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Heat Stress in Aviation at Jamnagar—Field Study

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The study was carried out in 8 low level and 12 medium level sorties in T-96/69 aircraft in the month of October between 1100 hrs to 1500 hrs. Heat stress was more in low level sorties than medium level sorties. There was significant heat load on the ground till take off which was common to both low and medium level sorties. Average rise in Mean Skin Temp. was 3.1°C during low level sorties while in medium level sorties it was 2.7°C. Mean rise in heat storage during low level sorties was 55 K Cals/m2 of body surface area while in medium level sorties it was 44 K Cals/m2 of BSA. Sweat loss to the tune of about 1% of body weight was detected in majority of the sorties.

Introduction

In military aviation we are particularly concerned with heat stress since it affects performance, lowers operational efficiency and may compromise flight safety. Studies of heat stress have been carried out in Assam Valley and at a fighter base in North West India. Distinct from these, present study was conducted at a fighter base on seashore of Saurashtra where humidity and surface salinity are quite high. Humidity is highest during the period of August to October though maximum temperatures recorded in this period are slightly lower than April & May. This study was carried out in the month of October.

Material and Methods

The study was done in 8 low level and 12 Medium level sorties in Mig Type-96 and 69 aircraft. Both these have an airconditioning system where heat exchange and cold air units depend on the ram air for cooling.

Sorties were flown between 1100-1500 hrs. Average Tdb on the tarmac during this period was 33.6°C while Twb was 24.05°C and air movement 10 kms/hr. Aircrew involved in the sorties were between 24-37 yrs and were medically fit.

Crewroom and cockpit dry bulb and wet bulb temperatures were measured by a whirling psychrometer. Crewroom temperatures were measured just before pilot left the crewroom for the sortie. Cockpit temperatures were measured after the pilot was strapped inside the cockpit. Cockpit temperatures

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Table I

Heat stress parameters in low level sorties (500 meters-2kms)

Sl. No.	Subject	Tdb in °C			Twb in °C			Ox Index in °C		
		Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)
1.	CHD	31.1	41.7	42.8	26.1	28.9	33.3	26.9	30.9	34.7
2.	SS	29.4	38.9	41.7	25.6	29.4	33.9	26.2	30.8	35
3.	RK	31.7	39.4	41.7	25.6	30.6	33.3	26.5	31.9	34.6
4.	SKJ	32.8	43.9	45	26.1	32.8	33.9	27.1	34.5	35.6
5.	AVS	31.1	40.6	42.8	28.3	34.4	36.7	28.7	35.3	37.6
6.	SWN	31.7	36.7	42.2	26.1	28.9	33.9	27	30	35.1
7.	BD	31.7	37.8	43.9	26.1	29.4	36.1	27	30.7	37.3
8.	CH	33.3	36.7	45.6	29.4	30	40	30	31	40.8
Mean		31.6	39.5	43.2	26.7	30.6	35.1	27.4	31.9	36.3
Std Deviation		1.2	2.5	1.5	1.4	2.0	2.3	1.3	1.9	2.1
Mean Drff			7.9	11.6		3.9	8.4		4.5	8.9
'P' Value			<0.001	<0.001		<0.001	<0.001		<0.001	<0.001

after the sortie were measured after the pilot returned to the dispersal area. Inflight temperatures could not be recorded since most of the sorties were in type-96 aircraft which is a single seater and it was not possible for the pilot to carry thermometers during flight and record temperatures. After the pilot reached the dispersal area the canopy was opened slightly, just enough to pass the thermometers inside and the temperatures were taken so that variation in temperature due to outside air rushing in was minimal.

Thermal strain was assessed with the help of para-meters like skin temperature, oral temperature, heart rate and sweat loss. A flier was weighed in the crewroom before and after the sortie, with only a brief on. The sweat loss was calculated from the differential weight.

Oral temperature was taken with the help of a clinical thermometer in the crewroom and in the cockpit before and after the sortie. Skin temperatures were taken over left side of chest and right thigh by a flat bulb thermometer. Mean skin temperature was calculated by the formula

MST = 0.6 Chest Temp + 0.4 Thigh Temp. (Gupta[1])

The mean body temperature was calculated using the Burton's formula. Heart rate was measured by digital palpation over the radial artery.

The level of thermal comfort/discomfort was purely a subjective parameter. History of any symptoms like fatigue/cramps/giddiness/tingling sensations was also taken.

