Original Article

Heat stress in strike aircraft : An objective study

Sqn Ldr P Pant[#] Wg Cdr PD Navathe[@] Wg Cdr JK Shrivastava[*]

Heat stress is one of the major problems frequently encountered during flying. In low level military flying, cockpit temperature can often reach dangerously high level in hot climatic conditions. The heat stress problem is more severe in high performance strike aricraft, when the climatic heat load is further increased by aircraft factors and the limited capacity of onboard cooling systems, thereby leading to higher cockpit temperature than that of ambient. Thus, proper ventilation of the cockpit throughout the sortie duration is a mandatory requirement. Though, modern aircraft cater for air-conditioning of cockpit, this was found to be ineffective during low level high speed flying, when pilots performance and efficiency has to be at its best. An objective study was conducted to evaluate the heat stress in strike aircraft. In-flight trials were carried out in MiG-27 aircraft by recording the cockpit temperatures throughout the sortie duration using a Heat Stress Monitor developed at IAM, IAF, Bangalore. A comparative study of cockpit temperatures of MiG-27 with that of Jaguar aircraft was also carried out by carrying out in-flight trials (since both operate in low level high speed environment). It was seen that the air-conditioning system in the MiG-27 aircraft was less effective as compared to the one in Jaguar aircraft. The data collected is presented and implications on flying performance discussed. Practical solutions are offered for consideration to ensure optimum utilisation of aircraft capability.

Keywords: **Heat stress, high speed low level flying, heat stress monitor, cockpit, air-conditioning**

Heat stress is an important problem in military aviation, especially in a tropical country like India. The problem assumes a larger magnitude because of the cumbersome flying clothing worn by the pilots to provide protection against the forces of acceleration and nature. The temperature has been observed to rise to uncomfortable levels in cockpits of aircraft parked in the open, in preparation for flying. This factor, coupled with absence of proper cooling system in the cockpit on ground, raises temperature by several degrees above the ambient. During operations in the hot summer months, more so during low-level high-speed flying, the cockpit temperature of military aircraft are likely to rise to a level which may compromise flight safety. In low level military flying, cockpit temperature can often reach dangerously high level in hot climatic conditions. The heat stress

[#] *PG Trainee, 37 Advance Course(Av Med), IAM IAF, Bangalore - 560017*

[@] *Classified Specialist (Av Med), 6 Sqn AF*

[*] *Classified Specialist (Av Med), 24 Sqn AF*

is particularly severe in high performance aircraft, when the natural climatic heat load is further aggravated by the avionics. The design considerations limit the capacity of the onboard cooling system, thereby leading to uncomfortable cockpit temperatures.

During low-level high-speed flying, the high ambient temperatures and aerodynamic friction contributes to the high cockpit temperatures. As much as 70% of heat, which is felt in the cockpit, is due to aerodynamic heating, 20% is due to radiation and the remaining 10% is by virtue of heat from aircraft equipment and body heat[1]. The cockpit temperature increases by 3-5°C or even higher during taxying[2,3]. During this phase of the flight, ventilation by hot ambient air provides little respite and cabin-conditioning system thus stays ineffective, because of its inherent dependence on the ram air.

This problem gets aggravated due to the cumbersome flying clothing worn by the pilots during flying. Thus, efficiency of the pilot is affected due to the heat load, during start-up, taxiing and line-up prior to take-off. This factor is vital, particularly during low level high speed flying, when pilot efficiency has to be at its peak, in the interest of operational performance and flight safety.

The MiG-27 is an all-weather aircraft and is designed for low-level, ground attack role, usually below an altitude of 2 km. The air-conditioning system is not effective at low level as it is designed to cut in at 2 km altitude. Besides this, its air-conditioning system is designed for the Russian climatic conditions, where the climate is very cold.

Therefore, a scientific study of the air-conditioning system is required so that it can match the prevailing Indian conditions. In contrast to this, Jaguar aircraft, which also has a strike role, is supposed to be more comfortable as far as heat stress is concerned. Hence, a comparative study was carried out, so as to assess the heat handling capability of MiG-27 aircraft with respect to Jaguar aircraft.

