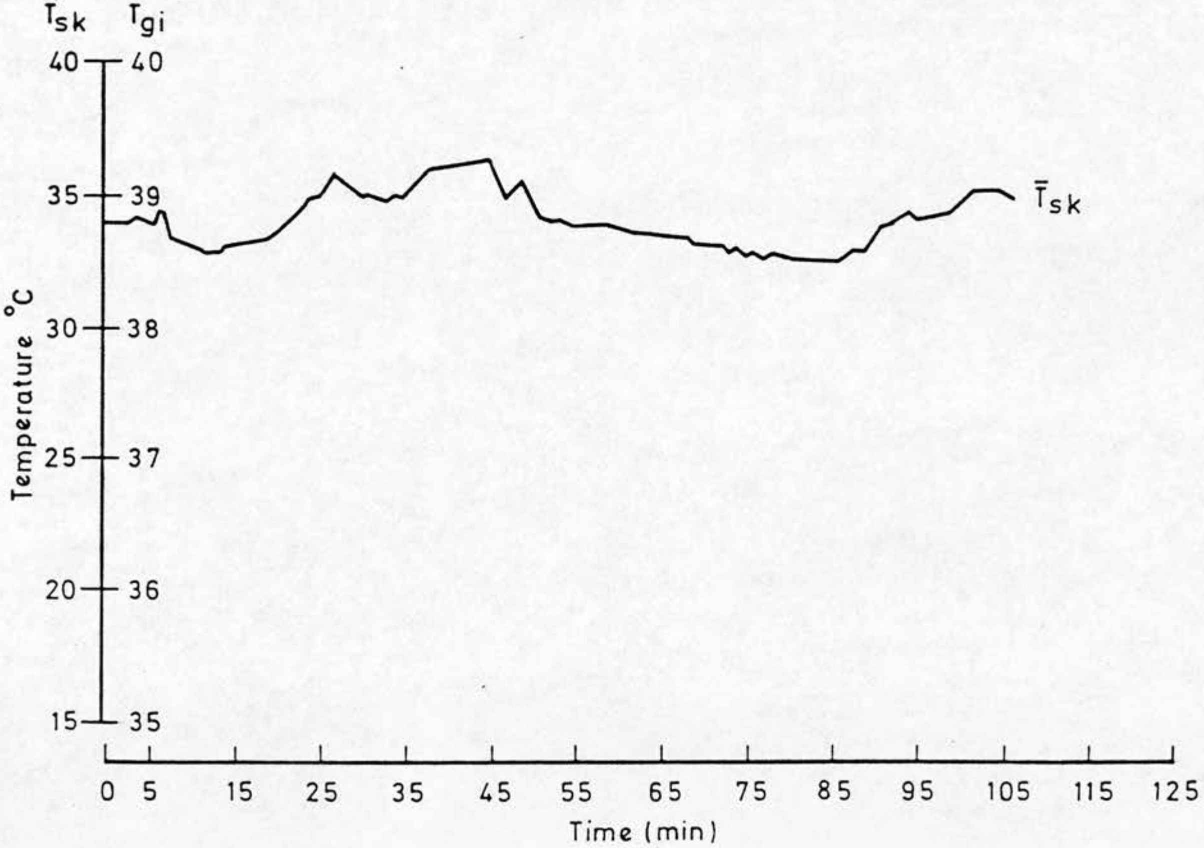
105
115
125
Time (min)



$\bar{T}_{sk}$
T_{gi}
40
40
35
39
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38
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20
36
15
35
Temperature °C
$\bar{T}_{sk}$
0
5
15
25
35
45
55
65
75
85
95
105
115
125
Time (min)

SORTIE DETAILS

Sortie number: H2

Date: 120483

Time of take-off: 1210

Length of sortie: 30 min

Type of sortie: Range

Aircrew: Harrier Pilot 2

Acclimatised

Weight: 84.7 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 31.15^{o}C Range: 30.5 - 32.0^{o}C

T_{bgs}: 42.65^{o}C Range: 41.3 - 43.8^{o}C

RH: 63% Range: 59 - 67%

Absolute humidity: 21.6 torr Range: 19.9 - 22.7 torr

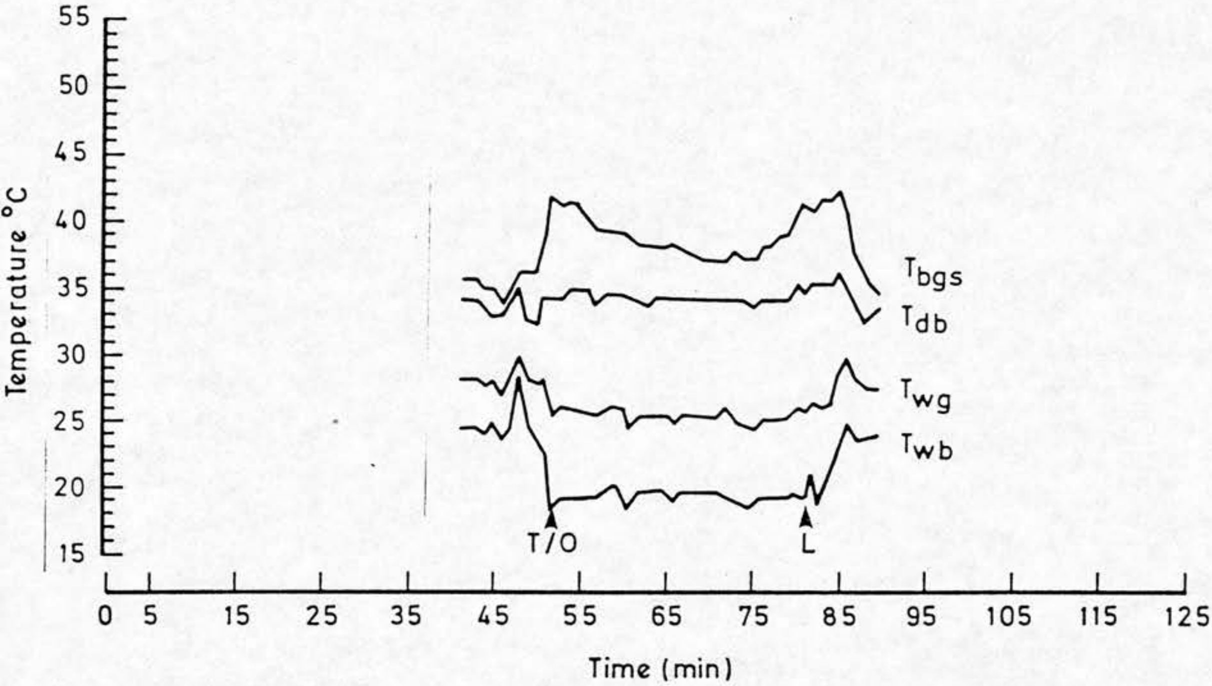
Windspeed: 2.0 - 3.0 ms^{-1}

WBGT: 30.84^{o}C Range: 30.24- 31.4^{1}C

Weight loss: 0.71 kg

% body weight loss per hour: 1.50

FIGURE 9


Temperature °C
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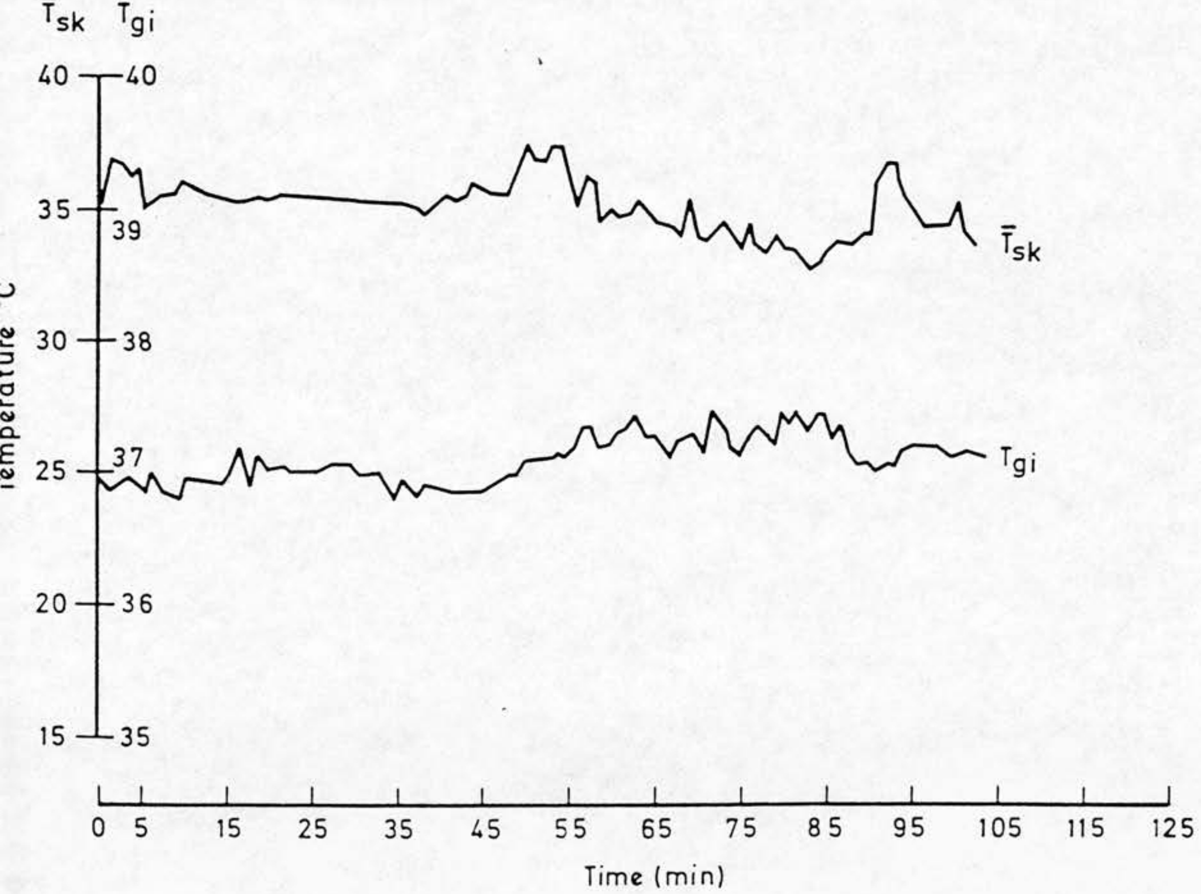
Time (min)


T̄sk
Tgi
Temperature °C
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36
35
T̄sk
Tgi
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5
15
25
35
45
55
65
75
85
95
105
115
125
Time (min)

SORTIE DETAILS

Sortie number: H3

Date: 140483

Time of take-off: 0906

Length of sortie: 55 min

Type of sortie: Photographic Reconnaissance

Aircrew: Harrier Pilot 3

New arrival

Weight: 81.2 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 31.85°C Range: 31.2 - 32.5°C

T_{bgs}: 36.90°C Range: 36.6 - 37.2°C

RH: 61% Range: 61 - 62%

Absolute humidity: 21.7 torr Range: 20.8 - 22.7 torr

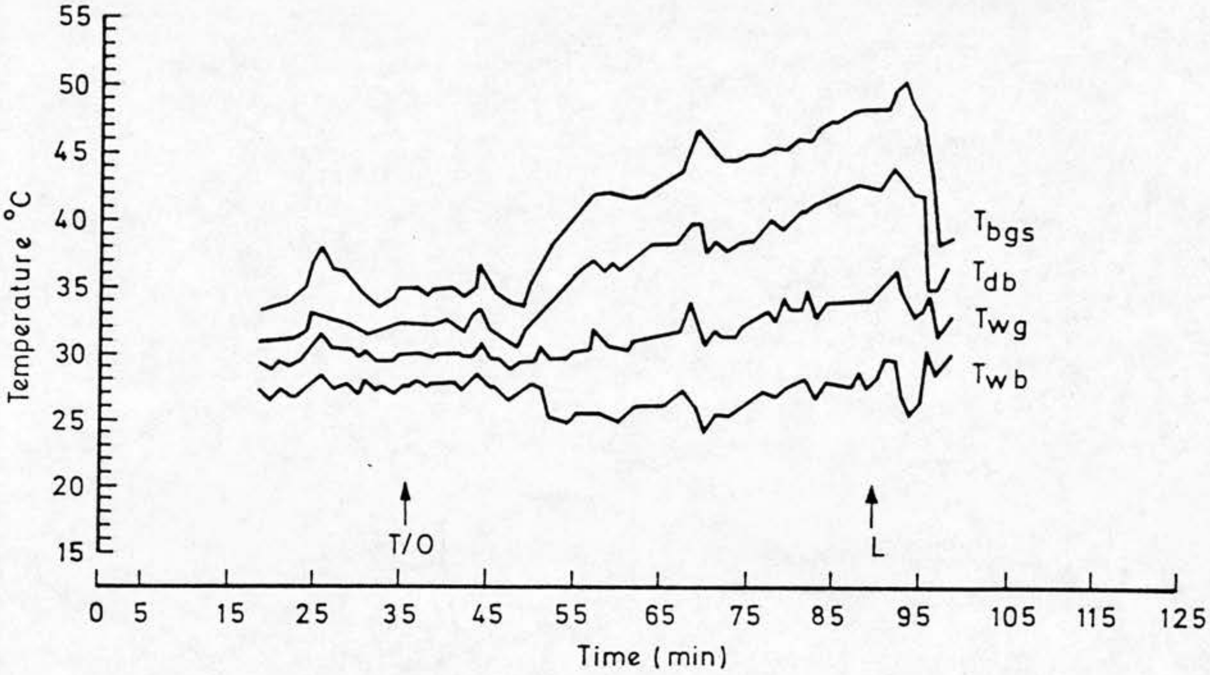
Windspeed: 1.8 - 4.5 ms^{-1}

WBGT: 29.24°C Range: 28.8 - 29.6°C

Weight loss: 0.92 kg

% body weight loss per hour: 1.10

FIGURE 10


Temperature °C
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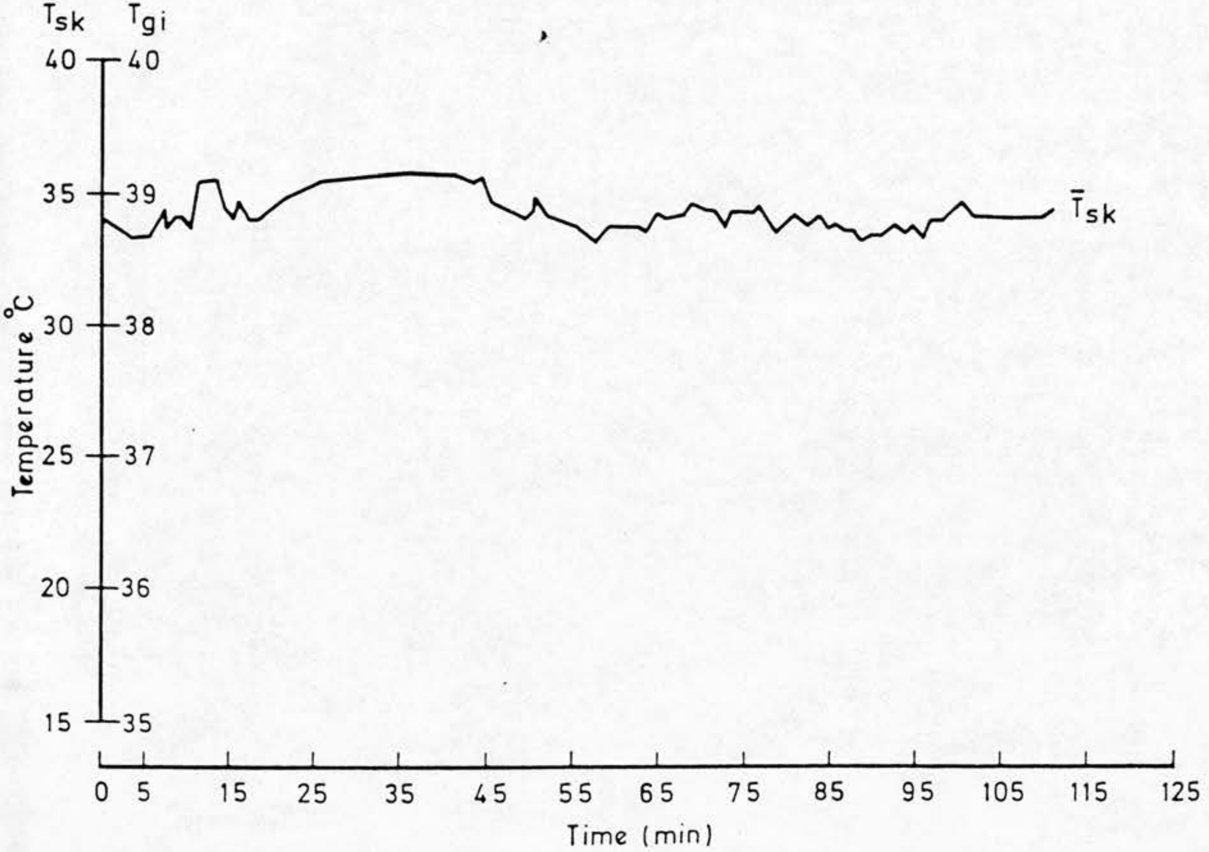
Time (min)


$\bar{T}_{sk}$
T_{gi}
Temperature °C
40
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30
38
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20
36
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35
$\bar{T}_{sk}$
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35
45
55
65
75
85
95
105
115
125
Time (min)

SORTIE DETAILS

Sortie number: H4

Date: 140483

Time of take-off: 1135

Length of sortie: 48 min

Type of sortie: Photographic Reconnaissance

Aircrew: Harrier Pilot 1

New arrival

Weight: 83.8 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 32.80°C Range: 31.4 - 34.0°C

T_{bgs}: 41.70°C Range: 41.4 - 42.2°C

RH: 63% Range: 58 - 67%

Absolute humidity: 22.3 torr Range: 21.1 - 23.8 torr

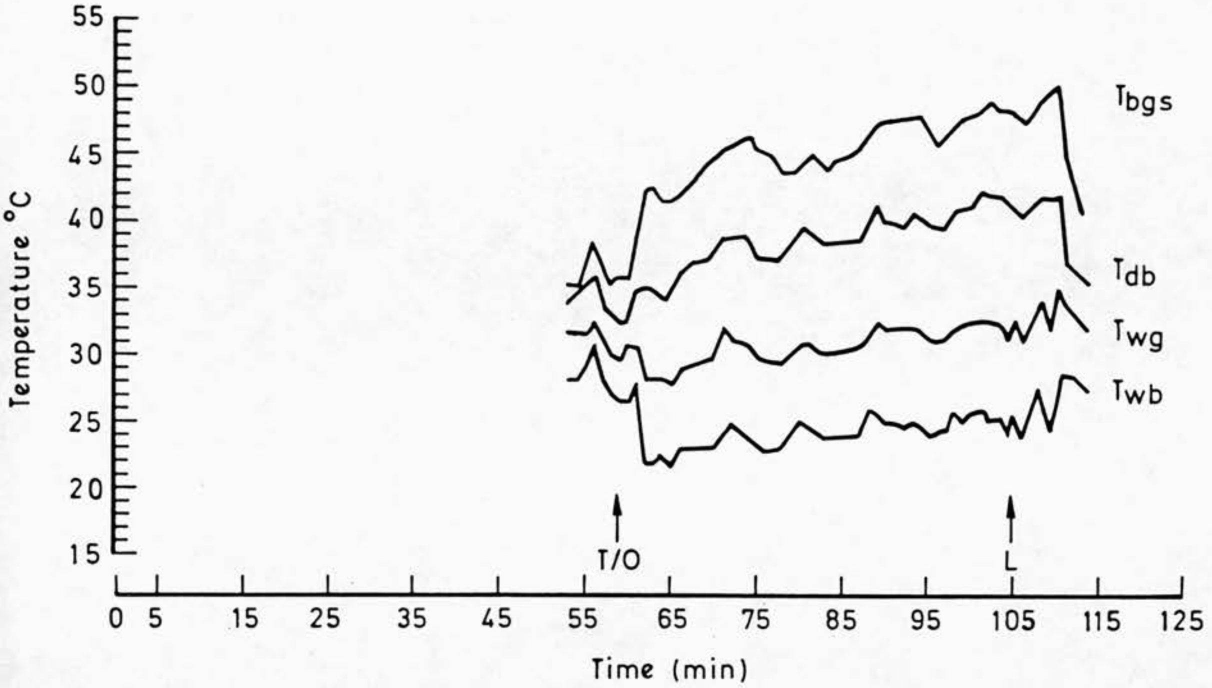
Windspeed: 0.3 - 3.4 ms^{-1}

WBGT: 31.20°C Range: 31.0 - 31.4°C

Weight loss: 0.45 kg

% body weight loss per hour: 0.60

FIGURE 11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Temperature °C
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T_{wg}
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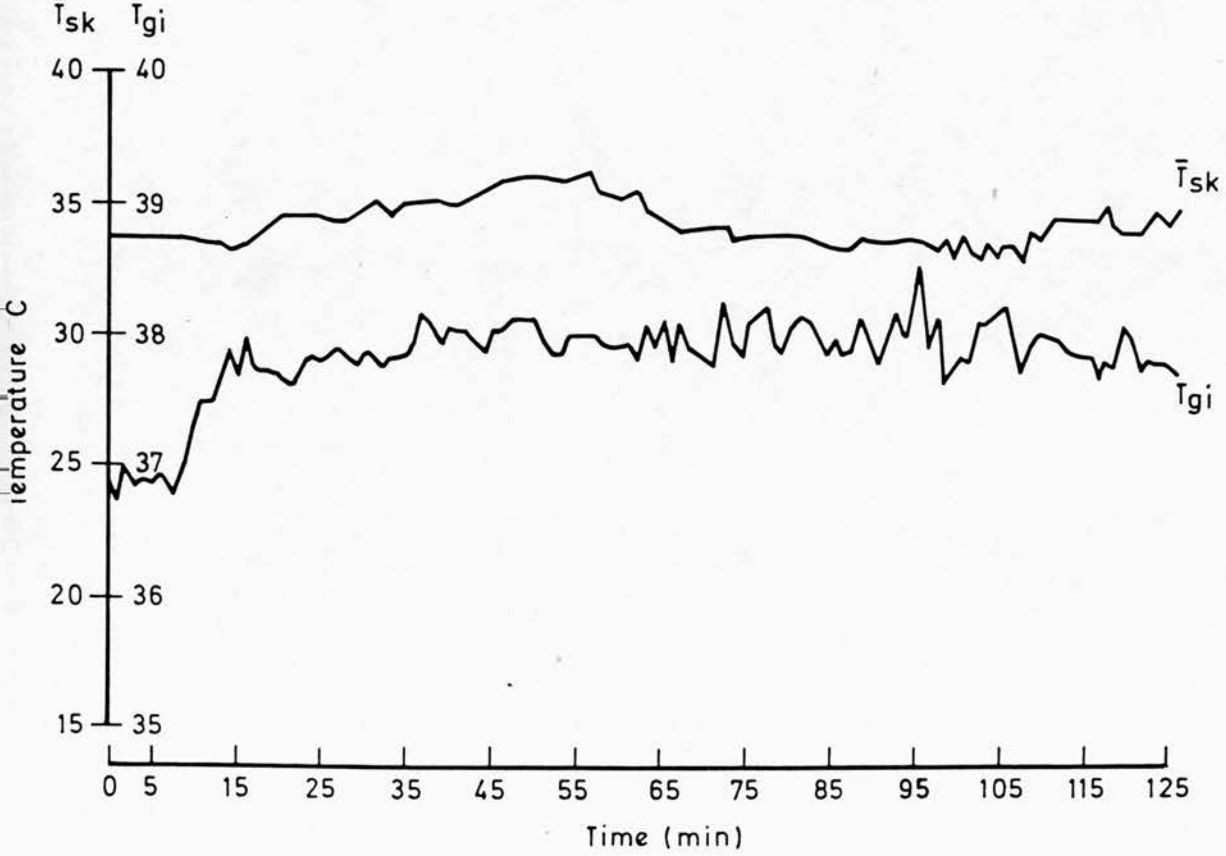
125
Time (min)


$\bar{T}_{sk}$
T_{gi}
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Temperature C
$\bar{T}_{sk}$
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Time (min)

Puma

Pilots. The highest mean airfield temperature was recorded during sortie P2A (WBGT 31.06°C, range 28.6-33.2). The highest cockpit temperature was recorded on sortie P5B (Figure 14), with a maximum WBGT (in flight) of 31.1°C, though the aircraft were operating up to 100 miles south of Airport Camp, where weather conditions were frequently different. Cockpit WBGT after a period of being left in the sun, rose to a maximum of 34.0°C (sortie P5B) and took up to 12 minutes of flight to equilibrate. Most of the cockpit data on sortie P2A (Figure 13) was lost due to a faulty connection between the sensor cluster and the ATDR. Cockpit T_{db} exceeded the environmental T_{db} by about 4°C throughout the sorties.