Quantification of heat stress was done by oxford index and it was calculated for crewroom, cockpit (before sortie) and cockpit (after sortie). Thermal strain was assessed by heat storage index and modified craig index. Changes in heat storage were calculated in two phases i.e. firstly in the cockpit before the sortie and secondly at the end of the sortie. Craig index was calculated at the end of the sortie.

A comparison of rise in heat stress parameters of a/c cockpits covered with taurapulins and those not covered was done. The parameters of Tdb, Twb & TG were recorded in the a/c parked side by side in the dispersal. After that one a/c cockpit was covered. Same stress parameters were measured again in both the a/c. after a gap of 1 hour. Oxford index and wet bulb globe temperature for cockpits before and after were calculated.

Results

The rises in heat stress parameters in low level sorties were as shown in Table-1. Dry bulb temperature showed a rise of 7.9°C in the first phase while it was 11.6°C at the end of the sortie. Twb registered a rise of 3.9°C in the cockpit (BS) and total rise was 8.4°C. These were reflected in the rises in the oxford index at 4.5°C in the first phase and 8.9°C at the end of the sortie.

Heat strain parameters in low level sorties showed significant rises as depicted in Table—2.

The core temperature showed a total rise of 1.1°C. Skin Temperature showed a rise of 1.8°C in the first phase while total rise was as high as 3.1°C. MBT registered a total rise of 1.8°C. Heart rate showed a mean rise of 14.5 beats/min. in the cockpit (BS) and total mean rise was 45.3 beats/min. Heat storage index showed a gain of 24 K Cals/Sq M of Body surface area in the first phase and total gain was as high as 55 K Cals/Sq M of BSA.

Table 3 shows sweat loss observed in low level sorties. The mean sweat loss was 806.3 gms/hr with standard deviation of 153 gms. Table-4 shows the Craig indices observed in low sorties. The mean was 3.23 with standard deviation of 0.49.

Table 3

Sweat loss in low level sorties (500 M-2 KMS)

Sl. No.	Subject	Sweat loss GMS/HR
1.	CHD	760
2.	SS	1022
3.	RK	800
4.	SKJ	670
5.	AVS	530
6.	SWN	720
7.	BD	940
8.	CH	810
	MEAN	806.3
	STD Deviation	153.08

Table

Heat strain parameters in low level

Sl. No.	Subject	Tc in °C			Tsk in °C		
		Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)
1.	CHD	36.4	37.1	38.1	34.6	36.5	37.1
2.	SS	36.7	37	37.6	34.6	35.4	36.8
3.	RK	36.8	37	38.2	34.6	36.3	37.1
4.	SKJ	36.8	37	38.2	35.2	36.3	37
5.	AVS	36.7	37	37.7	34.5	36.8	37.4
6.	SWN	36.8	36.8	37.4	32.6	34.5	37.3
7.	BD	36.7	36.8	37.6	32.8	35.9	37.3
8.	CM	36.4	36.7	37.9	33.7	35.2	37.9
Mean		36.7	37.0	37.8	34.1	35.9	37.2
Std. Devn.		0.2	0.1	0.3	0.9	0.8	0.3
Mean Diff.			0.3	1.1		1.8	3.1
'P' Value			<0.001	<0.001		<0.001	<0.001

sorties [500 Meters—2 kms]

MBT in °C			HR/Min			Heat Content K cals/Sqm		
Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)
35.8	36.9	37.8	86	120	144	1070	1103	1129
36	36.5	37.3	84	88	120	996	1010	1032
36	36.8	37.8	72	78	132	1171	1194	1228
36.3	36.8	37.8	84	102	130	1061	1075	1105
36	36.9	37.6	66	90	120	1032	1058	1078
35.4	36.2	37.3	78	88	106	1154	1180	1218
35.4	36.5	37.5	84	96	120	1153	1189	1221
35.5	36.2	37.9	88	96	132	982	1002	1049
35.9	36.6	37.6	80.2	94.7	125.5	1077	1101	1132
0.3	0.3	0.3	7.7	12.5	11.5	74	79	80
	0.8	1.8		14.5	45.3		24	55
	<0.001	<0.001		<0.001	<0.001		<0.001	<0.001

Table 4

Modified craig index in low level sorties [500 M-2 KMS]

Sl. No.	Subject	Craig Index
1.	CHD	3.90
2.	SS	3.32
3.	RK	3.43
4.	SKJ	3.37
5.	AVS	2.73
6.	SWN	2.38
7.	BD	3.04
8.	CH	3.63
	MEAN	3.23
	Standard Deviation	0.49

A total of eight subjects underwent low level sorties, five found the sortie environment very hot and complained of fatigue and tiredness after the sortie. Out of these five subjects one complained of fatigue and tiredness after the sortie. Out of these five subjects one complained of breathlessness during the sortie. Rest 3 subjects found the sortie environment hot but did not complain of any fatigue or tiredness.