Material and methods

Cockpit Trials: Initially, two sorties in MiG-27 were planned and the temperature recordings were obtained. The temperatures inside the cockpit were recorded each minute throughout the duration of the sortie. The recordings were stored in the memory of heat stress monitor, from start up till the time the aircraft was back at the dispersal, on completion of the sortie. Interfacing it with a computer the data was milked out. Simultaneously, the LUCH readings were also obtained for the entire duration of the sortie. The Thom's Discomfort Index was calculated for each minute with the help of available readings. It was then plotted along with the flight altitude profile in the form of graphical representation as shown in the readings of the study for easy comparison. However, it was noticed that for the major duration of the sortie the comfort levels were not satisfactory. Thus, to identify the existing levels of heat stress in MiG-27, one more sortie was planned in Jaguar aircraft, with the idea of comparing the existing comfort levels in MiG-27 with that of Jaguar aircraft. The sorties were done in a Jaguar trainer and since the equipment could not be mounted inside the aircraft because of space constraints, hence it was kept in the rear seat throughout the sortie duration. The readings were obtained in the same manner as was done in the previous two sorties of MiG-27 aircraft.

Thom's Discomfort Index encompasses the

readings of T_{db} and T_{wb} and can be calculated with the help of the following formula.

$$DI = 0.72\ [T_{db} + T_{wb}] + 40.6$$ where,

T_{db} is the dry bulb temperature, and T_{wb} is the wet bulb temperature in ^0C. Most people feel discomfort, as the index rises above 70; everyone is uncomfortable when the index reaches 79. The comfort zone for a group of people is a generalisation based on the comfort zones of the different people in the group[4].

Results

The readings have been shown in forms of graphical representation as reflected in the study. Throughout this study, Thom's discomfort index was taken instead of any other index because it gives a correct measure of the comfort levels and it also has well defined comfort zones.

Discussion

Aircrew generally encounters significant heat stress during ground operations and high speed low level flying. In the first cockpit trail in MiG-27, the heat stress monitor was mounted inside the cockpit of the aircraft and the canopy was kept closed throughout the sortie duration. The Discomfort Index (DI) was calculated and plotted in the form of graph against the flight altitude readings (Fig. 1). It was observed that during the pre-start checks for first 9 minutes the DI kept on rising and continued to rise during the taxy-out phase and line up point. Immediately after wheels roll (at 18th minute from startup) as the flight gained altitude it started dropping from 20th minute when flight altitude was 3 km. This shows that once the aircraft climbs to an altitude of 2 km or more, only then the air-conditioning system becomes effective, as it usually cuts in at 2 km altitude. Through out the period of taxy-in the DI was rising, and by the time the aircraft reached back the dispersal it crossed 90 which is considered to be highly uncomfortable. As suggested by Thom[4] in his equation from which DI can be calculated, DI more than 80 is absolutely uncomfortable and in a DI range of 65-75, all people feel comfortable.

In the second cockpit trial in MiG-27 where canopy was kept in partially open position while taxying, it was observed that at the time of startup checks, the DI increased marginally(Fig. 2). During taxy-out phase it dropped slightly and remained constant till the aircraft reached line up point, where again it showed an increasing trend. While taxying-out, it was found to be constant because the canopy was kept in partially open position. At line up point, because of closing of canopy, the ventilation inside the cockpit was found to be inadequate, as a result of which heat accumulation was there. This resulted in an increase in DI, which was found to be close to 82. As soon as the aircraft attained an altitude of 2 km in 24th minute the DI started dropping, which signifies that the air conditioning system of MiG-27 starts operating only at an altitude of 2 km[5]. The DI reached comfort levels within 4 minutes of attaining 2 km altitude and remained there for the next 20 minutes of flight duration. As the aircraft attained 1.8 km altitude, the temperature inside the cockpit started rising as shown by an increase of DI from 75 upwards. Thus, at this altitude, the air-conditioning is not found to be effective. After touch down, the index increased marginally during taxy-in. It was not found to rise steeply as in the previous sortie, because the canopy was kept in partially open position while taxying-in.