The highest T_{gi} was recorded at 37.9°C (a rise of 0.5°C) on sortie P2A (Figure 13), but a fall of 0.5°C was recorded on sortie P5B (Figure 14). T_{gi} on sortie P1A rose by 0.5°C to 37.7°C (Figure 12). The level of T_{gi} cannot always be relied upon as a measure of core temperature during these helicopter flights because the aircrew had free access to cold drinks in flight and hot food on the ground, as can be seen from the falls in T_{gi} after drinking (marked 'D' on the figures). The largest rise in $\bar{T}_{sk}$ was 0.5°C on sortie P5B, to 35.5°C.

SORTIE DETAILS

Sortie number: P1A

Date: 070483

Time of take-off: 1118

Length of sortie: 1 hr 42 min

Type of sortie: Training

Aircrew: Puma Pilot 1

New arrival

Weight: 87.4 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 30.83°C Range: 28.4 - 33.2°C

T_{bgs}: 36.15°C Range: 31.8 - 39.0°C

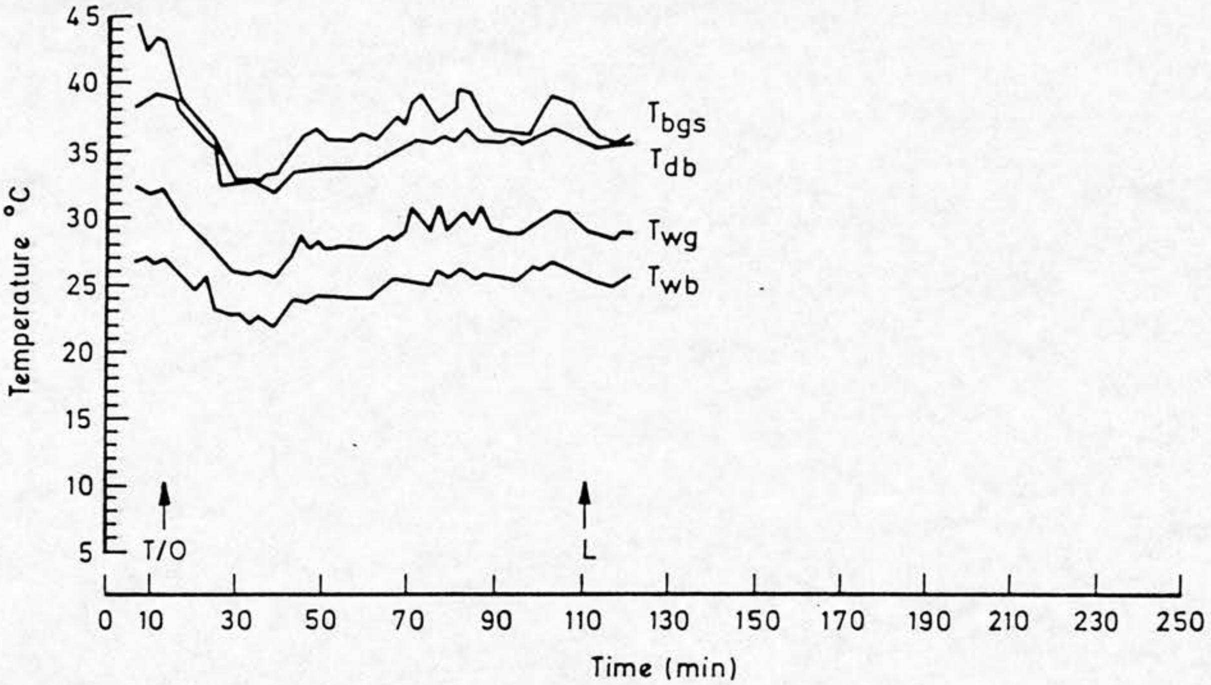
RH: 76% Range: 68 - 86%

Absolute humidity: 25.2 torr Range: 23.2 - 27.3 torr

Windspeed: 0.5 - 1.8 ms^{-1}

WBGT: 30.40°C Range: 27.9 - 38.3°C

FIGURE 12


Temperature °C
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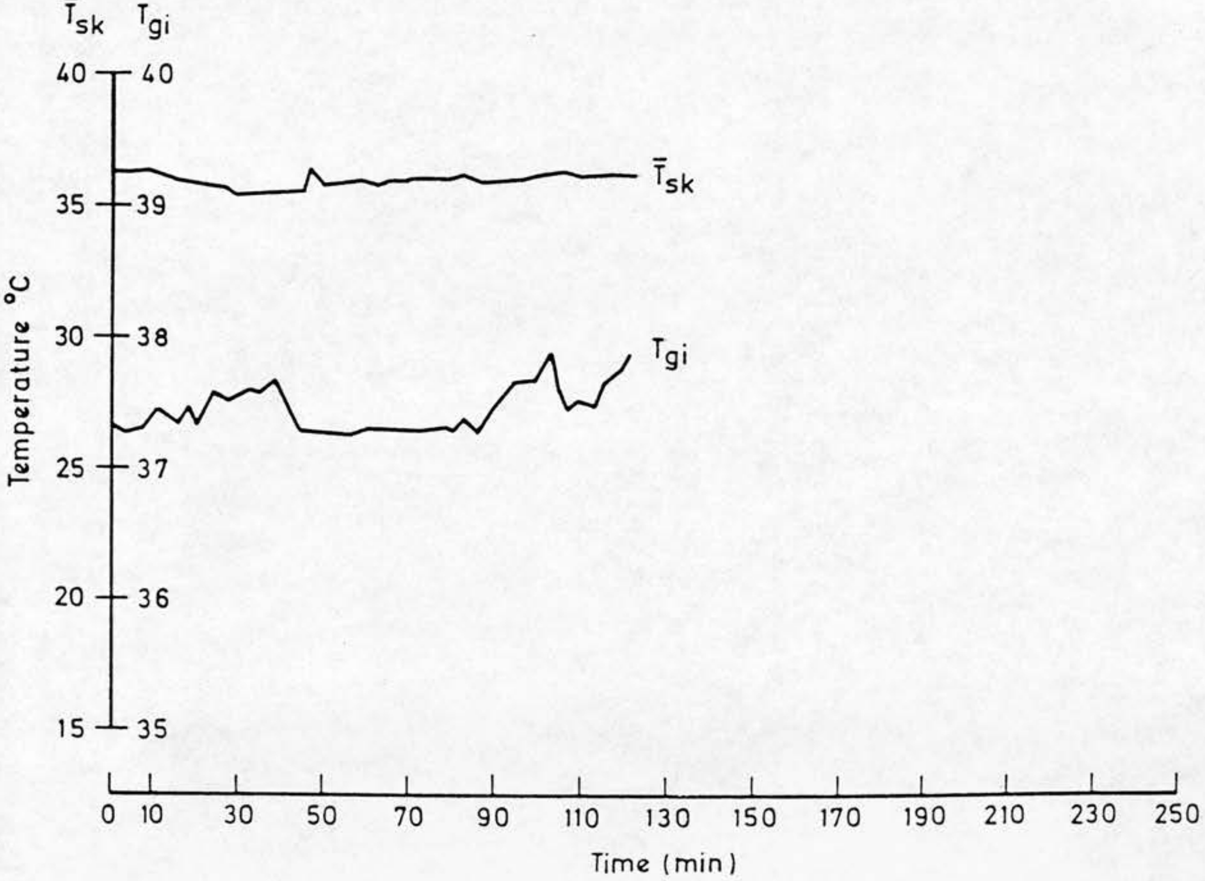
210
230
250
Time (min)


T̄sk
Tgi
Temperature °C
40
35
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25
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39
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37
36
35
T̄sk
Tgi
0
10
30
50
70
90
110
130
150
170
190
210
230
250
Time (min)

SORTIE DETAILS

Sortie number: P2A

Date: 080483

Time of take-off: 0805

Length of sortie: 7 hr 39 min

Type of sortie: Trooping

Aircrew: Puma Pilot 1

New arrival

Weight: 87.5 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 32.01°C Range: 30.0 - 34.5°C

T_{bgs}: 39.26°C Range: 34.2 - 43.3°C

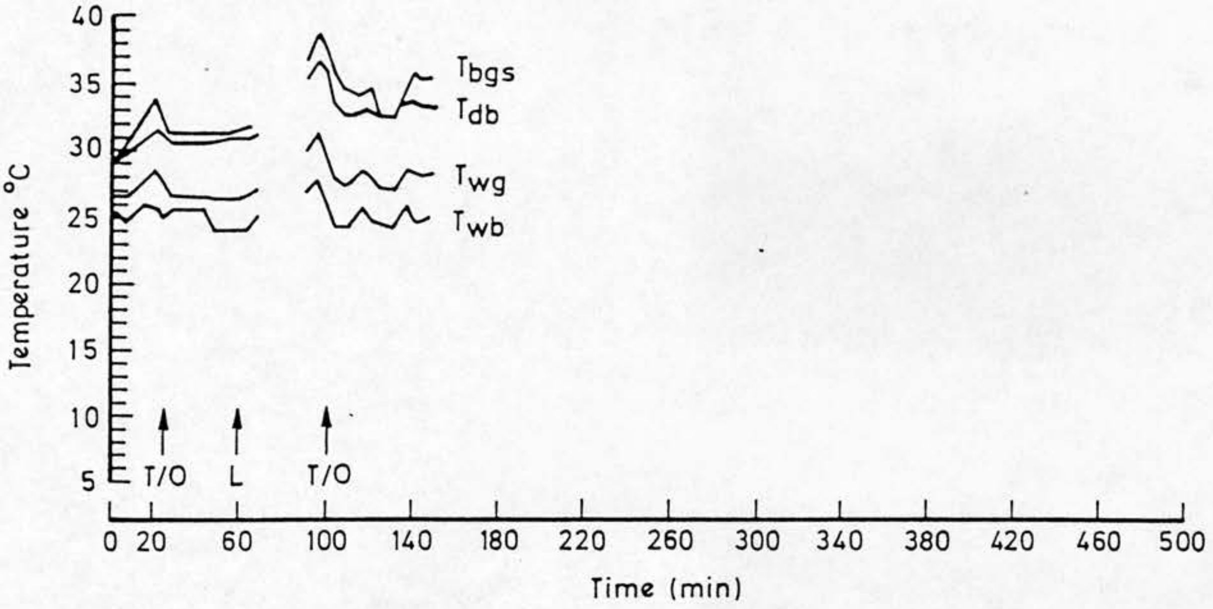
RH: 71% Range: 63 - 78%

Absolute humidity: 24.9 torr Range: 20.9 - 26.7 torr

Windspeed: 0.2 - 1.7 ms^{-1}

WBGT: 31.06°C Range: 28.6 - 33.2°C

FIGURE 13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Temperature °C
T_{bgs}
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T_{wg}
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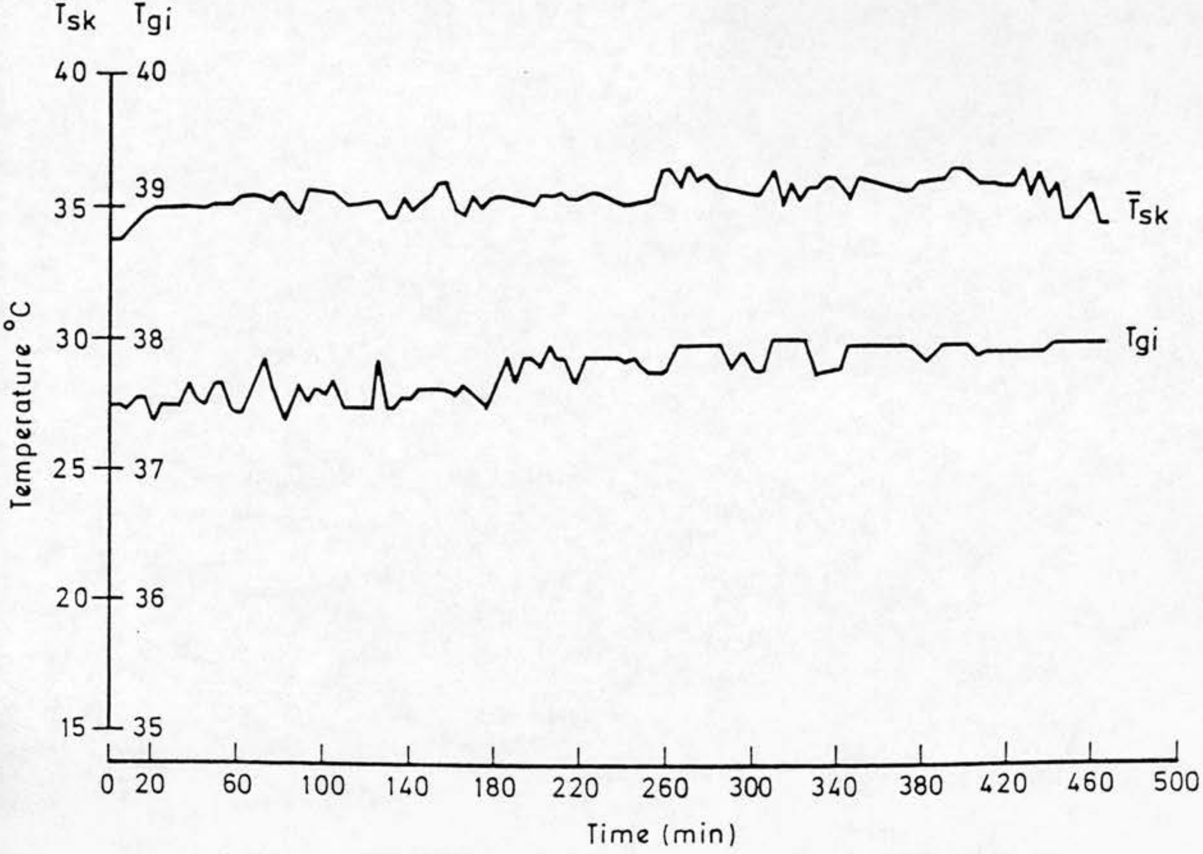
0 20 60 100 140 180 220 260 300 340 380 420 460 500
Time (min)


$\bar{T}_{sk}$
T_{gi}
40 40
35 39
30 38
25 37
20 36
15 35
Temperature °C
$\bar{T}_{sk}$
T_{gi}
0 20 60 100 140 180 220 260 300 340 380 420 460 500
Time (min)

SORTIE DETAILS

Sortie number: P5B

Date: 150483

Time of take-off: 0810

Length of sortie: 7 hr 40 min

Type of sortie: Trooping

Aircrew: Puma Pilot 3

Acclimatised

Weight: 75.1 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 31.10°C Range: 28.2 - 33.8°C

T_{bgs}: 37.99°C Range: 32.8 - 43.5°C

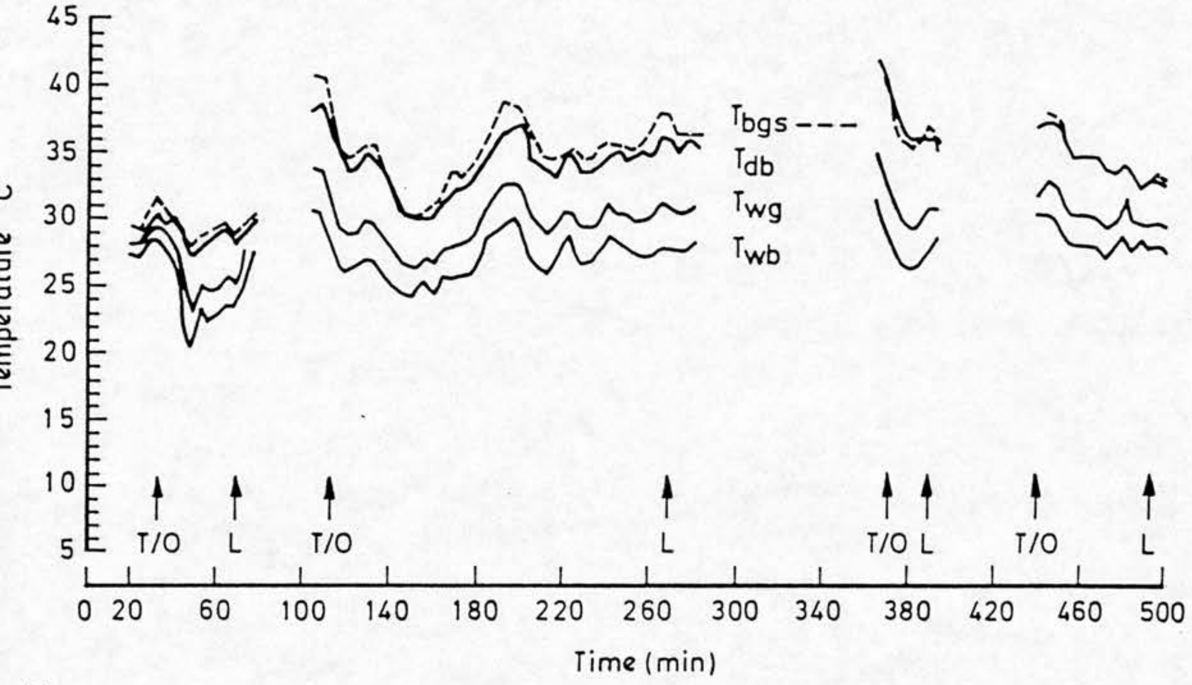
RH: 72% Range: 63 - 85%

Absolute humidity: 24.6 torr Range: 23.1 - 26.7 torr

Windspeed: 0.1 - 2.7 ms^{-1}

WBGT: 30.26°C Range: 27.9 - 32.5°C

FIGURE 14



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Temperature °C
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220
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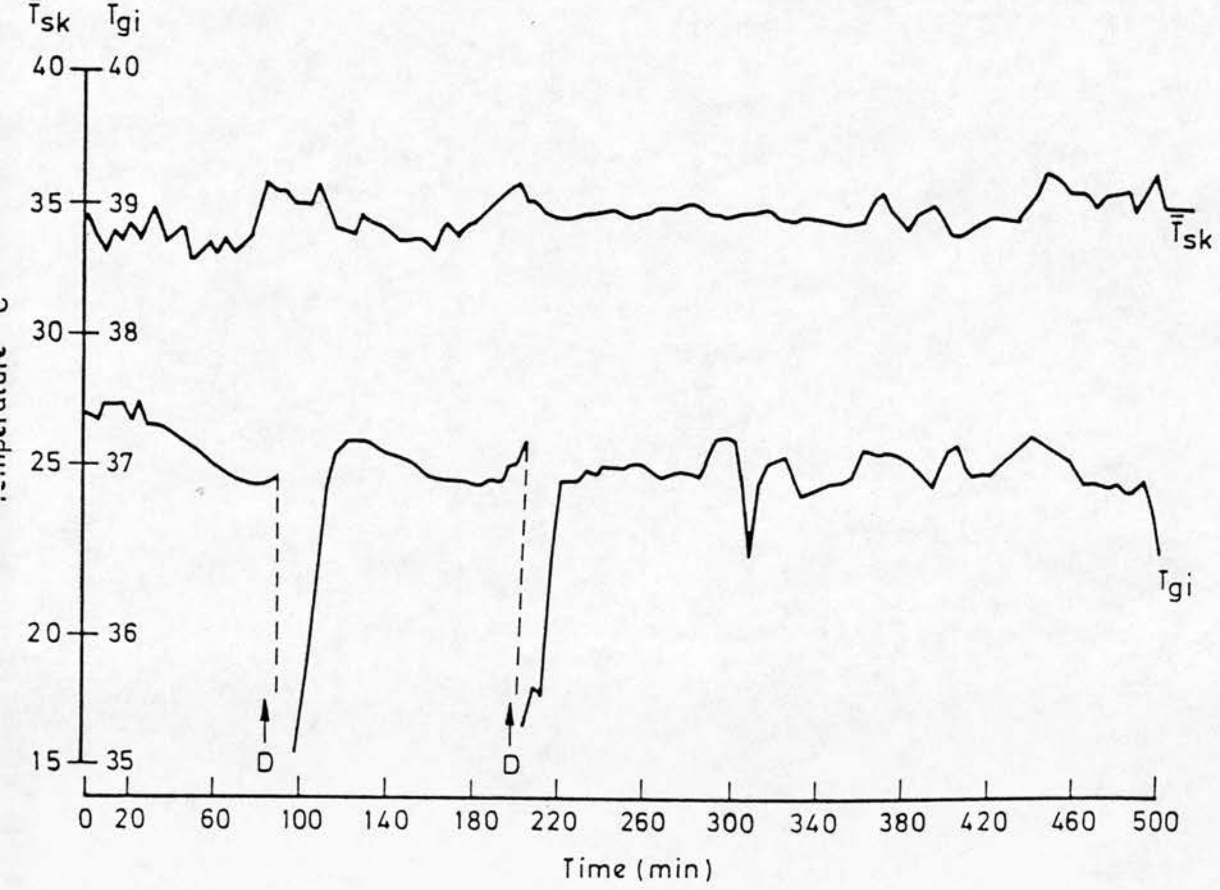
340
380
420
460
500
Time (min)



$\overline{T}_{sk}$
T_{gi}
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Temperature °C
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$\overline{T}_{sk}$
T_{gi}
0
20
60
100
140
180
220
260
300
340
380
420
460
500
Time (min)

Crewmen. The highest mean airfield temperature was recorded during sortie P1B (WBGT 31.02, range 26.3 - 38.5) (Figure 15). The highest cabin temperature in flight was recorded on the same sortie (WBGT 30.2°C), and after standing in the sun for 30 minutes, 31.1oC. The WBGT values are generally lower than in the cockpit as the T_{bgs} is lower because the sensor received no direct sunlight.

