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16. Abstract

The effects of high cockpit temperature on physiological responses and performance were determined on pilots in a general aviation simulator. The pilots (all instrument rated) "flew" an instrument flight while exposed to each of three cockpit temperatures: 1) 25.0° C. (77°F.), 2) 43.3°C. (110°F.), 3) 60.0°C. (140°F.). Each flight lasted about 50 minutes. Performance was scored as the deviations in heading from the pre-determined flight path. Deviations were scored for seven segments of the flight. Physiological parameters recorded were: heart rate, deep body temperature, skin temperature and urine output and sweat loss.

Deep body temperature increased 0.35°C.(0.63°F.) during exposure to 60°C. and decreased about 0.15°C. (0.27°F.) during the "neutral" (25°C.) run. Skin temperature increased 1.0°C. (1.8°F.) during the 25°C. run and 5.0°C. (9.0°F.) during the hottest run. Heart rate increased 25 beats/min at 60°C., 18 beats/min at 43°C. and 10 beats/min at 25°C. The largest body water loss was 360 gms at 60°C.

There were significant decrements in performance in three segments of the flight. Performance at 43°C. was degraded over performance at 25°C. during the 1st segment of flight. Performance at 43 and 60°C. was degraded over performance at 25°C. during Turn 1. Performance at 60°C. was worse than performance at 25 and 43°C. during the ILS segment.

Results are discussed in terms of the complexity of the flight segment being "flown."

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Physiological responses to heat, Simulator performance, Water exchanges, Heart rate, Body temperature, Skin temperature	Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

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HIGH TEMPERATURE AND PERFORMANCE IN A FLIGHT TASK SIMULATOR

. Introduction.

The effects of high temperatures on human ·erformance in high performance aircraft and pacecraft have received much attention.[1-5] The igh temperature problem associated with these ehicles is one of heat generated primarily by ıe great speeds they attain (friction) and not y environmental heat loading. Relatively little ttention has been given to the effects of high ›mperatures on pilots of relatively slow flying ircraft where the high temperatures are ambient ıther than frictionally generated. Aerial aplication activities, to some extent general aviaon activities, and some military flight operaons[6] are carried out in warm or hot ıvironments where the pilot can be exposed to considerable environmental heat load. The lot is exposed to these conditions for variable ngths of time while in his aircraft on the ‹ound as well as during the flight if it is conıcted at low altitudes. Crop dusting activities ıd some military operations are flown only)–100 feet above ground level where air temperares are essentially the same as at ground level. The possibility exists that exposure to high mperatures may be a contributing factor in me accidents where human error is suspected as ing causative.

The purpose of this work was to determine the 'ects of high cockpit temperatures on performce of pilots "flying" a general aviation type nulator.

. Methods.

Thirty-six simulator flights were flown by 12 lot subjects holding current FAA medical cericates and instrument ratings. The pilots were paid volunteers between ages 32–50. No atnpt was made to select the subjects on the basis physical characteristics, number of hours flown, age.

Each subject reported to the laboratory in the morning on four consecutive days. The first day was devoted to orientation and a familiarization flight in the simulator (General Precision Systems, Inc., Link General Aviation Trainer 1, GAT–1, Fig. 1). The next three mornings were devoted to data collection runs at three temperatures: 25.0° C. (77° F.), 43.3° C. (110° F.), and 60.0° C. (140° F.). Each run lasted about 50 minutes. The order of exposure to the three temperature conditions was adjusted so that each temperature was run four times on the first experimental day, four times on the second day and four times on the third day. Cockpit humidity was not controlled but was monitored. When the cockpit temperature was 25° C., relative humidity averaged 45%, at 43° C. it was 22% and at 60° C. it was 11%. Cockpit temperature was controlled by means of a forced air heater (5000 watts) mounted above the simulator and connected to it by a flexible hose (Fig. 1, A). The hose was attached by slip-rings which allowed the simulator to turn without twisting the hose. The temperature in the cockpit was controlled by varying the output of the heater via a variable transformer. Air flow was constant but turbulent and entered the cockpit behind the pilot and also above his head. Baffles (B) diverted the air to all parts of the cockpit without allowing a draft directly on the pilot. The temperature condition for the run was already established when the pilot entered the cockpit.

