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MEASUREMENT OF HEAT STRESS: KIOWA AND MUSKETEER COCKPITS

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ABSTRACT

During hot summer weather at CFB Portage la Prairie, measurements were made of the heat stress experienced in the cockpits of the Musketeer aircraft and the Kiowa helicopter while stationary (not-running) on the runway and during flight. It was found that severe heat stress can occur in either cockpit when monitored in closed configuration, either on the ground or in flight, and that such heat stress can lead to dire physiological strain in less than one hour. Use of air vents on the Musketeer aircraft did not completely ameliorate the cockpit heat stress problem and added considerably to communication difficulty because of wind nose. Air conditioning is recommended for alleviation of heat stress in this aircraft. It was found that no difference existed between the cockpit heat stress and ambient heat stress when the Kiowa aircraft was flown without its doors and it is recommended that this practice be encouraged during warm or hot weather to reduce pilot strain.

INTRODUCTION

Earlier work (1) by the Defence and Civil Institute of Environmental Medicine has shown that the cockpit of the Musketeer training aircraft suffers from a "greenhouse" effect and that occupants are exposed to high levels of heat stress during hot cloud-free weather. It was recommended that, during hot weather operations, the aircraft should be parked with its tail pointing toward the sun with its doors open for cockpit ventilation. Ensuing corrective ventilation modifications to the cockpit were made; however, complaints from CF training staff still occurred.

In May, 1974, DCIEM was requested to re-examine the heat stress problem in the CF Musketeer (2). In addition it was proposed that the heat stress experienced in the cockpit of the Kiowa helicopter also be measured. Evaluations of heat stress in both types of aircraft under operational conditions were conducted in the period July 22-26, 1974, at CFB Portage La Prairie. Warm weather was normally experienced at this site during this time of the year. The results of the evaluations are presented in this report.

METHOD

GENERAL METHODOLOGY

The experimental aircraft were properly oriented on a runway at CFB Portage La Prairie with their tails towards the sun. The ambient heat stress of the environment and the enclosed heat stress in the aircraft cockpits were measured throughout the experiment by electronic Wet Bulb Globe Temperature (WBGT) meters designed and constructed by DCIEM (3).

The WBGT index is a heat stress index invented for use in the prevention of military heat casualties in hot environments (4). It is defined by the following formula:

$$WBGT = 0.7\ WB + 0.2\ GT + 0.1\ DB$$

where WBGT = Wet Bulb Globe Temperature,

WB = natural wet bulb temperature,

GT = 6-inch diameter black Vernon globe temperature,

and DB = dry bulb temperature.

When expressed ^{o}F, it can serve as a guide to recommended work

practices for personnel in the following manner:

WBGT< 82^{o}F; No danger from heat stress.

82^{o}F<WBGT< 85^{o}F; Varying degrees of heat discomfort.

WBGT>85^{o}F; Active physical training should be suspended for recruits.

WBGT> 88^{o}F; Active training should be suspended for all troops.

Experiments usually took place in the late morning and early afternoon, which had been identified as the most stressful part of the day. In most experiments a subject sat in the cockpit to serve as a means of assessment of the degree of heat strain concomitant with the measured heat stress values. The skin temperatures of the subject were monitored by YSI Series 400 thermistor probes attached to the skin by adhesive electrode collars at seven locations:

(a) forehead (T_1)

(b) left forearm (T_2)

(c) back of left hand (T_3)

(d) sole of left foot (T_4)

(e) left calf (T_5)

(f) left thigh (T_6)

(g) abdomen (T_7)

These temperatures were used to obtain the mean skin temperatures (MST) of the subject from the formula (5):

$$\text{Mean Skin Temperature} = \bar{T}_s = 0.07\ T_1 + 0.14\ T_2 + 0.05\ T_3 + 0.07\ T_4 + 0.13\ T_5 + 0.19\ T_6 + 0.35\ T_7$$

The rectal temperature (T_r) of each subject was monitored throughout the experiment with a YSI rectal probe inserted prior to each test. Mean body temperatures (MBT) were calculated using the equation (5):

$$MBT = 0.67T_r + 0.33\ \bar{T}_s$$

EXPERIMENT 1: CLOSED MUSKETEER AND KIOWA AIRCRAFT WITH NO SUBJECT

One Musketeer and one Kiowa aircraft were placed on the runway at 1100 hours. After a WBGT meter had been placed in each cockpit, the aircraft were closed (Figures 1 and 2) and readings of the meters were taken externally and compared with control WBGT measurements of the ambient environment taken from a meter located 100 feet from the aircraft. After 30 minutes of observation, a pilot entered each aircraft briefly to ignite the engines and observations of heat stress in the enclosed empty cockpit continued for an additional fifteen minutes.