The T_{gi} values on sortie P3B were spurious as they quickly rose to 40.0°C, and stayed constant. The highest value otherwise was 38.1°C on sortie P1B, a rise of 0.7°C, whilst on sortie P4B it rose 0.8°C to 37.5°C (Figure 17). On sortie P6B the T_{gi} showed little change, though the values for both T_{gi} and $\bar{T}_{sk}$ did not register on the ATDR beyond 220 minutes from take-off. This followed a 90 minute spell on the ground for lunch, during which the ATDR switches may have been accidentally altered. $\bar{T}_{sk}$ did not rise.

A number of measurements of airspeed were made at random in the front and back of the Puma with a hand-held anemometer. The results are shown in Table 13. The mean value was 0.98 m sec^{-1} for the cockpit, 0.99 m sec^{-1} for the cabin.

TABLE 13. PUMA WINDSPEED DATA. (M SEC^{-1})

Windspeeds in m sec^{-1} are shown for the 2 crew positions, taken at random intervals during the first 4 Puma sorties.

Sortie	Cockpit	Cabin
P1A	1.3	1.4
	0.9	1.4
	0.7	0.7
P2A	1.1	1.2
	1.1	0.9
	0.6	0.7
P3B	0.9	0.8
	1.0	1.1
P4B	1.2	1.1
	1.0	0.6
mean	0.98	0.99
standard deviation	0.2	0.3

SORTIE DETAILS

Sortie number: P1B

Date: 090483

Time of take-off: 0927

Length of sortie: 5 hr 22 min

Type of sortie: Trooping

Aircrew: Puma Crewman 1

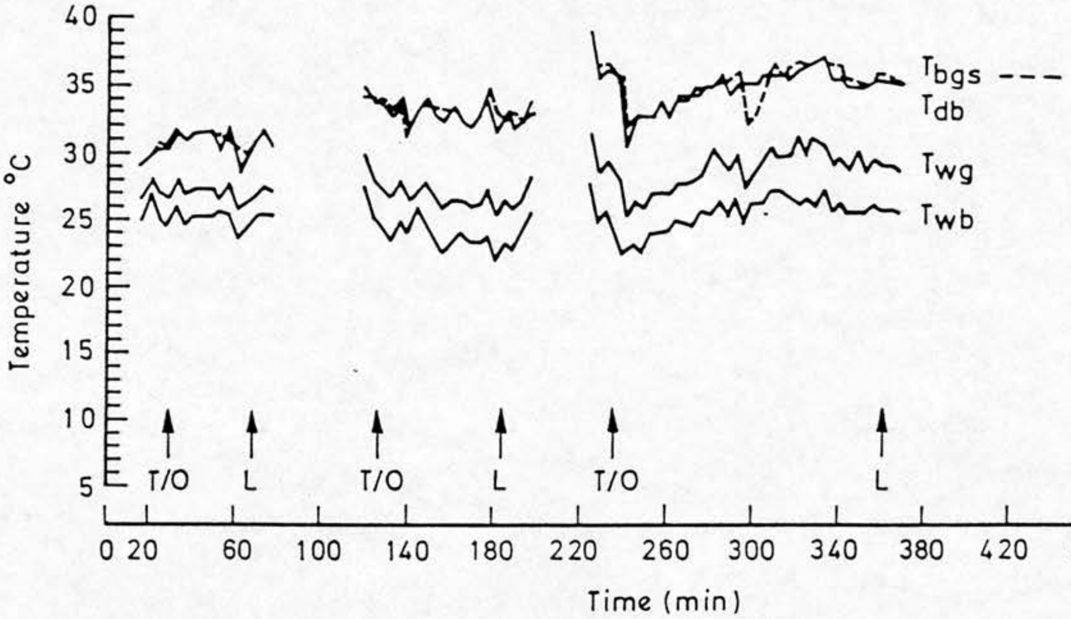
New arrival

Weight: 68.7 kg

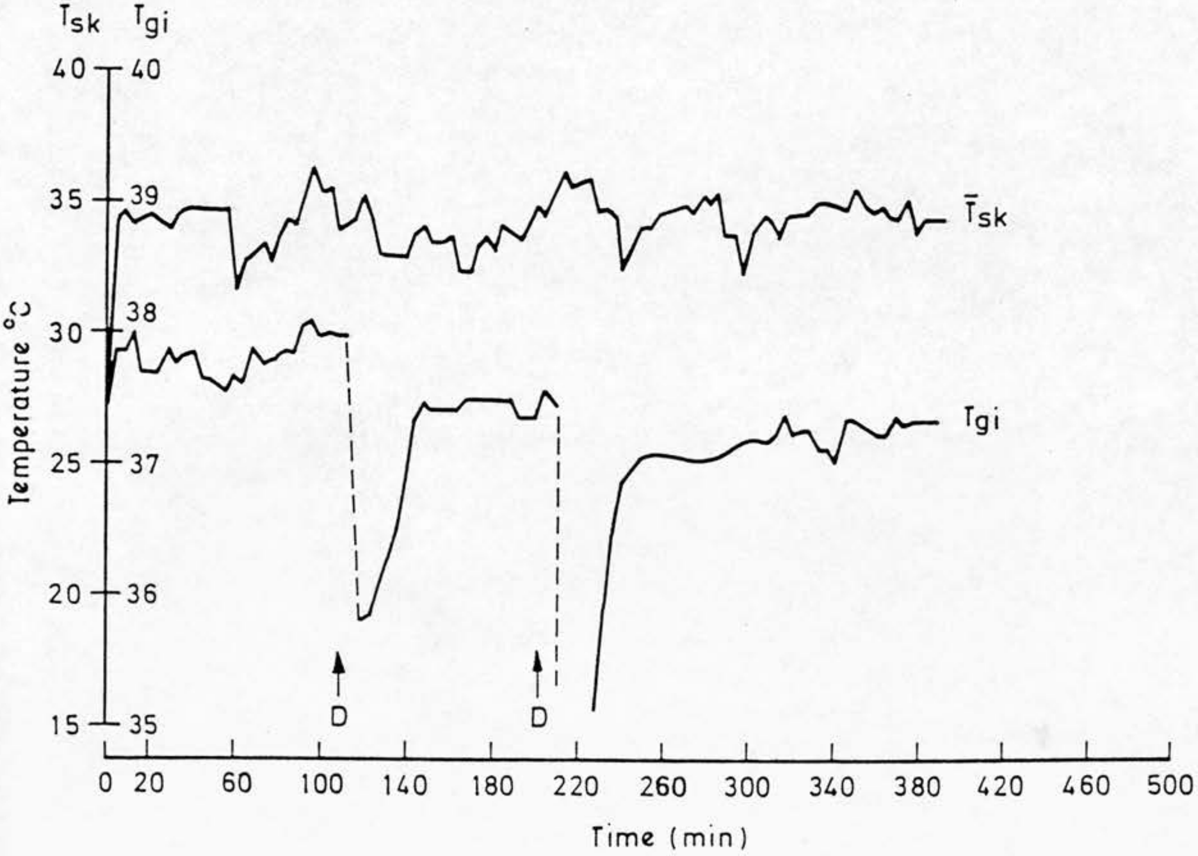
AIRFIELD CLIMATIC CONDITIONS

T_{db}: 31.17°C	Range: 26.9 - 34.1°C
T_{bgs}: 37.28°C	Range: 29.8 - 39.3°C
RH: 68%	Range: 63 - 76%
Absolute humidity: 23.4 torr	Range: 20.2 - 24.9 torr
Windspeed: 0.7 - 1.9 ms^{-1}	
WBGT: 31.02°C	Range: 26.3 - 38.5°C

FIGURE 15



Temperature °C
40
35
30
25
20
15
10
5
T/O
L
T/O
L
T/O
L
Tbgs ---
Tdb
Twg
Twb
0 20
60
100
140
180
220
260
300
340
380
420
460
500
Time (min)



$\bar{T}_{sk}$ T_{gi}
Temperature °C
40 40
35 39
30 38
25 37
20 36
15 35
$\bar{T}_{sk}$
T_{gi}
D
D
0 20
60
100
140
180
220
260
300
340
380
420
460
500
Time (min)

SORTIE DETAILS

Sortie number: P3B

Date: 110483

Time of take-off: 0906

Length of sortie: 7 hr 50 min

Type of sortie: Trooping

Aircrew: Puma Crewman 2

Acclimatised

Weight: 86.8 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 28.34°C Range: 25.6 - 30.2°C

T_{bgs}: 33.76°C Range: 27.4 - 37.6°C

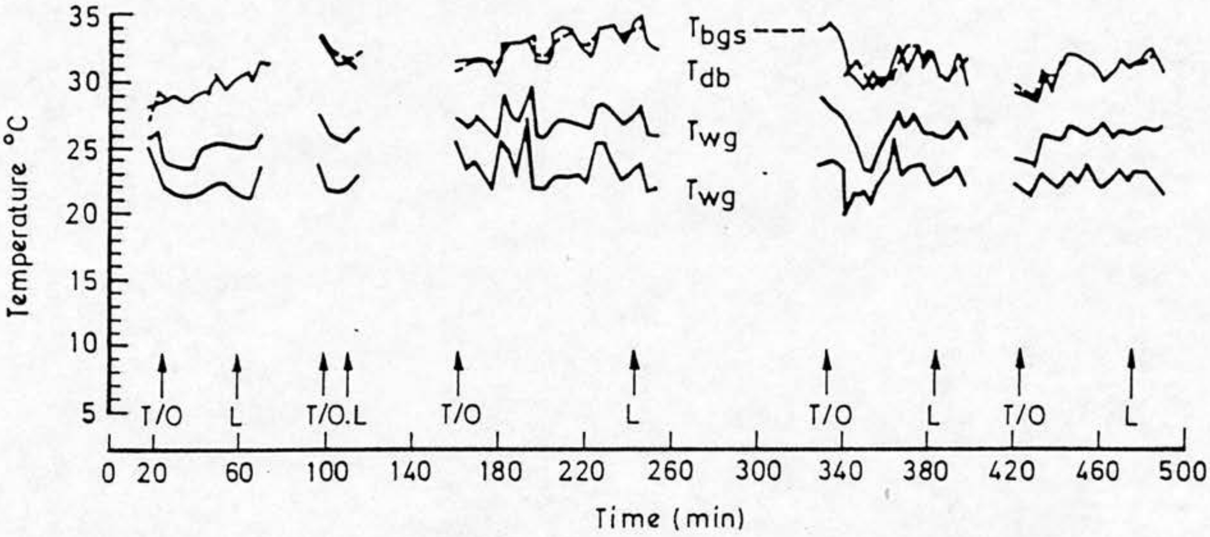
RH: 71% Range: 67 - 80%

Absolute humidity: 20.6 torr Range: 19.0 - 21.9 torr

Windspeed: 0.5 - 3.1 ms^{-1}

WBGT: 27.11°C Range: 24.3 - 28.9°C

FIGURE 16


35
30
25
20
15
10
5
Temperature °C
T/O
L
T/O.L
T/O
L
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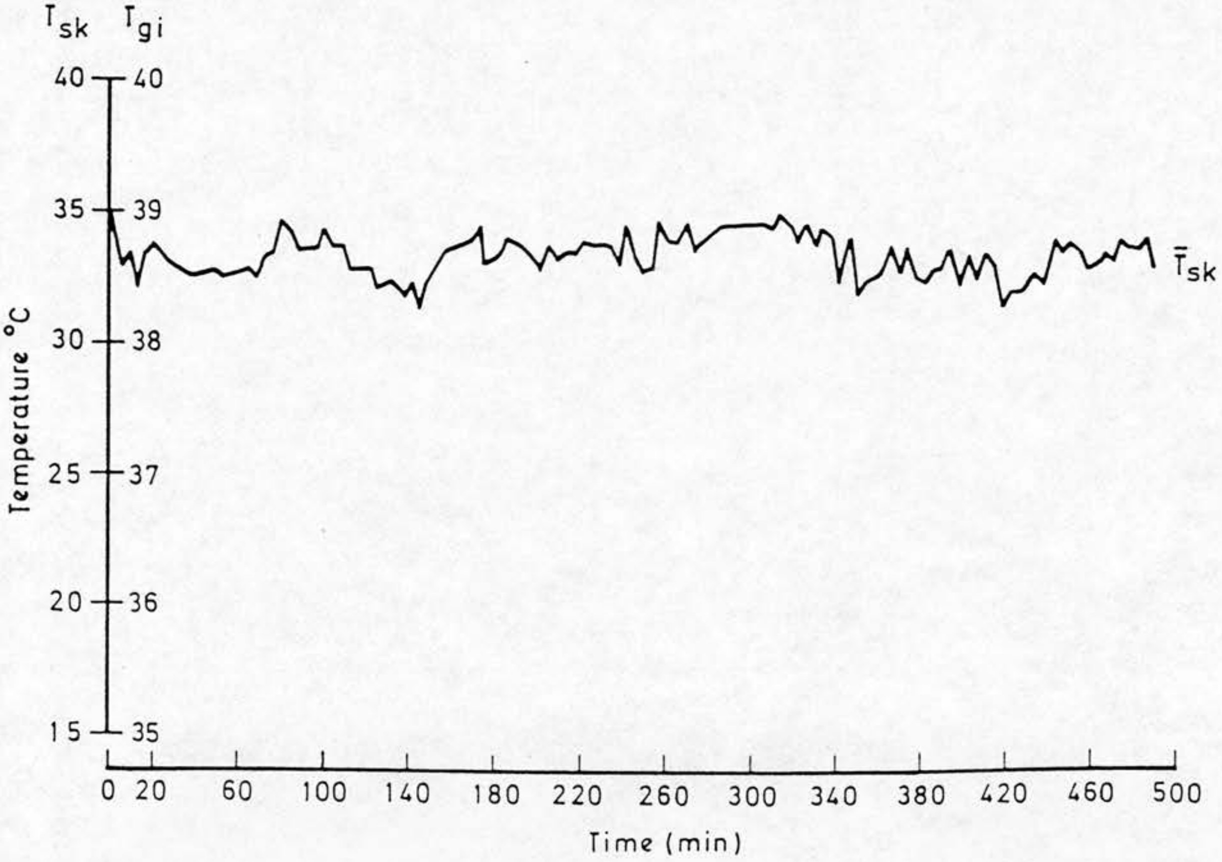
T/O
L
T_{bgs} ---
T_{db}
T_{wg}
T_{wg}
0
20
60
100
140
180
220
260
300
340
380
420
460
500
Time (min)


$\bar{T}_{sk}$
T_{gi}
40
40
35
39
30
38
25
37
20
36
15
35
Temperature °C
$\bar{T}_{sk}$
0
20
60
100
140
180
220
260
300
340
380
420
460
500
Time (min)

SORTIE DETAILS

Sortie number: P4B

Date: 130483

Time of take-off: 1450

Length of sortie: 1 hr 27 min

Type of sortie: Training

Aircrew: Puma Crewman 3

Acclimatised

Weight: 81.2 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 31.00°C Range: 30.5 - 31.8°C

T_{bgs}: 36.65°C Range: 34.2 - 38.8°C

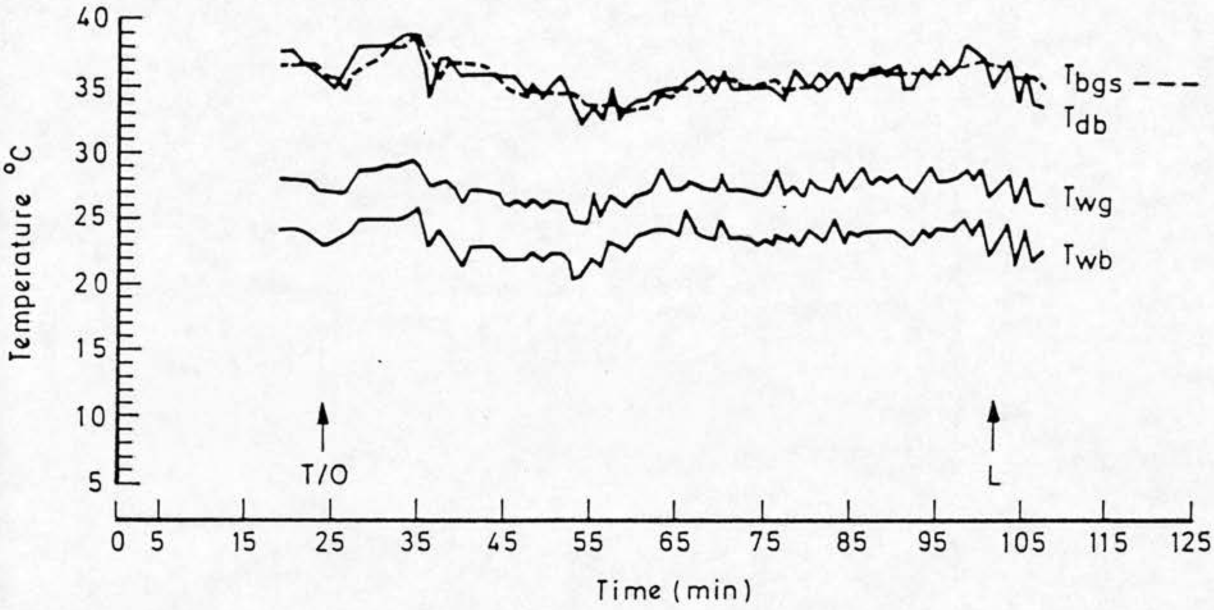
RH: 64% Range: 61 - 71%

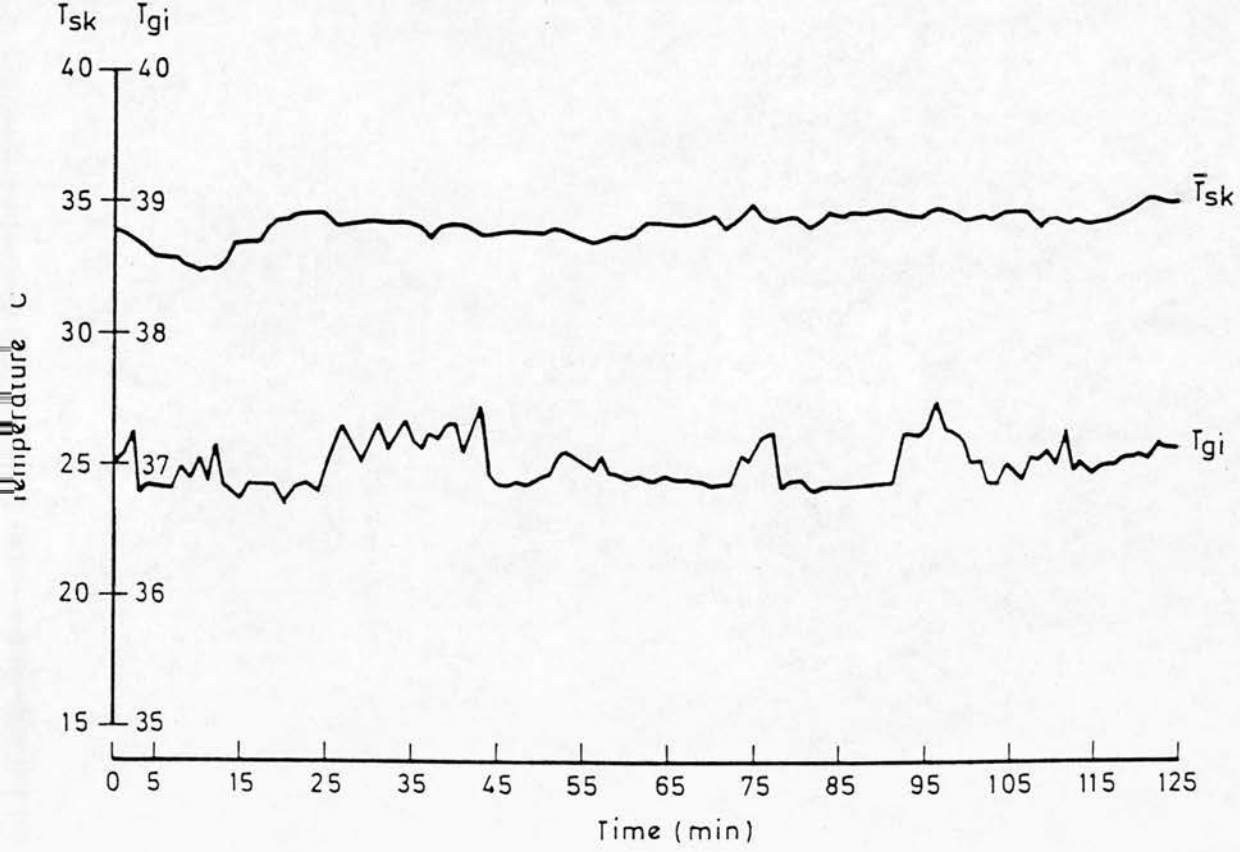
Absolute humidity: 21.7 torr Range: 20.3 - 25.0 torr

Windspeed: 0.6 - 2.2 ms^{-1}

WBGT: 28.67°C Range: 27.5 - 30.1°C

FIGURE 17


Temperature °C
40
35
30
25
20
15
10
5
T/O
L
Tbgs
Tdb
Twg
Twb
0
5
15
25
35
45
55
65
75
85
95
105
115
125
Time (min)


T̄sk
Tgi
Temperature °C
40
35
30
25
20
15
40
39
38
37
36
35
T̄sk
Tgi
0
5
15
25
35
45
55
65
75
85
95
105
115
125
Time (min)

SORTIE DETAILS

Sortie number: P6B

Date: 180483

Time of take-off: 0930

Length of sortie: 7 hr

Type of sortie: Trooping

Aircrew: Puma Crewman 1

New arrival

Weight: 68.7 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 28.95°C Range: 27.2 - 31.0°C

