Original Article

Assessment of cabin conditioning system in a fighter aircraft

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ABSTRACT

Heat stress is a known problem of low-level flying. To assess the efficacy of cabin conditioning system in the fighter aircraft no specific protocol is available. Heat stress monitor (HSM) developed at IAM, IAF was used to record heat stress from the cockpit at every minute of low level flying at 200-meter altitude. The data were further analysed for two phases of flying viz (a) Pre take off phase (duration 15 min), (b) low level flying phase (duration 29 min). Maximum heat stress during Pre take off phase was found as wet bulb globe temperature index (WBGT) 34°C at 15 min of this phase. Maximum heat stress during low level phase was a WBGT of 33.6°C at 23 min of this phase and it remained around that level till end of the low level flying. Cabin conditioning of the aircraft was not enough to control the increase in heat stress of low level flying.

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KEY WORDS : Heat stress, Low level flying, fighter aircraft, cabin conditioning system

Aircrew are required to operate at extremes of environment, which may have adverse effect on their physiological and psychomotor performance. The performance can deteriorate further when the aircrew is exposed to the added stresses of aviation, viz, hypoxia and acceleration. Heat stress is a known problem of low-level high speed flying, especially in India [1, 2]. To assess the efficacy of cabin conditioning system in a fighter cockpit no specific protocol is available. Most of the time, efficacy of the cabin conditioning system of aircraft is assessed by measuring the temperature of the dry air without considering the measurement of radiant temperature and humidity of the cockpit during actual flying conditions. Radiant temperature of the cockpit is expected to rise during low level flying due to aerodynamic heat and green house effect. In a

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normal resting person more than 50% of the heat from the body is lost by radiation to maintain normal body temperature. If the radiant temperature exceeds the mean skin temperature (33°C in a resting person), then heat loss by radiation from the body cannot take place and the body starts gaining heat in such an environment The humidity content of the cockpit is likely to increase due to sweat evaporation of the aircrew [3]. If the cabin conditioning system is not effective in removal of the humidity content of cockpit, sweating, the only means available to aircrew during environmental heat stress will also become ineffective and aircrew body temperature will rapidly rise beyond the acceptable limit of flying [3]. There is a need to assess the efficacy of cabin conditioning system of a fighter aircraft by the measurement of wet bulb globe temperature index (WBGT) in the cockpit especially during low level flying [4, 5]. This can be obtained by simultaneous measurement of temperature dry air (Tdb), wet bulb thermometer (Twb) and temperature of black globe (Tbg) by utilizing heat stress monitor (HSM) developed at the Institute of Aerospace Medicine, IAF, Bangalore [1]. In the preparation to assess the cabin conditioning system of a fighter cockpit in high ambient temperature of field bases during summer, it was decided to develop a protocol and test it at Bangalore region.

Heat stress is a major environmental stress in fighter aircraft, particularly in low level flying. However, actual environmental data for different phases of flying is grossly inadequate. Questionnaire survey from aircrew reveal that cabin conditioning system provided in one of the fighter series of aircraft was inadequate in maintaining the thermal comfort in the cockpit, especially during low level flying and taxiing [6]. Assessment of cabin conditioning system while flying at 200 m altitude had not been done in past due to non availability of appropriate heat stress measuring system. Earlier studies in this field have been based on measurement of cockpit temperature by pilot / copilot / experimenter by a hand held mercury / alcohol thermometer or a digital electronic fhermometric system [7]. These systems did not have the memory to store the automatically recorded data for further analysis after flying. Although, some studies were carried out in the past to record heat stress in fighter cockpit by utilising

HSM, but the recording were made with the aim of testing the airworthiness of HSM with no specific protocol to assess the cabin conditioning system of the aircraft [1, 2],

Wet bulb globe temperature index (WBGT) is an accepted index to assess severity of hot environment [4]. In military flying the validity and the practicality of WBGT index is well established for monitoring in-flight cockpit environment [5]. It was therefore planned to use HSM and develop a protocol for the assessment of cabin conditioning system in a fighter aircraft and validate this protocol for the assessment of cabin conditioning system while flying at 200 meter altitude.