The flight was made entirely on instruments and instructions were conveyed by intercom to the pilot by an observer who served as an air traffic controller. The flights which were used for performance evaluation consisted of a standardized instrument flight plan composed of the following elements (Fig. 2): flying a course inbound to a VOR (very high frequency omnidirectional radio range), executing a turn at the VOR and flying to a LOM (locator, outer

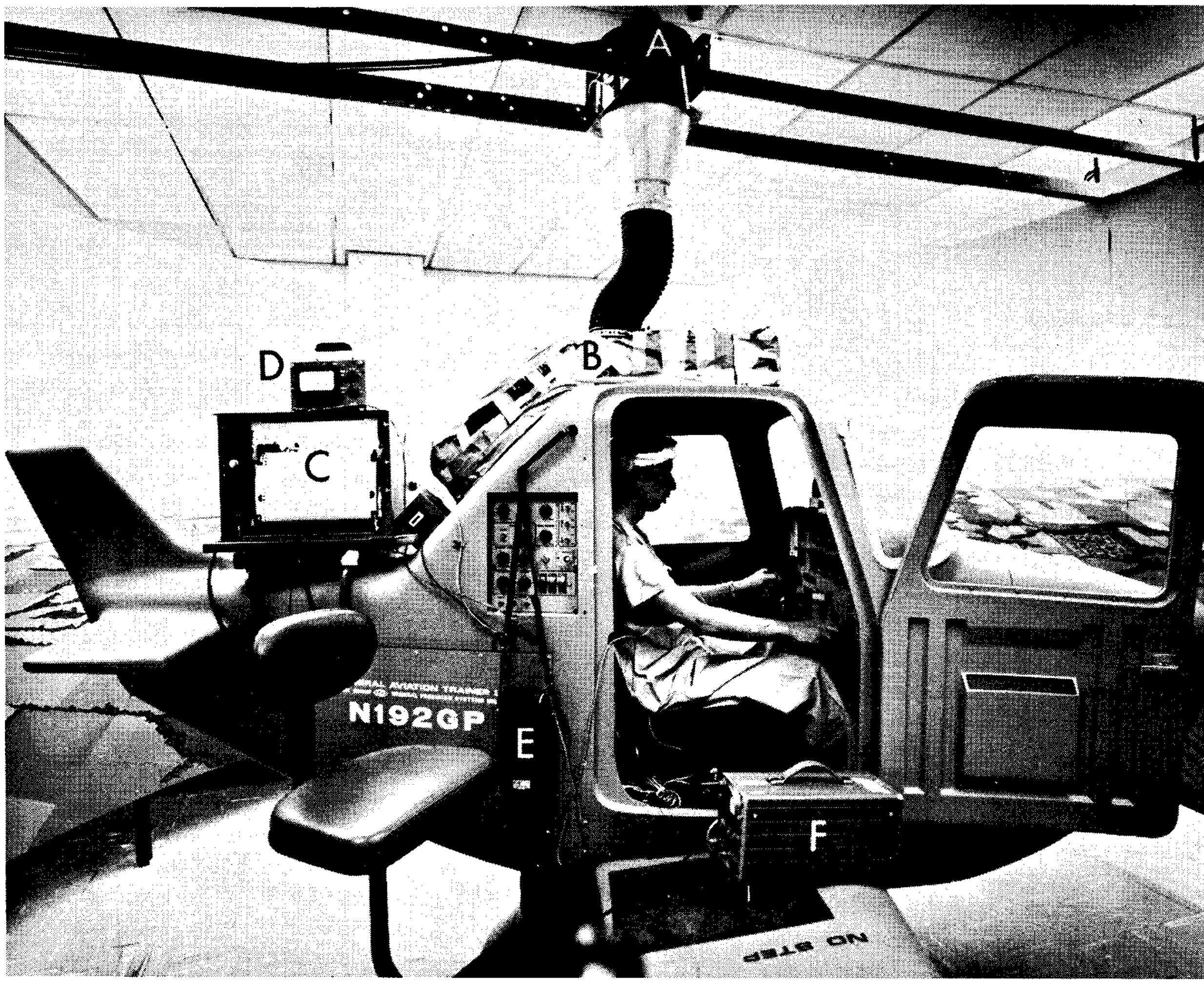
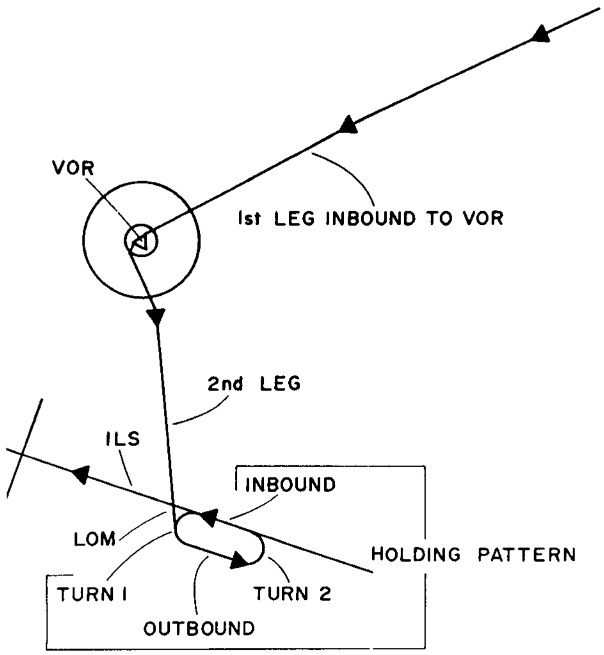