T_{bgs}: 33.79°C Range: 27.9 - 37.7°C

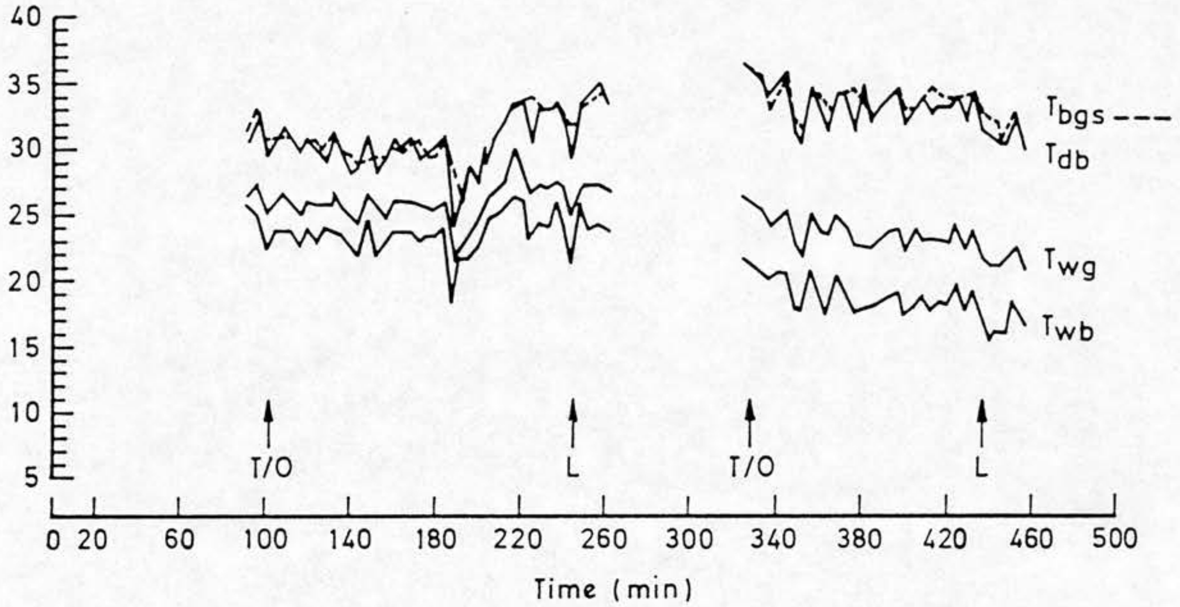
RH: 60% Range: 55 - 65%

Absolute humidity: 24.6 torr Range: 23.1 - 26.7 torr

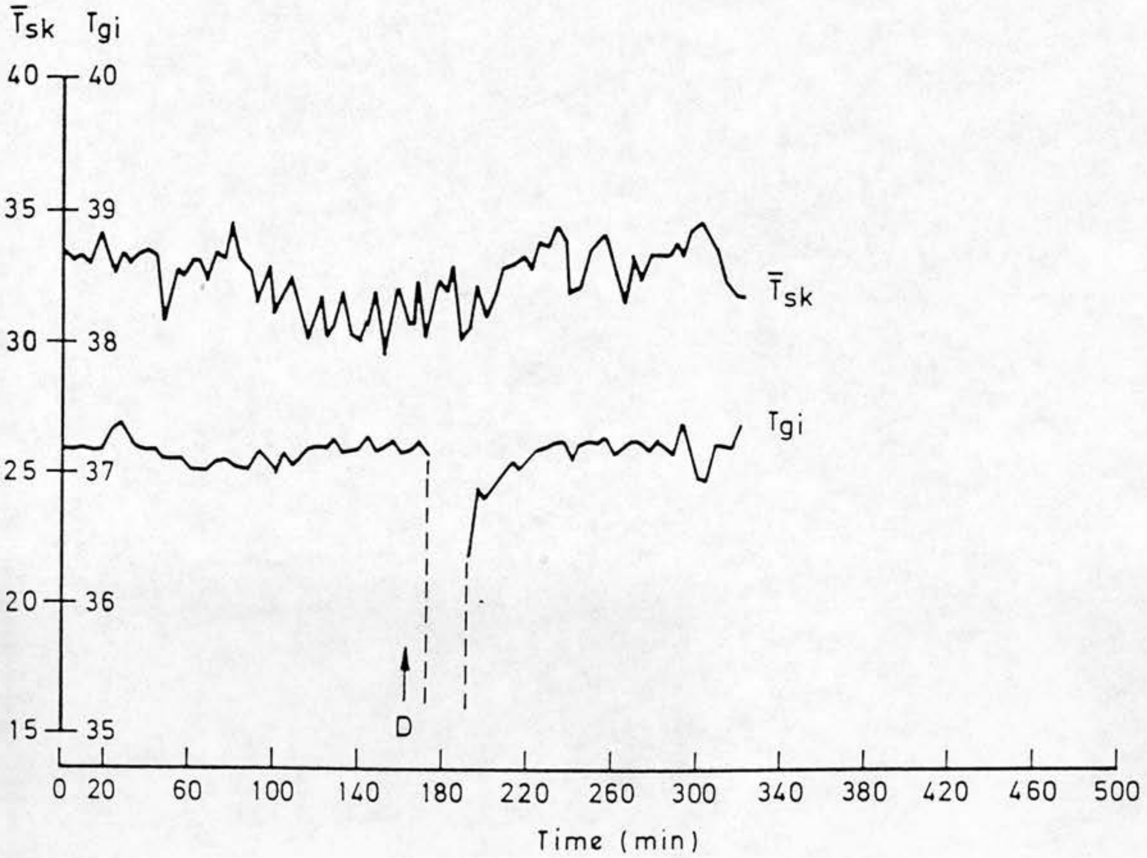
Windspeed: 1.5 - 5.4 ms^{-1}

WBGT: 26.20°C Range: 23.8 - 27.9°C

FIGURE 18



40
35
30
25
20
15
10
5
T/O
L
T/O
L
Tbgs ---
Tdb
Twg
Twb
0 20 60 100 140 180 220 260 300 340 380 420 460 500
Time (min)



$\bar{T}_{sk}$
T_{gi}
40 40
35 39
30 38
25 37
20 36
15 35
$\bar{T}_{sk}$
T_{gi}
D
0 20 60 100 140 180 220 260 300 340 380 420 460 500
Time (min)

Gazelle

Only 2 Gazelle pilots were instrumented. The maximum mean airfield temperature was recorded during sortie G2 (WBGT 29.71^{o}C, range 28.6-30.3).

The cockpit T_{wb} values for sortie G1 were lost because of a fault in the sensor, invalidating the WBGT values. Sortie G2 consisted of climbing and descending between ground level and 8000' for free-fall parachute training, with all the doors removed from the aircraft. The WBGT oscillated correspondingly between 30.3 and 13.5^{o}C (Figure 20)

T_{gi} on sortie G1 fell between the first (36.7^{o}C) and the final value (36.3^{o}C). The pilot consumed several cold drinks. The pill on sortie G2 was out of aerial range, and the values therefore were not recorded.

$\bar{T}_{sk}$ rose to a plateau in the early part of sortie G1, then fell in 2 steps, corresponding to periods of rest on the ground during which the pilot left the aircraft. In sortie G2, $\bar{T}_{sk}$ oscillated with altitude.

SORTIE DETAILS

Sortie number: G1

Date: 120483

Time of take-off: 1350

Length of sortie: 2 hr 45 min

Type of sortie: Reconnaissance

Aircrew: Gazelle Pilot 1

Acclimatised

Weight: 82.7 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 30.45^{o}C Range: 29.3 - 31.6^{o}C

T_{bgs}: 35.72^{o}C Range: 29.8 - 40.2^{o}C

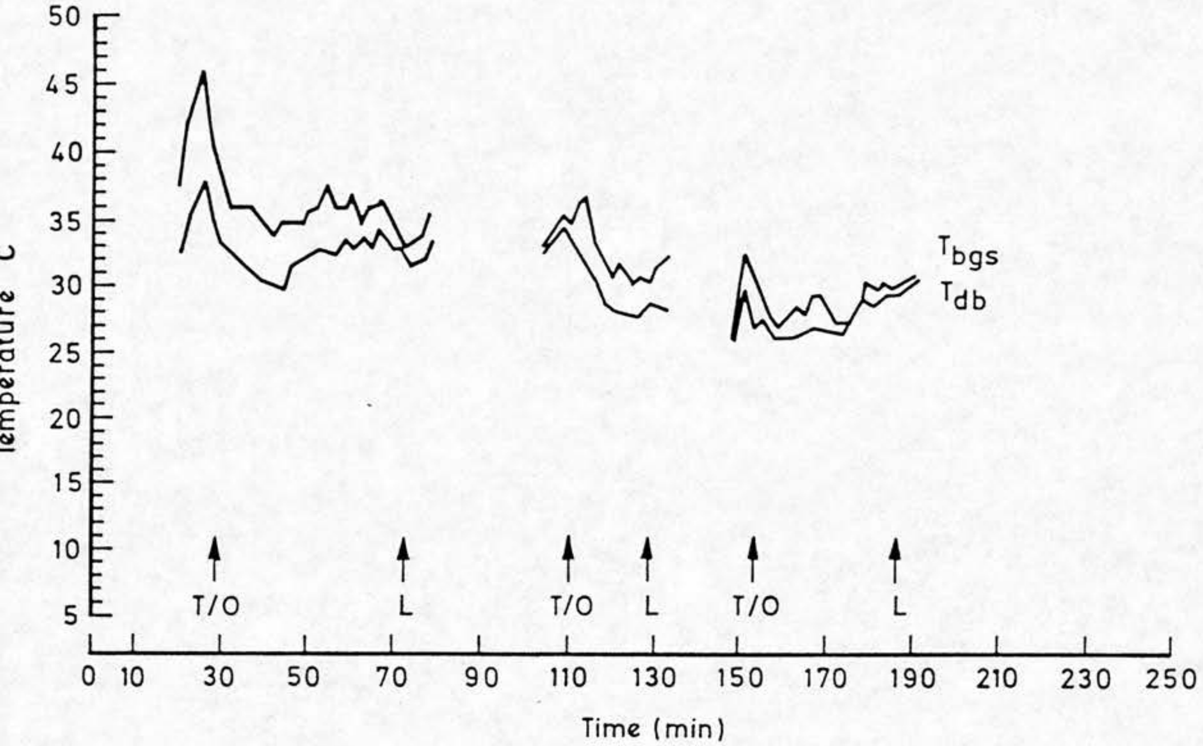
RH: 65% Range: 61 - 72%

Absolute humidity: 21.2 torr Range: 20.3 - 22.0 torr

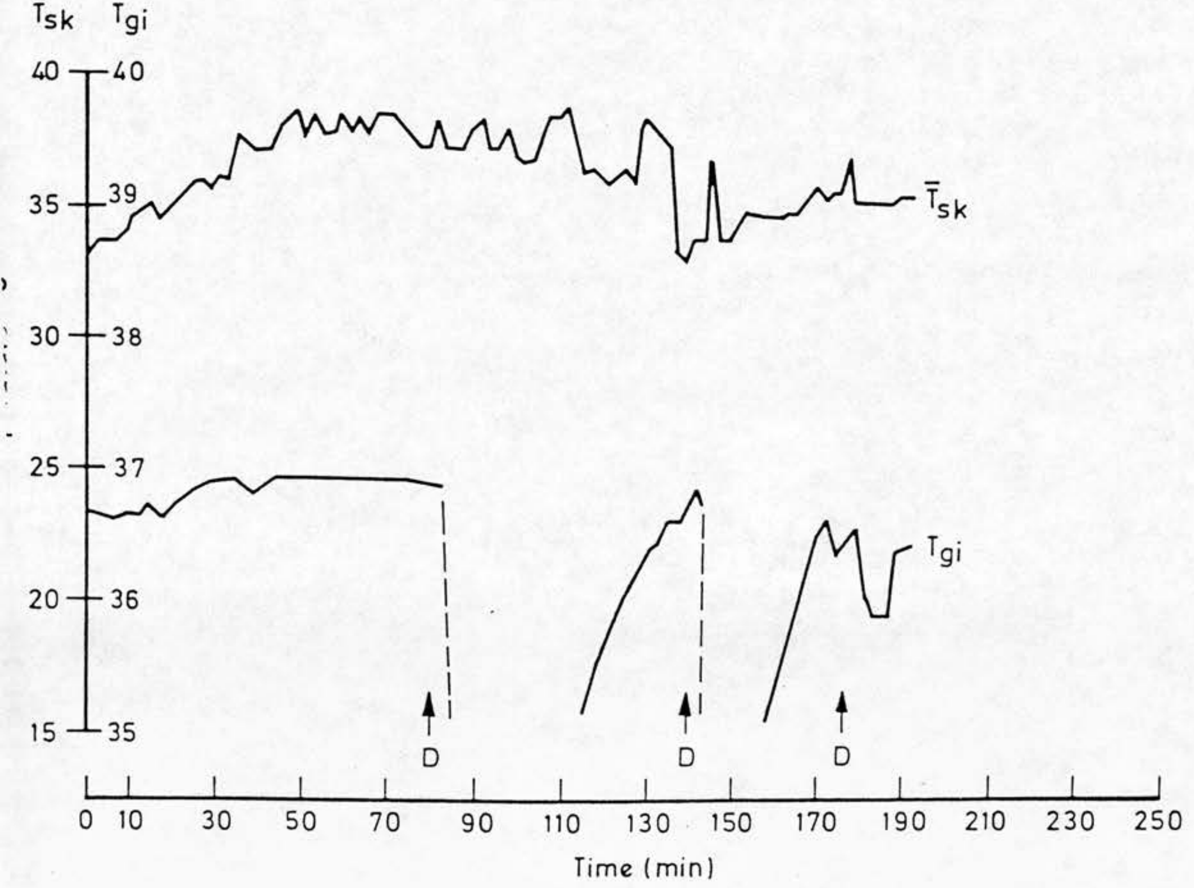
Windspeed: 0.8 - 2.9 ms^{-1}

WBGT: 28.23^{o}C Range: 26.2 - 30.0^{o}C

FIGURE 19



50
45
40
35
30
25
20
15
10
5
T/O
L
T/O
L
T/O
L
T_{bgs}
T_{db}
0
10
30
50
70
90
110
130
150
170
190
210
230
250
Time (min)



$\bar{T}_{sk}$
T_{gi}
40
40
35
39
30
38
25
37
20
36
15
35
$\bar{T}_{sk}$
T_{gi}
D
D
D
0
10
30
50
70
90
110
130
150
170
190
210
230
250
Time (min)

SORTIE DETAILS

Sortie number: G2

Date: 140483

Time of take-off: 1318

Length of sortie: 1 hr 50 min

Type of sortie: Free-fall Parachuting

Aircrew: Gazelle Pilot 2

Acclimatised

Weight: 70.1 kg

AIRFIELD CLIMATIC CONDITIONS

T_{db}: 31.28°C Range: 30.0 - 31.8°C

T_{bgs}: 37.25°C Range: 36.0 - 38.0°C

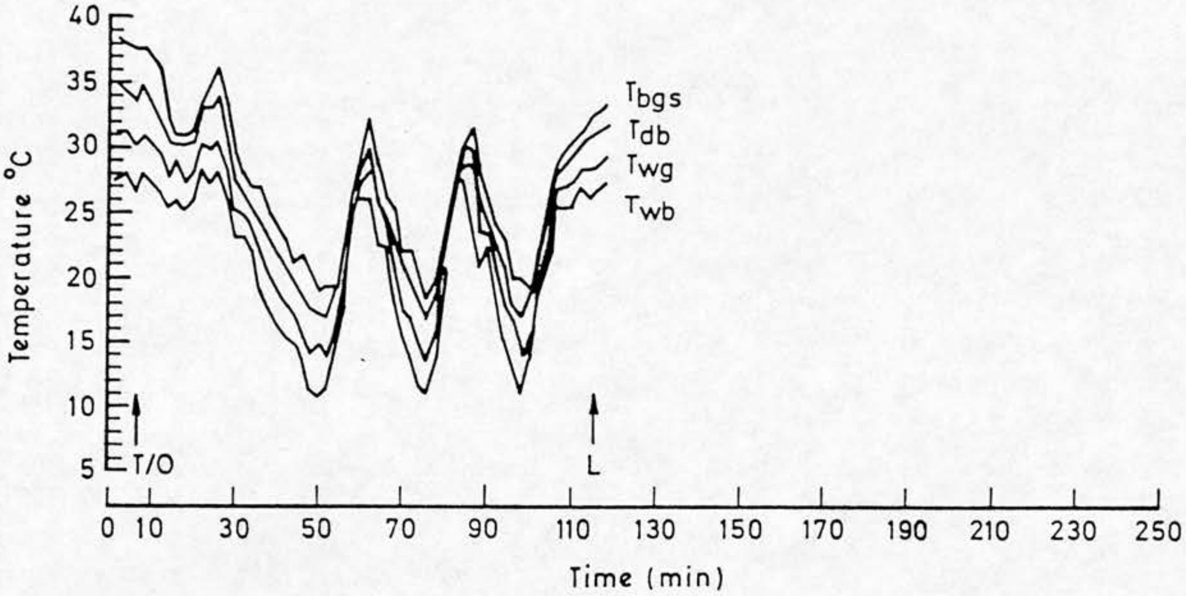
RH: 68% Range: 67 - 70%

Absolute humidity: 23.4 torr Range: 21.3 - 24.3 torr

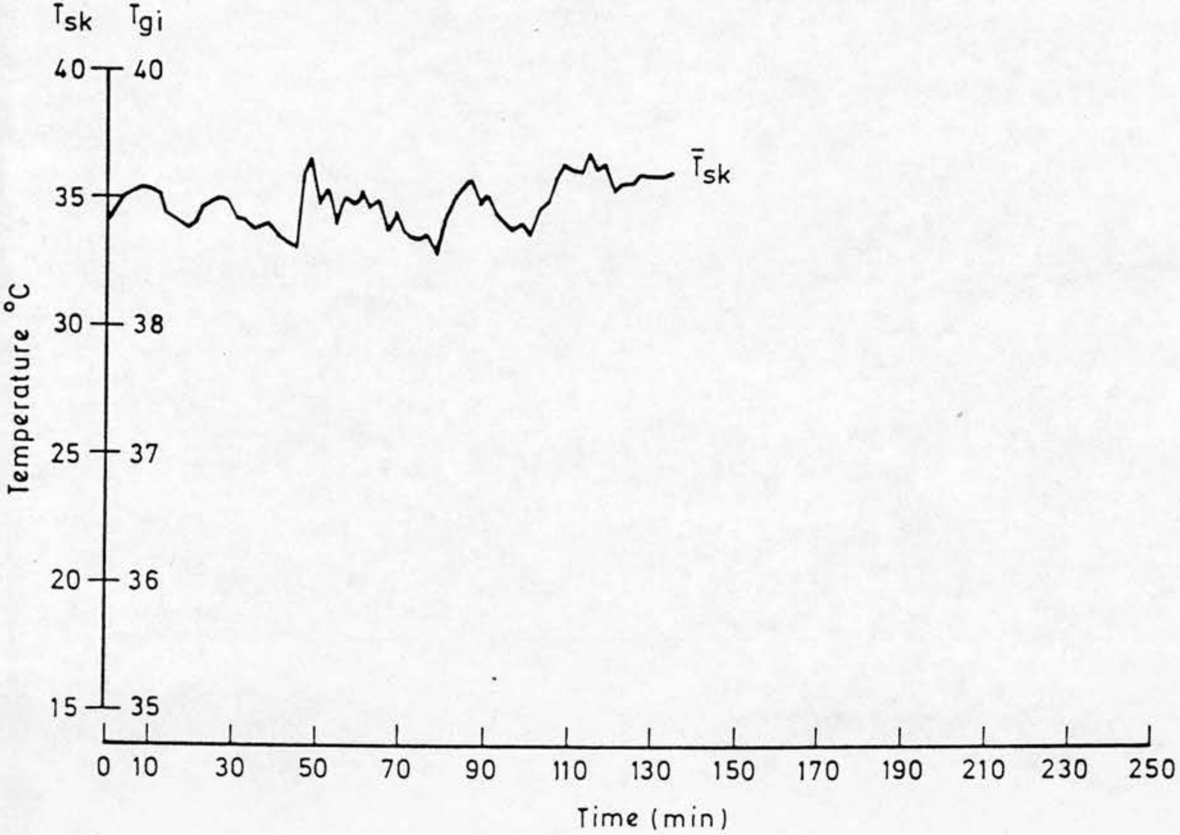
Windspeed: 1.5 - 5.0 ms^{-1}

WBGT: 29.71°C Range: 28.6 - 30.3°C

FIGURE 20



Temperature °C
40
35
30
25
20
15
10
5
T/O
L
T_bgs
T_db
T_wg
T_wb
0
10
30
50
70
90
110
130
150
170
190
210
230
250
Time (min)



T̄sk
Tgi
Temperature °C
40
35
30
25
20
15
40
38
37
36
35
T̄sk
0
10
30
50
70
90
110
130
150
170
190
210
230
250
Time (min)

Subjective Fatigue

To interpret the results of the subjective fatigue checklist, scores were given to the subjective descriptions used, as shown in Table 14. The checklist itself, and the instructions for completion are shown at Annex A. The fatigue checklist scores according to role are shown in Table 15.

TABLE 14. FATIGUE CHECKLIST SCORES IN RELATION TO DESCRIPTIVE PHRASES

1	Extremely lively	19
2	(Very lively (Very refreshed	16
3	Quite fresh	13
4	Somewhat fresh	11
5	Slightly tired	9
6	Quite tired	7
7	Very tired	5
8	(Extremely tired (Ready to drop	2

TABLE 15. FATIGUE CHECKLIST SCORES ACCORDING TO ROLE.

Sortie	Before Flight	After Flight
H1	16	11
H2	13	9
H3	13	9
H4	16	11
Harrier pilot mean	14.5	10.0
P1A	13	9
P2A	13	7
P5B	11	5
Puma pilot mean	12.3	7.0
P1B	16	11
P3B	16	9
P4B	13	11
P6B	16	9
Puma crewman mean	15.3	10.0
Overall mean	14.0	9.0

Before their sorties, the Harrier pilots had a mean score placing them between 'very lively' and 'quite fresh', as did the Puma crewmen. In both cases the after flight score fell to place them between 'somewhat fresh' and 'slightly tired'. The Puma pilots felt somewhat less lively before their sorties, with a mean score placing them between 'quite fresh' and 'somewhat fresh', with a post-sortie score making them 'quite tired.'

