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The physiologic and performance effects of low level reconnaissance flying in hot environments were documented and quantitated. RF-4C pilots and weapons system operators were studied in hot and cool seasons during both high and low missions to distinguish environmental temperature from flight level effects. EKG, sternal and thigh skin temperatures and cockpit temperature at helmet level were monitored continuously. Body weights, oral temperatures, sweat Na/K ratios and urine electrolytes, steroids and catecholamines, as well as

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Biomedical Cost of Low-Level Flight in a Hot Environment

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The physiologic and performance effects of low-level reconnaissance flying in hot environments were documented and quantitated. RF-4C pilots and weapons system operators were studied in hot and cool seasons during both high and low missions to distinguish environmental temperature from flight level effects. ECG, sternal and thigh skin temperatures, and cockpit temperature at helmet level were monitored continuously. Body weights, oral temperatures, sweat Na/K ratios, and urine electrolytes, steroids, and catecholamines, as well as sleep and fatigue scores, were measured. Mission performance was assessed using photo target acquisition scores. RF-4C aircrews are exposed to moderate heat stress and acute dehydration (1.2% over 90 min) during low-level summer flights where cockpit temperature occasionally exceeded 50°C. Photo target scores indicated that the potential for crew error was increased, and that the margin of safety was accordingly decreased, during such hot missions. The RF-4C cockpit air conditioning system proved inadequate.

LOW-LEVEL reconnaissance flying in hot environments exposes flight crews to multiple stressors. Considerable experimental work has been done to measure human responses to elevated temperature and dehydration in the laboratory under controlled conditions (6,10,12,16). However, little similar data are available on aircrew physiology and, especially, performance during comparable operational situations in high-performance aircraft. Thus, the application of laboratory derived physiologic principles to flight operations often rests on assumptions or empiric practice. Quantitative assessment of aircrew physiology in adverse operational situations is essential to relate laboratory findings to practical questions of flying safety and mission performance.

The problems of inadequate cockpit air conditioning, especially elevated temperature, humidity, and canopy fogging, were reported by RF-4C crewmen and confirmed by their flight surgeons. Review of the Category II Climatic Evaluations of the RF-4C Aircraft (15) revealed that these problems were detected during the initial hot weather flights in Panama. However, the cockpit conditions had been studied only from the avionics and sensor engineering viewpoint and their physiologic significance had never been determined. Consequently, Operation Phantom Flame was designed to quantitate the physiologic and performance effects of hot, low-level flight in the RF-4C and to relate operational data to existing experimental knowledge.

MATERIALS AND METHODS

Data were collected from crewmen of the 16th TRS, 363 TRW, Shaw AFB, SC, during regular student train-

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This research was conducted jointly by personnel in the Environmental Sciences Division, USAF School of Aerospace Medicine, and the Flight Medicine Office, Shaw Regional Hospital The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 80-33.

ing missions. Volunteers with similar prior flight experience from two consecutive classes were used at identical phases of their flight training when they were flying the same mission profiles. The flyers studied in August 1973 formed the hot-season group shown in Table I, while the next class, in January 1974, comprised the cool-weather group. In each case, information was obtained during both high- and low-level reconnaissance missions. Simultaneous control data were collected from crewmen performing administrative duties on the ground. Flights were classified as low level if they had 30 min or more of high-speed (420 knots), low-altitude (152 m AGL) flying over circuitous courses several hundred miles long. High-level missions included air-to-air refueling, area cover, and other reconnaissance missions flown at altitudes greater than 610 m. Multiple simulated military targets (dams, bridges, etc.) were preselected for photography. The courses were flown with pilotage techniques so that relatively minor errors in heading, timing, or crew coordination would cause a missed target, especially at the lower altitudes. G forces usually ranged from 0 to +3 or 4 G_z in the turns. No aerobatics or defensive combat maneuvers were performed.