FIGURE 1. The general aviation simulator used in this study. The trainer has pitch, roll and yaw capabiliti Explanation of letters in text.

marker); entering a holding pattern and executing the pattern for three complete turns; and flying an ILS (instrument landing system) approach to the runway. Performance was scored as heading deviations from the ideal flight path. Deviations were measured at 109 equal intervals along the flight path. The actual flight path was recorded on an area chart by means of an X–Y plotter coupled to the simulator.

Figure 1 also shows the instrumentation used to record physiological parameters. Skin temperature was measured by means of thermocouples at seven points on the body (forehead, chest, thigh, calf, dorsal foot, forearm, and palm) and recorded on a Honeywell Electronik 16 recorder (C). Mean skin temperature was calculated according to the formula of Hardy.[7]

Deep body temperature was measured by thermistor probe and a YSI Telethermomet (D). Heart rate was recorded on an Avion Electrocardiocorder Model 350 magnetic ta recorder (E) and displayed simultaneously on Tektronix oscilloscope (F). All physiologi parameters were recorded at five-minute interva In addition to the above, sweat loss (bo weight) and urine output were measured. order to insure adequate urine output and minimize dehydration, each subject drank ml/kg of water one hour prior to the expe mental runs. Body weight was measured one hc before the run and after the run (two ho elapsed time). Values for sweat loss are the fore available for the two hour period. Ur chemistries will be reported in another pap



IGURE 2. Diagram of the flight path used in this study. First leg was scored after pilot had climbed to altitude and was inbound to the VOR. The inbound leg of the holding pattern was flown down the instrument landing system approach to the runway.

.s in previous heat studies conducted in this ıboratory,[4 5] the subjects wore a headband to reclude sweat running into the eyes and thereby .terfering with vision.

I. Results.

All physiological values in Figures 3 and 4 are :trapolated back to zero time since the first easurements were made about 2½ minutes after e subject entered the simulator. Fig. 3 shows ›ep body temperature and skin temperature for l runs. Rectal temperature decreased about l5° C. (0.27° F.) during the "neutral" (25° C.) n and increased 0.35° C. (0.63° F.) during posure to 60° C. Skin temperature increased ring all runs; 1.0° C. (1.8° F.) during the ° C. run and 5.0° C. (9.0° F.) during the ttest run.

Heart rate changes are shown in Fig. 4. Heart :e increased during all runs; the greatest in›ase was about 25 beats/min during exposure 60° C. and 18 beats/ min at 43° C. During ›osure to 25° C., heart rate increased 10 ıts/min.

Some water exchange values are shown in Table 1. Skin and respiratory water losses varied from 132 gms for two hours at 25° C. to 613 gms at 60° C. Control urine output was about the same for all runs but urine excreted during the exposure varied from 498 gms at 25° C. to 272 gms at 60° C. Body water loss or dehydration was not extensive. During the 25° C. run body water content was essentially unchanged (~45 gms), while the loss was 108 gms at 43° C. and 360 gms at 60° C. The effect of temperature on performance was evaluated by the Wilcoxon matched-pairs signed-ranks test and is shown in Fig. 5. Statistical significance occurred on only three segments of the flight. However, in every segment of the flight, deviations in performance at 60° C. were greater than at 25° C. In one segment (1st leg) the performance decrement at 43° C. was greater than at 60° C. and in one segment (2nd leg) the decrement at 43° C. was less than at 25° C. Fig. 5 shows that significant differences in performance occurred as follows: 1st leg—43° C. worse than 25° C.; Turn 1—43° C. and 60° C. worse than 25° C.; ILS—60° C. worse than 25° C. and 43° C.