Cabin conditioning system of fighter cockpit

The cockpit is pressurized and ventilated with an automatic control for temperature regulating system [8]. The system is intended to give adequate comfort to the pilot at all altitude with necessary flying clothing. Based on flight altitude the pressure in the cockpit is automatically adjusted as per the requirement through a pressure controller. In the altitude range from 0 to 2000 meters the valve ensures only adequate ventilation of the cockpit while the pressure in the cockpit is kept approximately equal to the atmospheric pressure. Air supplied to the cabin is kept at a preset temperature, which is maintained automatically by an electrical control system. The system is designed to give a regulated temperature in the range of 10-20°C (normally at 12°C) in the working altitude range from 0 to 25000 meter while the ambient air temperature may be in the range of - 60°C to + 50°C. For this purpose, air is tapped from the 8* stage of engine compressor, which flows through the electrically operated distributing valve which is controlled constantly by a temperature regulator. Electrically operated mechanism controls the opening or closing of the shutters of the distributor valve. There is one channel for direct outlet of the hot air to the cockpit; the other channel is connected to the air-to-air cooler where it is cooled in the primary heat exchanger system to about 100°C from a temperature range of 300 - 350°C, which exists at the compressor stage. The temperature controller selector switch has four positions :

(a) Hot position in which the distributing valve feeds the hot air in the cabin from the engine compressor bypassing the coolers,

(b) Cold position in which the distributing valve feeds the air in the cabin after the air is cooled primarily in the heat exchanger and then in the turbo cooler where the air is cooled to about

10°C,

(c) Auto position in which the distributing

valve will feed the mixed air in the desired

proportion in the cabin, as per set point of the thermoregulator.

(d) Neutral position in which the cabin air supply is switched off. The hot, cold or mixed air supply of the cabin is maintained through the cabin supply valve, which works in two positions, open or closed. When the aircraft is parked on the ground, this valve is always closed and opened just before the starting of the engine [8].

Heat Stress Monitor (HSM)

It was developed at the Institute of Aerospace Medicine [1] and was tested for its capability to record heat stress from the fighter cockpit [1, 2]. HSM is a microprocessor - based, battery operated three - channel thermal sensor system for the purpose of recording Tdb, Twb and Tbg temperatures and the WBGT index in real time mode (Fig. 1). It also has the capacity to store date for retrieval through a computer. The model used in the present study is HSM II. The black globe measures 50 mm in diameter and gives it the advantage of small size and early equilibration of the sensor with the serial change in the environment, as is seen in a dynamic condition of an aircraft. The operative temperature range is 0 to 60°C. A fully charged battery lasts 8-12 hours.

HSM is a box type equipment of dimensions 200mm x 160mm x 55mm with a trident having the three sensors for Tdb, Tbg and Twb. It has four channels, which automatically compute the Tdb, Tbg and Twb and a calculated value of WBGT. The channels can be selected using the channel selector switch. It has following modes of operation, each of which can be selected by a mode selector switch.

Calibrate mode : which indicates that the system is functioning properly. It is also used for downloading the stored data on a computer,

Measure mode : In this mode, real time data is collected by using specific channel positions of Tdb, Tbg Twb and WBGT,

Store mode : Used for automatic storing of the data,

Replay mode : In this mode, stored data can be replayed by appropriate selection of the experiment number

Off mode: The system is to be kept in this mode when not in use or while charging.

Methods

HSM, sling psychrometer and a portable computer (Acer<S> laptop) were utilized to record the thermal data from fighter aircraft during low level flying at Bangalore (Fig. 1). A Protocol for recording thermal data from the aircraft by using HSM was formulated as described below.

Fig 1 : Heat stress monitor with its sensors and connection to laptop computer

Protocol for the assessment of heat stress by HSM

A successful recording of thermal data from a sortie is extremely essential and it needs to be failure proof since the sorties cost is prohibitive. It involves close co-ordination between technical, medical, aircrew and the ground duty personnel. Following steps were taken in order to successfully record heat stress data from a sortie.

1. Inspect the cockpit of the aircraft along with aircrew and the technical personnel to decide the place of fixing of HSM main console and its sensor at the same or different place. The HSM needs to be fixed so as not to obstruct the vision or operation of flying instrument during flying.
2. Request the technical personnel to make a suitable clamp for firmly fixing HSM in the cockpit and its trident of three sensors in a manner which ensures free airflow around the sensors **[4].**
3. Keep the HSM for charging overnight.
4. Data storage space in the recorder was cleaned in the morning prior to use.
5. Set the date and time in the HSM and also set the interval of recording by HSM to 1 min with the help of the computer.
6. Fill distilled water in the cup of wet bulb thermometer. The wick of the natural wet bulb thermometer is kept wet with distilled water for at least 30 minutes before the temperature reading is made. The wick should always be clean, and new wicks

should be washed before using [4].

7. Test record the thermal data of environment in shade by HSM in store mode for 5 min and replay it to compare it with the data recorded by dry bulb and wet bulb mercury thermometers of sling psychrometer. [9], This step will confirm the correct calibration of the HSM.

8. Tdb and Twb from a sling psychrometer are recorded in the shade without rotating the psychrometer to obtain natural wet bulb reading. While using the psychrometer it was ensured that the wick of the wet bulb was wet with distilled water for at least 30 minutes [9].