In the third sortie, which was carried out in Jaguar aircraft with canopy kept in partially open position, it was observed that during the first 9 minutes of the pre-start checks, the DI showed a rising trend and was found to be more than

FIG 1
MIG - 27 COCKPIT THOMS INDEX VS AIRCRAFT ALTITUDE

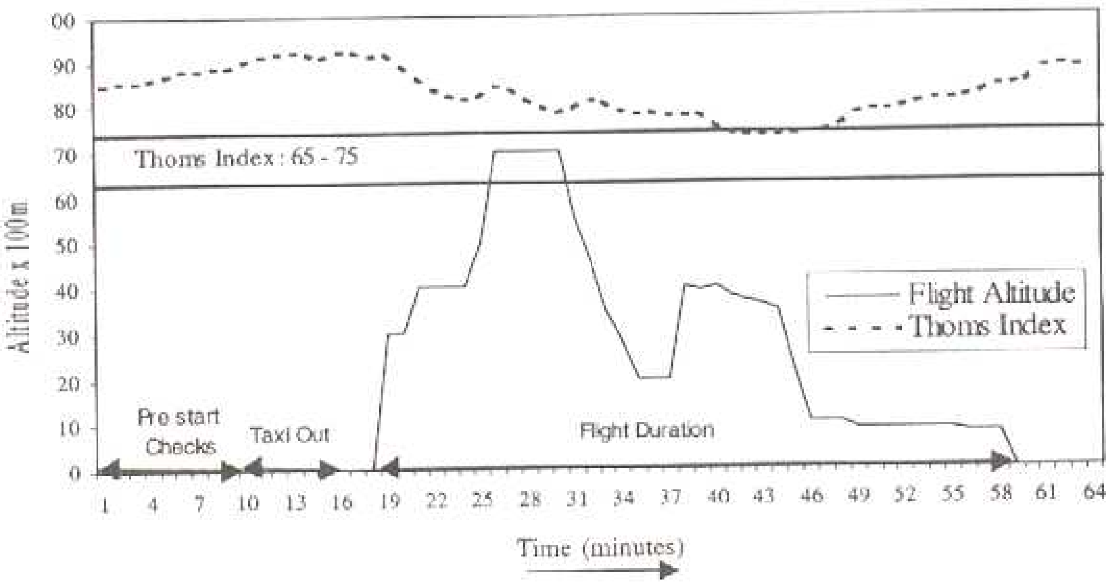
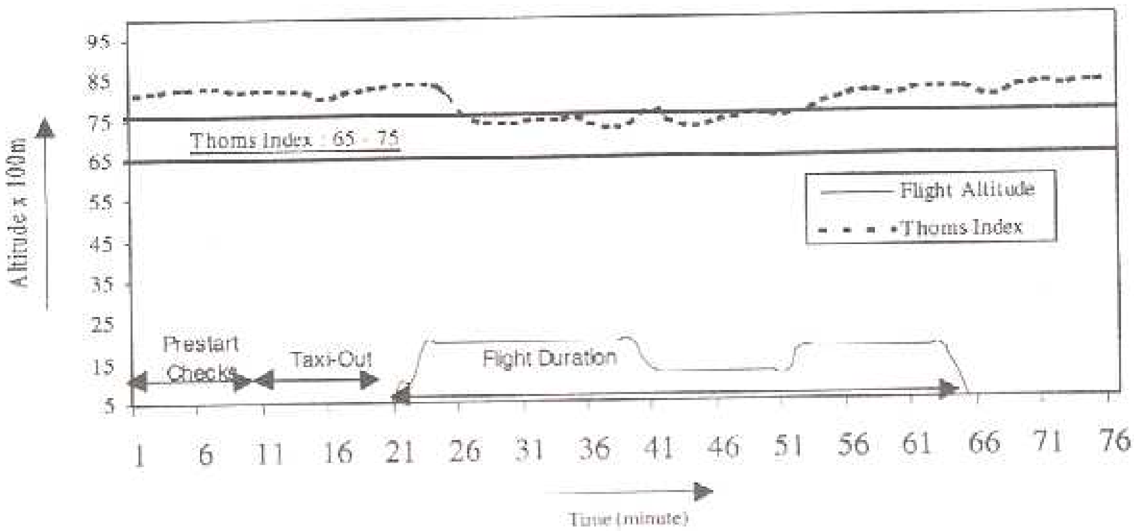


Fig 2
MIg-27 COCKPIT THOMS INDEX VS AIRCRAFT ALTITUDE



80 (Fig. 3). Within 3 minutes of take-off, as the aircraft gained altitude, the DI showed an obvious falling trend and reached partial comfort levels. It remained within absolute comfort levels even after landing and the DI showed a rising trend only once the aircraft reached the dispersal. Inspite of the Jaguar trainer aircraft having problems relating to the cabin conditioning system, the comfort levels were observed to be much better than MiG-27 aircraft.