TABLE 1.—The water exchanges of pilots (12) flying simulator flights at 25, 43 and 60°C. Total water exchange is sum of sweat and urine output. Body water loss is difference of water intake and total water exchange.*

	Exposure Temperature		
	25.0°C (77°F)	43.3°C (110°F)	60.0°C (140°F)
Sweat and/or insensible loss (2 hr period)	132	319	613
Urine			
Control (1 hr period)	202	201	263
Experimental (1 hr period)	498	372	272
Total Water Exchange	832	892	1148
Water Intake	787	784	788
Body Water Loss	45	108	360

*All values in grams

Fig. 5 also shows that deviations were greater when the pilot was flying without localizer guidance. Turn 1, Outbound and Turn 2 were all off-localizer segments and the deviations were much greater than for segments where the pilot was flying on the localizer.

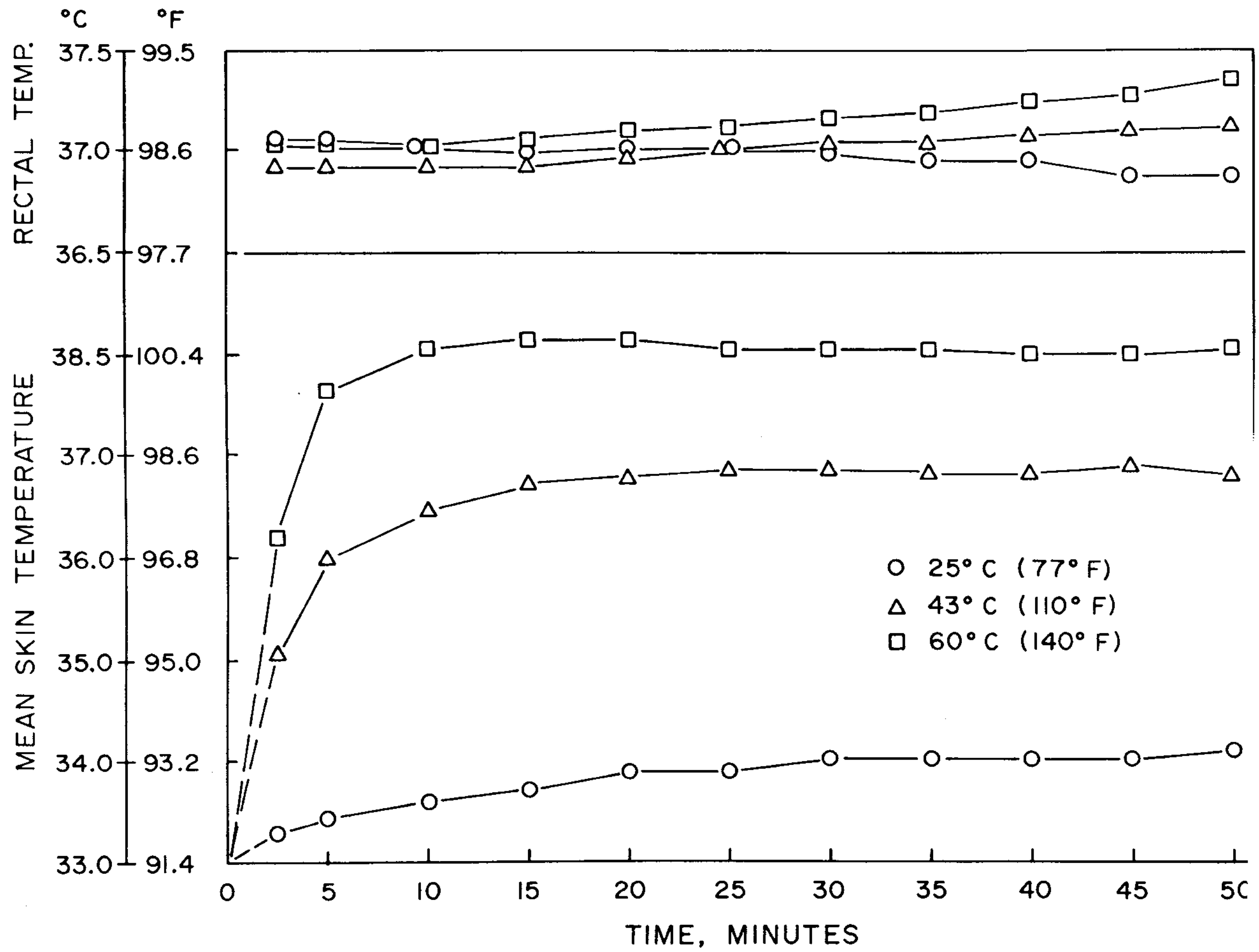


FIGURE 3. Deep body and mean skin temperature are plotted at five minute intervals during simulator flights ; cockpit temperatures of 25, 43 or 60° C. Values are means of 12 subjects.

IV. Discussion.

In an earlier study [4] we showed that performance on a complex task device which required time-sharing of different functions was not degraded after 30 minutes exposure to 60° C. but was after 5 minutes at 71° C. Another study [5] corroborated the results at 60° C. The present study was conducted to extend the earlier studies to a more direct simulation of the flying task. The General Aviation Trainer 1 (GAT–1) provides a very high degree of realism and is therefore relevant to the flying situation. Contrary to the earlier studies, the present study showed decrements in performance at 60° C. and further showed that decrements occurred at 43° C. In our earlier studies [4, 5] the subjects were exposed to hot conditions for 30 minutes plus the time required both to increase the temperature to the exposure condition (5–8 minutes) and to retu the temperature to the neutral condition (1 minutes); the total time of exposure to highe than-"neutral" temperature was thus 50–E minutes, with 30 minutes of that time at the e: posure temperature (60° C. or 71° C.). In tl present study the subjects were exposed to tl high temperature for the entire 50 minutes of tl run so comparisons of the studies are not entire in order. However, the fact that decrements : performance were observed at both 43° C. ar 60° C. during the early segments of the run (le than 30 minutes) indicates that time of exposu is not the only factor for consideration.

It is also apparent, as it was in our earli studies [4, 5] and also in the studies of oth workers,[8-11] that there is no clear relationsh between the degree of physiological change aı performance. Blockley [8] speculated that tole