A total of 12 subjects underwent medium level sorties and out of these six found the sortie environment hot while two found it warm. Four subjects described the period on ground including taxying and at line up as hot but they described the period in air as comfortable.

Heat stress parameters recorded in medium level sorties are shown in Table No. 5. The mean rises in stress parameters were more or less same as those in low level sorties in the first phase of crewroom to cockpit before sortie. However the rises in 2nd phase were comparatively less.

The changes in heat strain parameters were as shown in Table-6. Here there was a gain of 21 K Cals/Sqm of Body surface area in the first phase while total gain was 44 K Cals/Sqm of Body Surface Area.

Sweat loss observed in medium level sorties is shown in Table No. 7. The mean sweat loss was 641.7 gms/hr with standard deviation of 188.8 gms.

Craig indices during medium level sorties were as shown in Table 8. The mean was 2.44 with standard deviation of 0.48.

Comparison of rises in heat stress parameters between a/c cockpits covered and cockpits not covered is shown in Table-9. The mean rises in stress parameters of a/c cockpits not covered were significantly higher than the a/c cockpits which were covered with taurapulin covers.

Discussion

From the comfortable environment of crewroom the environment became stressful in the cockpit of parked a/c as seen from rises in stress parameters. This was reflected in the corresponding rise in heat storage of 24 K Cals/Sqm of BSA. This constituted about 40% of the total rise in heat storage. The time involved in this phase was 15-30 minutes. This time was due to walking from the crewroom to dispersal carrying out pre-flight checks and getting Appa to feed the power before startup. During the exercise time when there are a number of aircraft taxying out from dispersal this time interval is further increased.

In the low level sorties there was increase in oral temperature by 1.1°C, in MST by 3.1°C and heart rate rose by 45 beats/min. According to Wadhawan ML[3], aircrew in tropical countries acclimatized to heat suffer from a subjective feeling of heat when there is an increase in oral temperature by 1.4°C, MST by about 4°C & heart rate about 50 beats/min. In the low level sorties most of these criterion were met. Five out of the eight subjects involved found the sortie environment very hot and complained of fatigue and tiredness after the sortie.

According to Gibson[3] dehydration of body weight by 1% is enough to limit the performance. Dehydration of this degree also causes sigificant reduction in G-tolerance. The mean sweat loss observed during low level sorties was 806 gms/hr which was definitely more than 1%.

Medium level sorties were comparatively less

Table 5

Heat stress parameters in medium level sorties (2 kms—7 kms)

Sl.	Subject	Tdb in °C			Twb in °C			Oxford Index in °C		
		Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)
1.	PS	29.4	35	37.8	26.7	30	32.2	27.1	30.8	33
2.	SWN	31.7	40.6	42.2	24.4	31.7	33.3	25.5	33	34.6
3.	BD	31.7	39.4	42.2	24.4	30	34.4	25.5	31.4	35.7
4.	DK	32.8	41.1	42.2	26.7	32.2	33.3	27.6	33.5	34.6
5.	JB	32.8	42.8	43.9	26.9	33.3	33.9	27.6	34.7	35.4
6.	SKH	30.6	41.1	41.7	25.6	30	30.6	26.4	31.7	32.3
7.	MHN	30.6	41.7	42.2	25.6	30.6	31.7	24	32.3	33.3
8.	SKJ	30.6	40.6	41.1	22.8	29.4	33.3	24	31	34.5
9.	DVD	30.6	41.7	43.3	22.8	29.4	33.3	27.2	31.3	34.8
10.	BL	33.3	35.6	42.2	26.1	27.8	35	27.2	29	36
11.	DNT	33.3	35.6	42.8	26.1	27.8	35	26.4	29	36.1
12.	VPP	33.3	36.7	40.6	28.3	28.9	34.4	29	30	35.3
Mean		31.7	39.3	41.8	25.5	30.1	33.4	26.5	31.5	34.6
Std. Dev.		1.4	2.8	1.5	1.6	1.7	1.8	1.5	1.7	1.2
Mean Diff.			7.6	10.1		4.6	7.9		5.0	8.1
'P' Value			>0.001	<0.001		<0.001	<0.001		<0.001	<0.001

