Original Article

Heat stress in fighter-upgrade aircraft

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ABSTRACT

Heat stress is an important aviation stress during low-level high speed flying in fighter aircraft (Fighter-Existing). Recently, some of these aircraft have been modified for better flying efficiency along with the improved air conditioning system (Fighter-Upgrade) to reduce the adverse effects of heat stress on aircrew performance. Efficacy of new air conditioning system of the Fighter-Upgrade in maintaining desired temperature in the cockpit while flying at low level was assessed by utilizing heat stress monitor (HSM). Assessment of thermal stress in Fighter-Existing was also made to compare the improvement in the cabin conditioning system of Fighter-Upgrade. HSM measured the environmental parameters viz temperature of dry air, temperature of wet bulb for humidity, temperature of black globe for radiant heat and wet bulb globe temperature index (WBGT) from the cockpit every minute during lpw level flying. Air conditioning systems in both types of aircraft were inadequate to maintain the cockpit temperature at the desired and preset Tdb of 25°C. Heat stress in Fighter-Existing was found to increase even beyond the acceptable limit of cockpit WBGT of 32°C while it could be maintained below 32°C in Fighter-Upgrade aircraft (WBGT 293°C). Cabin conditioning of Fighter-Upgrade was superior to Fighter-Existing. Cabin conditioning system in Fighter-Upgrade was also quick enough to control the thermal environment of the cockpit as maximum heat stress was noticed at 4 min of low level flying in contrast to 23 min of low level flying in Fighter-Existing.

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KEY WORDS: Wet bulb globe temperature, Cabin conditioning system, Heat stress in aviation, Heat stress monitor

Heat stress is an important aviation stress during low-level high speed flying in fighter aircraft [1, 2]. Recently, some of these aircraft were modified for better flying t""': .ZT.C) along with the improved air conditioning system to reduce the adverse effects of heat stress on aircrew performance. It was planned to assess the efficacy of new air conditioning system of the aircraft in maintaining thermal comfort for the aircrew while flying at low level, by utilizing heat stress monitor (HSM) available at IAM [1, 2].

Methods

The study was carried out during the month of Aug 2001 at moderate climate at various places of India. Name of the fighter aircraft and

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the places of the study are not being mentioned due to security reasons. One fighter aircraft, recently modified to upgrade the aircraft for better flying efficiency along with better air conditioning system (Fighter-Upgrade) and another fighter aircraft with older version of cabin conditioning system (Fighter-Existing) were used in this study. Heat stress monitor (HSM) capable of measuring and storing the environmental parameters viz temperature of dry air (Tdb), temperature of wet bulb for humidity (Twb), temperature of black globe for radiant heat (Tbg) and a laptop computer for retrieval of data via software of HSM were utilized during the study [1,2]. Calibration of HSM was checked with the help of sling psychrometer and the protocol established for the assessment of cabin conditioning system was utilized during the study [1]. Aircraft was inspected for the suitable placement of HSM and its sensors by the team. The installation of the HSM and its sensors

Table 1. Analysis of thermal data recorded form Fighter-Existing and Fighter-Upgrade during flying at 200 meters

Parameters (in **°C)**	*Fighter-Existing*	*Fighter-Upgrade*
Ambient		
1. Tdb	**30**	**28**
2. Twb	**235**	**23.5**
3. **Tbg**	**31**	**29.2**
4. WBGT	**25.9**	**25.4**
Low level flying		
1. Duration of low level flying	**29 min**	**38 min**
2. Tdb		
a. Average	**39.50**	**32.02**
b. Maximum	**42**	**33.5**
c. Time of Maximum	**23rd min**	**4th min**
3. Twb		
a. Average	**28.90**	**26.73**
b. Maximum	**30.2**	**27.5**
c. Time of Maximum	**23rd min**	**4th min**
4. Tbg		
a. Average	**39.86**	**32.53**
b. Maximum	**41.7**	**34.2**
c. Time of Maximum	**23rd-24* min**	**1st min**
5. WBGT		
a. Average	**32.22**	**28.53**
b. Maximum	**33.6**	**29.3**
c. Time of Maximum	**23rd min**	**4th min**

