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EXPLORATORY STUDY OF PILOT PERFORMANCE DURING HIGH AMBIENT TEMPERATURES/HUMIDITY

Stephen Moreland
John A. Barnes

March 1970
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HUMAN ENGINEERING LABORATORIES

ABERDEEN RESEARCH & DEVELOPMENT CENTER

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ABSTRACT

The purpose of this study was to measure performance changes which may occur when Army personnel, wearing complete operational/combat flight clothing and equipment, fly a Light Observation Helicopter during periods of high ambient temperature and humidity. Important relationships were found between physiological changes and crew station environment. An equation was developed to quantify a hypothetical relationship between performance, environment and physiological changes.

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EXPLORATORY STUDY OF PILOT PERFORMANCE

DURING HIGH AMBIENT TEMPERATURES/HUMIDITY

INTRODUCTION

This study was undertaken to explore techniques which could provide quantifiable information to:

1. Determine if changes in pilot physiological and psychological performance could be detected and correlated with changes in relatively high crew-station ambient temperature, humidity, and solar radiation.

2. Assess quantitatively the compatibility of pilots wearing complete combat flight clothing and survival equipment, with a new (prototype) Army aircraft system operating in a hot, humid environment. The intent of this analysis was to point out hardware and clothing problem areas, if any should exist, and to make appropriate corrective design recommendations before the aircraft became operational.

Isolating and measuring the factors contributing to pilot fatigue and efficiency has challenged the scientific community since aircraft began to fly. The principal question unanswered has been to what degree do these factors contribute to or cause human performance decrements and errors, and ultimately, to what degree should they be considered in the design of the aircraft.

Previous Army field reports have suggested that one of the most significant environmental factors contributing to pilot flight-performance decrements may be the combined effect of high temperature and humidity. A search of related literature, however, indicates that no one has been able to define these decrements in sufficiently precise quantifiable terms to verify significant performance changes or fatigue, or to establish adequate criteria for the design of aircrew environmental control/ventilation systems (ECS) and related aircrew clothing and survival equipment.

The design and development of ECS hardware has by necessity been determined more by crewmembers' subjective opinions and, to some degree, by what the airframe contractors happened to furnish as "off-the-shelf" hardware and systems. Unfortunately, subjective opinions are difficult to design to, are unreliable regarding estimates of heat, and in general do not provide the framework of data needed to develop crew-station design standards.

There is also a tendency to rely on an assumed ability of the aircrew to adapt to the environment. This allows the tradeoff arguments of increased costs and weight to dominate the design of the crew station, to the neglect of an adequate environmental system.

The net effect of this design approach has been that Army crews, in order to compensate for inadequate cooling/ventilation, make field changes such as removing the doors from the aircraft to provide additional ventilation.

The increased performance capability of current and projected Army aircraft (LOH, AH-56A, AH-1G, UTTAS, etc.), however, will require that the doors and/or windows remain in place to achieve the full aircraft flight performance envelope. Their mission requirements will require flight at near ground levels at which reflected solar radiation and high air-temperature levels will, in warm climates, be likely to aggravate the crew heat-stress problem.

METHOD

Aircraft and Study Site

A prototype light observation helicopter (LOH, OH-6A no. 4211, Fig. 1) was instrumented as the test vehicle (Figs. 2, 3).

Fort Rucker, Ala., was selected as the study site because of its capability to maintain and support the aircraft, availability of additional personnel needed to conduct the study, and a favorable climatological history, which indicated that relatively high temperatures and humidities would prevail during the study period. Predictions were August 1966, 91°F mean maximum temperature with 70% mean Relative Humidity (RH); September, 1966, 88°F mean temperature with 65% RH.

These temperatures and relative humidities were similar to the environment of Southeast Asia (13), one of the likely candidate areas for the deployment of the LOH.

Subjects

Four fully qualified Army LOH pilots served as subjects. Complete medical histories of each pilot-subject were reviewed by Army Flight Surgeons before their selection as subjects. Complete anthropometric measurements were taken on each pilot-subject as a basis for comparative measures of proper clothing fit and potential cockpit compatibility problems. In addition, personal history data and flight-experience data questionnaires were used to determine the degree of matching between