9. Switch on the HSM to store mode and firmly fix the HSM and its sensor tripod at the selected place in the cockpit. Once again check for the water for Twb and tightness of the screw of sensor trident connecting cord with the main console of HSM before flying.

10. Note the time of 'switch on' of HSM to the store mode. Instruct the aircrew to note the time of closure of canopy, take off, different phases of flying, landing and opening of canopy after sortie. Also ask the aircrew to note the other details of sortie like speed and altitude in different phases of flight.

All the steps as per the protocol were followed to record the heat stress data successfully during a low level sortie. The HSM was fitted at the "Gyrogun site" point with the sensor trident fitted with the main body of HSM (Fig 2). Flight clearance for the test sortie was obtained from "Chief Research and Project Officer" of ASTE.
Data so recorded were downloaded to a PC for analysis.

Results

Recording of temperature profile in the fighter cockpit by HSM in respect of Tdb, Twb, Tbg and WBGT was obtained in the month of Aug at Bangalore during flying at 200 AGL. The data are presented in Table 1 and Fig 2. The data were further analysed to obtain average, maximum and time of the maximum changes for the various phases of flying (Table 2) viz.

(a) Pre-take off phase consisting of all the actions after the closure of the canopy till the take off of the aircraft (duration 15 min),

(b) Low level flying phase (duration 29 min) and

(c) For the total sortie including above and also time of flying at other altitude and time taken after landing till the opening of the canopy (duration 54 min).

Ambient parameters at the time of flying were Tdb 30°C, Twb 23.5°C (RH of 55%), Tbg 31°C and WBGT 25.9°C on a bright sunny day. Speed of the aircraft during low level flying was 750 TAS and temperature setting of the aircraft for cabin control was kept at auto for maintaining the temperature at 25°C.

Discussion

Heat stress parameters viz Tdb, Tbg, Twb and WBGT for the low level sortie were found to increase in preflight phase of the flying, during low

Table 1 : Dry bulb temperature (Tdb), wet bulb temperature (Twb), black globe temperature (Tbg) and wet bulb globe temperature index (WBGT) in fighter cockpit flying at 200 meter altitude at ambient temperature of Tdb 30°C and relative humidity 55%

Time (hrs)	Tdb(°C)	Twb(°C)	Tbg(°C)	WBGT (°C)	Remarks
16:15	33.5	25.7	34.7	28.6	Canopy open
16:16	34.2	26	35	28.8	Canopy Closed
17:17	35.5	27	35.2	29.4	
16:18	36.2	27.7	36	30.2	
16:19	35.5	27.5	36.2	30.2	Engine start
16:20	36.5	27.7	. 37	30.6	
16:21	37	28.5	37.2	31.1	
16:22	37.2	28.5	37.5	31.2	
16:23	38.2	28.7	38	31.5	
16:24	37.7	28.7	38.2	31.6	
1625	37.7	29	38.5	31.9	
1626	39	29	38.5	31.8	
1627	40.5	29.2	39.5	32.2	
16:28	39.2	29.5	41.5	33.4	
16:29	39	29.5	41.5	33.4	
16:30	40.2	30	42.5	34	
16:31	40.5	29.2	42.5	33.4	Aircraft takes off
16:32	38.5	28.2	42.2	32.9	
16:33	36.5	27.2	40.5	31.7	Level off at 500 meter
16:34	36	27.5	39	31.3	Commence descent
16:35	35.5	272	37.7	30.6	Level off at 200 meter
16:36	36	27.7	37	30.6	and continued flying at 200
1637	35.7	28	36.5	30.6	meter for 29 min
16:38	37.2	28.7	36.5	31	
16:39	372	29	37	31.3	
16:40	372	28	37.7	31	
16:41	382	28.2	38.7	31.4	
16:42	39.5	29.2	39	32.1	
16:43	40	29.7	39	32.4	
16:44	39.5	29.2	39.5	32.3	
16:45	39.5	29.2	39.2	31.8	
16:46	38.5	28.2	39.5	31.7	
16:47	39	28.5	40.2	32.1	

Time (hrs)	Tdb(°C)	Twb (°C)	Tbg(°C)	WBGT (°C)	Remarks
48			5	5	
49	7	7	5	2	
50		5	5	8	
51			7	6	
52	2		5	4	
53	2	7	7	4	
54	5		2	7	
55	7	2	2	9	
56	5	5	5	1	
57		2	7	6	
58		7	7	4	
59		2	2	8	
00	7	5	5	2	
01	7		5	7	
02		5	7	2	
03	2		5	9	
04	2	2	2	9	mbed to 300 meter
05	5	2	7	7	
06			7	6	nding
07	5	7			
08		7	5	9	
09	5		5	5	itching off engine
10	2	5	5	5	nopy open

level flying and also in the phase after landing till the opening of the canopy, when compared with the ambient temperature.