In one of the taxy-run which was carried out in MiG-29 aircraft (Fig. 4) with the canopy closed and temperature setting to auto (10°C) position, it was observed that initially at idle RPM after the start up and on keeping the temperature setting on auto position, the temperature started dropping from 6th minute after start up and reached comfort levels of 75 in the 10th minute. Between the 14th to 16th minute of start up, the temperature dropped further below DI of 65 when the engine RPM was increased to 80%. Throughout, from the start up phase to taxy-out phase, the comfort levels were within DI range, thus exhibiting the effectiveness of the air-conditioning system. The MiG-29 air-conditioning system was thus found to be effective even at ground level. This aircraft engine has 13 stages (4 low pressure and 9 high-pressure stages) and the air for cabin conditioning is trapped from 3rd stage of high pressure (i.e. 7th stage). The air passes from air to air heat exchanger (I stage of cooling) and then goes to the evaporator (II stage of cooling) which has a water and alcohol mixture in a container of 10 litres. The hot air then passes from here, exchange of heat takes place and thus the temperature of the hot air drops rapidly. The MiG-29 aircraft is also said to possess larger volume turbo coolers which help in further dropping of the temperature of engine bled hot air.

Conclusion

On completion of this study and after going through the analytical details of MiG-27 aircraft from all aspects it is concluded that there is a relative ineffectiveness of the so-called cooling appliances in temperate and hot climates. The cabin conditioning system is effective only above an altitude of 2 km from where the cabin pressurisation starts, whereas the Jaguar has a much more efficient cabin conditioning system as seen in this study. The effectiveness of air-conditioning system in Jaguar aircraft has already been proved earlier in one of the studies conducted in southern Europe[6].

Hence, the answer lies in suitable technical modifications to improve the cockpit airconditioning of Russian aircraft, to be at par with the Western aircraft. To alleviate the problems of heat stress, the following changes could be of value :

i) Improvement in the design of existing air-conditioning system to be planned by changing of base rheostat setting from 10°C to 6°C, so that it now ranges between 6°C-20°C. The Russian designers have catered for this particular setting in the aircraft. Larger volume Turbo coolers of MiG-29 aircraft are recommended for use in MiG-27 aircraft.

ii) Airconditioning to be effective from ground level itself and not at an altitude of 2 km, as seen in the present set up. For all these, technical feasibility is to be taken into consideration before a modification is planned. The mechanical air-conditioning system, which is taking hot air from engine directly, should be replaced by an independent air-conditioning system.

iii) Water in the evaporative cooler should be replaced by water and alcohol mixture, which

FIG 3
JAGUAR COCKPIT THOMS INDEX VS AIRCRAFT ALTITUDE
(Canopy Open While Taxying)