Fig. 1. PROTOTYPE OF OH-6A LIGHT OBSERVATION HELICOPTER

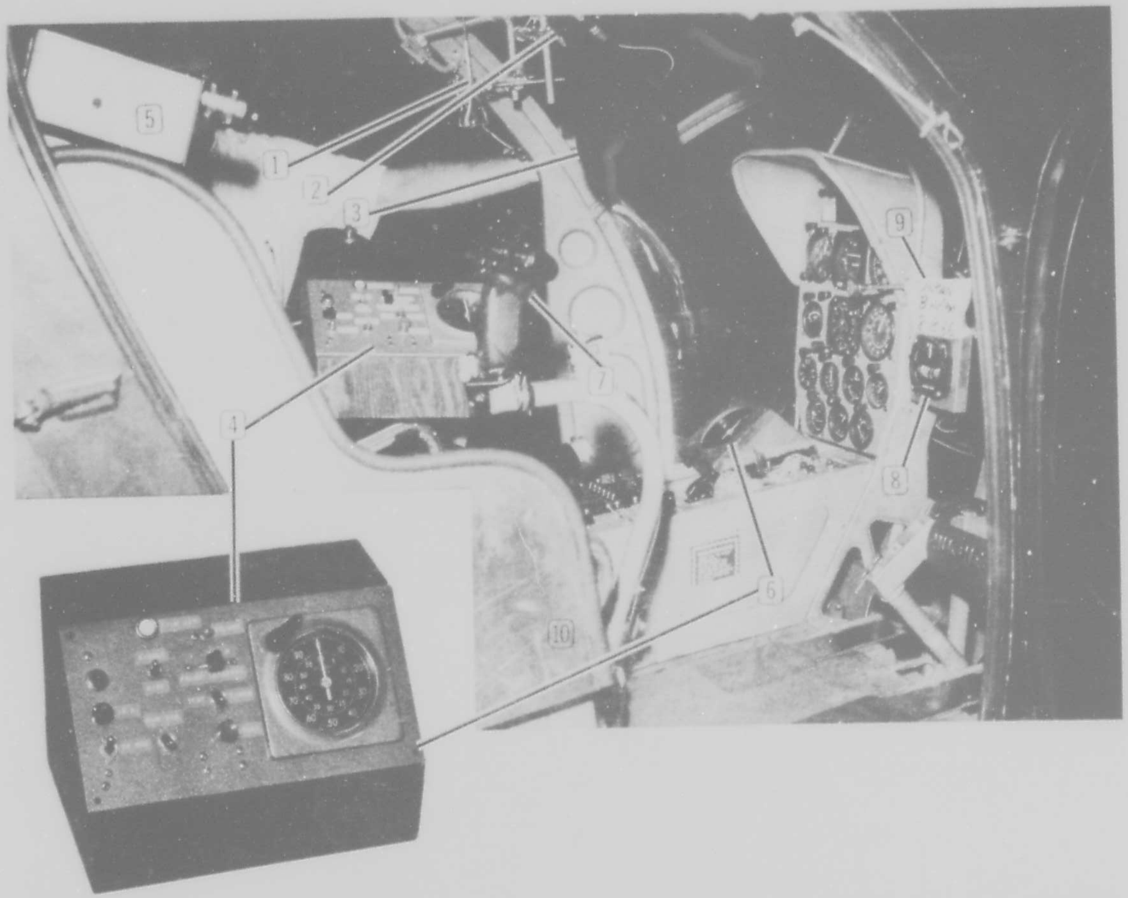


Fig. 2. PILOT COMPARTMENT INSTRUMENTATION (View illustrates: Mounting of WB (1), DB (2), & GT (3) environmental sensors; control box used (4); and response time signal switch (7); turn and bank indicator (8); flight identification placard (9); and imitation seat armor (10).)

Fig. 3. VIEW OF INSTRUMENTATION INSTALLED FOR THE PHYSIOLOGICAL OBSERVER (Shown are: (1) Tele-thermometer displays; (2) electrocardiograph recorder; (3) oscilloscope, and associated wiring to physiological and environmental sensors.)

subjects. (The formats used to collect this data are provided in Appendix A.)

The pilot-subjects had similar flight experience, were highly qualified, highly motivated instructor pilots, and as permanent residents of the Fort Rucker area, were acclimatized* and accustomed to flying in that area. Their qualifications tended to assure that learning effects, performance and flight variability due to acclimatization or area peculiarities like air traffic, weather conditions, special regulations, etc., would be minimized. No attempt was made to control or change the living patterns of the pilots during the course of the study. All were family men and enjoyed normal work and home activities. They were asked to be rested and not to fly other aircraft the day they were to fly as subjects.