It was decided not to use the fatigue checklist on the 2 Gazelle pilots as the results would not be significant.

DISCUSSION

Harrier

The Harrier pilots did not complain of a heat stress problem and were generally satisfied with the performance of their cabin conditioning system. They had the smallest fall in fatigue checklist score (Table 15). In view of the rate of rise of deep body temperature, their satisfaction must be based on the fall in skin temperature due to the very dry conditioning air flow. The rise in deep body temperature appears to be limited only by the duration of the sortie. The initial sharp rise in deep body temperature occurs on entry to the cockpit. It is associated with the increased energy expenditure of walking the short distance to the aircraft from their vehicle, doing the external checks, then climbing the ladder into the cockpit. Once the engine is started, they use the air conditioning system which provides a brief respite before the canopy is closed at the last possible moment prior to take off.

Any factor reducing the rate of evaporative cooling, for example wearing NBC clothing assemblies, would clearly increase the rate of deep body temperature rise, and would have a dramatic effect on subjective comfort. Similarly, in sustained operations, when aircrew may not have the opportunity to cool down between sorties, heat stress would be increased.

At body temperatures recorded during these sorties there is laboratory evidence of motor performance decrement.[3,5,23] Dehydration of up to 1.5% per hour was also encountered, which can cause a decrement in physical work capacity,[44] but here again the short sorties effectively prevent unacceptable dehydration. The aircrew themselves did not report any impairment in their own performance.

Puma

Both Puma pilots and crewmen had larger falls in fatigue checklist score than the Harrier pilots, though their sorties were much longer. This bears little relationship to changes in skin temperature, which did not rise significantly during any of the sorties, despite the higher work rates of the crewmen, suggesting that thermal strain is not a significant problem. T_{gi} figures cannot be relied upon for the helicopter sorties because of the effect of cold drinks on the radio pill. Some sorties showed an overall rise in T_{gi}, others a fall.

The length of the Puma sorties means that in the environmental conditions encountered, fatigue will always be a potential problem, even in the absence of frank heat strain, though it is notoriously difficult to quantify objectively. The free availability of fluids during the sortie is essential in the prevention of dehydration.

Gazelle

The small amount of data for the Gazelle, and the fact that one sortie was atypical precludes any useful discussion of the results. The relatively small number of successfully instrumented sorties for all aircraft types was due to a variety of problems with the recording equipment, notably the failure of one of the two ATDR's after only one sortie.

LABORATORY SIMULATION

INTRODUCTION

The aircrew chemical defence assembly is divided into above neck and below neck components. The above neck assembly, the AR5, is concerned with providing protection to the eyes and respiratory tract and was conceived in 1976 in an attempt to design an aircrew respirator which was compatible with aircraft weapons sights. The main features of the AR5 (Figure 21) are an oronasal mask enclosed within a close fitting, shaped polycarbonate face-plate, to the edge of which is attached an elastic rubber head cowl which is worn immediately over the head, beneath the aircrew protective helmet. Some of the gas passages and valves are mounted remotely on the chest. The respirator is matched to the oxygen supply systems used in specific aircraft by means of one of 3 chest-mounted manifolds.

The gas-containing portion of the AR5 is divided into 2 compartments, the respiratory and the hood, by an oronasal mask which seals on the skin of the face. Each of the compartments is supplied separately with clean filtered air by way of a chest-mounted manifold and a pair of hoses. The manifold is supplied with clean filtered air by an electrically driven fan-filter unit (the portable ventilator).

FIGURE 21. AIRCREW RESPIRATOR NBC NO 5

This air passes directly through the manifold and up the mask hose to the inlet port of the oronasal mask through a connector which can be broken in certain emergencies. Expired gas is conducted to the exterior by a double expiratory valve assembly. Filtered air flowing to the hood compartment passes through a non-return valve (hood inlet valve) in the manifold and thence by the hood hose to the hood inlet adaptor. This air flows primarily across the space between the face and the face-plate, providing a visor demisting function, and reducing subjective discomfort by cooling the face. Air leaves the respirator through the hood outlet valve. When required, a continuous flow of oxygen is added to the filtered air flowing to the mask. This continuous flow of oxygen is fed into the mask at a point just upstream of the mask inlet valve, from the aircraft system.

A drinking facility is incorporated into the AR5 to allow aircrew to drink water whilst wearing the assembly on the ground. It consists essentially of a plastic tube which can be passed through the face-plate and the oronasal mask, into the cavity of the latter, and thence to the wearer's mouth.

Below the neck, protection is provided mainly by the Inner Coverall, Aircrew, NBC, Mk1. This is a one-piece, long-limbed coverall constructed of the standard UK NBC fabric (non-woven nylon with a small proportion of viscose rayon, impregnated with a fluorochemical to make it liquid repellant to organic chemicals and coated on the undersurface with activated charcoal). A sliding fastener with an impregnated fabric backing fly is fitted running from the front neckline vertically down the garment to the crutch. (Figure 22). Because sweat degrades the performance of the suit, it is worn over a layer of long limbed fine cotton rib underclothes.

The feet are protected by socks of the same material, worn over the normal aircrew sock. The NBC gloves are made of neoprene rubber, worn next to the skin. The remainder of the aircrew's normal clothing assembly, according to role and climatic conditions, is then worn over the NBC assembly (Figure 23). The UK aircrew chemical defence assembly has been described in detail by Ernsting et al.[20]

FIGURE 22. AIRCREW NBC UNDER COVERALL

FIGURE 23. AIRCREW NBC ASSEMBLY (HELICOPTERS)

METHODS

An assessment of the effect of NBC equipment on aircrew thermal strain was carried out using 6 male subjects whose details are given in Table 16. None was heat acclimatised at the start of the study, and the statistical design was arranged to cancel the effect on the results of any acclimatisation acquired during the experiment.

The subjects were all volunteers from the scientific and support staffs of the RAF Institute of Aviation Medicine. They all had to be already familiar with wearing the equipment, and medically fit.

Each subject undertook 4 experiments; 2 simulated the energy expenditure of a Puma pilot while wearing either normal summer or NBC summer AEA, and the other 2 simulated the energy expenditure of a Puma crewman while similarly clothed. Experiments were conducted at the same time each day. The subjects were offered cold water to drink at regular intervals throughout the experiment.

Each experimental period consisted of alternate periods of rest and exercise to simulate the energy expenditure rate of either a Puma crewman or pilot. The statistical design is summarised in Table 16.

TABLE 16. SUBJECT DATA AND STATISTICAL DESIGN

Subject	Age (yr)	Height (cm)	Weight (kg)	Statistical Design Run 1	Run 2	Run 3	Run 4
1	31	183	66	C+	C-	P+	P-
2	33	176	73	P+	P-	C+	C-
3	20	189	75	C-	C+	P-	P+
4	36	179	77	P+	C+	P-	C-
5	23	170	70	C+	P+	C-	P-
6	23	180	67	P-	P+	C-	C+

Notes:

P- = Pilot control

P+ = Pilot NBC

C- = Crewman control

C+ = Crewman NBC

Climatic Chamber

The Institute of Aviation Medicine's climatic chamber consists of a circular wind tunnel of 2.7m cross-sectional diameter. A large fan fills the cross-sectional area of the tunnel to circulate the air, 10% of which is diverted through the conditioning unit. This uses a brine heat exchanger to transfer heat to and from an ammonia refrigeration plant. Humidity is controlled at the same time. There is an overhead radiant heat facility, treadmill, kitchen and toilet within the tunnel.

The dry bulb temperature can be controlled between -10 and +80°C, relative humidity between 3 and 100% at 50°C. Wind speeds of up to 7.5 m/sec can be produced.

Environmental Conditions

The environmental conditions were chosen to represent those likely to be found in the cabin of a Puma flying in central Germany, based on the mean monthly maximum temperature[38] and the observations in Pumas flying under similar climatic conditions in Belize. No radiant heat load was used as it has little direct effect on the pilot, and none on the crewman. The wind speed used was the minimum required to maintain environmental equilibrium, though it was rather higher than that measured in the Puma. The relative humidity was as ambient because of a fault in the environmental control system of the climatic chamber which prevented humidity regulation. The conditions were:

Dry bulb temperature (T_{db}) 35°C
Wet bulb temperature (T_{wb}) 19°C
Relative humidity (rh) 28-32%
Wind speed 2.0 ms^{-1}

Measurements

The following measurements were made:

1. **Deep body temperature.** Deep body temperature (T_{ac}) was measured using a thermistor situated in the external auditory canal (Edale Instruments (Cambridge) Ltd), and well insulated (with cotton wool and the aircrew protective helmet) from the external environment. This site was preferred to the gastrointestinal radio pill because of the unreliability experienced in detecting the radio signal, the flight safety problems of using the external auditory canal no longer being relevant. The radio pill would also have been affected by drinking water.

2. Skin temperature. Skin temperatures were measured at 4 sites (chest, upper arm, inner thigh and outer calf) using thermistors (accurate to within 0.25^{o}C) (Edale Instruments (Cambridge) Ltd) as described by Allan et al.[3] Mean skin temperature ($\bar{T}_{sk}$) was calculated in the manner of Ramanathan.[42]

T_{ac} and $\bar{T}_{sk}$ were recorded automatically every minute by a data logging scanning device based on an RML 3802 microcomputer (Research Machines Ltd, Oxford).

3. Water balance. Total body water loss was derived from the difference between nude weighing before and after each experimental run plus the weight of water drunk. Evaporative water loss was obtained from the difference between fully dressed and instrumented weighings before and after each run plus the weight of water drunk.

Aircrew Clothing

The aircrew equipment assemblies (AEA) worn were as follows:

1. Control Summer AEA.
   - a. Personal underwear.
   - b. Vest, cotton ribbed, aircrew.
   - c. Socks, Terryloop, olive drab.
   - d. Coverall, aircrew, Mk 14.
   - e. Boots, aircrew, 1965 pattern.
   - f. Gloves, cape leather, S/R.
   - g. Helmet, protective, Mk 3C.

2. NBC Summer AEA
   - a. Drawers, cotton ribbed, aircrew.
   - b. Vest, cotton ribbed, aircrew.
   - c. Socks, Terryloop, olive drab.
   - d. Undercoverall NBC Mk 1.
   - e. Socks NBC.
   - f. Coverall, aircrew, Mk 14.
   - g. Boots, aircrew, 1965 pattern.
   - h. Aircrew respirator NBC No 5 (AR5).
   - i. Gloves, aircrew, NBC.
   - j. Gloves, cape leather, S/R.
   - k. Helmet, protective, Mk 3C
   - l. Portable ventilator.

Conduct of the Experiment

Subjects were weighed naked, then instrumented and dressed in the appropriate assembly, and reweighed. They then rested in a chair for 15 minutes to allow the sensors to equilibrate. The experiment started with 10 minutes walking round a circuit in the climatic chamber to simulate walking to the aircraft and pre-flight checks, before beginning the 2 hour exercise routine. During the 5 minute resting periods they were offered cold water to drink, and the weight consumed was recorded. At the end of the 2 hours, they were reweighed, clothed and naked.

Two grades of exercise were chosen to simulate the energy cost of piloting a helicopter or of flying as a crewman. The pilot's energy expenditure was simulated by a simple leg exercise while seated as described by Harrison et al[30]. It entailed pushing a horizontal bar with the feet to raise and lower a 20kg weight through a vertical distance of 29cm at a rate of 30 times per minute, as indicated by a flashing light. The technique was modified to allow the use of the arms to prevent the muscle fatigue produced by this repetitive action, by attaching a rope to the weight, which was strung over a pulley to a handle, which could be used as an alternative or in addition to the leg exercise, at the discretion of the subject. The simulation was designed to produce a rate of energy expenditure of around

200W, as described for Puma pilots. The protocol consisted of exercise periods of 10 minutes interspersed with 5 minute periods of rest, for two hours. The crewman's work rate was simulated by walking on a flat treadmill at 5 km/hr. This was designed by a process of trial and error to produce an overall rate of energy expenditure of around 300 W.

Statistical Methods

Analysis of variance (ANOVA) was used to test for significance of the change with time within each particular condition for both deep body temperature and mean skin temperature. ANOVA was also used to investigate the differences in sweat loss, water drunk, water in clothing and dehydration for each condition, and for sweat loss and dehydration considered as a percentage of body weight.

The Newman-Keuls test procedure[48] was used to analyse the difference between each condition and the other 3 at 0, 60 and 120 minutes.

The Newman-Keuls test is a useful approach to the problem of tests on sets of means obtained in the analysis of variance, using the studentized range statistic (q). The basic strategy underlying the Newman-Keuls procedure is that the set of ranked means is divided into subsets which are consistent with the hypothesis of no differences (in this case, the mean temperatures at 0, 60 and 120 minutes). Within any specified subset no tests are made unless the range of the set containing the specified subset is statistically different from zero. The test procedure focuses upon a series of ranges rather than a collection of differences between the expected values of order statistics.

For this purpose, the q_r statistic is used, where r is the number of steps two means (or totals) are apart on an ordered scale. Critical values for q_r are obtained from tables of the studentized range statistic, by setting r equal to the range.

RESULTS

Deep Body Temperature

Deep body temperatures are shown in Table 17, and summarised in Figure 24. By analysis of variance, the pilot NBC condition (P+) showed no significant increase in temperature with time. The pilot control condition (P-) showed a significant increase in temperature with time* ($p<0.05$) and the crewman NBC (C+) and crewman control (C-) a highly significant increase ($p<0.001$).

The difference between the various conditions was considered using the Newman-Keuls test procedure. At 0 minutes, the conditions cannot be significantly separated. At 60 minutes there is a significant increase in temperature for the C+ condition compared with the other 3 ($p<0.01$). At 120 minutes the difference has become highly significant ($p<0.001$) between C+ and the other 3, and significant ($p<0.01$) for the difference between P+ and P-.

* The fact that P+ showed no significant rise in deep body temperature with time when P- did, is because the initial temperature at the start of the P+ condition was higher. This in turn was probably due to an insufficient rest period following the excertion of donning the NBC assembly.

TABLE 17. DEEP BODY TEMPERATURE (^{o}C)

a. Pilot NBC

Subject	Time (min) 0	10	20	30	40	50	60
1	36.8	36.9	37.0	37.0	37.0	37.1	37.0
2	37.4	37.4	37.4	37.3	37.3	37.3	37.2
3	37.0	37.2	37.2	37.3	37.3	37.3	37.3
4	36.6	36.8	36.9	37.0	37.1	37.1	37.1
5	36.9	37.1	37.1	37.1	37.1	37.0	37.0
6	36.7	36.7	36.7	36.6	36.6	36.7	36.7
mean	36.90	37.02	37.05	37.05	37.07	37.08	37.05
standard deviation	0.28	0.26	0.24	0.30	0.26	0.22	0.21

Subject	Time (min) 70	80	90	100	110	120
1	37.2	37.2	37.2	37.2	37.2	37.2
2	37.3	37.2	37.2	37.2	37.2	37.2
3	37.3	37.3	37.3	37.4	37.4	37.4
4	37.1	37.1	37.0	37.1	37.1	37.1
5	37.0	37.0	37.0	37.0	37.0	37.0
6	36.7	36.7	36.7	36.8	36.8	36.8
mean	37.10	37.08	37.06	37.12	37.12	37.12
standard deviation	0.23	0.21	0.22	0.20	0.21	0.20

TABLE 17. DEEP BODY TEMPERATURE (^{o}C) (CONTD)

b. Pilot control

	Time (min)						
	0	10	20	30	40	50	60
Subject							
1	36.4	36.5	36.6	36.7	36.8	36.8	36.8
2	36.8	36.9	37.0	37.0	37.0	37.0	37.0
3	36.7	36.8	36.9	36.8	36.9	36.9	36.9
4	36.5	36.6	36.7	36.8	36.7	36.6	36.7
5	36.5	36.5	36.6	36.7	36.9	36.9	36.9
6	36.9	37.0	37.0	37.0	37.0	37.0	37.0
mean	36.63	36.72	36.80	36.83	36.88	36.86	36.88
standard deviation	0.20	0.21	0.19	0.14	0.12	0.15	0.12

	Time (min)					
	70	80	90	100	110	120
Subject						
1	36.9	36.8	36.8	36.9	36.9	36.9
2	37.0	37.0	37.0	37.0	37.0	37.0
3	37.0	36.9	36.9	36.9	36.9	36.9
4	36.6	36.6	36.6	36.6	36.7	36.7
5	36.9	36.8	36.9	36.9	36.9	36.9
6	37.0	36.9	36.9	36.7	36.8	36.7
mean	36.90	36.83	36.85	36.83	36.87	36.85
standard deviation	0.15	0.14	0.14	0.15	0.10	0.12

TABLE 17. DEEP BODY TEMPERATURE (°C) (CONTD)

c. Crewman NBC

	Time (min)						
	0	10	20	30	40	50	60
Subject							
1	36.9	37.0	37.3	37.3	37.3	37.3	37.3
2	37.1	37.2	37.3	37.4	37.6	37.6	37.6
3	36.9	37.2	37.6	37.8	37.8	37.8	37.8
4	36.5	36.7	36.9	37.0	37.1	37.1	37.3
5	36.8	36.9	37.2	37.2	37.3	37.4	37.5
6	36.8	36.8	36.9	36.9	36.8	36.8	36.8
mean	36.83	36.97	37.20	37.27	37.32	37.33	37.38
standard deviation	0.12	0.21	0.27	0.32	0.35	0.36	0.34

	Time (min)					
	70	80	90	100	110	120
Subject						
1	37.3	37.3	37.3	37.3	37.3	37.3
2	37.6	37.6	37.6	37.5	37.6	37.6
3	37.8	37.8	37.9	37.9	38.1	37.9
4	37.3	37.4	37.5	37.5	37.5	37.5
5	37.5	37.6	37.6	37.6	37.7	37.7
6	37.0	37.0	37.2	37.1	37.1	37.1
mean	37.42	37.45	37.52	37.48	37.55	37.52
standard deviation	0.28	0.28	0.25	0.27	0.34	0.29

TABLE 17. DEEP BODY TEMPERATURE (^{o}C) (CONTD)

d. Crewman control

	Time (min)						
	0	10	20	30	40	50	60
Subject							
1	36.6	36.8	36.9	37.0	37.0	37.1	37.0
2	36.8	37.0	37.1	37.2	37.2	37.3	37.3
3	36.8	36.8	36.9	36.9	36.9	36.9	36.9
4	36.4	36.4	36.4	36.6	36.7	36.7	36.6
5	36.5	36.8	36.9	36.9	37.0	37.0	37.1
6	36.6	36.7	36.8	36.8	36.8	36.8	36.8
mean	36.61	36.75	36.83	36.90	36.93	36.97	36.95
standard deviation	0.16	0.20	0.23	0.20	0.18	0.22	0.24

	Time (min)					
	70	80	90	100	110	120
Subject						
1	37.0	37.0	37.0	36.9	37.0	37.1
2	37.3	37.3	37.3	37.3	37.4	37.4
3	36.9	37.0	37.0	37.0	37.0	37.0
4	36.6	36.6	36.6	36.7	36.7	36.7
5	37.1	37.1	37.1	37.0	37.0	37.0
6	36.8	36.8	36.8	36.8	36.8	36.8
mean	36.95	36.97	36.97	36.95	36.98	37.00
standard deviation	0.24	0.24	0.24	0.21	0.24	0.24

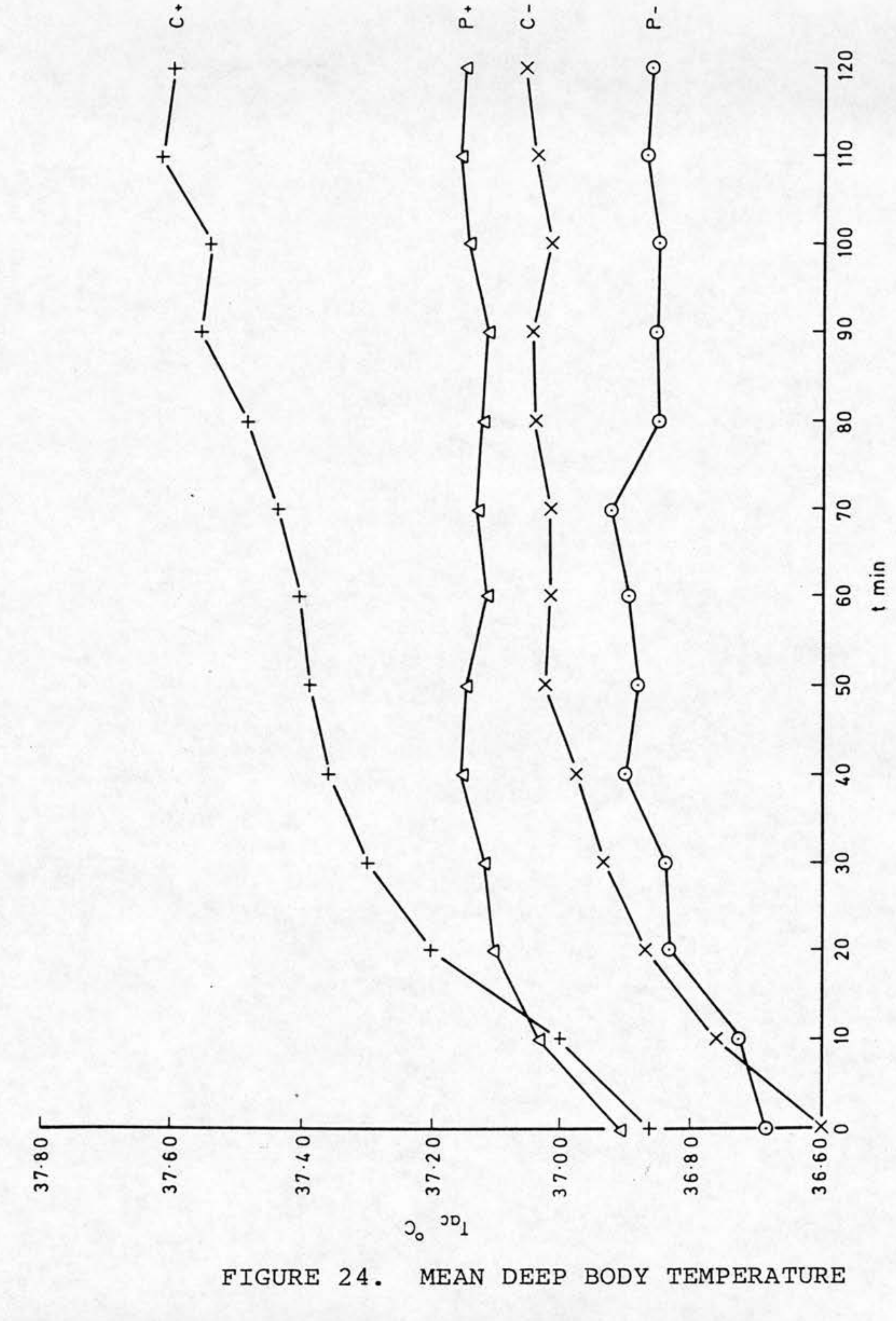


FIGURE 24. MEAN DEEP BODY TEMPERATURE

T_{ac} °C = Temperature Auditory Canal °C (Deep body temperature)
P+ = Pilot NBC P- = Pilot control t = time
C+ = Crewman NBC C- = Crewman control
For each point, the results are expressed as the mean for all subjects for a particular condition at that time.