Tdb = temperature of dry bulb thermometer, Twb = temperature of wet bulb thermometer, Tbg = temperature of black globe thermometer, WBGT = wet bulb globe temperature index.

did not affect flight safety in terms of obstruction to control movements, visibility, safe ejection etc. The weight and center of gravity of the aircraft were not affected by this installation. Necessary flight clearance was obtained prior to sortie. A successful recording of heat stress parameters was done from the aircraft flying at low level (200 meters AGL). Recording from Fighter-Existing flying at 200 meters was done to compare the efficacy of the cabin conditioning system of two variants of the aircraft. A recording from the stationary aircraft with the canopy closed and parked in open was also made from Fighter-Upgrade by keeping HSM with its sensors on the seat.

Results

Recording of thermal parameters by HSM from stationary Fighter-Upgrade for 60 min (Fig 1) and flying at 200 meters altitude in Fighter-Existing for 29 min (Fig 2) and Fighter-Upgrade for 38 min (Fig 3) were carried out at every 1 min during the sortie. The data were further analyzed to obtain average, maximum and time of the maximum changes for the low level phase of flying and are presented in Table 1. Ambient parameters at the time of flying were Tdb 30°C, Twb 23.5°C, Tbg 31°C and WBGT 25.9°C on a bright sunny day for the recording from Fighter-Existing and Tdb 28°C, Twb 23.5°C, Tbg 29.2°C and WBGT 25.4°C for the recording from Fighter-Upgrade. 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 cockpit Tdb of 25°C.

Discussion

WBGT is an accepted index of severity of hot environment [3]. In military flying the validity and practicality of WBGT is well established as the index for monitoring in-flight cockpit environment [1, 4]. Ambient temperature at the time of flying Fighter-Existing was Tdb 30°C (WBGT 25.9°C) while it was Tdb 28°C (WBGT 25.4°C) at