An experimental station was set up in the squadron personal equipment room. Urine samples were collected in dilute hydrochloric acid and further preserved by immediate freezing at −20°C They were shipped to the School of Aerospace Medicine where they were analyzed for urea by Auto-Analyzer, sodium and potassium by flame photometer, and catecholamines by a fluorometric method (19). 17-OH corticosteriods were measured by Endocrine Laboratories, Inc., Madison, Wi. All urinary variables were expressed as ratios to the sample creatinine, which was also determined by Auto-Analyzer. Accurate body weights were obtained before and after each flight using a scale sensitive to 5 g and accurate to the nearest 20 g. Sweat loss was calculated by subtracting the weight of fluid lost as urine from the total change in postvoiding body weight occurring during the mission. Sleep histories were filled out before each flight and questionnaires probing for details of the mission, cockpit conditions, and crew reaction were completed afterwards. Subjective fatigue forms were filled out both pre- and post-flight. Filter paper squares with impermeable backings were applied to two sites on the back of each crewman to absorb sweat. These were subsequently dissolved in concentrated HCl and the resulting solutions tested by flame photometer to determine the Na/K ratio of the sweat. Oral temperatures were measured pre- and post-flight using a Yellow Springs Instruments Telethermometer. During 16 of the summer and 17 of the winter flights, each crewman was monitored continuously with sensors for electrocardiogram (ECG) and cockpit temperature at helmet level, as well as for sternal and thigh skin temperatures. The outputs were taped on a 4-channel cassette-type analog recorder, which fit into the map compartment of the aircraft. The recorder was connected via a breakaway plug to a signal conditioner in the crewman's G-suit leg pocket. Simultaneous data were obtained from the pilot and weapons systems operator (WSO) to allow comparison of conditions in the front versus the rear cockpits. Ground temperature and dew points were recorded hourly by the Shaw AFB weather station. Cockpit humidity was measured on selected flights with a hand-held psychrometer. Mission performance was assessed on the basis of aircrew photo target acquisition scores by comparing the exposed sensor films with preflight target maps. Squadron photo interpreters determined the number of targets missed during all missions flown in each of the 2-week study periods whether or not the crews were being monitored. Misses due to pilot error were distinguished from those due to bad weather, in-flight emergencies, mechanical failures, or other factors beyond the crew's control.

TABLE I. PHANTOM FLAME SUBJECTS[1].

Group / Season	Ground control	Low level	High level	Season totals
HOT (Aug. 73)	24	26	30	80
COOL (Jan. 74)	23	20	46	89
Group Totals	47	46	76	169

[1]Some squadron personnel were sampled more than one time, in different groups on different days.

RESULTS

A representative low-level flight temperature profile for a WSO is shown in Fig. 1. After takeoff, the helmet-level temperature declined as the aircraft climbed to altitude. The temperature rose to more than 48°C. (118°F) during the low-level portion of the flight, then fell precipitously as the crew climbed back to altitude, leveled slightly as they landed, and fell again as they entered an air conditioned debriefing area.

The cockpit temperatures measured during low- and high-level flights were much higher than the ambient

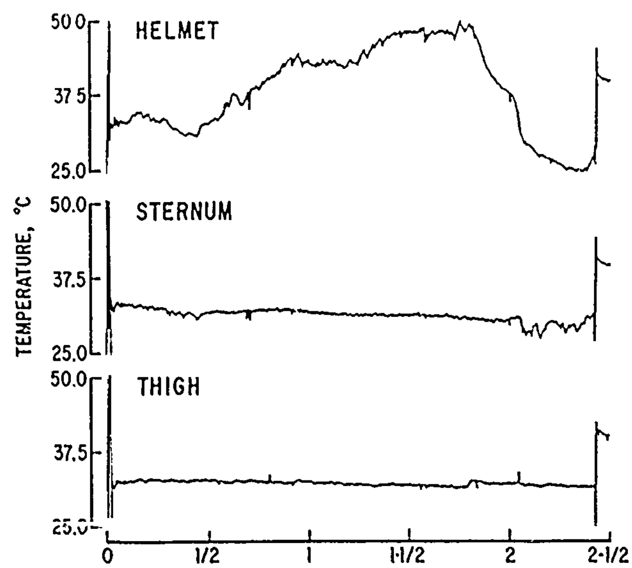

Fig. 1. Phantom Flame in-flight recording.