Mean Skin Temperature

Skin temperatures are shown in Table 18 and summarised in Figure 25. There was no significant change with time for each of the 4 conditions. The Newman-Keuls test shows a highly significant difference between each NBC condition and its control ($p<0.001$) at 120 minutes, but none at 0 or 60.

TABLE 18. SKIN TEMPERATURE (°C)

a. Pilot NBC

Subject	Time (min) 0	10	20	30	40	50	60
1	36.0	36.4	36.3	36.2	36.2	36.1	36.2
2	35.2	35.9	36.1	36.2	36.2	36.3	36.0
3	36.0	36.3	36.2	36.0	36.1	35.9	35.8
4	34.3	34.9	35.3	35.3	35.8	35.6	35.6
5	34.1	34.7	35.3	35.1	35.6	35.3	35.4
6	35.5	36.0	36.0	35.9	36.0	36.0	36.2
mean	35.18	35.70	35.87	35.78	35.98	35.87	35.87
standard deviation	0.82	0.72	0.45	0.47	0.24	0.36	0.33

Subject	Time (min) 70	80	90	100	110	120
1	35.6	35.6	35.7	35.6	35.7	35.6
2	36.1	35.8	35.9	36.0	35.9	36.0
3	35.8	35.8	35.8	36.0	36.1	36.0
4	35.7	35.6	35.7	35.8	35.6	35.4
5	35.6	35.5	35.8	35.7	35.7	35.7
6	36.6	36.4	36.2	36.2	36.1	36.0
mean	35.90	35.78	35.85	35.88	35.85	35.78
standard deviation	0.39	0.33	0.19	0.22	0.22	0.26

TABLE 18. SKIN TEMPERATURE (°C) (CONTD)

b. Pilot control

	Time (min)						
	0	10	20	30	40	50	60
Subject							
1	35.2	35.7	35.7	35.5	35.6	35.4	35.2
2	34.7	35.0	35.5	35.3	35.5	35.6	35.7
3	35.5	35.6	35.9	35.7	35.8	35.8	35.8
4	33.5	34.0	34.3	34.1	34.3	34.2	33.9
5	35.3	35.5	35.4	35.4	35.3	35.3	35.0
6	35.3	35.7	35.4	35.4	35.3	35.3	35.0
mean	34.92	35.25	35.37	35.23	35.30	35.27	35.10
standard deviation	0.74	0.67	0.56	0.57	0.53	0.56	0.68

	Time (min)					
	70	80	90	100	110	120
Subject						
1	35.3	35.2	35.0	35.0	35.0	35.0
2	35.9	35.9	35.9	35.9	35.9	35.2
3	35.9	35.9	35.6	35.6	35.6	35.4
4	34.2	34.1	33.9	34.0	34.0	33.6
5	35.8	35.9	35.6	35.6	35.5	35.0
6	35.4	35.3	35.3	35.4	35.3	34.9
mean	35.42	35.38	35.22	35.25	35.22	34.85
standard deviation	0.65	0.71	0.71	0.68	0.67	0.64

TABLE 18. SKIN TEMPERATURE (^{o}C) (CONTD)

c. Crewman NBC

	Time (min)						
Subject	0	10	20	30	40	50	60
1	35.8	36.0	36.2	36.2	36.2	36.1	36.0
2	34.7	35.4	35.5	35.6	36.2	36.1	35.9
3	35.6	36.0	36.2	36.0	36.0	35.9	35.7
4	34.0	34.6	35.0	35.3	35.4	35.6	35.6
5	33.9	34.4	34.6	35.1	35.3	35.2	35.3
6	35.0	35.6	35.8	35.9	35.9	36.2	36.5
mean	34.83	35.33	35.55	35.68	35.83	35.85	35.83
standard deviation	0.79	0.69	0.65	0.43	0.39	0.38	0.41

	Time (min)					
Subject	70	80	90	100	110	120
1	35.8	35.8	35.9	35.8	35.9	35.7
2	36.0	36.0	36.0	36.0	35.9	36.0
3	35.9	35.9	35.8	36.0	36.1	36.1
4	35.6	35.8	35.7	35.6	35.8	35.6
5	35.6	35.6	35.8	35.7	35.7	35.6
6	36.6	36.5	36.5	36.4	36.4	36.0
mean	35.92	35.93	35.95	35.92	35.97	35.83
standard deviation	0.37	0.31	0.29	0.29	0.25	0.23

TABLE 18. SKIN TEMPERATURE (°C) (CONTD)

d. Crewman control

	Time (min)						
Subject	0	10	20	30	40	50	60
1	34.6	34.6	34.5	34.3	34.0	34.0	33.9
2	34.6	34.7	34.7	34.8	34.6	34.8	34.6
3	34.7	34.9	35.0	35.0	35.0	35.0	35.3
4	34.6	34.2	34.5	34.5	34.7	35.0	35.2
5	33.7	33.4	33.2	33.1	32.9	32.8	32.5
6	35.2	35.2	34.7	34.5	34.5	34.3	34.3
mean	34.57	34.50	34.43	34.37	34.28	34.32	34.30
standard deviation	0.48	0.63	0.63	0.67	0.75	0.84	1.03

	Time (min)					
Subject	70	80	90	100	110	120
1	34.0	33.8	34.0	34.4	34.0	34.3
2	34.5	34.4	34.4	34.7	34.7	34.8
3	35.2	35.1	35.3	35.3	35.3	35.5
4	35.3	35.2	35.2	35.0	35.1	35.2
5	32.5	32.4	32.6	32.8	32.8	32.8
6	34.2	34.0	34.1	34.0	34.1	34.2
mean	34.28	34.15	34.26	34.36	34.33	34.47
standard deviation	1.02	1.03	0.98	0.89	0.91	0.96

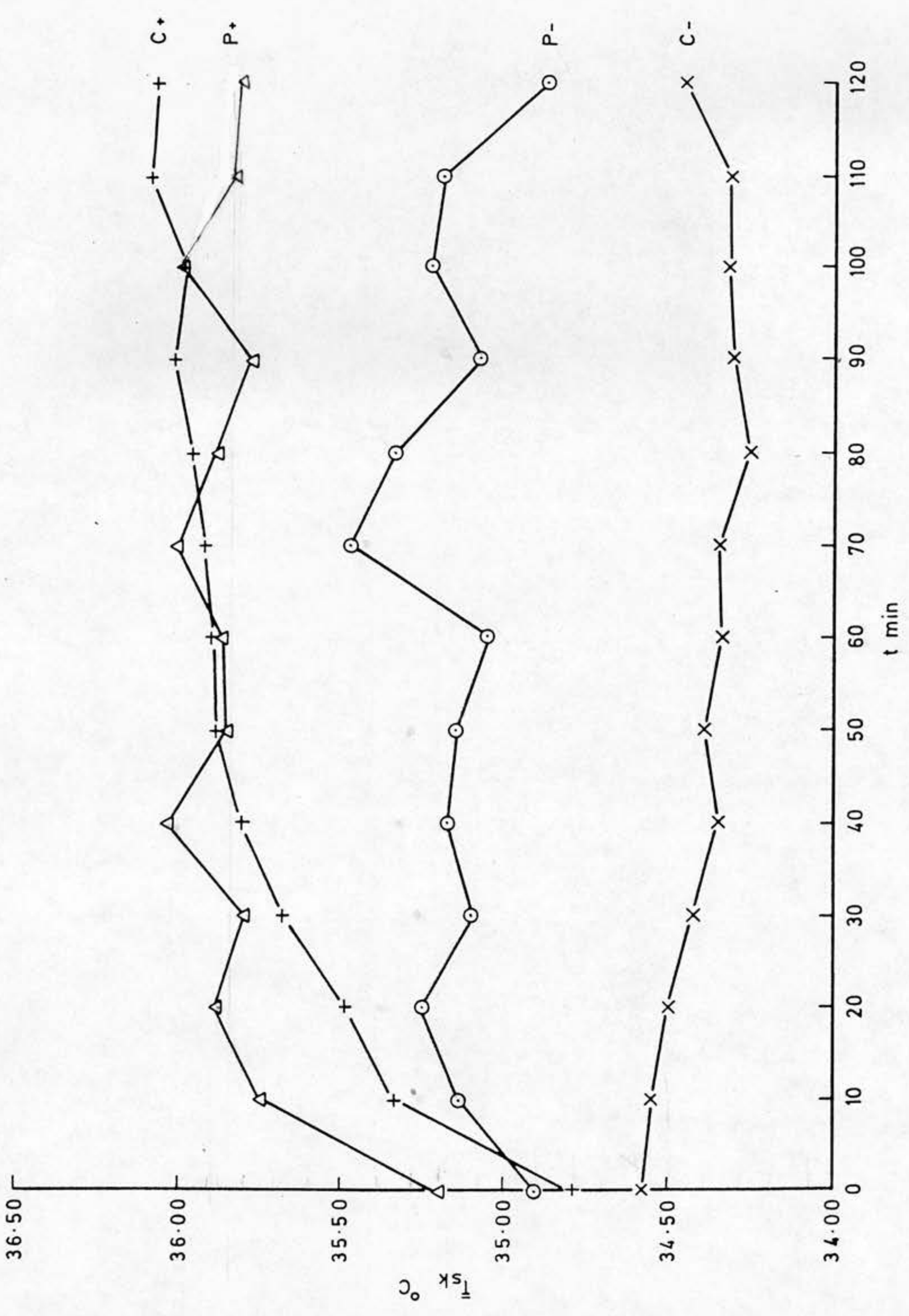


FIGURE 25. MEAN SKIN TEMPERATURE

$\bar{T}_{sk}$ °C = Mean Skin Temperature
P+ = Pilot NBC   P- = Pilot control   t = time
C+ = Crewman NBC   C- = Crewman control
For each point the results are expressed as the mean for all subjects for a particular condition at that time.

Weight Loss

Table 19 shows the figures for water balance, with mean weight of sweat lost, water drunk, dehydration and sweat in clothing for different conditions, with means and standard deviations. It is summarised in graphical form in Figure 26. There is a significant difference ($p<0.05$) between the sweat loss for each NBC condition and its control, and a highly significant difference ($p<0.001$) between C+ and P+ and between C- and P-. The derivation of the water balance is summarised in Table 20.

The mean volume of water drunk in the C+ condition was significantly greater than its control ($p<0.05$). The only significant difference in the amount of sweat soaked up by clothing was between P+ and P- ($p<0.01$).

Table 21 and Figure 27 show the degree of sweat loss and dehydration considered as a percentage of body weight. The difference between the sweat loss for P+ and P- is significant at $p<0.01$ and between C+ and C- at $p<0.05$. The difference between C+ and P+ is also significant ($p<0.01$) as is that between C- and P- ($p<0.05$). The only significant difference for dehydration is between C+ and C- ($p<0.05$).

TABLE 19. WATER BALANCE (KG)

a. Pilot NBC

Subject	Sweat Loss	Drink	Dehydration	Sweat in Clothing
1	0.89	0.69	0.2	0.6
2	1.32	1.02	0.3	0.6
3	0.87	0.57	0.3	0.4
4	1.01	0.81	0.2	0.5
5	0.81	0.51	0.3	0.4
6	1.25	0.95	0.3	0.4
mean	1.03	0.76	0.27	0.48
standard deviation	0.21	0.20	0.05	0.10

b. Pilot Control

Subject	Sweat Loss	Drink	Dehydration	Sweat in Clothing
1	0.77	0.37	0.4	0.2
2	0.76	0.46	0.3	0.1
3	0.68	0.48	0.2	0.1
4	0.61	0.41	0.2	0.1
5	0.55	0.45	0.1	0.2
6	0.68	0.48	0.2	0.1
mean	0.68	0.44	0.23	0.13
standard deviation	0.09	0.04	0.10	0.05

TABLE 19. WATER BALANCE (KG) (CONTD)

c. Crewman NBC

Subject	Sweat Loss	Drink	Dehydration	Sweat in Clothing
1	1.42	0.82	0.6	0.6
2	1.65	0.95	0.7	0.6
3	1.97	1.07	0.9	0.8
4	1.72	1.02	0.7	1.0
5	1.50	0.70	0.8	0.5
6	1.51	0.81	0.7	0.7
mean	1.63	0.90	0.73	0.70
standard deviation	0.20	0.14	0.10	0.18

d. Crewman Control

Subject	Sweat Loss	Drink	Dehydration	Sweat in Clothing
1	0.71	0.51	0.2	0.1
2	1.35	0.95	0.4	0.4
3	0.72	0.62	0.1	0.2
4	0.61	0.31	0.3	0.5
5	1.07	0.87	0.2	0.4
6	1.12	0.92	0.2	0.3
mean	0.93	0.70	0.23	0.32
standard deviation	0.29	0.26	0.10	0.15

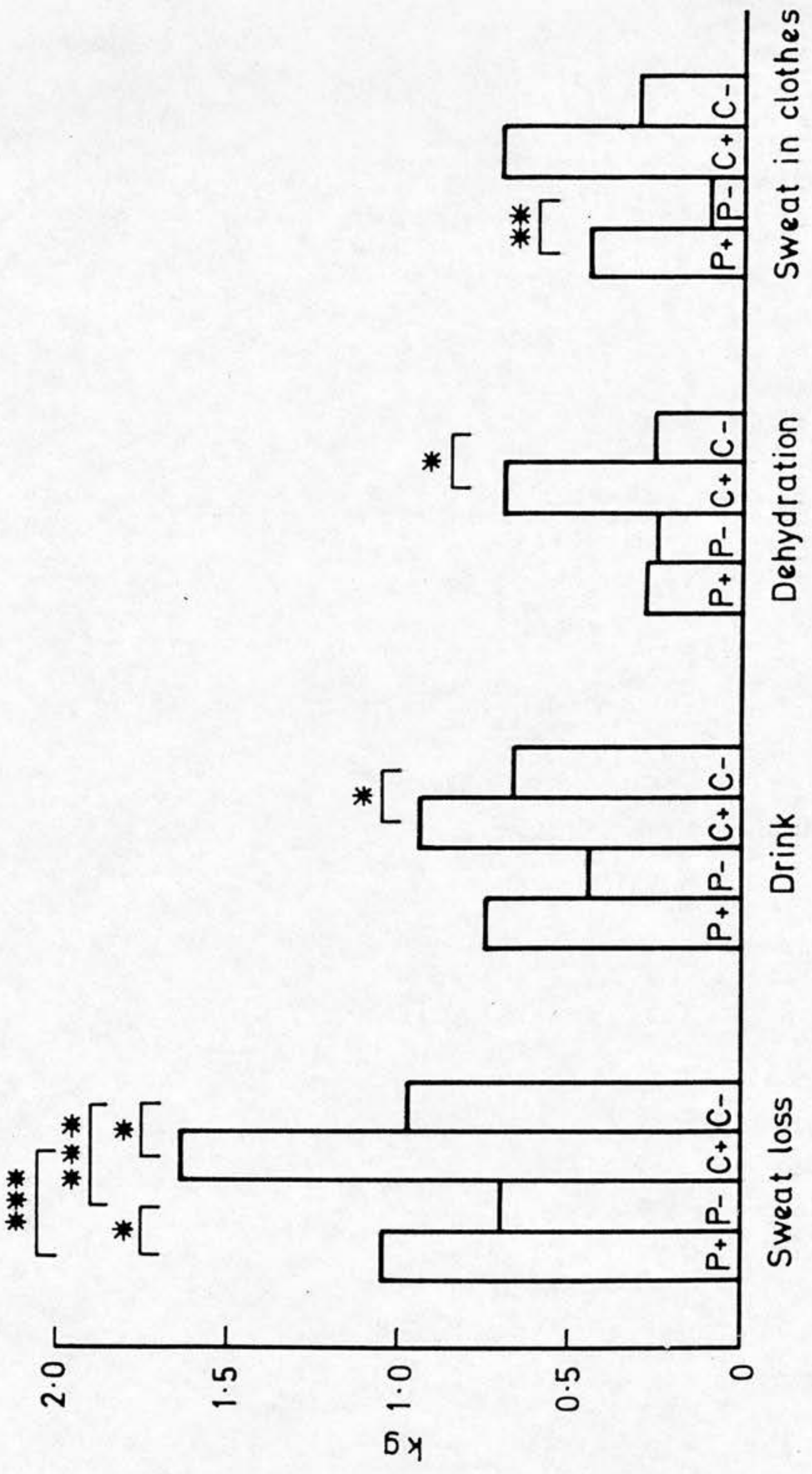


FIGURE 26. MEAN WATER BALANCE

P+ = Pilot NBC P- = Pilot control
C+ = Crewman NBC C- = Crewman control
Significance of differences shown as:
*** $p<0.001$ ** $p<0.01$ * $p<0.05$

TABLE 20. DERIVATION OF WATER BALANCE (KG)

Figures are for Subject 1, Pilot NBC

Initial Nude Weight (IN)	Initial Clothed Weight (IC)	Final Nude Weight (FN)	Final Clothed Weight (FC)
66.0	75.2	65.8	75.6

Water Drunk (W)	Dehydration (IN-FN)	Total Body Water Loss (IN-FN+W)	Sweat in Clothes ((FC-FN)-(IC-IN))
0.69	0.2	0.89	0.6

TABLE 21. MEAN WATER LOSS

(PERCENTAGE BODY WEIGHT)

	Sweat loss				Dehydration			
Subject	P+	P-	C+	C-	P+	P-	C+	C-
1	1.35	1.17	2.15	1.08	0.30	0.61	0.91	0.30
2	1.81	1.04	2.23	1.85	0.41	0.41	0.96	0.55
3	1.16	0.91	2.63	0.96	0.40	0.27	1.20	0.13
4	1.31	0.79	2.23	0.79	0.26	0.26	0.91	0.39
5	1.16	0.79	2.14	1.53	0.43	0.14	1.14	0.29
6	1.87	1.01	2.25	1.67	0.45	0.30	1.04	0.30
mean	1.44	0.95	2.27	1.31	0.38	0.33	1.03	0.33
standard deviation	0.32	0.15	0.18	0.43	0.08	0.16	0.12	0.14

P+ = Pilot NBC
C+ = Crewman NBC
P- = Pilot Control
C- = Crewman Control

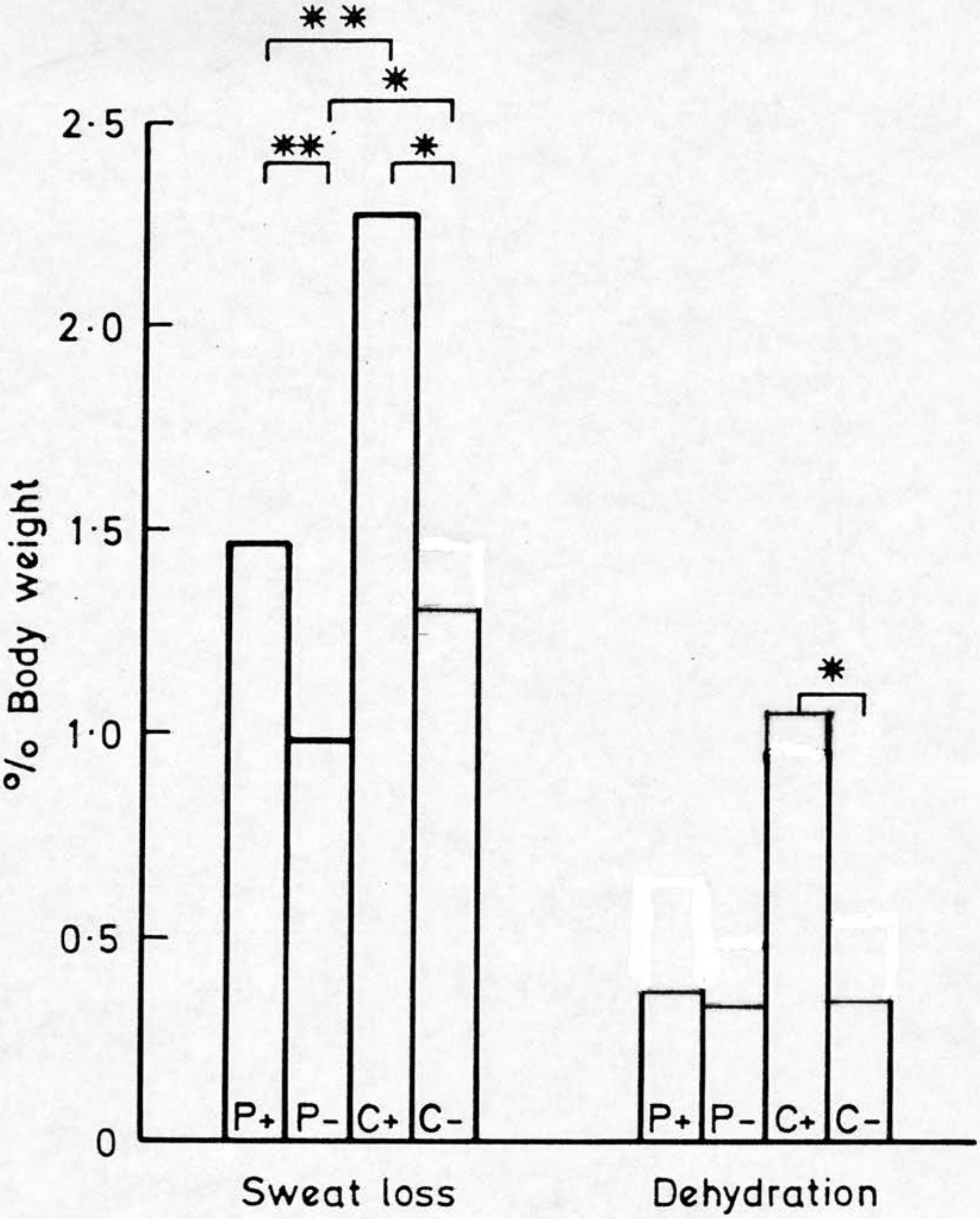


FIGURE 27. MEAN WATER LOSS

P+ = Pilot NBC
C+ = Crewman NBC
P- = Pilot control
C- = Crewman control
Significance of differences shown as:
*** $p<0.001$ ** $p<0.01$ * $p<0.05$

DISCUSSION

Environmental Conditions

The environmental conditions chosen are those which would be found in the cabin of a Puma with an outside air T_{db} of 31°C, the mean monthly maximum for Hanover in July being 30.8°C. This temperature is normally exceeded in every month from May to September.[38] The ambient humidity was rather lower than might normally be expected.