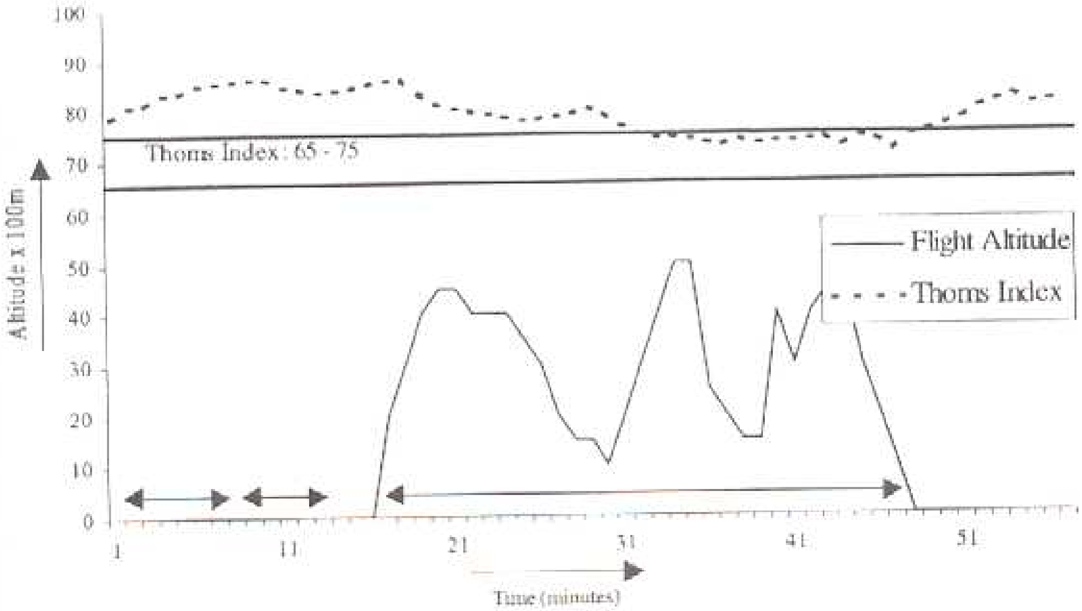
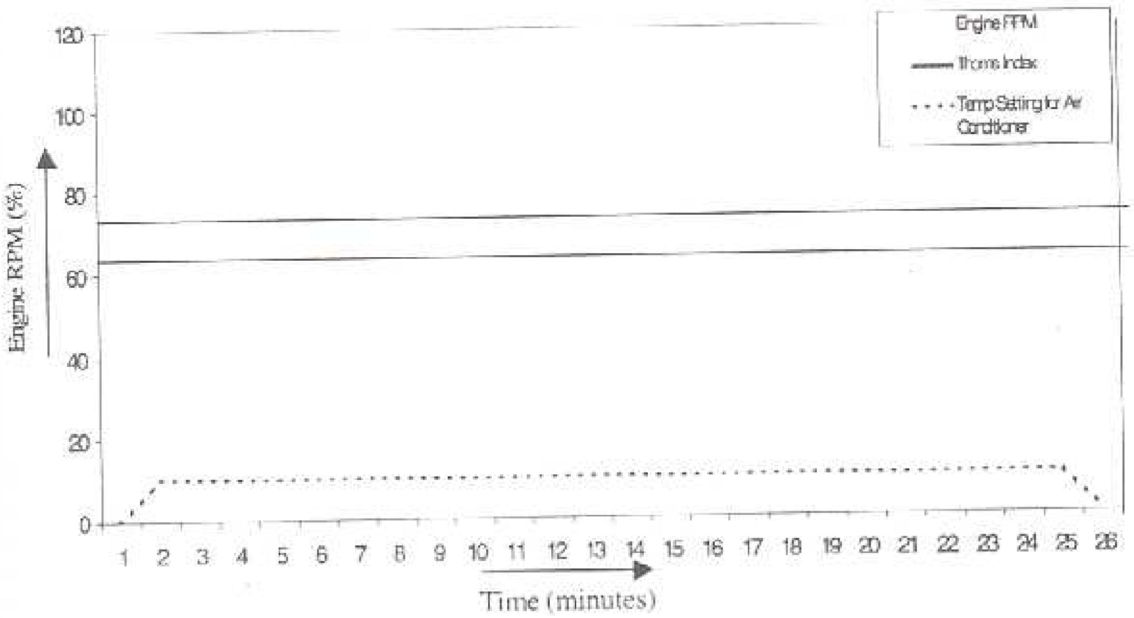


FIG 4
MIG 29: THOM'S INDEX VS. ENGINE RPM



is also used in the cooling stage of MiG 29 aircraft so that it helps in better dissipation of heat from the engine bled hot air.

Other points, which do not involve aircraft modification, are as under -

i) Briefing rooms/crew rooms should be provided with air-conditioners.

ii) Aircraft cockpits to be covered by tarpaulin covers before and in between the sorties so as to avoid the 'green house effect'.

iii) Design and fabrication of Air Ventilated Suit to be carried out since the provision for the use of such a suit is available inside the aircraft.

iv) Pre-cooling of the cockpit with the help of ground cooling trolley should be carried out for effectively reducing the cockpit temperatures before start-up.

v) Provision of a 'Punkah louvre' arrangement as TS-11 Iskara aircraft should be made which will help in providing ram air into the desired direction inside the cockpit.

vi) Adequate fluid replenishment in the form of fresh fruit juice / fresh lime to be provided to make up the fluid and salt loss due to heat.

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