EXPERIMENT 2: CLOSED MUSKETEER AND KIOWA AIRCRAFT WITH SUBJECTS

Simultaneous with Experiment 1, subjects sat in different Musketeer and Kiowa aircraft in the pilot's seats in the manner indicated previously. WBGT values pertinent to the cockpit and measurements of subject mean skin and rectal temperatures were made externally for the duration of Experiment 1.

EXPERIMENT 3: DOORLESS KIOWA AIRCRAFT WITH SUBJECTS

Measurement of ambient WBGT, cockpit WBGT and mean skin and rectal temperatures of a subject were taken externally in a Kiowa helicopter from which the doors had been removed. The experiment was of the same duration as Experiment 2. An analogous experiment could not be performed on the Musketeer aircraft because the doors could not be removed.

EXPERIMENT 4: EFFECT OF FLIGHTS OF ENCLOSED AND DOORLESS KIOWA AIRCRAFT ON HEAT STRESS OF PILOT

One Kiowa aircraft was taken on an operational flight in which the effect of two configurations, doors closed and doors off, on the thermal comfort of the pilot could be measured as previously indicated by an onboard observer with pertinent portable equipment.

EXPERIMENT 5: EFFECT OF FLIGHT OF CLOSED MUSKETEER ON HEAT STRESS OF PILOT

One Musketeer aircraft was taken on an operational flight in which the effect of the closed normal-mode of operation on the thermal comfort of the pilot could be measured as previously indicated by an onboard observer with pertinent portable equipment.

RESULTS

EXPERIMENT 1: CLOSED MUSKETEER AND KIOWA AIRCRAFT WITH NO SUBJECTS

Results shown in Table 1 indicate that within five minutes of being closed, the cockpits of both aircraft experienced WBGT heat stress levels greater than 100°F although the ambient environmental measurements indicated a comfortable level of approximately 74°F. Ignition of the engine did not cause a reduction of the closed cockpit heat stress below WBGT values of 100°F.

EXPERIMENT 2: CLOSED MUSKETEER AND KIOWA AIRCRAFT WITH SUBJECTS

The subject in the Kiowa aircraft gained heat rapidly and at the end of 10 minutes, the MST was higher than T_r (Table 2). No appreciable decrease in heat gain occurred after ignition of the engine. A slight drop in MST occurred when a pilot entered the aircraft to ignite the engine. At the end of the test it was discovered that the subject had lost 4.5 lbs. in body weight, presumably due to sweat loss.

The subject in the Musketeer also gained heat rapidly but not as fast as for the Kiowa subject. The MST was always less than T_r (Table 3); nevertheless the subject lost 5 lbs. of body weight during the experiment, presumably due to sweat loss. A slight drop in MST occurred when the engines were started. This may be due to convective heat loss from the cockpit via propeller-driven air motion.

EXPERIMENT 3: DOORLESS KIOWA AIRCRAFT WITH SUBJECT

No increase in heat stress of cockpit or heat strain in subject was detected (Table 4).

EXPERIMENT 4: EFFECT OF FLIGHTS OF ENCLOSED AND DOORLESS KIOWA AIRCRAFT ON HEAT STRESS OF PILOT

Detailed results are shown in Table 5. In the closed condition, the pilot quickly experienced heat stress, due both to the effects of his hot environment and the task of flying. With open air vents and doors, no heat stress occurred.

EXPERIMENT 5: EFFECTS OF FLIGHT OF CLOSED MUSKETEER ON HEAT STRESS OF PILOT

Detailed results are shown in Table 6. These aircraft had been modified to incorporate air vents shown in Figures 3 and 4.

When these vents were open, little heat stress in the cockpit was observed, however when the vents were closed, high levels of WBGT were encountered.

DISCUSSION

All tests were performed under relatively mild conditions of ambient heat stress with WBGT measurements near 75°F. When either the Musketeer or Kiowa aircraft were operated in the closed condition, high levels of cockpit heat stress occurred, with WBGT measurements well in excess of 85°F, the level at which reduction of work effort is stipulated by CFAO 34 - 47. Higher ambient temperatures would probably have resulted in intolerable levels of cockpit heat stress.

