Original Article

Development of a heat stress monitor for thermal data collection from aircraft cockpit

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Heat stress is recognized as a major environmental stress in military flying. However, hard data on prevailing thermal load in otherwise known 'Hot Aircraft' in different stages of flying are not many. Non-availability of suitable measuring system is most likely a reason. This paper describes design considerations of a microprocessor based battery operated 3 - channel heat stress monitor system developed for the purpose of recording dry bulb (Tdb), wet bulb (Twb) and black globe (Tbg) temperature and WBGT index against a real time clock. Subsequent retrieval of the data into a PC file allows registration of the data with date and time for further analysis including temporal relationship with flight data otherwise obtained. Results from a few in-flight trials are also presented in the text.

Key Words : Heat Stress Monitor, Inflight thermal data recording

In spite of a general awareness of high thermal load in the cockpit of the fighter and rotary wing type of aircraft [1,2] particularly in low level flying in tropical weather conditions, actual hard data for different types of aircraft in different phases of flying and at varied ground ambient weather conditions are grossly inadequate, mainly due to lack of an appropriate measuring system that is specifically designed for the purpose. Our earlier studies from this Institute were based on pilots' or copilot / experimenter's effort in noting down temperature data on a note pad as observed from a hand-held mercury thermometer [3-6] and later from a digital electronic thermometric system [7, 8]. Studies from RAF and USAF, aided by superior technology, had been distinctly more specific on temporal reference of data and in simultaneous records of several thermal parameters [9, 10].

An automated thermal measurement system with on-line recording of ambient heat stress parameters is an obvious requirement for repetitive data collection in respect of several heat stress parameters during different stages of rapidly changing external conditions of a military flying sortie. Such a system will be of immediate use in :—

(i) Quantitative identification of 'Hot Aircraft'

(ii) Commenting on the effectivity of cabin conditioning system in different types of aircraft.

(iii) Modelling and prediction of cockpit temperature from flight data and ground ambient temperature measures and

(iv) deciding on suitable measures in alleviation of the stress factors.

For its use within the limited space availabile of fighter aircraft, the system has to be small. For the desired analysis of the thermal data with flight data, it has to log data against running time. Also, preferably, it should not be dependent on aircraft power supply. Data storage capacity of the microprocessor system and the battery backup for the same should be sufficient for the desired volume of data to be stored before its retrieval. Safety of the stored data and its retrieval should be foolproof.

This article describes in detail the above design considerations of the heat stress monitor and describes the system and its use in acquisition of in-flight data.

Design Considerations

Thermal measures : The system was designed to have three temperature sensor inputs viz. for (i) air temperature, Tdb (ii) Wet bulb temperature, Twb and (iii) Black Globe temperature, Tbg. For black globe temperature, it was decided to use a 50 mm metallic globe in place of a conventional 150mm for the purpose of miniaturization of the system and an early equilibration of the sensor with the serial change in the environment, as it would be necessary for the purpose of its use in the aircraft. Temperature range of operation was decided to be 0 to 60^0 C. Suitable semiconductor sensors with amplifier circuit for each channel was to be connected to an AD converter with a minimum resolution of 0.2/ 0.3^0 C.

Heat stress index: It was decided to incorporate WBGT since it has great advantage of simplicity and direct on-line calculation. WBGT index has been used extensively in military aviation [2, 9 - 11] and is also recommended by ISO [12]. Its calculation was based on the following computational relationship that not only needs the simplest features for the sensors but also has been recommended to have a more appropriate weighting for solar radiation components [11,13]:

WBGT = 0.7 Twb + 0.3 Tbg

Microprocessor Control : The design of the system was considered to be based on a suitable microcontroller with appropriate EPROM and static RAM. It was to be supported by a Real Time Clock (RTC). It was considered that the microcontroller would select one input channel at a time and store the data with the RTC time into the RAM. The RAM data is backed by battery power supply till it is transferred into a PC file at a convenient time.