Table

Heat strain parameters in medium

Sl. No.	Subject	Tc in °C			Tsk in °C		
		Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)
1.	PS	36.5	36.7	37	33.9	34.3	35.8
2.	SWN	36.8	36.9	37.3	34.2	35.2	36.3
3.	BD	36.9	37.3	37.6	33.5	36.5	37.0
4.	DK	36.5	37	37.4	35.4	36.3	36.9
5.	JB	36.9	37	37.6	34.8	35.2	37.3
6.	SKH	37	37.2	37.6	34.4	35.7	36.9
7.	MHN	37.1	37.2	37.4	34.2	36.2	36.7
8.	SKJ	36.6	36.7	37.4	34.2	35.3	36
9.	DVD	36.4	36.9	37.6	33.0	35.2	37.2
10.	BL	36.3	36.9	37.6	34.1	35.8	37.2
11.	DNT	36.2	36.7	37.4	33.2	35.2	36.8
12.	UPP	37	37.1	37.4	33.7	34.3	35.8
Mean		36.7	37.0	37.5	34.0	35.4	36.7
Std. Dev.		0.3	0.2	0.2	0.7	0.7	0.5
Mean Diff.			0.3	0.8		1.4	2.7
'P' Value			<0.001	<0.001		<0.001	<0.001

VI

level sorties [2 kms—7kms]

MBT in °C			HR/Min			Heat Content Kcal/Sqm		
Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)	Crew room	Cockpit (BS)	Cockpit (AS)
35.7	36.1	36.6	78	78	90	1078	1091	1106
36	36.3	37.0	78	86	96	1155	1167	1188
35.8	37	37.4	84	104	108	1171	1210	1223
36.1	36.8	37.2	72	78	86	1133	1156	1168
36.2	36.4	37.5	72	84	100	1294	1301	1340
36.1	36.7	37.3	84	96	108	1121	1140	1159
36.1	36.8	37.2	68	90	98	1112	1133	1146
35.8	36.2	36.9	90	96	112	1047	1059	1079
35.3	36.3	37.5	76	90	124	1142	1175	1214
35.6	36.5	37.5	72	78	114	1108	1136	1167
35.2	36.2	37.2	84	96	110	1130	1162	1194
35.8	35.9	36.9	78	90	96	1179	1189	1211
35.8	36.5	37.2	78.0	88.8	103.5	1139	1160	1183
0.3	0.3	0.3	6.5	8.4	11.0	61	60	66
	0.7	1.4		10.8	25.5		21	44
	<0.001	<0.001		<0.001	<0.001		<0.001	<0.001

Table 7

Sweat loss in medium level sorties [2KMS-7KMS]

Sl. No.	Subject	Sweat loss in GMS/HR
1.	PS	170
2.	SWN	610
3.	BD	520
4.	DK	750
5.	JB	730
6.	SKH	580
7.	MHN	900
8.	SKJ	670
9.	DVD	880
10.	BL	570
11.	DNT	650
12.	VPP	670
	MEAN	641.7
	Standard Deviation	188.8

Table 8

Modified craig index in Medium level sorties

Sl. No.	Subject	Craig Index
1.	PS	1.57
2.	SWN	2.07
3.	BD	2.30
4.	DK	2.51
5.	JB	2.43
6.	SKH	2.26
7.	MHN	2.22
8.	SKJ	2.59
9.	DVD	3.32
10.	BL	3.01
11.	DNT	2.95
12.	VPP	2.03
	MEAN	2.44
	Standard Deviation	0.48

stressful though the first phase of crewroom to strapping up inside the cockpit remained more or less equally stressful. However, the rises in stress parameters during the second phase were comparatively less.

The heat stress in medium level sorties was less yet the parameters indicate that fliers were consistently in the environment of above 25-27°C which is considered the comfort zone for heat acclimatized Indian subjets (Bhagwanani[4]).

Mean sweat loss during medium level sorties was 642 gms/hr. This amounted to 0.9% of body weight. Even though this was less than low level sorties, it is enough to reduce G-tolerance and limit the performance.