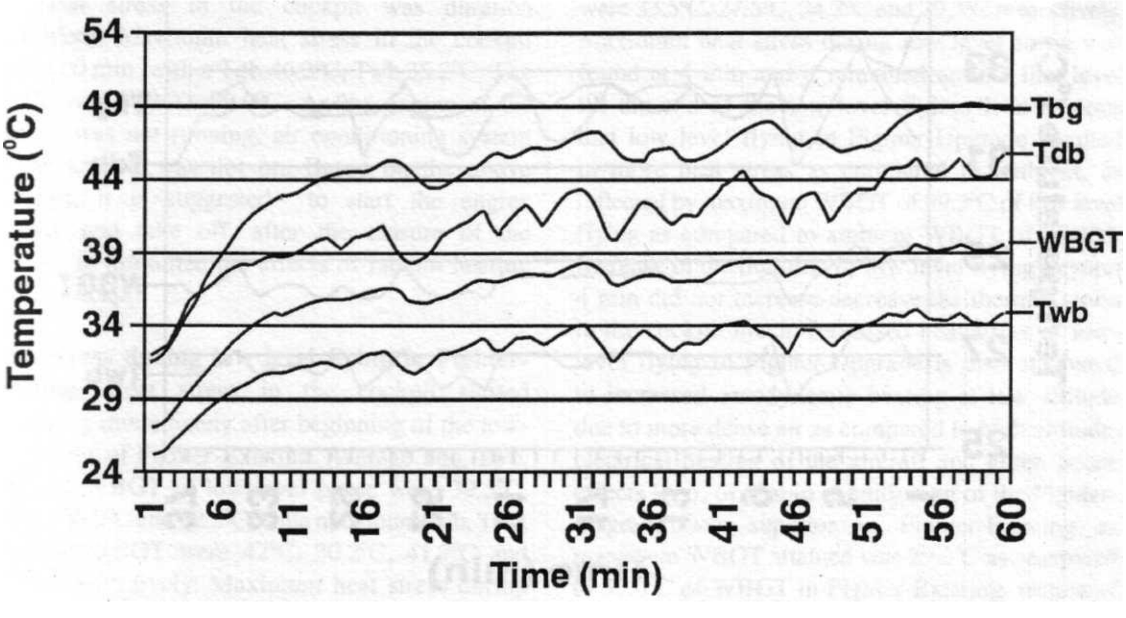
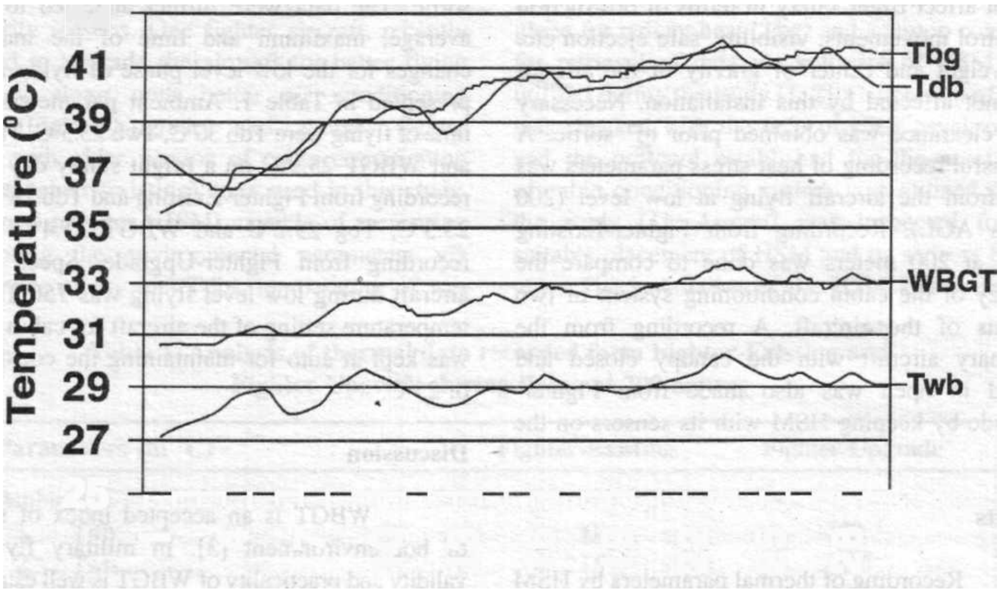


Fig 1. Thermal stress in stationary Fighter-Upgrade'


Temperature (°C)
41
39
37
35
33
31
29
27
Tbg
Tdb
WBGT
Twb

the time of flying Fighter-Upgraded. Thermal environment for both the days of flying was < 32°C of WBGT and is considered suitable for low level flying [4]. Heat stress parameters viz Tdb, Twb, Tbg and WBGT were found to increase in both types of aircraft during low level flying and also during stationary conditions in Fighter-Upgrade.

Heat stress in stationary Fighter-Upgrade. Heat stress in the cockpit of stationary aircraft, with the canopy closed but without starting of engine, increased gradually with the passage of time. Ambient Tdb, Twb, Tbg and WBGT were 28.5°C, 23.7°C, 27.7°C and 24.8°C respectively. Cockpit temperatures at the time of closure of canopy were Tdb 32°C, Twb 25.2°C, Tbg 31.5°C and WBGT 27°C. Increased level of heat stress in the cockpit as compared to environment is attributed to an increased radiant heating of the cockpit and inadequate ventilation in the small space of the cockpit. Closure of the canopy resulted in rapid increase in the heat stress due to the trapping of radiant heat waves by the green house effect inside the cockpit and absence of ventilation [5, 6]. Heat stress in the cockpit was duration dependent. Maximum heat stress in the cockpit was at 60 min with a Tdb 46.2°C, Twb 35.2°C, Tbg 49.5°C and WBGT 39.9°C. As the engine of the aircraft was not running, air conditioning system of the aircraft was not on. Based on the above findings, it is suggested to start the engine quickly and take off, after the closure of the canopy, to minimize the effects of radiant heating of the cockpit.