Battery Supply: The power supply of the system should be from a rechargeable battery housed on board the equipment. The battery should provide a sufficient length of operation time, i.e, about 8-12 hours, for supporting a whole day's work. Whenever not in use, the system will be connected with an external battery charger unit. Indication of the charge status was considered important to be included in the display. An LED indicator was felt necessary to show the presence of charging voltage when the battery is put on charge.

Digital Display : A 3 1/2 digit LCD display was decided upon for showing the temperature data from the selectcd channel. The display would also be used for indicating the battery charge status and the calibration values on suitable position of control switches.

Operational Mode : It was decided to have 4 modes of operation of the equipment other than its OFF position to be selected by a mode selector switch

1. Calibrate : The instrument will display a standard numerical value indicating the proper operation of the instrument in general.

2. Measure : In the measure mode, on - line data collected by a specific channel as selected by a channel selection switch will be indicated on the display. The channel selector switch would select one from its 4 positions viz. Tdb, Twb, Tbg and WBGT. For routine manual noting of thermal data on the ground, this mode alone should suffice.

3. Store : In this mode, the instrument is to automatically scan all three channel inputs at a predetermined interval and store the data including that of the computed WBGT index along with the RTC time data in the local memory (RAM). This mode is the primary mode for the desired purpose of automatic recording of in-flight data and its subsequent retrieval on a PC file. The time interval for data storage was decided to be 1 minute.

Stored Data Retrieval into PC: It was decided that the system will be PC based for serving several purposes including unloading of the RAM data into data files. Every time it is taken to STORE mode, the system would record a new Experiment number, date and time of the beginning of the experiment and with thermal data viz. Tdb, Twb, Tbg, WBGT logged under respective headings at each minute interval. An RS-232 serial interface with the PC and a suitable software were considered an essential part of the system. Downloading of the stored data from the monitor, clearing of the stored data from the monitor RAM, and also setting of the time and date of the monitor RTC would be possible only through suitable commands from the PC.

4. Replay : For immediate field requirements, it was considered necessary to call back the stored data on the equipment display itself. It is possible in REPLAY mode when the stored data can be called back using additional switches that would select the number of experiment, date and time. With channel selector switch in respect of a particular thermal parameter, additional switches would display the respective thermal parameter serially for each minute forward or backward. With the help of his mode, the experimenter can note down the data from the display of the respective parameter when a PC system is not immediately available.

Dimension, Weight and other physical considerations:

For the purpose of using the equipment within the cockpit of a fighter aircraft , it was desired that the system should be as small as permitted by the available technology. The basic external feature of the system was decided to be in two pieces: (i) the main body with battery supply, microcontroller, EPROM, sensor connectors, amplifiers, display and selector switches, and (ii) the sensor trident that holds three semiconductor sensors with suitable housing for wet bulb wick and water sponge and the metallic globe for the black globe thermometer. The cable from the sensor trident was decided to be 1 meter long in order to house the main body and the sensors at two separate places if so needed. Otherwise, the trident is to be fixed on the main body of the monitor itself with a suitable clamp.

Heat Stress Monitor -First Model (HSM - I)

Developmental work of the Heat Stress Monitor, both model I and II were made with the help of a local firm, Numag Data System, Bangalore, by possible incorporation of all the above mentioned design considerations in its structural, electronic and software elements.

In Model I, the main box measures 185 x 220 mm at the base with a height of 72 mm. The LCD display and the control switches were housed in the front panel located at a slant of 45^0 with the base. This made it more suitable as a laboratory equipment from the product design point of view(Fig 1).