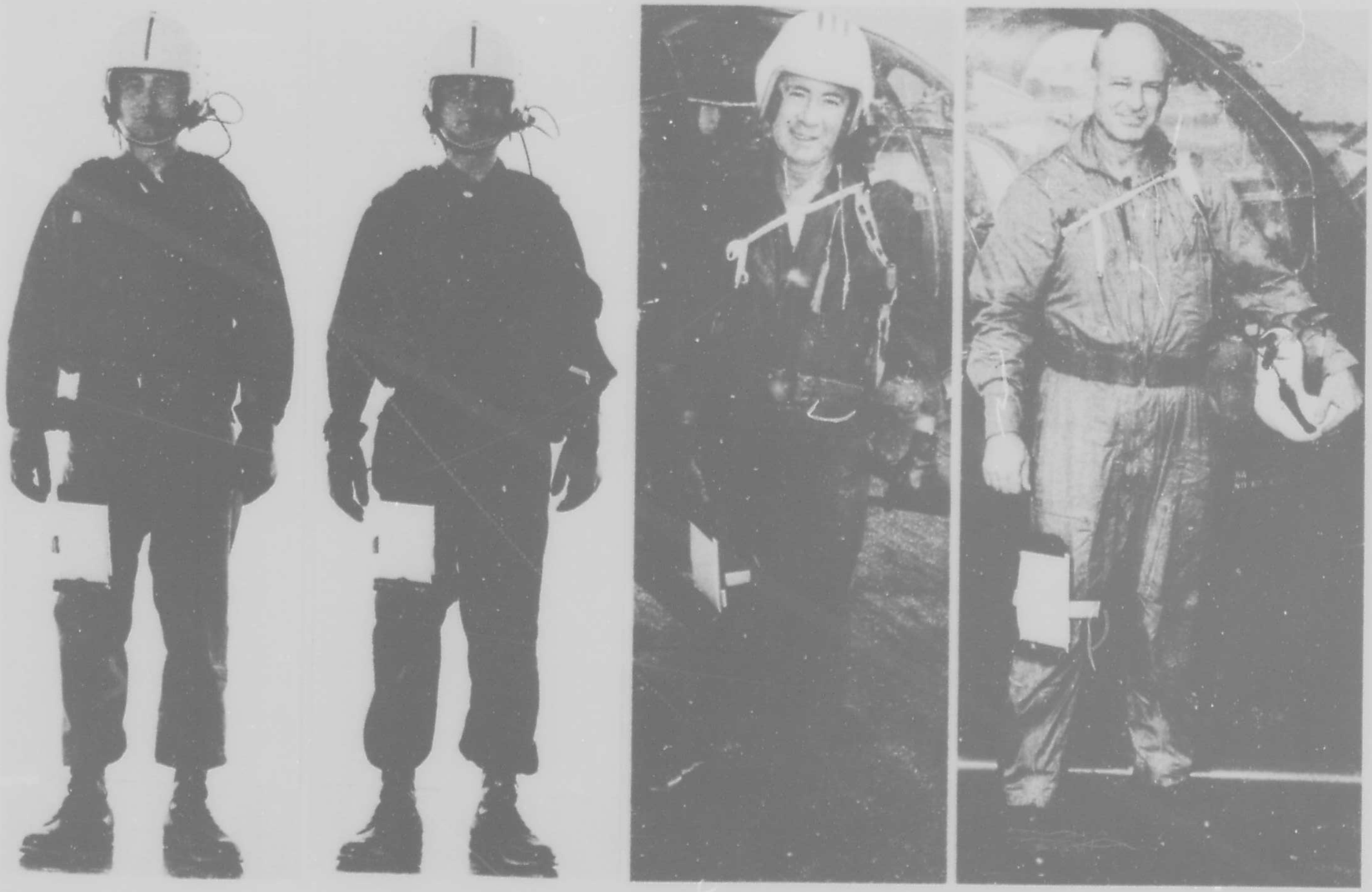
Pilot-Subject Flight Schedule and Clothing Matrix

The pilot flight clothing and survival configurations A, B and C (Fig. 4) were considered representative of what Army aviators are currently wearing and will be wearing in the near future. They were worn by the subjects during the study to duplicate the thermal insulation effects of operational clothing and equipment. The ventilated clothing configuration D (Fig. 4) was added to the study for an assessment, rather than as part of the experimental design. (A detailed description of the clothing and survival equipment worn during the study is provided in Appendix B.)