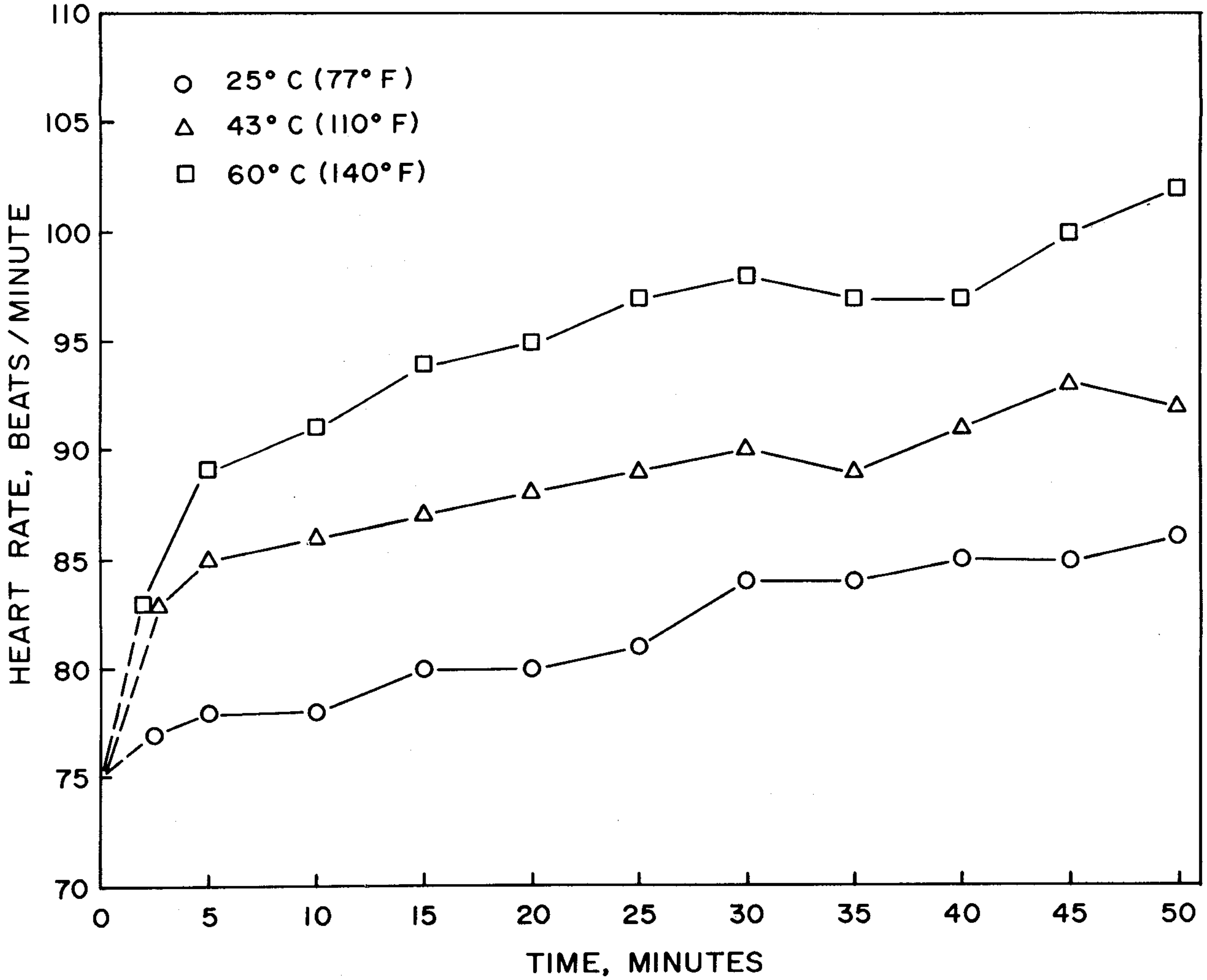


FIGURE 4. Heart rates at five minute intervals are plotted during simulator flights at 25, 43 or 60° C. Values are means of 12 subjects.

ance time may be influenced by the complexity of the psychomotor test performed by the subject. The changes in physiology in our studies were always within tolerable ranges and, except for the exposure to 71° C., had not even approached physiological limits. In addition, performance decrements, in some cases, appeared before any changes in physiology occurred. The degree of dehydration in the present study was minimized since the subjects were hydrated prior to the run. The largest body water loss (360 gms) was experienced during exposure to 60° C. However, it is possible that flights of this duration (50–60 minutes) and under the environmental conditions used here (43° C.–60° C.) could produce considerable dehydration if the pilots (subjects) did not replace any of the body water lost in sweat and urine. Performance decrements might then be related to the complex physiological functions which would be altered because of body water loss, i.e., increased body temperatures, increased heart rate (decreased blood volume). The increase in heart rate during exposure to 25° C. was probably autonomically induced. The excitement, as well as the difficulty of the flying task, were probably both involved.

Performance on complex task devices which require a high degree of alertness, mental function, muscular coordination and time-sharing of functions is more readily susceptible to degradation under adverse conditions than is performance of simple tasks (i.e., reaction time, meter moni-