TABLE II ENVIRONMENTAL CONDITIONS—SHAW AFB, SC

	Study Day	1	2	3	4	5	6	7	8	9	10
	Condition										
	Max Temp[1]	34	34	32	33	31	33	31	29	27	32
Aug	Min Temp	28	31	27	27	26	27	22	24	23	24
1973	Max Humid[2]	53	74	83	78	83	70	77	72	77	83
	Min Humid	31	49	55	55	66	44	44	49	63	49
	Max Temp	21	16	24	24	22	3	16	26	24	12
Jan	Min Temp	17	8	16	17	19	2	9	18	17	10
1974	Max Humid	100	53	82	100	94	93	100	88	82	83
	Min Humid	44	29	60	68	77	63	82	49	44	74

[1]Temperatures in °C
[2]Relative humidity in percent
Temperatures and humidities are for the daily period 1000-1700 hours during which time Phantom Flame flights were airborne

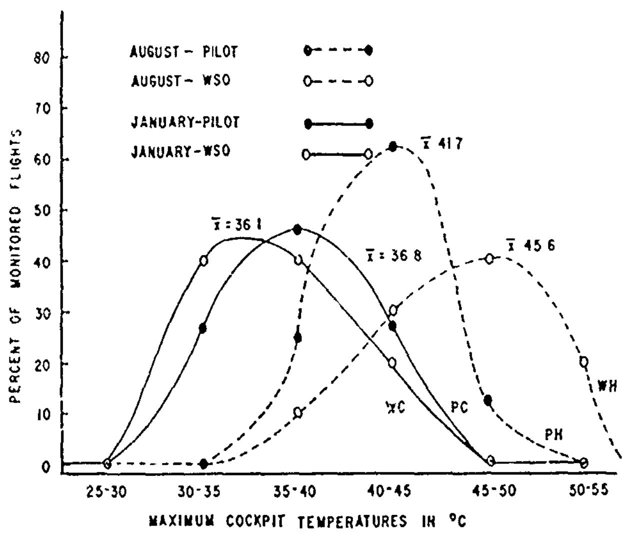

Fig 2 Phantom Flame cockpit temperature by season

temperatures The cockpit temperature distributions by season and position are shown in Fig 2 The corresponding environmental temperatures and humidities are shown in Table II. The in-flight wet- and dry-bulb temperature measurements revealed relative humidities varying from near 0 to 80%, depending on flight level. Before takeoff and at 152m AGL, cockpit humidity was usually greater than that of the surrounding atmosphere. The high humidity and problems with canopy fogging limited effectiveness of the aircraft air conditioning system at just the time when the high-speed low flight, relatively high ambient temperature, and marked heat trapping "green house" effect of the canopy were combining to produce uncomfortably high cockpit temperatures. Temperatures greater than 49°C (120°F) were recorded on three occasions and the maximum measured was 51.7°C (125°F). The seasonal nature of the problem is also evident from Fig. 2. The air conditioning system will provide a suitable environment during cool seasons, but not during hot, humid weather.

Interestingly, there was a marked difference between front and rear seat temperatures. During summer flights, the WSO was nearly 5.5°C (10°F) warmer at helmet level than the pilot. The WSO routinely experienced temperatures greater than 38°C (100°F) for more than 1 h, while the pilot's cockpit was warmer than 32°C (90°F). In the winter, the WSO was cooler than the pilot at head level. Sternal skin temperatures were nearly identical in the two positions, but thigh skin temperature was cooler in the rear seat during summer flights. Postflight oral temperatures showed no significant seasonal variations. However, the postflight measurements were made in the temperature-controlled squadron equipment room about 0.5 h after completion of each mission and thus may have been too late to detect heat stored during hot flights

The electrocardiograms were adequate for determining heart rate and the occurrence of gross arrhythmias. None of the latter were observed on recordings from either season Heart rates just before and during takeoff were 90-100 beats/min in the winter. Rates of 110 beats/min or more were generally observed at the corresponding times in the summer. After takeoff, heart rate could not be correlated directly with cockpit temperature but, rather, appeared to depend more upon what maneuvers or events were taking place at the time. However, heart rates greater than 120 beats/min occurred infrequently during winter flights, whereas they were observed during portions of nearly all summer flights The highest rates recorded were 150-160 beats/min during a hot weather mission.