The experimental design for the study required each subject to serve as his own control. A total of 11 flights per pilot was scheduled; two in the morning plus nine in the afternoon. Eleven flights appeared to be adequate to sample the temperature region of concern (WBGT range of 80°F through 100°F). The subjects, flights and clothing configurations were assigned according to a random-number matrix to minimize experimental bias factors. (A copy of the resulting flight schedule is provided in Appendix C.)

AM flights were scheduled for one hour and PM flights for two hours. The AM flights were to be completed during the hours of 0530-0900, to obtain a level of pilot performance during cool or more ideal temperature conditions (WBGT < 85°F, but preferably within a range 70-80°F). Theoretically, it would have been desirable to duplicate two-hour AM flights for each two-hour PM flight flown, but this approach had to be abandoned because it was impossible to guarantee sufficient pilot and aircraft availability or to control ambient environmental temperatures. On the other hand, there appeared to be considerable evidence, both in the literature and from trial flights before the start of the study, to substantiate that no more than one-hour AM flights were needed.

*Previous work by Hendler (4) suggests that performance measures taken on acclimatized personnel would not be as sensitive to daily fluctuations of temperature and humidity as non-acclimztized personnel.



A. Army fatigues, armor chest plate.

B. Nomex fire resistant coveralls, armor chest plate.

C. Nomex fire resistant coveralls.

D. Ventilated flying suit.

Fig. 4. CLOTHING CONFIGURATIONS

1. Previous studies by Hornick (5), U. S. Army (14) and others report that measures of pilot flight performance (aircraft heading, altitude and airspeed control, navigation, etc.) indicated that there were no effective performance decrements or indications of fatigue during flights up to four hours duration, in a low-altitude high-speed flight simulator (operating with an assumed constant cool room temperature). These simulator flights also exposed the pilots to random gusts and vibrations up to .4RMS G and 1-12 CPS.

2. Trial flights of one to two hours in the prototype OH-6A before the start of the study indicated that pilot performance (P_1) seemed to level off within one hour.

3. The pilots' physiological responses were not expected to change significantly from the normal classical form during cool flights; i.e., some deviations at the beginning of the flight, then gradually returning to a normal state.

Two-hour PM flights were selected to enable ample time for physiological changes to occur, as has been demonstrated by studies of Hendler (4), DuBois (2) and others. These flights were to be completed during the hours of 1000-1600 to utilize the period of highest temperatures (WBGT > 85°F) in the Fort Rucker area.

Pilot Performance and Physiological Observers

During each flight two observers (usually non-pilots) obtained simultaneous pilot physiological and psychological performance and crew-station environmental measures. They also assisted in the instrumenting and weighing of the pilots on the ground, and conducted post-flight pilot debriefings. (Appendix D provides copies of forms used by the observers to log pilot performance data.)

They were required to closely monitor the pilot's physiological condition in-flight; primarily because no safety pilots were used during the flights and because inflight heat-stress exposure could not be accurately predicted. The following predetermined pilot physiological safety limit criteria were applied to determine when it was necessary to cancel a flight:

1. Any heart rate above 140.

2. If heart rate at takeoff was less than 100, the flight was to be terminated if the heart rate increased to 120.

3. Any rectal temperature exceeding 100.5°F.

4. If starting rectal temperature was less than 99.5°F, the flight was to be terminated if the temperature exceeded 100.0°F.

5. In all cases the flight was to be terminated if the rectal temperature exceeded 100.5°F.

A flight surgeon was also available for consultation via radio link, if required. Frequently, a flight surgeon flew on the flights as the physiological observer.

Ground Crew

A ground crew was also required for each flight to periodically change the configuration of the ground target, measure ground-level meteorological conditions and ocasionally monitor the pilot physiological data which was either voice-communicated or telemetered to the ground station. They also prepared the next pilot-subject ahead of schedule to minimize flight turn-around time.