When the Kiowa was operated without doors, the cockpit heat stress level was similar to that of the environment and there was no heat stress problem. It has been suggested (1) that the heat stress problem in the Musketeer could be reduced by allowing the Musketeer to taxi with the doors held open. In practice, this is a difficult operation and, when effected, it distracts the pilot and his instructor from concentration on the controls. Incorporation of air vents in the Musketeer windshield and air scoop immediately in front of the windshield has been carried out at CFB Portage La Prairie and is known as the "Portage Modification". The modification does aid in reducing heat stress levels in the Musketeer cockpit but does add considerably to the noise in the cockpit. Pilot students and instructors usually fly with such modifications closed to permit conversation to take place.

Assessment of the heart rate of a qualified flying instructor while flying the Musketeer aircraft with the air vents in the open and closed conditions proved to be very interesting. The heart rate on landing in the open configuration was 104 beats per minute. On landing in the closed configuration and under heat stress, the heart rate increased to 132 beats per minute.

CONCLUSIONS

1. In operations in warm weather, severe cockpit heat stress problems were encountered in the Musketeer and Kiowa aircraft when flown in closed configuration. The levels of heat stress experienced were in excess of levels permitted by CFAO 34 - 47.

2. No difference between cockpit heat stress and ambient heat stress existed in the Kiowa aircraft when it was flown without its doors.

3. Use of air vents on the Musketeer aircraft (the so-called Portage Modification) did not completely ameliorate the cockpit heat stress problem and added considerably to difficulty in communication because of wind noise.

RECOMMENDATIONS

1. To avoid pilot heat stress in warm or hot weather, the Kiowa aircraft should be flown without its doors. Levels of cockpit heat stress will then approximate levels of ambient heat stress.

2. To reduce heat stress in the cockpit of the Musketeer aircraft, air conditioning should be considered. The manufacturer of the Musketeer, Beechcraft, reported (6) that there is no air conditioning unit designed for it but that it may be possible to adapt a Piper Cub air conditioning unit for this purpose.

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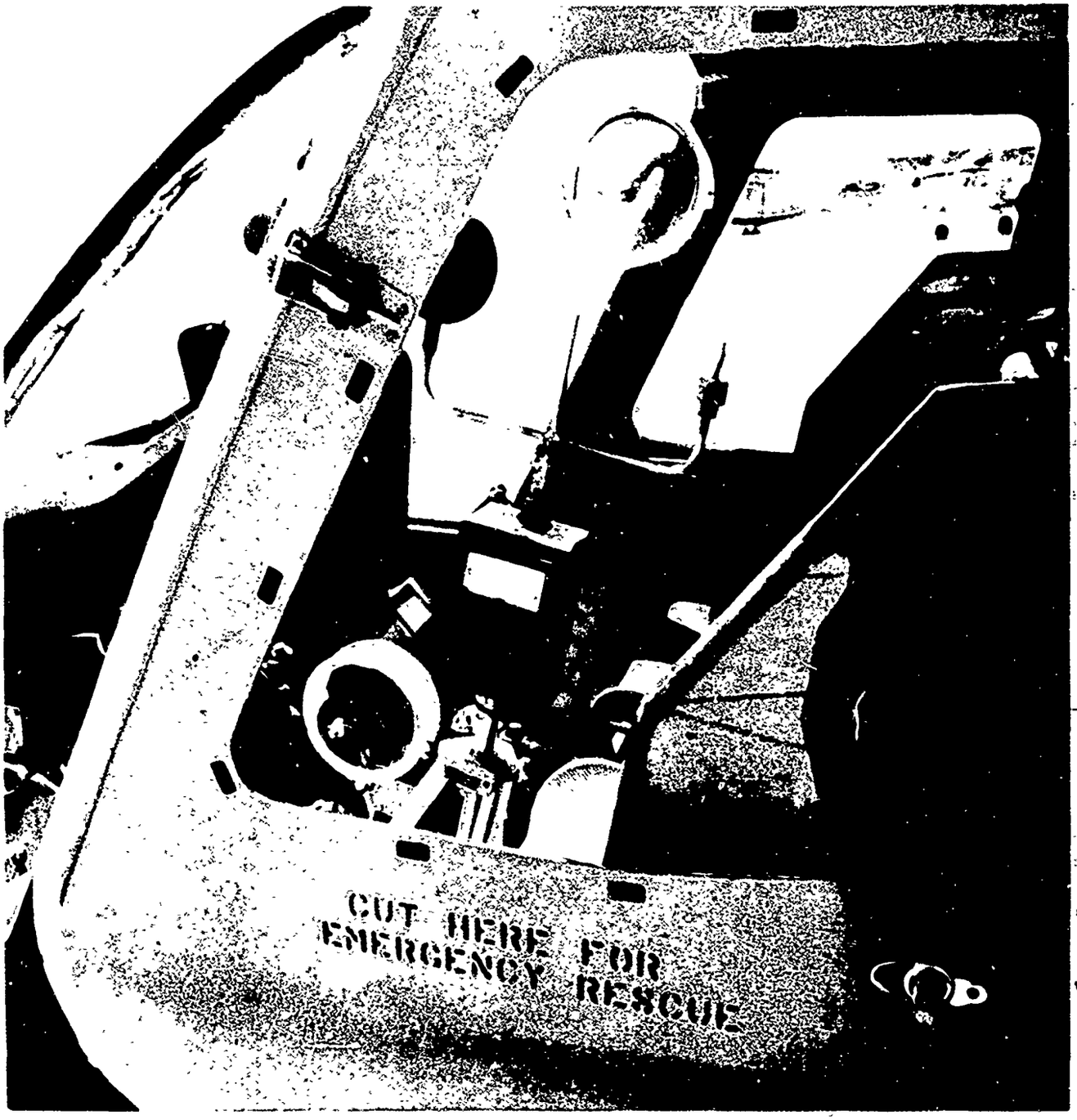
Figure 1:. Control heat stress meter for measurement of ground ambient environmental conditions, with a Musketeer aircraft and Kiowa helicopter in the background.