As a first step in the analysis of physiological parameters, ground control data from both seasons were compared to detect any baseline shifts. Urine volume, potassium, sodium, Na/K ratio, urea, and 17-OHCS, as well as fatigue scores and oral temperature, showed no significant changes. The ground control epinephrine was 65% higher during the hot period ($p<0.025$) and sweat loss on the ground was nearly 300 g in the summer as compared to a negligible change in the winter ($p<0.005$). Interestingly, sleep scores were significantly higher ($p<0.01$) for the summer ground control group. Since most of these subjects flew the day before, the nearly 1-h longer sleep noted after flying in hot weather can be interpreted as an increase in recovery time necessitated by more stressful flying circumstances. In addition to this seasonal difference in sleep scores, there was a significant ($p=0.025$) variation by anticipated flight Crews that flew low-level flights got less sleep the night before their missions than did those who were scheduled for high-level flights.

Once baseline stability was known, the physiological data from both seasons could be compared. Sweat loss (Table III), expressed in terms of percent of total body weight lost, showed a significant season by level by position interaction (p=0.027). Both pilots and WSOs flying *low-level* flights lost much more fluid as sweat during the summer period. However, when *high-level* flights are compared by season, the backseat crewman again lost significantly more fluid in the summer (p=0.004) while the front seat occupant did not. When time of day, season, and position are considered (Table IV) an environmental effect is obvious in both positions (p=0.042). The seasonal increase in sweat loss is due primarily to hot, afternoon flights.

Crewmen flying in the summer and experiencing markedly increased water loss from sweating showed a significant (p=0.009) decrease in urine volume (Table V). The same crewmen excreted less urea than their winter counterparts (p=0.012). The Na/K ratio of the urine tended to show increased sodium conservation during hot weather, but the seasonal difference was not statistically significant. The Na/K ratio of the sweat also failed to show any significant seasonal variation.

Sodium excretion (Fig. 3) showed a significant (p=0.005) season by level interaction. Sodium loss was markedly diminished during low-level summer flights when compared to similar flights in the winter (p=0.001). In contrast, sodium excretion during high-level flights showed no such seasonal difference.

Urinary epinephrine showed a significant season by position by level interaction (p=0.028). Epinephrine excretion was greatest during low-level summer flights and least during high-level winter ones. Low flights in the winter and high flights during the summer produced intermediate levels. As in the case of sweat loss, WSOs flying on high-level missions showed significantly (p=0.035) increased epinephrine excretion in the summer relative to the winter, whereas pilots on high-level flights did not. The environmental basis for the effect is again confirmed by the position by level by time interaction

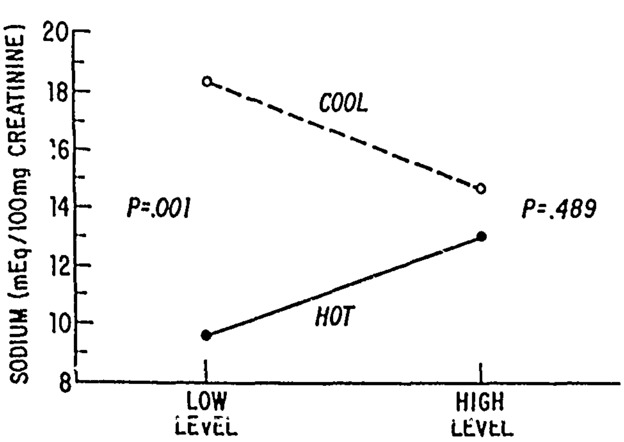

Fig. 3. Phantom Flame sodium excretion (season * level interaction: p=0.005).

TABLE III PHANTOM FLAME PERCENT SWEAT LOSS BY FLIGHT LEVEL.

	PILOTS		WSOs	
Season	Low	High	Low	High
Hot	1.128	.818	1.166	1.048
Cool	.439	.689	.616	.511
p	.002	.469	.012	.004

Season * Level * Position Interaction; p = .027

TABLE IV PHANTOM FLAME PERCENT SWEAT LOSS BY TIME OF DAY.