Psychological Performance Measurement and Equipment

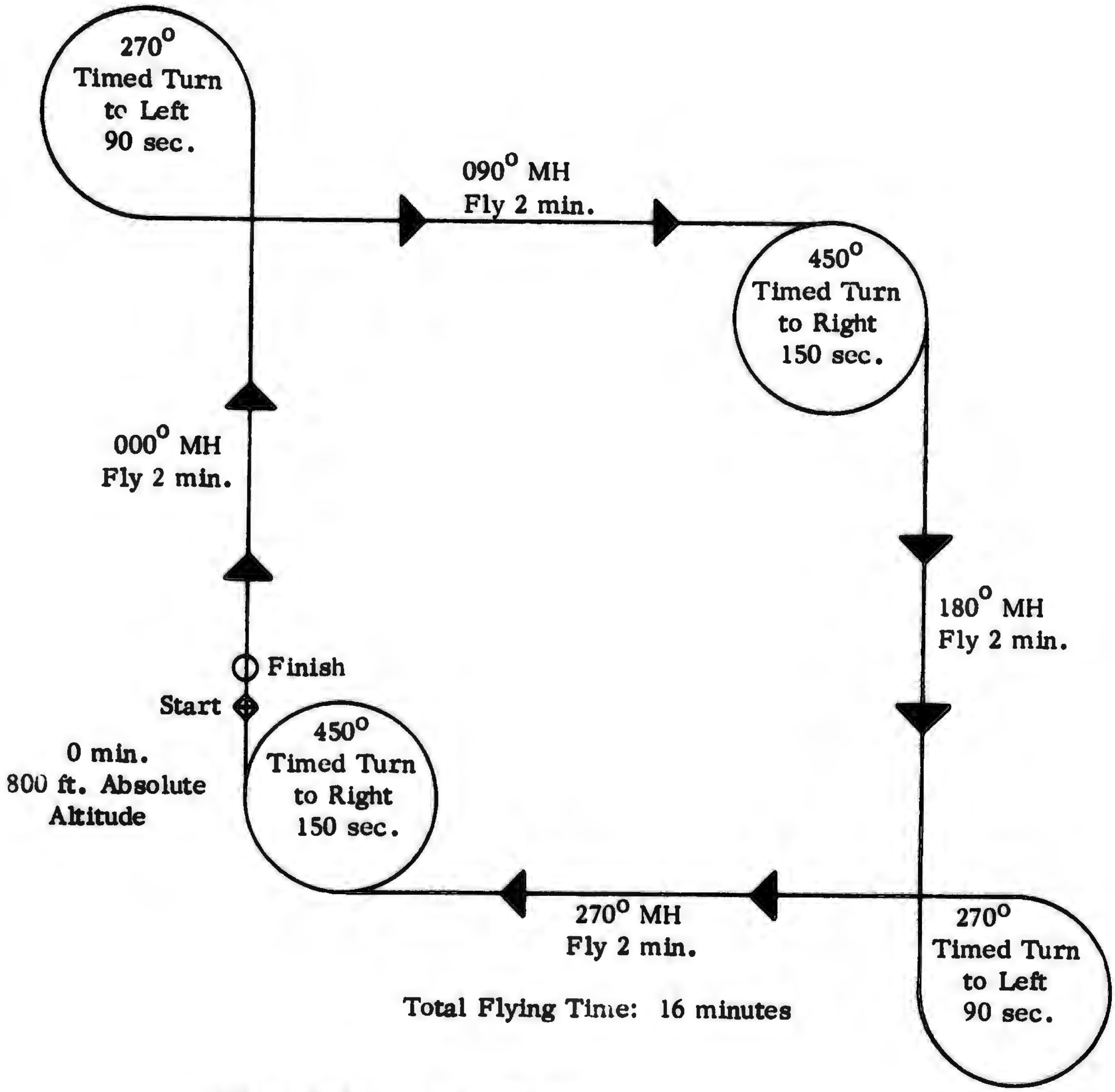
Precision Flight Pattern

A precision flight pattern entitled BRAVO (Fig. 5) was flown to obtain measures of pilot psychomotor flight tasks. No safety pilot was carried in the aircraft; therefore, the pilot had to fly the pattern as well as perform the pilot's normal duties of monitoring flight and engine instruments, fuel management, communications and other tasks. These normal duties appeared to be similar to the concentration, decision making and aircraft-control activities anticipated for pilots flying LOH missions.

The BRAVO pattern was derived from the U. S. Navy's "Charlie" pattern, used during WW II to train pilots to fly instruments and qualify for the standard Navy instrument card. A further discussion of the pattern may be found in the Navy All-Weather Flight Manual (17).

Flying the BRAVO pattern during this study was not considered as complex as flying by instruments alone, mainly because the pilot was allowed to see out of the aircraft to cross-reference his flight instruments. The performance criteria for the BRAVO pattern, therefore, appeared achievable and realistic as a performance measure for this study.

A movie camera was mounted in the aircraft (Fig. 2) to take pictures of the flight instrument panel at the rate of one frame per second (shutter speed of 1/250 second) during each BRAVO pattern flown. A turn-and-bank indicator, sweep-second timer and clock were installed (Fig. 2) for the pilot and performance observer to use during each flight pattern. (A photograph, illustrating some details of the camera mounting is provided in Appendix E.)