After the calibration trials of the basic thermistor sensors (LM 335 series of National Semiconductor) and amplifier system conducted at steady state temperatures in a normal room, a cold simulator and a hot simulator room against a standard mercury thermometer, the whole system was studied for several trials on the ground. Total duration of continuous data collection was studied. A total of 10 hours data collected at every min interval could be stored in its RAM. The battery back up was found to be adequate for the period. PC software system for data retrieval, resetting of RTC and erasing of memory were tested and found to perform to the desired requirement. The system was then taken to Aircraft Systems Testing Establishment, AF, Bangalore for their opinion on its acceptability for on board trial in test flying different types of aircraft of our fleet.

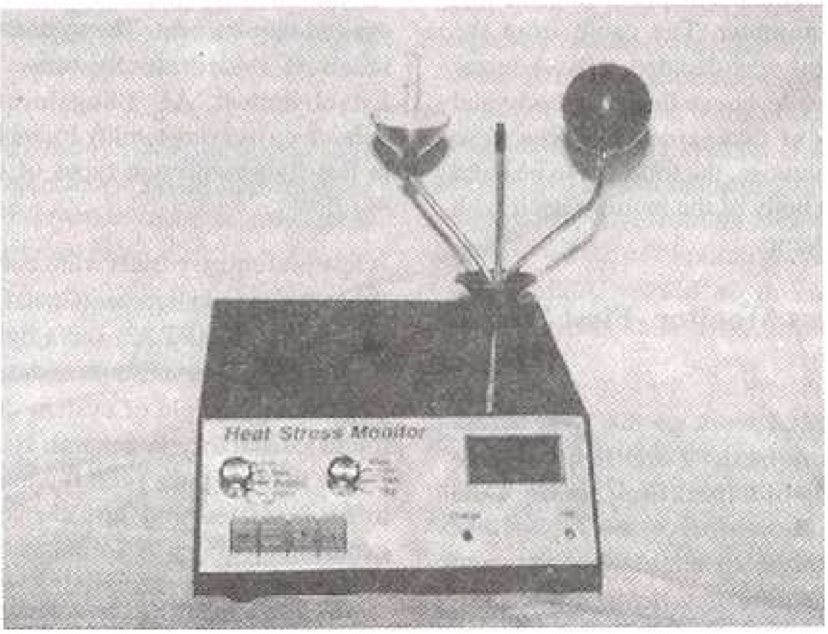
A few preliminary trials were conducted in the cockpit of a helicopter (Chetak), a piston engine trainer(HPT 32) and a fighter (MiG 21, Type 69) with subsequent data retrieval. The basic principle of system design was found satisfactory in general. However for its use in the fighter aircraft where it needs to be installed and not carried by the experimenter, it was found necessary to reduce the size of the system even further.

Second Model of Heat Stress Monitor (HSM - II) :

This model was different from the HSM-I primarily in size and shape. The main box measures 160 x 200 x 55 cm with all its display and control switches located on the top surface itself. The mounting clamp for the sensor trident had to be changed. The housing of the wet bulb sensor was changed from its metal base in the first model to a plastic one. The electronics and the software were kept same as those in HSM-I.

After initial calibration and endurance tests for the total duration of battery power supply and vibration tolerance of the equipment as evaluated in IAM vibration simulator, the equipment were first used in studying of outdoor conditions on ground including stationary aircraft with and without a canopy cover. The system was then taken to ASTE, AF, Bangalore for flight trials.