Position 2: Position of the heat stress meter within the closed Musketeer cockpit.

Figure 3: Air vent modification on Musketeer aircraft. Part of the Portage modification.

Figure 4: Air scoop on Musketeer aircraft side window. Part of the Portage modification.

TABLE 1

COCKPIT HEAT STRESS IN STATIONARY AIRCRAFT

(All temperatures in ^{o}F.)

Morning test commencing at 11:15 hours, under cloudless skies, aircraft doors closed after 15 minutes on tarmac.

TIME (min)	AMBIENT CONDITIONS				COCKPIT CONDITIONS	
	DB	WB	GT	WBGT	KIOWA WBGT	MUSKETEER WBGT
0	78	67	96	74	>100	>100
5	78	66	92	73	>100	>100
10	79	67	100	75	>100	>100
15	78	66	94	73	>100	>100
20	78	66	94	73	>100	>100

Afternoon test commencing at 14:15 hours, under intermittant cloudy conditions, aircraft doors open.

TIME (min)	AMBIENT CONDITIONS				COCKPIT CONDITIONS	
	DB	WB	GT	WBGT	KIOWA WBGT	MUSKETTER WBGT
0	82	67	107	76	82	>100
5	80	64	98	73	78	>100
10	84	68	106	76	82	>100
15	82	66	99	74	82	>100
20	78	63	82	68	76	98
25	79	63	84	69	76	96
30	82	66	103	75	80	100

TABLE 2

PHYSIOLOGICAL RESULTS IN SUBJECT DB IN KIOWA AIRCRAFT

Doors Closed; Engine Off

TIME (min)	AMBIENT CONDITIONS (°F)				COCKPIT WBGT (°F)	PHYSIOLOGICAL RESPONSES (TEMPERATURES IN °C)		
	DB	WB	GT	WGBT		Tr	MST	MBT
0	78	67	96	74	97	37.2	36.0	36.8
5	78	66	92	73	102	37.2	36.6	37.0
10	79	67	100	75	106	37.1	37.2	37.2
15	78	66	94	73	106	37.1	37.6	37.3
20	78	66	94	73	106	37.1	38.1	37.4
25	78	66	96	74	108	37.1	38.6	37.6
30	79	66	95	74	107	37.2	38.7	37.7

Doors Opened To Permit Entry Of Pilot; Engine On

5	79	66	98	74	103	37.3	38.0	37.5
10	79	66	95	74	103	37.5	37.8	37.6
15	80	66	97	74	103	37.6	37.7	37.6

Subject Weight: Before Experiment = 173 lbs.

: After Experiment = 168.5 lbs.