Heat stress during low level flying in Fighter-Existing. Heat stress in the cockpit started increasing immediately after beginning of the low-level sortie of Fighter-Existing. Average Tdb, Twb, Tbg and WBGT of low-level phase were 39.5°C, 28.9°C, 39.9°C and 32.2°C 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 of the low level flying. It is obvious that low level flying in Fighter-Existing resulted in more heat stress as compared to ambient, as reflected by higher WBGT of 33.6°C of low level flying as compared to ambient WBGT of 25.9°C. Increase in the duration of low level flying beyond 23 min did not increase/ decrease the thermal stress in the cockpit much. Increased heat stress of low-level flying is attributed to increase aerodynamic heating at low altitude due to more dense air as compared to high altitude, electrical heating of the aircraft and green house effects [1, 5, and 6]. Cabin conditioning of the aircraft was not enough to maintain cockpit Tdb of 25 C and could not control the increase in heat stress of low level flying as claimed in the manual of the fighter aircraft.

Heat stress during low level flying in Fighter-Upgrade. Heat stress in the cockpit of Fighter-Upgrade during low level flying for 38 min was found much less than the Fighter-Existing. Average Tdb, Twb, Tbg and WBGT of low-level phase of Fighter-Upgrade were 32.02°C, 26.73°C, 32.53°C and 28.53°C while maximum Tdb, Twb, Tbg and WBGT were 33.5°C, 27.5°C, 34.2°C and 29.3°C respectively. Maximum heat stress during low level sortie was found at 4 min and it remained around that level till the end of the low level flying. It is obvious that low level flying in Fighter-Upgrade resulted in more heat stress as compared to ambient, as reflected by maximum WBGT of 29.3°C of low level flying as compared to ambient WBGT of 25.4°C. Increase in the duration of low level flying beyond 4 min did not increase/decrease the thermal stress in the cockpit much. Increased heat stress of low-level flying in Fighter-Upgrade is also attributed to increase aerodynamic heating at low altitude due to more dense air as compared to high altitude, electrical heating of the aircraft and green house effects [1, 5, and 6]. Cabin conditioning of the Fighter-Upgrade was superior to Fighter-Existing as maximum WBGT attained was 29.3°C as compared to 33.6°C of WBGT in Fighter-Existing, inspite of the longer duration of low level flying of Fighter-Upgrade. Cabin conditioning system in Fighter-Upgrade was also quick enough to control the thermal environment of the cockpit as maximum heat stress was noticed at 4 min of low level flying in contrast to 23 min of low level flying in Fighter-Existing.

It is concluded that cabin conditioning system of the Fighter-Existing is ineffective in preventing the heat stress of low level flying even in the ambient temperature of Tdb 30°C and there is an immediate need of improving the cabin conditioning system of the Fighter-Existing. In our study, although the cabin conditioning system of Fighter-Upgrade was found superior to Fighter-Existing, it was not enough to maintain the desired preset temperature of Tdb of 25°C in the cockpit even in the comfortable ambient of Tdb 28°C [4]. However, a maximum WBGT of 29.3°C in Fighter-Upgrade was within the acceptable limit of < 32°C of WBGT for flying, in contrast to a maximum WBGT of 33.6°C attained in Fighter-Existing which is considered unsafe for low level flying [3, 4]. It is possible that a high ambient temperature of Tdb > 40°C will result in increased heat stress in both types of aircraft. If the improved cabin conditioning system of Fighter-Upgrade does not allow to increase the WBGT > 32°C during low level flying when ambient temperature is >40°C, only then will it be safer to conclude that efficacy of the improved cabin conditioning system in Fighter-Upgrade is acceptable.

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