Ambient temperature at the time of flying was Tdb 30°C, Twb 23.5°C (RH of 55%), Tbg 31°C and WBGT 25.9°C. Tdb, Twb, Tbg and WBGT of the cockpit before the start of flying were found more than the ambient parameters. Preflight phase consisted of time to start the engine, taxying and clearance from, the ATC. It took 2 min to start the engine of the aircraft after the

closure of the canopy and a total of 15 min for the aircraft to take off. Tdb, Twb, Tbg and WBGT kept on rising continuously during the pre take-off phase and were found maximum as 40.5°C, 30°C, 42.5°C and 34°C respectively at the end of this phase. Continuous increase of heat stress in the cockpit during pre take-off phase is attributed to the green house effect as well as electrical heating of the aircraft after the start of engine [10]. Although ventilation of the cockpit started soon after the start of engine, it was found insufficient in preventing the increase in heat stress in the

Fig 2 : Thermal data from fighter cockpit flying at 200 meter altitude

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Table 1 : Dry bulb temperature (Tdb), wet bulb temperature (Twb), black globe temperature (Tbg) and wet bulb globe temperature index (WBGT) in fighter cockpit during pre take-off phase [8]. Turbo cooling of the aircraft does not start before the take off of the aircraft [8]. Therefore, all the increase in heat stress during pre take-off phase is attributed to the green house effect as well as electrical heating of the cockpit [10]. It was obvious that more the duration of preflight phase, more was the heat stress.

There were immediate reductions in the heat stress after take off and it continued to decrease till aircraft leveled off at 200 meter. It took 4 min for the aircraft to level off and the temperature in the cockpit kept on reducing. Thermal parameters at the time of level off of the aircraft at 200 meter were Tdb 35.5°C, Twb 27.2°C, Tbg 37.7°C and WBGT 30.6°C. Reduction of heat stress in the cockpit during this phase is attributed to starting of the cabin conditioning system of the aircraft [8]. It was obvious that heat stress is reduced in the cockpit soon after the take off. But cabin conditioning was unable to maintain the Tdb in the cockpit at <20°C when the temperature selection controller switch was in auto position during 4 min of this phase [8].

Heat stress in the cockpit started increasing during the 29 min of low level flying phase. Average Tdb, Twb, Tbg and WBGT of low level phase were 39.5°C, 28.9°C, 39.9°C and 32.2°C respectively while maximum Tdb, Twb, Tbg and WBGT were 42°C, 30.2°C, 41.7°C and 33.6°C respectively. Maximum heat stress during low level sortie was found at 23 min and it remained around that level till the end the low level flying. It is obvious that low level flying resulted in more heat stress as reflected by higher WBGT of 33.6°C at low level flying as

compared to WBGT of 25.9°C on ground. There

was no change in thermal stress in the cockpit after 23 minutes of flying. Cabin conditioning of the aircraft was found inefficient to control the increase in heat stress during low level flying as claimed in the manual of the fighter aircraft [8].

Thermal parameters at the time of landing were Tdb 40°C, Twb 29°C, Tbg 40.7°C and WBGT 32.6°C. It took 3 min for switching off the engine. Thermal parameters rose fast even with in 3 min of post - landing phase. Tdb, Twb, Tbg and WBGT were 41.5°C, 31°C, 42.5°C and 34.5°C respectively at the time of switching off the engine.

Cabin conditioning of the aircraft was inefficient to prevent heat stress in the cockpit during low level flying. Average and maximum WBGT in the cockpit for the total sortie was found to be more than 32, which is in the caution zone of heat stress for the aircrew [5].

An effective cabin conditioning of an aircraft also needs to control humidity along with controlling the Tdb and WBGT. Ambient RH at the time of flying was 55%. Aircrew in a low level sortie is expected to sweat and the resulting evaporation of sweat is likely to increase RH in any confined environment like cockpit [4]. There was no increase in RH during any phase of the flying. For most part of flying RH was 45%. It is obvious that cabin conditioning system of the cockpit assessed was sufficient in preventing increase in the RH.

It is concluded that the protocol used in the present study for the assessment of heat stress by HSM was successful in recording of heat stress data from the fighter aircraft during low level flying.

cockpit flying at 200 meter altitude at ambient temperature of Tdb 30°C and relative humidity 55%

It is also concluded that cabin conditioning system of the assessed cockpit was ineffective in preventing the heat stress that existed in of low level flying even when ambient temperature was 30°C at ground.

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