TABLE 3

PHYSIOLOGICAL RESULTS IN SUBJECT MO IN MUSKETEER AIRCRAFT

Doors Closed; Engine Off

TIME (min)	AMBIENT CONDITIONS (°F)				COCKPIT WBGT (°F)	PHYSIOLOGICAL RESPONSES (TEMPERATURES IN °C)		
	DB	WB	GT	WBGT		Tr	MST	MBT
0	78	67	96	74	95	37.6	33.4	36.2
5	78	66	92	73	101	37.6	35.8	37.0
10	79	67	100	75	100	37.6	36.0	37.1
15	78	66	94	73	101.5	37.6	36.5	37.2
20	78	66	94	73	101.5	37.6	36.6	37.3
25	78	66	96	74	102	37.6	36.8	37.3
30	79	66	98	74	101	37.8	36.9	37.5

Engine On

5	79	66	98	74	100	37.8	36.1	34.9
10	79	66	95	74	100.5	37.8	35.9	37.2
15	80	66	97	74	99	37.8	35.9	37.2

TABLE 4

PHYSIOLOGICAL RESULTS IN SUBJECT DB IN KIOWA AIRCRAFT

Doors Open

TIME (min)	AMBIENT CONDITIONS (°F)				COCKPIT WBGT (°F)	PHYSIOLOGICAL RESPONSES (TEMPERATURES IN °C)		
	DB	WB	GT	WBGT		Tr	MST	MBT
0	82	67	107	76	75	36.6	34.5	35.9
5	80	64	98	73	75	36.6	35.0	36.1
10	84	68	106	76	74	36.6	35.3	36.2
15	82	66	99	74	70	36.5	35.7	36.2
20	78	63	82	68	72	36.4	35.3	36.0
25	79	63	84	69	70.5	36.4	35.1	36.0
30	82	66	103	75	71.5	36.3	35.4	36.0

TABLE 5

PHYSIOLOGICAL RESULTS FOR SUBJECT BR IN KIOWA AIRCRAFT

TIME (min)	AMBIENT CONDITIONS (°F) DB	WB	GT	WBGT	COCKPIT WBGT (°F)	PHYSIOLOGICAL RESPONSES (TEMPERATURES IN °C) Tr	MST	MBT
0	80	68.5	96	74.5	83	37.2	34.7	36.4
5	80	68	94.5	74.5	86	37.2	36.1	36.8
10	80	68.5	94.5	74.5	88	37.2	36.8	37.1
Airborne; Doors On								
15	80	70	96.5	76	81	37.2	36.6	37.0
Hovering Over Ground; Vents Closed								
20	80	68.5	94	76	96	37.2	37.1	37.2
Flight; Followed By Landing								
25	80.5	70	96.5	76	99	37.2	37.4	37.3
30	80	68.5	94.5	76	101	37.25	37.7	37.4
35	80.5	68.5	94	76	104	37.3	38.2	37.6
Hovering Over Ground; Vents Open								
40	82	68.5	94	76	96	37.35	37.0	37.2
Landing; Doors Off								
45	80.5	68.5	94	76	81	37.4	36.2	37.0
50	82	70	94.5	76	75	37.4	35.5	36.8
On Ground								
55	80.5	68.5	92.5	76	79	37.45	35.7	36.9
Flight								
60	82	70	96	76	78	37.5	35.5	36.8
65	82	70	98	76	81	37.5	35.7	36.9
70	82	70	96.5	76	78	37.4	35.7	36.8

TABLE 6

PHYSIOLOGICAL RESPONSES IN SUBJECT MO IN MUSKETEER AIRCRAFT

TIME (min)	AMBIENT CONDITIONS (°F)				COCKPIT WBGT (°F)	PHYSIOLOGICAL RESPONSES (TEMPERATURES IN °C)		
	DB	WB	GT	WBGT		Tr	MST	MBT
0	82.5	68.5	92	74.5	80	37.9	36.7	37.5
Taxi; Take Off And Landing								
5	82.5	70	94.5	76	86.5	37.95	36.8	37.6
10	82	70	94	76	77	38.0	36.4	37.4
15	82.5	70	94.5	76	77	38.0	36.1	37.4
20	82.5	70	96	76.5	80	38.05	36.0	37.4
Vents Closed; Take Off And Landing								
25	84	72	94.5	76.5	85.5	38.05	36.6	37.6
30	82.5	70	96	78	87.5	38.05	36.7	37.6
35	82.5	70	92	76	88.5	38.1	36.8	37.7
40	82	68.5	92	74.5	93	38.15	37.0	37.8
Vents Open; Take Off And Landing								
45	82.5	70	92	74	80.5	38.1	36.7	37.6
50	84	70.5	94.5	76.5	79	38.1	35.8	37.4
55	82	70	92.5	76	80	38.1	35.4	37.2

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