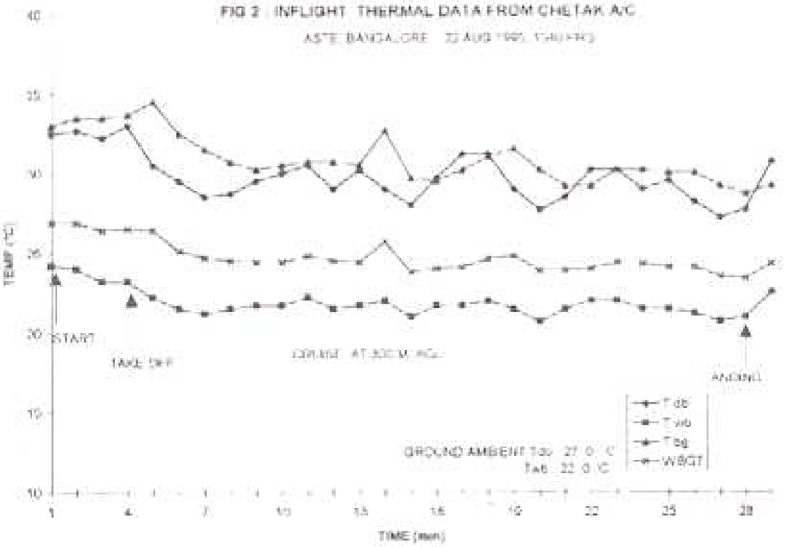
Fig - 1 : Heat stress monitor - 1

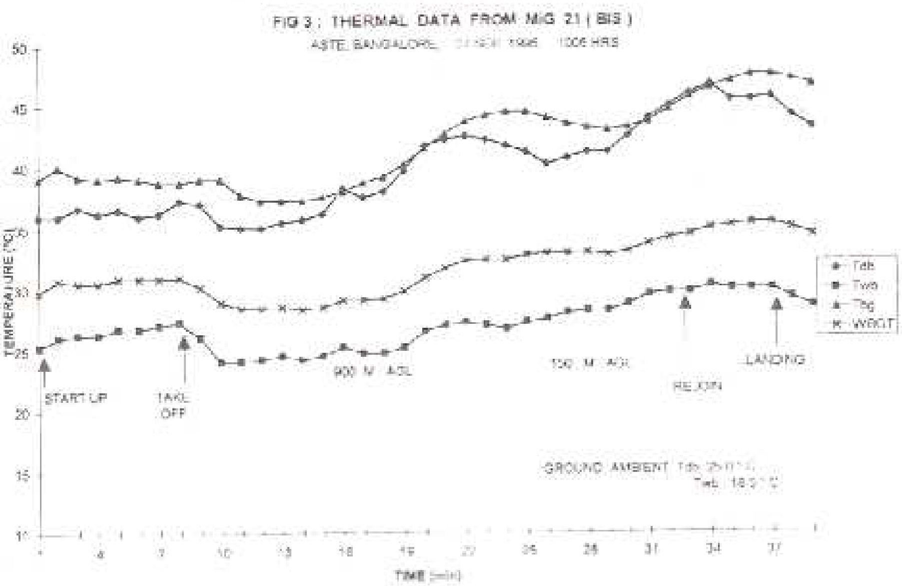


Flight trials with HSM II was first conducted in a helicopter (Chetak). Subsequent data retrieval from the equipment into the laboratory PC was found satisfactory (Fig 2). A test sortie was then conducted on a MiG 21 (Type 69) by ASTE team members themselves. The system was fitted at the gunsight point with the sensor trident in its usual place i.e., clamped with the main body of the equipment. Switching on the equipment to the STORE mode coincided with the closing of the canopy and start up of the aircraft. The aircraft went through a low-level navigational sortie. The system was switched off after opening of the canopy following landing. Fig 3 presents a typical in-flight thermal data from a low level navigational sortie from Mig 21 type 69 flown at ASTE,AF.

Conclusion

A Heat Stress Monitor has been specially developed for the purpose of use in the field particularly within the limited space of a fighter aircraft. Measurements included Tdb, Twb, Tbg and computation of WBGT as per ISO 7243. However, a small Globe of 50 mm diameter was used as against the standard 150mm for obvious reason of miniaturization as well as quick appraisal of changes as it would be likely in case of fighter flying. Logging of thermal data against running time allows studying of its relationship with flight data otherwise obtained and in modelling of inflight cockpit temperature from the ground temperature parameters at the base, in the similar line of FITS [10] or SKITS[11]. Information on the actual extent of the existing heat stress problem in military flying will be a definite necessity in deciding on the quantitative requirement of the possible means of countermeasures.





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