Various operational tasks during flying involve considerable amount of reasoning, judgement and other kinds of cognitive functions. Wadhawan JM[5] has reported that cognitive performance scores remain approximately normal or even surpass normal until environmental temperature exceeds 29.4°C. This indicates that even the moderate heat stress experienced in medium level sorties is definitely not desirable for flier, particularly during fighter flying which involves other stresses.

In view of this it is considered that mitigating measures are essential in low level sorties and desirable in medium level sorties.

Aircrafts are parked in the dispersal between the sorties and canopies are closed but not covered by taurapulins. The gap in between the sorties is sometimes as high as 2-3 hours. All this time the cockpit is exposed to solar radiations and inside temperature is more than the tarmac temperature due to Green House effect. Present study showed a significant difference in the stress parameters between cockpits covered and those not covered. Therefore it is advisable to keep the aircraft cockpits covered between the sorties.

A significant heat load was observed in the phase of crewroom to strapping up inside the cockpit. This stress is avoidable to a great extent. Maximum use of crew transports should be made. Another measure would be to have the aircraft external checks carried out by other aircrew or by ground crew. It is also worth pointing out that external checks of the aircraft in the Royal Swedish airforce are carried out by the ground crew (Gibson[3]).

Prior body cooling has been found to be useful. IAF station Jamnagar crewrooms and ORPs are not airconditioned. Properly airconditioned crewrooms and ORPs will aid in quick recovery from the pre-

Table 9

Comparison between a/c cockpits not covered and covered

Sl. No.	ΔTdb		ΔTwb		ΔTG		ΔOX Index		ΔWBGT	
	Cockpit (not covered)	Cockpit (covered)	Cockpit (not covered)	Cockpit (covered)	Cockpit (not covered)	Cockpit (covered)	Cockpit (not covered)	Cockpit (covered)	Cockpit (not covered)	Cockpit (covered)
1.	4.0	2.3	3.3	1.1	1.1	—1.9	3.4	1.3	3	0.62
2.	1.1	—3.0	1.1	—2.0	1.1	—0.6	1.1	—2.3	1.1	—1.90
3.	4.4	—0.6	3.8	±0	1.2	—1.1	4.0	—0.1	3.5	—0.28
4.	1.1	—0.5	0.5	—1.1	1.1	0.6	0.7	—0.9	0.7	—0.40
Mean	2.65	—0.45	2.17	—0.50	1.12	—0.75	2.30	—0.50	2.07	—0.55
Std Dev	1.80	2.17	1.62	1.34	0.05	1.05	1.64	1.50	1.38	1.08
Mean Diff		3.10		2.67		1.87		2.80		2.62
'P' Value		<0.05		<0.05		<0.05		<0.05		<0.05

vious exposure and improve aircrew combat readiness in a short time.

In Mig 21 variants the canopy has to be closed all the time once the engine has started and this induces considerable amount of heat stress and sweating. The normal defence mechanism of sweating is effective against overheating only if the sweat evaporates. This can be facilitated by the use of ventilating air. Therefore it is considered advisable to have a fan inside the cockpit.

Present study has shown that there is dehydration to the extent of more than 1% in low level sorties while in medium level sorties it was about 0.9% of body weight. Adequate supply of replacement fluids should be available and consumed by aircrew to make up fluid and salt loss.

In the present study it was seen that there was a significant rise in mean skin temperature by 3.1°C in low level sorties. In one such sortie it was found to equal the core temperature. This brings the requirement for skin cooling. Skin cooling during the sortie can be done either by short burst cooling by means of an air ventilated suit or liquid cooled suit. LCS because of higher specific heat of the liquid in circulation is more effective way. Sant et al[6] of Institute of Aviation Medicine have conclusively demonstrated the efficacy of a liquid cooled suit.

In view of the above, following measures are recommended for mitigation of heat stress :-

(a) Aircraft cockpits should be covered by taurapulin covers in between the sorties.

(b) Crewroom and ORPs should be airconditioned.

(c) In summers the a/c pre-flight checks may be carried out by other aircrew, if acceptable. This should be resorted to particularly for the sorties carried out between 1100-1600 hours during summers.

(d) A small fan with rubber blades should be fitted in the cockpit of Mig T-96, Mig-B's and front cockpit of T-69, since the point is available.

(e) Adequate replacement fluids in the form of fresh fruit juice for making up fluids and salt loss available in the crewroom must be consumed by the aircrew.

(f) Liquid cooled suit system may be used to keep aircrew in the thermal state close to comfort zone during summer operations.

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