	PILOTS		WSOs	
Season	AM	PM	AM	PM
Hot	.872	1.073	.869	1.346
Cool	.534	.594	.630	.496
p	.090	.013	.228	<.001

Season * Time * Position Interaction; p = 0.042

TABLE V. PHANTOM FLAME SEASONAL VARIATIONS IN URINARY EXCRETION PATTERN.

Mean / Season	Vol. (cc)	Urea[1]	Na/K
Hot	85.2	987	2.72
Cool	141.1	1198	3.37
p	.009	.012	.122

[1]mg/100 mg creatinine.

TABLE VI. PHANTOM FLAME VARIATIONS IN 17-OHCS EXCRETION[1] BY SEASON, LEVEL AND POSITION.

Season	Pilot Low	WSO Low	Pilot High	WSO High
Hot	413.4	384.4	403.2	380.7
Cool	295.2	353.9	306.4	294.5
p	.034	.616	.020	.027

[1]In μg/100 mg creatinine.

(p=0.029). The difference between pilots and WSOs on high-level flights is significant only in the afternoon (p=0.020).

Steroid excretion was higher in August than in January for both pilots and WSOs (Table VI). The differences were statistically significant in three of the four groups when the comparisons included the appropriate ground control data. In the fourth, weapons systems operators flying at low level, the unusually large winter value is due to inexplicable large morning steroid values from a small number of subjects. WSOs flying similar missions in the afternoon showed changes paralleling the other three groups. Interestingly, the seasonal variation in steroid excretion showed a significant interaction with aircrew age. The older crewmen showed higher summer values and low winter values than their younger cohorts. Flight level did not affect 17-OHCS excretion.

Under all conditions of flying, subjective fatigue was highly significantly (p≤0.003) increased over ground control values. This increase in fatigue tended to be great-

TABLE VII PHANTOM FLAME PHOTO TARGET ACQUISITION SCORES

Season	Result	Missions	Targets
Summer	Successful	75 (75 8)	337 (91 8)
	Unsuccessful¹	24 (24 2)	30 (8 2)
	Total	99 (100)	367 (100)
Winter	Successful	76 (90 5)	245 (95 7)
	Unsuccessful¹	8 (9 5)	11 (4 3)
	Total	84 (100)	256 (100)

¹Due to crew error Percentages are shown in parentheses

er in the summer than the winter. However, variations in fatigue by season, flight level, and crew position were not statistically significant

The proportion of successful missions and the proportion of successful targets for the two seasons are compared in Table VII. The vast majority (>90%) of targets was photographed in both seasons. However, nearly twice the percentage of targets was missed in the summer (8.2%) as in the winter (4.3%). Moreover, the misses due to pilot error were not isolated in one or two extremely poor missions but, rather, were spread over 24% of the summer and 10% of the winter flights. The proportion of targets successfully acquired in the winter approached being statistically significantly higher ($p = 0.070$) than in the summer period. More definitely, reconnaissance crews were significantly ($p = 0.011$) more likely to have a completely successful mission in the winter time.

DISCUSSION

The Phantom Flame results indicate that RF-4C aircrews are exposed to moderate heat stress and dehydration during low-level flights in a hot environment. The 1.2% acute dehydration experienced by the men over 90 min has been shown to cause a 15-18% decrease in $+G_z$ tolerance (0 5-1.0 G) in similar subjects during centrifuge testing (17). Blackouts occurred at 3.8 to 4.3 G_z in 1% dehydrated subjects without G suits. No blackouts were reported by the aircrews during Operation Phantom Flame. However, all subjects were wearing G suits and were exposed to 3-4 $+G_z$ for relatively short periods of time. Under more stressful maneuvering in emergency or combat situations, the decreased G tolerance in dehydrated individuals would be significant.

The Na/K ratios of sweat and urine were determined for both the summer and winter groups as an index of temperature acclimation. A reduction in the concentration of sodium in these fluids often accompanies heat adaptation (11). However, finding no statistically significant differences is not surprising Since the Phantom Flame pilots spent only a small part of each day in the hot environment and the balance of their time in air conditioned facilities, their acclimation would only be partial. Moreover, if the subjects maintained a high salt intake, they might not have shown a change in the sodium content of their sweat even if they were heat adapted to some extent (11).