Indices of Thermal Strain

The effect of the aircrew NBC assembly on aircrew is demonstrated by the difference in T_{ac} and $\bar{T}_{sk}$ between the NBC conditions and their respective controls by the end of the experiment. The rate of rise in core temperature suggests that pilots are unlikely to suffer thermal strain in NBC clothing during the period of the time tested (2 hours). They had a mean auditory canal temperature stabilised at 0.3°C above the pilot controls. Crewmen, on the other hand, are clearly shown to be vulnerable to a considerable rise in core temperature with time because of their higher work rate. The levels of T_{ac} encountered during the experiment are likely to cause a reduction in physical work capacity[36] and a decrement in psychomotor performance.[5,23] With longer sortie times, which would occur in time of war, when flying is likely to be more or less continuous throughout the daylight hours, with little opportunity to rest and cool down, temperatures would be even higher.

Subjects wearing NBC clothing sweated considerably more than when wearing normal AEA. It is significant that despite the free availability of water through the AR5 drinking facility, a dehydration of 1% of body weight still occurred in the C+ condition. Saltin[44] reported that this level of dehydration can also cause a diminution in physical work capacity. This too would become more significant with longer sorties.

Prevention of thermal strain could be achieved in the following ways:

a. Reduction of work rate.
b. Reduction of sortie length.
c. Reducing the insulation of the NBC AEA.
d. Providing cabin conditioning.
e. Providing personal conditioning.

Reduction of work rate is unlikely; indeed the opposite would be expected in time of war, as is the case for sortie length. Any major change to the NBC AEA is unlikely in the near future. Cabin conditioning would be effective, but does not exist in Service helicopters, and would be expensive to retrofit. The option of personal conditioning might be unpopular with aircrew, as yet another item of AEA to endure, but would allow a satisfactory thermal equilibrium.[19]

Aircrew Personal Conditioning

Historically, there have been 2 concepts used for providing personal cooling for aircrew. The oldest (the first British version was made in 1940 by McArdle) was the air ventilated suit (AVS) a sort of personal air conditioning. The other utilises the higher thermal capacity of water as a coolant, the liquid conditioned suit (LCS).[28]

The first air ventilated suit was a very cumbersome affair, but soon progressed to a much lighter ventilating harness of narrow bore, polyvinyl chloride (PVC) tubing, mounted on a light nylon base. Air, cooled by passing through copper coils immersed in ice-water, was distributed to a series of 32 outlets. The first suit to enter service in 1954 covered only the trunk and thighs.

With experience, it became obvious that aircrew would be more comfortable with a suit which covered the whole body, and the Mark 2 version did just that, with an increase in the number of air jets in the tubing to 144. These jets were so arranged as to distribute the ventilating air evenly over the body surface. The small diameter of the jets ensured a high air velocity locally which served to break up the layers of warm air lying over the surface of the skin, increasing the effectiveness of heat exchange.

The fate of the AVS was sealed once chemical defence became a recognised part of the UK defence strategy. If aircrew are to fly through an environment which is chemically contaminated, it is obviously the height of folly to blow air from that environment over them. Initially it was thought that it might be possible to filter the air, but this so reduced the flow that the cooling provided was totally inadequate. Liquid conditioning, on the other hand, could be totally self-contained.

Although liquid conditioned suits are not being used by the RAF or any other air force, they have been well proved by the Apollo space programme, and the idea, British in origin, dates back to 1959, with the first prototype garment produced by the Royal Aircraft Establishment (RAE) in 1962. The first LCS was a one-piece cotton undergarment, fitted with socks and gloves. Threaded in and out of the material were some 50 metres of black PVC tubing, of which three quarters were in direct contact with the skin surface.

At the time the early development work was taking place on the LCS, the American National Aeronautics and Space

Administration (NASA) requested a demonstration. The Americans were suitably impressed, and undertook a development programme of their own, culminating, in the late 1960s, in the Apollo suit.

The major advantages of the LCS over the AVS are the fact that it is compatible with chemical defence operations, and that if the conditioning fluid is warmed instead of cooled, it can be used for heating. Because of this, a formal programme of research and development was financed, resulting in the evaluation of several different commercially produced designs. To begin with, the main problem was local over-cooling of the skin, overcome by enclosing the tubing in fabric tunnels, and doubling its length. This latter, by providing a larger skin area beneath the tubing allowed the same amount of cooling to be achieved at a higher skin temperature.

Despite progressing to successful flight trials, the LCS was axed in 1973 in the Defence Review, along with the aircraft it was principally destined for, the Vulcan. Two years later, however, it was revived with the decision to install it in the Tornado in place of the AVS.

The definitive version of the LCS produced at this time (though still as a prototype version) was made of crimped nylon, with 120 metres of PVC tubing contained within fabric tunnels stitched to the garment's undersurface. The suit covered all the body, apart from the head, neck, hands and feet. One fifth of the covered body surface was in direct contact with the tubing tunnels. A water/antifreeze mixture circulated through the pipework at a flow rate of one litre per minute.

During the next two years the LCS was subjected to further laboratory evaluation. The main concern was whether the suit would protect against the extremes of heat and cold which could be encountered by aircrew waiting on standby in their aircraft. It is anticipated that periods of up to 4 hours might have to be spent simply sitting in the cockpit awaiting orders to fly. This could be in Norway in winter with temperatures in the cockpit down to minus 26°C, or in Europe on a sunny summer day, where a closed cockpit on an unshaded runway can exceed 50°C, both of which temperatures have been shown to be adequately coped with.

In 1978, the LCS programme was again 'shelved', not because of any problems with the suits, but with the system needed to supply the suits with cool liquid. A fairly substantial refrigeration and pumping plant was needed to pump liquid at a suitably low temperature through the suit. There was simply insufficient room in small fighter aircraft, where space is at a premium.[27] A potential solution to this problem was developed in the RAE by Bewley.[9] This consisted of a one-man vapour-cycle cooling pack, small enough to be mounted on an ejection seat. (It was to be the size of a house brick, and known as the 'Bewley Brick'). A big advantage of a unit of this type would be the ability to use an auxiliary power unit to provide standby cooling independent of the aircraft's engines. Unfortunately, existing refrigeration equipment could not be miniaturised sufficiently at reasonable cost, and it too was abandoned. Recently the Bewley Brick has been re-developed in the USA by United States Air Force (USAF) contracts, and has emerged as a pre-production prototype which is currently undergoing evaluation by the RAF. It can produce 300W of cooling at a T_{db} of 55°C.

Another cooling unit has been designed and produced as a prototype using the thermo-electric principle to provide 150W of cooling at 25°C inlet temperature in an ambient environment of T_{db} 40°C[22]. It has the maintenance advantage of fewer moving parts than the vapour cycle pack. This is also undergoing evaluation. Both types of cooling unit are also potentially capable of heating.

Head cooling alone has been investigated by Blair and Harrison[11] using a liquid conditoned hood of similar basic design to the LCS. Although only a small benefit in terms of alleviating thermal strain was observed, the rate of rise of deep body temperature was decreased by a third, and sweat losses were halved. Head cooling could be used in less extreme conditions and produces feelings of general thermal comfort as well as of the head.

Two new partial coverage garments have been tested in recent years, the liquid conditioned vest (LCV) and the liquid conditioned waistcoat (LCW). The advantages of these garments are that they are much cheaper to produce, provide a smaller addition to total clothing insulation, and fewer sizes are needed. Again, they are less efficient than the LCS, as a smaller body area is cooled. They can still provide up to 500W of cooling with a suitable conditioning unit, allowing subjects to maintain thermal equilibrium at, albeit, high levels (37.9-38.1°C at 50°C T_{db})[18].

In summary, after a gestation period of 44 years there is still no personal conditioning available for aircrew. The suits have been developed and proven in laboratory conditions; the cooling units, given adequate funding, could be available soon.

CONCLUSIONS AND RECOMMENDATIONS

1. The thermal strain on helicopter crewmen operating in chemical defence clothing in Western Europe at summer mean monthly maximum temperatures is unacceptable. Core temperature will rise to levels at which work capacity is limited, and at which decrements in performance are expected.

2. Helicopter pilots are unlikely to suffer significant thermal strain when flying for up to 2 hours.

3. Some degree of dehydration in crewmen seems inevitable despite the availability of the drinking facility, to a level which will also limit work capacity.

4. Personal conditioning is required for helicopter crewmen under NBC conditions.

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ANNEX A

'FATIGUE CHECKLIST'

The statements which follow are to help you decide how you feel at this time - not yesterday, not an hour ago - but right now. For each statement you must determine whether you feel (1) "Better than", (2) "Same as", or (3) "Worse than" the feeling described by that statement.

As an example, take a person who feels a little tired. He might respond to the following items as follows:

	Better than	Same as	Worse than	Statement
a	( )	( )	(X)	extremely fresh
b	( )	(X)	( )	somewhat tired
c	(X)	( )	( )	completely exhausted

In other words, this person feels worse than "extremely fresh", about the same as "somewhat tired", but, on the other hand, better than "completely exhausted".

Now answer each of the following statements as follows:

If you feel <u>better than</u> the statement, place an "x" in the "better than" column.

If you feel about the <u>same as</u> the statement, place an "x" in the "same as" column.

If you feel <u>worse than</u> the statement, place an "x" in the "worse than" column.

Remember, answer each question with regard to how you feel at this instant.

NAME: PILOT/CREWMAN DATE:
TIME:

No	Better than	Same as	Worse than	Statement
1	( )	( )	( )	very lively
2	( )	( )	( )	extremely tired
3	( )	( )	( )	quite fresh
4	( )	( )	( )	slightly tired
5	( )	( )	( )	extremely lively
6	( )	( )	( )	somewhat fresh
7	( )	( )	( )	very tired
8	( )	( )	( )	very refreshed
9	( )	( )	( )	quite tired
10	( )	( )	( )	ready to drop

ANNEX B

ABBREVIATIONS

All abbreviations are explained when first used in the text. For the convenience of those who might be unfamiliar with the preponderance of military abbreviations, however, a separate list is included here.

AAC	Army Air Corps
AEA	Aircrew Equipment Assembly
AGL	Above Ground Level
AMSL	Above Mean Sea Level
AR5	Aircrew Respirator NBC No 5
ATDR	Automatic Thermal Data Recorder
AVS	Air Ventilated Suit
CD	Chemical Defence
CW	Chemical Warfare
D	Drinking
FITS	Fighter Index of Thermal Stress
IAM	(RAF) Institute of Aviation Medicine
L	Landing
LCS	Liquid Conditioned Suit
MAW	Maximum All-up Weight
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organisation
NBC	Nuclear Biological and Chemical
RAE	Royal Aircraft Establishment
RAF	Royal Air Force
S/R	Sweat Resistant (Gloves)
T/O	Take Off
USAF	United States Air Force

ANNEX C

FIGHTER INDEX OF THERMAL STRESS IN °C (LOW-LEVEL FLIGHT, CLEAR SKY TO LIGHT OVERCAST)

Instructions: Enter with local dry bulb temperature and dewpoint temperature; at intersection read FITS value and zone. Applies only to lightweight flight clothing. See notes for zone explanation. The X denotes combinations above saturation temperature.

Dry Bulb Temp. (°C)	Zone	Dewpoint Temperature (°C) ≤ 0	5	10	15	20	25	30	35	40	≥ 45
20.0	Normal	21	22	24	26	29	X	X	X	X	X
22.5		23	24	26	28	30	X	X	X	X	X
25.0		24	26	27	29	31	35	X	X	X	X
27.5		26	27	29	31	33	36	X	X	X	X
30.0		28	29	31	32	35	37	41	X	X	X
32.5		29	31	32	34	36	39	42	X	X	X
35.0		31	32	34	36	37	40	43	46	X	X
37.5	Caution[1]	33	34	35	37	39	42	45	48*	X	X
40.0		34	35	37	39	41	43	46	49*	52	X
42.5		36	37	38	40	42	44	47*	50	54	X
45.0		37	39	40	41	43	46	48*	52	55	58
47.5	Danger[2]	39	40	41	43	45	47*	50	53	56	59
50.0		41	42	43	44	46	48*	51	54	57	61

[1] Caution Zone:
(1) Be aware of heat stress.
(2) Limit ground period (preflight and ground standby) to 90 min.
(3) Minimum 2-hr recovery between flights.

[2] Danger Zone:
(1) Cancel low-level flights (below 915 m AGL).
(2) Limit ground period to 45 min.
(3) Minimum 2-hr recovery between flights.

*When value is greater than 46, cancel all nonessential flights.

Comments:

Observe the following general hot-weather precautions: (1) Allow time for acclimatization to hot weather; avoid extreme efforts on the first several days of exposure. (2) Try to drink more water than thirst dictates; water intake is vital to sweat secretion, the body's main defense against heat.

This table is not to be used when CD, immersion, or arctic flight equipment is worn.

APPENDIX A

Published Papers.

Two papers have been published relating to studies within this thesis, both in the American journal Aviation Space and Environmental Medicine, this being the most widely read journal within the Aviation Medicine field.

The first paper, 'The Energy Expenditure of Helicopter Pilots', was also presented at the 54th Annual Scientific Meeting of the Aerospace Medical Association.

TECHNICAL NOTE

The Energy Expenditure of Helicopter Pilots

R. THORNTON, M.B., D.AV.MED.,
G. A. BROWN, B.SC., PH.D., and C. HIGENBOTTAM

Royal Air Force Institute of Aviation Medicine,
Farnborough, Hampshire, England

THORNTON R, BROWN GA, HIGENBOTTAM C. *The energy expenditure of helicopter pilots*. Aviat. Space Environ. Med 1984; 55:746–50.

The energy expenditure of Army Air Corps and Royal Air Force pilots has been measured during flight in Gazelle and Puma helicopters respectively. Heart rates were also recorded.

The results were compared with resting values obtained in the rewroom before flight, and confirmed the findings of other auhors that the energy cost of flying helicopters in level flight is about 50% higher than that of sitting at rest.

A KNOWLEDGE OF ENERGY expenditure in a variety of flying tasks is essential in the design and development of aircraft and personal thermal condiioning systems, and in assessing the effects of thermal tress on aircrew. The latter assumes particular imporance when considered in the context of wearing airrew chemical defence (CD) assemblies, due to an inrease in the number of insulating layers. Laboratory xperiments to assess the thermal effects of such an ssembly can simulate environmental conditions and hysical workload, but the degree of workload must be ased accurately on energy expenditure measured in ight if the results are to be valid. Recent climatic hamber studies of the thermal load imposed by NBC semblies have emphasised the need for more inforation on the workloads faced by helicopter aircrew ,4).

There is considerable information regarding the engy cost of a wide variety of human activities (14), but rprisingly little research has been performed on airew in flight. Sharp *et al.* (15), in their review of the erature, found only three studies on helicopter airew; none were in UK helicopters. French *et al.* (6) performed a limited study of four pilots flying Army Air Corps Scout helicopters.

The aim of this experiment was, therefore, to measure the energy cost of flying helicopters in different phases of flight using two aircraft types. To obtain a basis for comparison, the energy expenditure of the subjects was also measured at rest and while walking to and from the aircraft.

METHODS

Measurements of energy expenditure and heart rates were made on two groups of six helicopter pilots. One group (Army Air Corps pilots) flew the Gazelle AH1, the other (Royal Air Force pilots) flew the Puma HC1. In each case measurements were taken continuously throughout a training sortie. Details of the subjects are shown in Table I.

No attempt was made to standardise the sorties, aircrew equipment assemblies (AEA), climatic conditions or the walk to the aircraft. The subjects rested in the crewroom in a chair for 10 min before the start of the sortie to obtain a baseline for comparison.

The subjects were volunteers selected at random from the squadrons concerned and varied in experience from newly qualified pilots to helicopter instructors. Their height and weight were recorded immediately before flying.

Measuring Techniques

Previous studies have used cumbersome techniques involving Douglas bags (3,11) or a Franz-Muller gas meter (12). Measurements of energy expenditure in this study were made using the Oxylog (10). The Oxylog is readily portable and will measure oxygen consumption ($\dot{V}o_2$) and inspiratory volume ($\dot{V}_I$) to an accuracy which compares favourably with standard laboratory techniques (2). The Oxylog precludes the need to collect expirate for later analysis and provides continuous mon-

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uthor R. Thornton is now with the Royal Army Medical College, llbank, London, WC1.

his paper was presented at the 54th Annual Scientific meeting of Aerospace Medical Association, Houston, TX, May 23–26, 1983.

TABLE I. SUBJECT DATA.

Subject	Age (yr)	Height (mm)	Weight (kg)	Surface Area (m²)*	Ac Type	Flying Hours	
						Total	On Type
1	32	1773	77	1.92	Gaz	2400	1200
2	27	1788	74	1.90	Gaz	920	800
3	42	1831	83	2.08	Gaz	4500	900
4	27	1734	72	1.86	Gaz	1400	1280
5	28	1729	70	1.82	Gaz	645	525
6	36	1841	83	2.08	Gaz	2500	1000
7	30	1676	83	1.92	Puma	3200	600
8	21	1834	88	2.14	Puma	2800	1600
9	39	1801	82	2.02	Puma	4500	150
10	29	1831	78	1.92	Puma	1200	120
11	27	1752	70	1.84	Puma	900	150
12	33	1910	90	2.20	Puma	2300	200
Mean	30.92	1791.67	79.17	1.97			

* Dubois—Meeh

itoring over an extended period. Errors in measurement of V_{O_2} produced by assuming a respiratory exchange ratio of one are largely cancelled by the calculation of energy expenditure using a fixed calorific value for the oxygen consumed, as proposed by Weir (16).

To enable the Oxylog to be used with the aircrew's normal flying helmet, the soft face mask supplied with the equipment was replaced with a RAF P or Q mask modified to take the collecting hose and flowmeter. This method also provided a microphone facility.

The Oxylog was used in conjunction with a portable data recorded (ATDR) (9) to record V_{O_2} and V_I at 1-min intervals. A third channel of the ATDR was used to record heart rate every minute.

Recovery of recorded data from the ATDR was accomplished using a Powerhouse 48K microcomputer and an Oki Microline printer, which were sufficiently portable to be used in the field. This equipment transferred the data from the ATDR onto a microcassette for torage, and produced a printed copy.

The Aircraft

The Gazelle AH1 is a light observation helicopter, with a maximum all-up weight (MAW) of 1800 kg. It is ormally crewed by a pilot and aircrewman and can arry three passengers. The flying controls are hydrau-cally operated, but no autopilot or stabilising system fitted.

The Puma HC1 is a medium battlefield support heli-opter, (MAW 7000 kg). It is normally crewed by a pilot nd a crewman and can carry up to 16 passengers. The ying controls are hydraulically operated and there is autopilot providing full stability in pitch, yaw and ll, and height hold.

Conduct of the Experiment

The experimental subjects donned their normal nter AEA and silver/silver chloride ECG chest elec-des were then attached. They then donned their ng helmet and were fitted with an oxygen mask with hose of the Oxylog connected to an adaptor in the iratory port. The Oxylog flow meter was attached he end of an oxygen hose fitted to the inspiratory port. The electrical connections between the flowmeter and the Oxylog, the Oxylog and the ATDR, and the chest electrodes and the ATDR were made. The subjects then rested in a chair for 10 min. Recording commenced at the beginning of this rest period.

The pilot then walked to the aircraft and did his external pre-flight checks before strapping in. The Oxylog was carried over his shoulder by its strap, and the ATDR was held in a lower leg pocket of his flying coverall. Inside the aircraft, the Oxylog was held by the experimenter in the rear seat in the Gazelle or the crewman's jump-seat in the Puma. A safety pilot was carried to cover any potential lookout problems caused by limitation of head movement or visual fields.

The subject then flew a normal training sortie while the experimenter monitored the function of the Oxylog and manually recorded the time at which different stages of flight were begun.

At the end of the sortie, the pilot again carried the Oxylog to the crewroom where recording was ended and the data retrieved from the ATDR.

RESULTS

The tabulated data for each subject were divided into groups according to phase of flight. The first reading in each group was discarded to remove the effect of lag in the Oxylog; the rest, the number of which is denoted by 'n', were averaged to produce the results shown in Table II. The overall subject mean was then calculated for each phase of flight, according to aircraft type. Energy expenditure is shown as W and W per kg body weight. The heart rates were treated in a similar manner (Table III).

The phases of flight considered were the hover, level flight at 1000 ft AMSL, low level flight (100–200 ft AGL), instrument flying, and a circuit with the hydraulics selected out. The instrument flying phase represents the period when the aircraft was under positive air traffic control while conducting an instrument approach to an airfield. In the majority of cases instrument flying conditions were simulated.

Some of the training sorties from which the data were obtained did not include all the phases of flying considered in the tables. In Table III, heart rates are not shown for subjects 7–10 due to recording problems in the field.

Energy Expenditure (Table II)

Gazelle Pilots: (Subjects 1–6). There was no significant difference between the energy cost of flying the Gazelle in the cruise (mean 1.7 $W \cdot kg^{-1}$, range 1.4–2.0 $W \cdot kg^{-1}$), at low level (1.5 $W \cdot kg^{-1}$), or while instrument flying (1.5 $W \cdot kg^{-1}$). In the hover and flying with the hydraulics out, the mean value was greater at 1.9 $W \cdot kg^{-1}$ in each case ($p<0.01$ by analysis of variance). The mean value at rest was 1.2 $W \cdot kg^{-1}$ (range 0.9–1.5) and while walking to the aircraft 3.5 $W \cdot kg^{-1}$ (range 2.4–4.5).

Puma pilots: (Subjects 7–12). The energy expended by the Puma Pilots was consistently higher than that of the Gazelle pilots in all forms of activity ($p<0.05$). Flying in the cruise, the mean result was 2.5 $W \cdot kg^{-1}$ (range 1.6–4.5). Again, flying at low level and on instruments gave similar values of 2.5 and 2.8 $W \cdot kg^{-1}$, respectively. Hovering required a greater energy expenditure at 3.1 $W \cdot kg^{-1}$ (range 2.1–5.0), as in the Gazelle. Similarly, the result for flying without hydraulics was greater, at 2.2 $W \cdot kg^{-1}$, than that for cruise flight, at 1.9 $W \cdot kg^{-1}$, in the three subjects for whom direct comparison could be made.