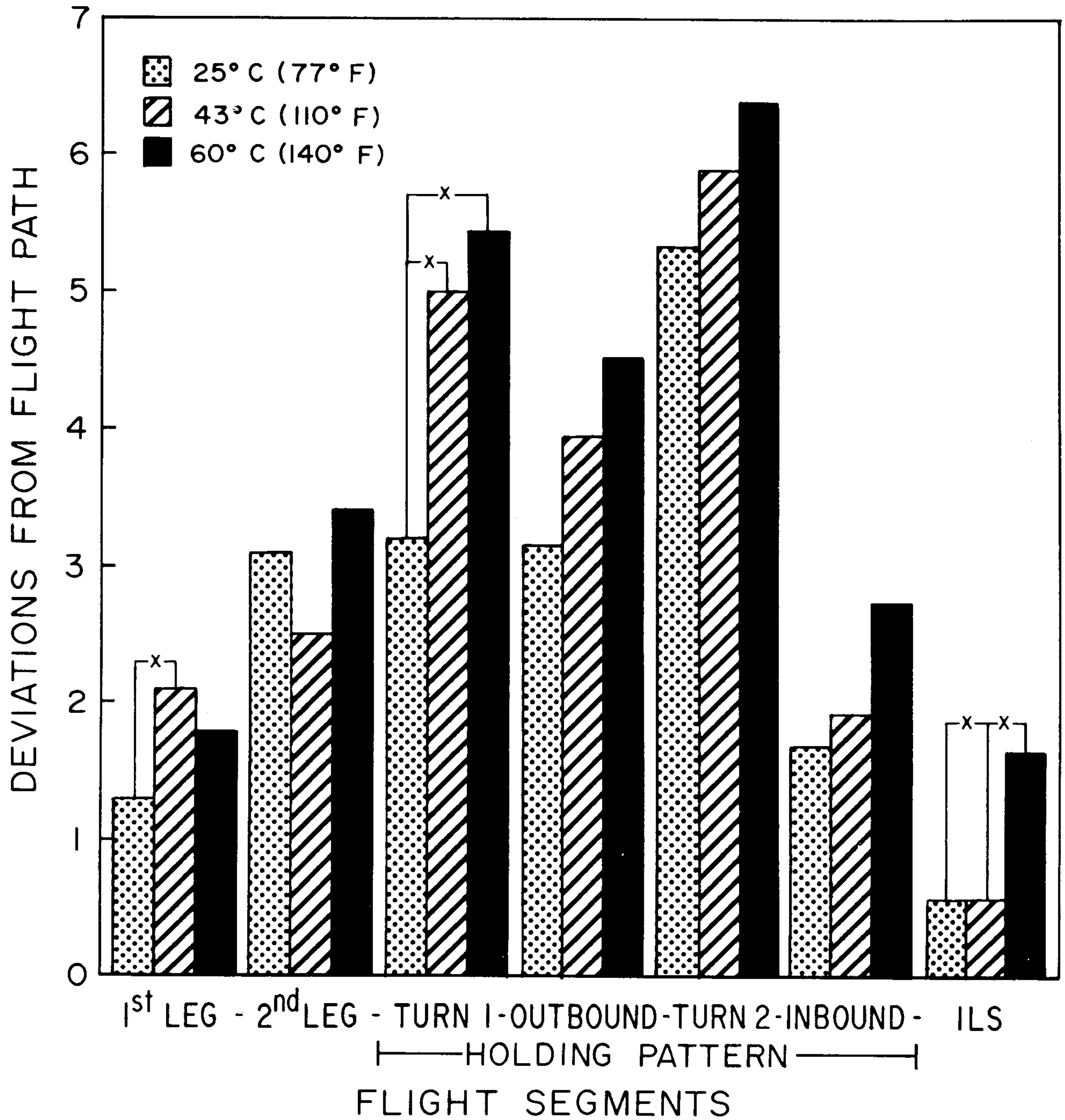


FIGURE 5. Deviations from a pre-determined flight path for the various segments of simulator flights are plotted for three exposure temperatures: 25, 43 and 60° C. All values are means of 12 subjects.

toring).[12] Performing an instrument flight in a simulator can be considered a highly complex task. The present study indicates that portions of the flight can be performed with no significant decrements in performance even during exposure to high temperature (43° C. and 60° C.). Those segments seem to be more "routine" and are associated with straight and level flight after becoming established on a radial. Performance on more complex segments of the flight (transitions or off-localizer operations) was adversely affected by the addition of a stress (exposure to high temperatures). It is important to point out that the effects of the heat are most apparent when the pilot is involved in the most complex and critical aspects of the flight segments. Thus, heat and criticality of operations can be considered as separate but summative stressors.

The results of this study should have implications for those flight activities which are conducted in hot areas and which require a great number of critical maneuvers. One such activity is agricultural spraying. The flights are at low levels, require a great deal of skill and alertness, and are flown under other adverse conditions than temperature, i.e. possibility of exposure to agricultural poisons. The pilots of general aviation aircraft in hot areas of the country may also be exposed to high temperature before and during flight and should be aware of the adverse effects of heat on performance. High ambient temperatures, in addition to altering physiology and performance of the pilot also alter performance characteristics of the aircraft, by increasing density altitude. Increased runway length is required; rate of climb is decreased; landing speed is increased; and maneuverability of the aircraft, in general, is decreased. The combination of factors, degraded pilot and aircraft performance, could be contributory in some general aviation, and particularly aerial applicator, accidents.

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