The cockpit temperatures (90-125°F) and humidities (50%+) experienced by RF-4C crewmen flying summer low-level flights constitute an environment far outside of the ASHRAE thermal comfort envelope (14). When such cockpit measurements are substituted into the Rohles-Nevins equation for predicting thermal sensation, they yield a value in the highest (hot) category. Although the aircrews' clothing insulation values and activity levels may not be identical to those used in determining the comfort envelopes, the flyers' subjective impressions confirm the mathematical predictions. In many cases, the cockpit temperatures were higher than body temperature so that radiation, conduction, and convection added to the body heat load rather than serving as a means of heat removal. Under these circumstances, sweating was the only major mechanism available for heat elimination. However, in the face of high humidity, evaporative heat loss is inefficient Sweat soaking the flight suit and rolling off the skin, but providing little effective cooling, accounted for much of the water lost when, for example, one crewman lost 4 8 lbs during a 90-min flight. The discomfort, inconvenience, and distraction caused by massive sweating may have been partly responsible for the observed performance decrement. However, heat by itself has demonstrable performance effects.

Several authors have recently reviewed the literature on performance at elevated temperatures (4,8,20). The levels of heat stress experienced by the Phantom Flame crews have been shown to decrease visual monitoring accuracy and tracking ability under experimental conditions. These performance decrements are most apparent in complex tasks, such as instrument flying Early flight simulation studies showed increasing performance errors as the temperatures and durations of exposure approached the limits of physiological tolerance (1). More recent simulation studies have demonstrated marked decreases in pilot performance when the temperature exceeds 43.3°C or 110°F (7). U.S. Army investigations of helicopter pilots revealed performance decrements and increased variability at cockpit temperatures above 43.3°C (13). However, other experiments using complex performance devices, monitoring, tracking, or arithmetic tasks have failed to demonstrate performance decrements at elevated temperatures (3,5,18). Consequently, it was not possible to predict from laboratory experience whether the performance of RF-4C aircrews would be affected by the stress of hot, low-level reconnaissance flights. The Phantom Flame photo target acquisition scores indicate that the potential for crew error is increased and that the margin of safety is, accordingly, decreased during such hot missions. These data lend operational support to the concept of increasing performance decrements in tracking, cognitive, and other skilled tasks at environmental temperatures greater than 29.4°C (4).

The temperature differences between the pilot and WSO cockpits are due, at least in part, to peculiarities of the RF-4C air conditioning system. Whereas the pilot receives cool air over his head and shoulders, the rear seat ducts open at the level of the WSO's knees. The back seat, consequently, has much poorer temperature control at head level than does the front seat. Since head temperature is a critical determinant of general thermal comfort, this difference may be reflected in the higher incidence of nausea observed among WSOs during hot summer flights relative to cooler winter ones. Other physiological differences detected between the two positions may also be related to the differing cockpit environments.

This study was conducted during hot and cool seasons with a difference in mean temperature of about 10°C so that environmental temperature effects could be distinguished from flight-level effects in a multistress situation. However, meteorological data alone are inadequate for predicting thermal conditions in the cockpit (9). The maximum ground temperature observed during the summer study period was 34°C, which is many degrees lower than the ground temperatures that aircrews must sometimes cope with elsewhere in the world. In contrast, cockpit temperatures occasionally exceeded 50°C. Relative humidity was also higher in the cockpit than the surrounding air. The physiological and performance changes indicate that an unacceptable cockpit environment developed despite air and surface weather conditions that were not extreme.

Operation Phantom Flame documented and quantitated the biomedical cost of low-level flight in a hot environment The RF-4C cockpit air conditioning system proved inadequate under the high temperature and humidity conditions of the study The degree of physiological change observed in the aircrews has resulted in diminished G-tolerance and decreased accuracy in critical tasks under laboratory conditions Most significantly, this study demonstrated an associated decrement in mission performance in an operational situation.