Heart Rate (Table III)

Because of technical difficulties in recording heart rate, results were retrieved for only two of the Puma pilots. These are therefore not considered further. Considering the mean of the Gazelle results, there is no apparent difference between heart rate at rest and any phase of flying. Examining individual results, the reason appears to be that subject 2 had a particularly high resting heart rate at 97 bpm; higher indeed than while walking, possibly due to apprehension. The values for the individual subjects show no particular trend, other than the fact that heart rate increased slightly from the resting level with the various forms of flight, the increase ranging from 0–15 bpm. The mean heart rate rose from 75 bpm at rest to 92 bpm on walking.

DISCUSSION

The results for mean energy expenditure for pilots of both aircraft types show that the energy cost of level flight is 50% higher than that of sitting at rest, and that of hovering is higher than level flight. In the hover, control inputs are continuously required due to variations in the wind, particularly as the aircraft is in close proximity to the ground.

During instrument flying the mental workload rises,

TABLE II. ENERGY EXPENDITURE.

FLIGHT PHASE		REST				WALKING				HOVER				LEVEL FLIGHT			
SUBJECT		Vo_2	W	$W \cdot kg^{-1}$	n	Vo_2	W	$W \cdot kg^{-1}$	n	Vo_2	W	$W \cdot kg^{-1}$	n	Vo_2	W	$W \cdot kg^{-1}$	n
GAZELLE	1	0.3	105	1.4	8	0.7	244	3.2	6	0.4	139	1.8	5	0.3	105	1.4	8
	2	0.2	70	0.9	7	0.8	279	3.6	7	0.4	139	1.9	4	0.4	139	1.9	18
	3	0.3	105	1.3	9	0.9	314	3.8	7	0.4	139	1.7	5	0.4	139	1.7	13
	4	0.2	70	1.0	9	0.5	174	2.4	6	0.4	139	1.9	5	0.3	105	1.5	16
	5	0.3	105	1.5	9	0.9	314	4.5	5	0.4	139	2.0	4	0.4	139	2.0	11
	6	0.3	105	1.3	9	0.9	314	3.8	6	0.5	174	2.1	9	0.4	139	1.7	11
	mean	0.3	93	1.2		0.8	275	3.5		0.4	145	1.9		0.3	128	1.7	
PUMA	7	0.3	105	1.3	8	1.2	418	5.1	11	0.5	174	2.1	4	0.4	139	1.7	5
	8	0.3	105	1.2	7	1.3	453	5.2	5	—	—	—	—	0.4	139	1.6	11
	9	0.3	105	1.3	5	1.1	383	4.7	10	0.5	174	2.1	3	0.4	139	1.7	7
	10	0.3	105	1.3	5	1.0	349	4.5	10	—	—	—	—	0.7	244	3.2	5
	11	0.4	139	2.0	7	1.3	453	6.5	10	1.0	349	5.0	3	0.9	314	4.5	3
	12	0.5	174	1.9	4	1.3	453	5.1	3	—	—	—	—	0.6	209	2.3	27
	mean	0.3	122	1.5		1.2	418	5.2		0.7	232	3.1		0.6	197	2.5	
GAZELLE	1	0.3	105	1.4	10	0.3	105	1.4	7	0.4	139	1.8	4				
	2	0.3	105	1.3	5	0.3	105	1.4	4	0.3	105	1.4	7				
	3	0.4	139	1.7	8	0.4	139	1.7	5	0.5	175	2.4	6				
	4	0.3	105	1.5	11	0.3	105	1.5	4	0.4	139	1.9	5				
	5	0.3	105	1.5	12	0.3	105	1.5	4	0.4	139	2.0	4				
	6	0.4	139	1.7	12	0.4	139	1.7	4	0.4	139	1.7	4				
	mean	0.3	116	1.5		0.3	116	1.5		0.4	139	1.9					
PUMA	7	0.4	139	1.7	10	—	—	—	—	0.5	174	2.1	5				
	8	0.4	139	1.6	6	—	—	—	—	—	—	—	—				
	9	—	—	—	—	0.4	139	1.7	14	0.4	139	1.7	5				
	10	0.6	209	2.7	5	0.6	209	2.7	9	—	—	—	—				
	11	0.8	279	4.0	7	0.8	279	4.0	4	—	—	—	—				
	12	—	—	—	—	0.7	244	2.7	19	0.7	244	2.7	9				
	mean	0.5	191	2.5		0.6	217	2.8		0.5	186	2.2					

TABLE III. HEART RATE (BEATS PER MINUTE).

FLIGHT PHASE	REST	WALKING	HOVER	LEVEL FLIGHT	LOW LEVEL	INSTRUMENT FLYING	MANUAL
SUBJECT							
1	63	85	73	69	70	67	70
2	97	88	71	70	72	69	67
3	76	105	85	87	92	94	91
4	66	78	70	68	70	66	74
5	74	96	85	83	81	76	88
6	73	95	83	85	87	78	81
mean	75	92	78	77	79	75	78
11	90	115	91	92	90	85	—
12	108	143	—	111	—	110	109

s the aircraft must be controlled within much more
recise limits in terms of height, air speed, and heading
an is generally the case in transit flying. This might
easonably be expected to be accompanied by an in-
rease in physical workload, as more frequent control
djustments must be made to achieve this degree of
ccuracy. The results presented, however, show no
ch increase.

Flying at low level also requires an increase in mental
ffort. Lookout must be more thorough to pick up
ires, birds and other obstacles, and map reading is
ore difficult close to the ground because of the lower
erspective. Again, more control inputs are required
ecause of the frequent changes of height and heading
avoid obstacles, built-up areas and livestock. How-
er, in this study, there was no measurable difference
tween flying in the cruise and flying at low level.

Each of the Gazelle pilots flew a circuit with the hy-
aulics selected out, leaving a purely mechanical
kage between the flying controls and the rotors. The
ntrol forces which must be applied simply to maintain
aight and level flight are considerable, and rise even
gher during the approach to landing. This was re-
cted by an increase of nearly 12% in mean energy
penditure over normal level flight from 1.7 to 1.9
$\cdot\text{kg}^{-1}$. The Puma pilots showed an increase in energy
penditure in manual flight of nearly 16% from 1.9 to
$\text{W}\cdot\text{kg}^{-1}$, when comparing results from the three pi-
s concerned.

When comparing the results of Gazelle pilots with
se of Puma pilots, it appears that for all the activities
nsidered, the Puma pilots expended considerably
re energy, whether resting, walking or flying
<0.05). No attempt has been made to match pilots in
h groups for age, weight or experience, but the en-
y expenditure calculated in $\text{W}\cdot\text{kg}^{-1}$ should at least
e account of weight differences, though not of dif-
ences in body density.

Resting conditions were not controlled in any way
er than by instructing subjects to sit in a chair and
t. All values are within the range quoted by Durnin
Passmore (5), for seated subjects.

Walking to the aircraft was again not controlled in
way. The Puma pilots had further to walk than the
elle pilots as can be seen by the generally higher
es for n in Table II. They tended to carry more in
way of equipment than the Gazelle pilots and their
k was over grass, and in some cases snow, rather
asphalt.

The difference in energy expenditure in the various forms of flight is less easy to explain. Littell and Joy (12) found no such difference between helicopters of different size (Table IV). The Gazelle has particularly light controls, especially in the version flown by the Army, which lacks any stability aids. Conversely, it would be expected that few control adjustments would be required when flying the Puma, by virtue of its autopilot system.

When the resting values are considered as a covariate and the conditions of flight are analysed by analysis of covariance, the effect of helicopter type is dramatically reduced and becomes no longer significant. This would suggest that the difference between the two groups simply reflects a difference in resting values between them, within the normal range, which is carried through to other activities.

Comparison with other Studies

In order to compare these results with those of other authors in the field, all values considered have been converted to express energy expenditure as W per square meter of surface area ($\text{W}\cdot\text{m}^{-2}$). The results for the Gazelle pilots in this study compare very closely with those of other authors, while those for the Puma pilots are somewhat higher (Table IV).

Limitations

The energy expenditure of pilots in this study for flying both types of aircraft has been measured over a variety of flight conditions. Before these results are used as a basis for laboratory studies of thermal stress in flight, several factors must be borne in mind:

a. The study was conducted in conditions of minimal stress as part of a training sortie from a peace-time airfield. In war, flying would be from field locations, under far greater pressure.

b. Any particular sortie in war would be unique in terms of the flying involved. In general, however, all transit flying would be at low level, and in the case of the Gazelle carrying out observation tasks, a large percentage of the sortie time would be in the hover in observation positions.

c. Even when the pilot is working at his maximum rate, i.e. in the hover, his energy expenditure is still considerably lower than when he is walking. It is when on the ground wearing chemical defence assemblies that the highest workloads will be met. No attempt has been made in this study to measure such workloads other

TABLE IV. COMPARISON WITH OTHER STUDIES.

Source	Aircraft Type	Mean and range of energy expended ($W \cdot m^{-2}$) during Rest	Level flight	Hover
Littel and Joy (1969)	OH-6A (light)	62 (56–67)	57 (55–59)	78 (73–83)
	UH-1D (medium)	58 (53–63)	57 (55–59)	64 (58–70)
	CH 47A (heavy)	56 (49–63)	60 (58–63)	72 (70–74)
Billings et al. (1970)	UH-12E (light)	56 (51–59)	85 (74–93)	113 (99–128)
Kaufman et al. (1970)	J-CH3 (heavy)	62 (58–65)	60 (57–64)	—
French et al. (1973)	Scout (light)	49 (45–51)	58 (46–71)	65 (63–69)
Present Study	Gazelle (light)	48 (36–54)	66 (54–72)	75 (72–90)
	Puma (medium)	61 (52–87)	98 (69–156)	116 (87–173)

han while walking to the aircraft. Such information is vailable from a variety of sources (1,5,8,13,14).

ONCLUSIONS

The energy expenditure of Gazelle and Puma heliopter pilots in flight is about 50% higher than that of he same individuals at rest and substantially less than he energy cost of walking. The workload of flying is probably a relatively minor contribution to any thermal strain experienced by helicopter pilots.

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The Effect of the UK Aircrew Chemical Defence Assembly on Thermal Strain

R. THORNTON, M.B., D.AV.MED., G. A. BROWN, B.SC., PH.D., and P. J. REDMAN

Royal Air Force Institute of Aviation Medicine, Farnborough, Hampshire, United Kingdom

THORNTON R, BROWN GA, REDMAN PJ. *The effect of the UK aircrew chemical defence assembly on thermal strain.* Aviat. Space Environ. Med. 1985; 56:208-11.

The thermal strain imposed on helicopter aircrew by chemical protective (NBC) clothing in summer in Germany has been assessed in a laboratory simulation. The environmental conditions used were dry bulb temperature 35°C, wet bulb temperature 19°C and a wind speed of 2.0 m · s^{-1}. The NBC equipment imposed a significant thermal strain on the crewman when compared with standard summer flying clothing, but not on the pilot whose tasks involve lower energy expenditures. Deep body temperature exceeded 37.6°C and a significant degree of dehydration (1% of body weight) also occurred, despite the availability of a drinking facility in the respirator. It is recommended that the only practical way of preventing thermal strain in helicopter crewmen under NBC conditions is by providing personal conditioning.

The addition of chemical protective (NBC) clothing to aircrew equipment assemblies (AEA) will increase the thermal stress imposed upon aircrew during flight in hot weather conditions. Previous studies have uggested that the resulting degree of thermal strain will e unacceptable under the climatic conditions that may e encountered during the summer months in central Europe (2, 5, 6, 7).

The present report describes a thermal evaluation of he aircrew NBC assembly based upon a simulation of reflight and flying activities, with climatic conditions hat might be encountered by the crew of a Royal Air Force Puma helicopter operating in Germany in midsummer.

METHODS

The assessment was carried out on six male subjects whose details are given in Table I. None was heat acclimatised at the start of the study, and the statistical design was arranged to balance the effect on the overall results of any acclimatisation acquired during the trial.

Conduct of the Experiment: Each subject undertook four experiments; two simulated the energy expenditure of a Puma pilot while wearing either normal summer or NBC summer AEA, and the other two simulated the energy expenditure of a Puma crewman while similarly clothed. The energy expenditure of a crewman is higher than that of a pilot due to tasks involving moving around the aircraft and assisting in loading and unloading. Experiments were conducted at the same time each day.

Subjects were weighed naked, then instrumented and dressed in the appropriate assembly, and reweighed. They then rested in a chair for 15 min to allow sensors to equilibrate. The experiment started with 10 min of walking round a circuit in the climatic chamber to simulate walking to the aircraft and preflight checks, before beginning the 2-h exercise routine.

Two grades of exercise were chosen to simulate the energy cost of piloting a helicopter or of flying as a crewman. The pilot's energy expenditure was simulated by a simple leg exercise while seated, as described by Harrison *et al.* (7), but modified to allow the arms to be used to raise the weight as well as, or instead of, the legs, in an attempt to overcome the problem of muscular fatigue inherent in this type of repetitive exercise. The simulation was designed to produce a rate of energy expenditure of around 200 W, as described by

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Address reprint requests to Dr. G. A. Brown, RAF Institute of viation, Farnborough, Hants., GU14 6SZ, United Kingdom.

Author R. Thornton is now with Headquarters, Director, Army Air rps, Middle Wallop, Stockbridge, Hants., U.K.

TABLE I. SUBJECT DATA AND STATISTICAL DESIGN.

Subject	Age (yr)	Height cm	Weight (kg)	Statistical Design Run 1	Run 2	Run 3	Run 4
1	31	183	66	C+	C−	P+	P−
2	33	176	73	P+	P−	C+	C−
3	20	189	75	C−	C+	P−	P+
4	36	179	77	P+	C+	P−	C−
5	23	170	70	C+	P+	C−	P−
6	23	180	67	P−	P+	C−	C+

Notes: P− = Pilot control; P+ = Pilot NBC; C− = Crewman control; and C+ = Crewman NBC.

Thornton *et al.* (12) for Puma pilots. The exercise was carried out for 10 min, followed by 5 min rest, for 2 h. The crewman's work rate was simulated by alternately walking on a flat treadmill at 5 km· hr⁻¹ for 5 min, then standing at rest for 5 min for a total period of 2 h. This was designed to produce an overall rate of energy expenditure of around 330 W (13).

During the 5-min rests between exercise periods they were offered cold water to drink, and the weight consumed was recorded. At the end of the 2 h, they were reweighed, clothed and naked.

Environmental Conditions: The environmental condi-ions were chosen to represent those likely to be found n the cabin of a Puma flying in central Germany, based on the mean monthly maximum temperature (9) and he observations of Thornton *et al.* (14) in Pumas flying under similar climatic conditions in Belize. No radiant heat load was used as there is little direct sunlight on the ilot, and none on the crewman. The wind speed used was the minimum required to maintain environmental quilibrium, although it was rather higher than that measured in the Puma. The relative humidity was s ambient. The conditions used were dry bulb ermperature (T_{db}) 35°C, wet bulb temperature (T_{wb}) 9°C, relative humidity (rh) 30%, and wind speed 2.0 $m \cdot s^{-1}$.

Measurements: The following measurements were made:

a. Deep body temperature. Deep body temperature (T_{ac}) was measured using a thermistor situated in the external auditory canal, and well insulated (with cotton wool and the aircrew protective helmet) from the external environment.
b. Skin temperature. Skin temperatures were measured at 4 sites (chest, upper arm, inner thigh, and outer calf) using thermistors (accurate to within 0.25°C) as described by Allan *et al.* (3). Mean skin temperature ($\overline{T}_{sk}$) was calculated in the manner of Ramanathan (10). Deep body temperature and mean skin temperature were recorded every minute.
c. Water balance. Total body water loss was derived from the difference between nude weighings before and after each experimental run plus the weight of the water drunk. Evaporative water loss was obtained from the difference between fully dressed and instrumented weighings before and after each run plus the weight of water drunk.

Aircrew Clothing: The aircrew equipment assemblies EA) worn were as follows:

1. Control Summer AEA—underwear, socks, coverall, boots, leather gloves, and protective helmet.
2. NBC Summer AEA—underwear, socks, NBC coverall, NBC socks, coverall, boots, NBC respirator, NBC gloves, leather gloves, protective helmet, and portable ventilator.

RESULTS

Deep Body Temperature: Mean body temperatures are shown in Fig. 1. Analysis of variance showed the increase in deep body temperature to be significant for the pilot control ($p<0.05$), the crewman NBC and control conditions ($p<0.001$), but not for the pilot NBC. The difference between the various conditions was considered using the Newman-Keuls test procedure, at time 0, 60, and 120 min. At 0 min, the conditions cannot be significantly separated. At 60 min there is a significant increase in temperature for the C+ condition compared with the other 3 ($p <0.01$). At 120 min the difference has become highly significant ($p <0.001$) between C+ and the other 3, and significant ($p<0.01$) for the difference between P+ and P−.

Mean Skin Temperature: There was no significant change in mean skin temperatures with time. The Newman-Keuls test shows a highly significant difference between each NBC condition and the respective control ($p<0.001$) at 120 min. The overall mean value during the experiments for mean skin temperature was 35.8°C for C+, 34.4°C for C−, 35.8°C for P+, and 35.1°C for P−.

Weight Loss: Fig. 2 shows the mean weight of sweat lost, water drunk, dehydration and sweat in clothing for the different conditions. There is a significant difference ($p<0.05$) between the sweat loss for each NBC condition and its control, and a highly significant difference ($p<0.001$) between C+ and P+ and between C− and P−.

The mean volume of water drunk in the C+ condition was 0.95 L, significantly more than the C− ($p<0.05$). The amount of dehydration in the C+ condition was significantly greater than its control ($p<0.05$). The only significant difference in the amount of sweat soaked up by clothing was between P+ and P− ($p<0.01$).

Dehydration expressed as a percentage of body weight was 0.6% for P+, 0.5% for P−, 1.0% for C+, and 0.6% for C−. The only significant difference was between C+ and C− ($p<0.05$).

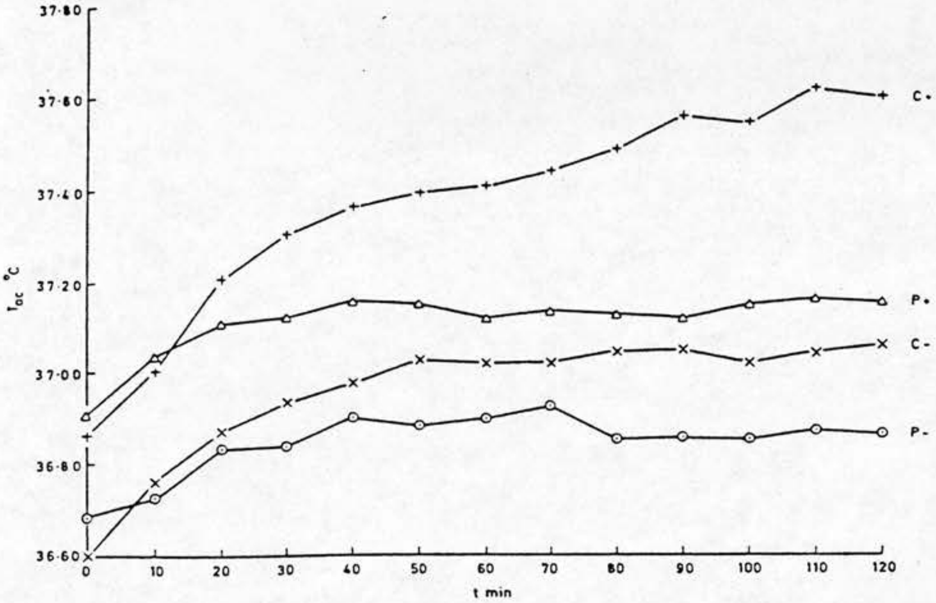

Fig. 1. Mean deep body temperature.

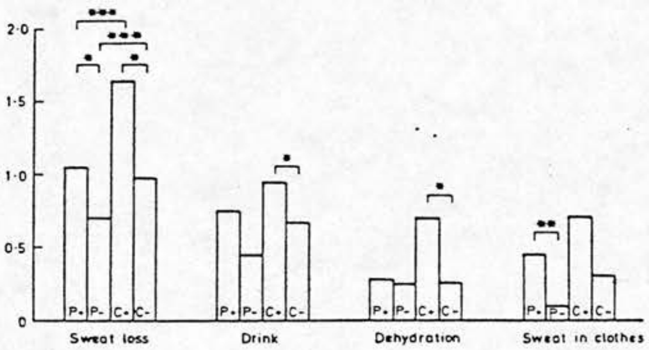

Fig. 2. Mean water balance.

DISCUSSION

Indices of Thermal Strain: NBC clothing imposes another layer of clothing on the aircrew and restricts the ventilation of clothing by having sealed neck, wrists, and ankles. This is confirmed by the difference in T_{ac} and $\overline{T}_{sk}$ between the NBC conditions and their respective controls by the end of the experiment. The equilibration of core temperature after 20 min or so suggests that pilots are unlikely to suffer serious thermal strain in NBC clothing, although it should be noted that control of core temperature is achieved in NBC conditions at an absolute level some 0.35°C above the non-NBC level. Crewmen, on the other hand, are clearly shown to be vulnerable to a considerable rise in core temperature with time because of their higher work rate. The levels of T_{ac} encountered during the experiment are likely to cause a reduction in physical work capacity (8) and a decrement in psychomotor performance (1).

With longer sortie times, which would occur in war, when flying is likely to be more or less continuous throughout the daylight hours, with little opportunity to rest and cool down, body temperatures would be even higher.

Subjects wearing NBC clothing sweated considerably more than when wearing normal flying clothing. It is significant that despite the free availability of water through the respirator drinking facility, a dehydration of 1% of body weight still occurred in the C+ condition. Saltin (11) reported that this level of dehydration can also cause a diminution in physical work capacity. This too would become significant with longer sorties.

Prevention of thermal strain could be achieved in the following ways: a). reducing the work rate; b). reducing the sortie length; c). reducing the insulation of the NBC AEA; d). providing cabin conditioning; and e). providing personal conditioning.

Reduction of work rate is unlikely; indeed the opposite would be expected in time of war, as is the case for sortie length. Any major change to the NBC AEA is unlikely in the near future. Cabin conditioning would be effective, but does not exist in Service helicopters. It would be expensive to retrofit, and would affect helicopter performance. The option of personal conditioning might be unpopular with aircrew, as yet another item of AEA to endure, but would allow satisfactory thermal equilibrium (4). If a liquid cooled vest were adopted, it would replace the long-sleeved vest required in current NBC AEA.

CONCLUSIONS AND RECOMMENDATIONS

1. The thermal strain on helicopter crewmen operating in CD clothing in conditions simulating summer mean monthly maximum temperatures in Germany is unacceptable. Core temperature will rise to levels at which work capacity is limited, and at which decrements in performance are expected.
2. Some degree of dehydration seems inevitable despite the availability of the drinking facility, to a level which will also limit work capacity.
3. Personal conditioning is required for helicopter crewmen under NBC conditions.

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