Special attention must be given to cockpit air conditioning when designing high-performance aircraft for low-level flight. The current RF-4C system is inadequate and should be revised. For example, ducting to provide head-level cooling to the WSO would markedly improve his situation Most flights studied were in aircraft manufactured prior to 1972 Later model RF-4Cs have a water separator, which was designed to solve the cockpit humidity and canopy fogging problems. Only a few flights in these aircraft were available for study and no significant improvement in cockpit conditions was noted However, no ducting changes have been made. Until revisions are possible, crew education and proper mission design will ameliorate the problems. Low-level training flights during hot weather should be limited in duration and preferably scheduled for the coolest times of day The importance of rehydration and adequate rest following hot, low flights must be emphasized to aircrews Finally, when operational requirements dictate that long, low, hot missions be flown, commanders should be aware of the possibility of decreased mission success and increased hazard to flying safety that such flights entail.

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REFERENCES

1 Blockley, W V, and J Lyman. 1951 Studies of human tolerance for extreme heat IV Psychomotor performance of pilots as indicated by a task simulating aircraft instrument flight USAF Aeromedical Laboratory Technical Report No 6521
2 Blockley, W V 1963 Heat storage rate as a determinant of tolerance time and duration of unimpaired performance above 150°F *Fed Proc* 22 Part I 887-890.
3 Chiles, W D, P F. Iampietro, E A. Higgins, J. A Vaughan, G West, and G E Funkhouser 1971 Combined effects of altitude and high temperature on complex performance FAA Report No AM71-17
4 Grethe, W F 1973. Human performance at elevated environmental temperatures. *Aerospace Med* 44 747-755.
5. Iampietro, P F, W D Chiles, E A Higgins, H. L. Gibbons, A Jennings, and J Vaughan 1969 Complex performance during exposure to high temperatures FAA Report No AM 69-10.
6. Iampietro, P F 1970 Tolerance to thermal extremes in aerospace activities *Aerospace Med* 41.1278-1281.
7 Iampietro, P F, C E Melton, Jr. E A Higgins, J. A. Vaughan, S M Hoffman, G. E Funkhouser, and J. T. Saldivar. 1972 High temperature and performance in a flight task simulator *Aerospace Med* 43 1213-1218.
8 Jones, R D 1970 Effects of thermal stress on human performance A review and critique of existing methodology. US Army, Human Engineering Laboratory, Aberdeen Proving Ground, Md Technical Memorandum 11-70
9 Kaufman, W C 1968 Inadequacies of meteorological data for predicting thermal stress *Aerospace Med.* 39:1326-1328
10 Klemm, F K, A. T Kissen, and J F Hall, Jr. 1972 Preflight heat stress and recovery AMRL Technical Report No 72-87
11. Leithead, C S 1963 Water and electrolyte metabolism in the heat *Fed Proc* 22 Part I 901-908.
12 McConnell, W J, F. C Houghton, and C. P. Yaglou. 1923, 1924 Some physiological reactions to high temperatures and humidities ASHVE Transactions 29.129, and 30·167
13 Moreland, S, and J. A Barnes 1970 Exploratory study of pilot performance during high ambient temperature/humidity US Army, Human Engineering Laboratories, Aberdeen Proving Ground, Md Technical Memorandum No 6-70.
14 Rohles, F H., Jr, and R G Nevins 1973 Thermal comfort New directions and standards *Aerospace Med* 44 730-738
15 Sandstrom, C K. 1967 Category II climatic evaluations of the RF-4C Aircraft Aeronautical Systems Division, Wright-Patterson AFB, Oh Technical Report No 6712.
16 Saltin, B, A. P Gagge, and J. A Stolwijk 1970 Body temperatures and sweating during thermal transients caused by exercise *J Appl Physiol* 28 318-327.
17. Taliaferro, E H., R R Wempen, and W J White 1965. The effects of minimal dehydration upon human tolerance to positive acceleration *Aerospace Med* 36.922-926.
18 Vaughan, J A, E A. Higgins, and G. F. Funkhouser. 1968. Effects of body thermal state on manual performance *Aerospace Med* 39 1310-1315
19 Von Euler, U. S, and F Lishajko 1959 The estimation of [illegible] *Acta Physiol. Scand* [illegible] 132
20. Wing, J F. 1965 Upper thermal tolerance limits for unimpaired mental performance *Aerospace Med.* 36 960-964.