PERFORMANCE CRITERIA:

1. Hold Heading within $\pm 5^{\circ}$
2. Hold Altitude within ± 50 ft.
3. Hold Airspeed within ± 5 knots.
4. Fly Precision Timed Turns of 3° per/sec. within ± 2 seconds accuracy.

Fig. 5. BRAVO PRECISION FLIGHT PATTERN

Observation of Ground Targets

The pilot was given an inflight task of periodically observing and recording the configuration, time of flying the BRAVO pattern (Fig. 5). The task was designed to provide a quantitative assessment of pilot observation and reporting of ground targets while performing regular tasks -- a task similar to the actual mission requirements for the LOH.

The target consisted of nine parts, which could be arranged into any one of 20 circle-and-stick combinations (Appendix F). The largest portion was a plywood circle (doughnut) with an outside diameter of 16 ft. and an inside diameter of 14 ft. The remaining portions consisted of eight plywood boards, each measuring 8' x 2'. Each part was painted international fluorescent orange, which made the target detectable to a slant range of approximately two miles at an altitude of 800 feet, and identifiable at just under a mile. These ranges were based on a calculation using a visual angle of 2 minutes for target identification with daylight illumination and a brightness contrast ratio of target to background of more than 50 percent.

During each test flight a two-man ground crew positioned in the aircraft operating area changed the target configuration and orientation relative to true north each time the aircraft headed away from the target area, thereby assuring a new target display and orientation when the aircraft returned to the vicinity. These target changes were accomplished without communication with the aircraft, except for the use of a VHF air-ground radio link to alert the ground crew of the beginning and ending of the flight. All targets were displayed in accordance to the prearranged order obtained from the random number target assignment shown in Appendix E. The ground crew also recorded the time period in which each target was displayed. Pilot performance scoring was accomplished after the flight by comparing the ground crew's log (Appendix G) with the pilot's written observations. As a control on possible errors of omission by the pilot, the performance observer reported in the flight log each time the aircraft was within identification range of the target.

Response/Reaction Time Measures

The pilot's response and reaction times were measured 30 to 40 times during each flight. To accomplish the reaction time measurement, the pilot was alerted ahead of time that he was to receive a continuous tone 2000 CPS signal in his headset. At the onset of the signal, the pilot responded by pressing the trigger switch on his cyclic control, which stopped the signal and an elapse timer accurate to 1/100 second. The 2000 CPS signal was selected because it was not masked by the aircraft's ambient noise levels, because it did not resemble any existing aircraft signal or interfere with normal or emergency signals, and because it did not interrupt communications.

The response-time measures were taken the same way, except that the pilot did not receive any prior warning of the signal. In both cases the pilot was engaged in a primary task of flying the aircraft, which required his right hand to be on the cyclic control. Figure 2 illustrates the control box which the performance observer used during each flight to control the camera, elapse timers and pilot response-time signal.

Post Flight Debriefing

The pilot was debriefed after each flight for an appraisal of the environmental conditions, the clothing and survival equipment worn, and other flight conditions. Selected questions, which encouraged objective answers, were grouped on separate cards and given to the pilot to read and answer. All his comments were tape recorded.

The pilot interview was considered structured but open-ended. The interviewer remained silent during most of the recording to minimize any biasing of the pilot's responses to the questions. The pilot, in turn, was free to select question cards in any order of importance to him and could spend as much time as he wished to respond to the questions. (A copy of each question card used during the study is provided in Appendix H.)

Physiological Measurements and Equipment

Heart Rate

Measurement of the pilot's heart rate was taken by the physiological observer before, during and after each flight. Two silver electrodes were applied to the skin of the pilot's chest at the sternum (Fig. 6). Two wire leads (reference and recorder) connected the electrodes to a battery-powered oscilloscope and to a small (3 1/2 lb.) electrocardiographic recorder (Fig. 3). The observer manually recorded pilot heart-rate readings from observations of the oscilloscope every five minutes. The portable recorder made a continuous, permanent heart electrocardiograph record which was analyzed after each flight.

A "breadboard" portable telemetry unit was installed in the aircraft to assess the capability of the hardware to transmit both an electrocardiograph signal of the pilot's heart rate and the rectal temperature (Fig. 6). The system was installed as a redundant heart-rate monitor, primarily for test purposes.

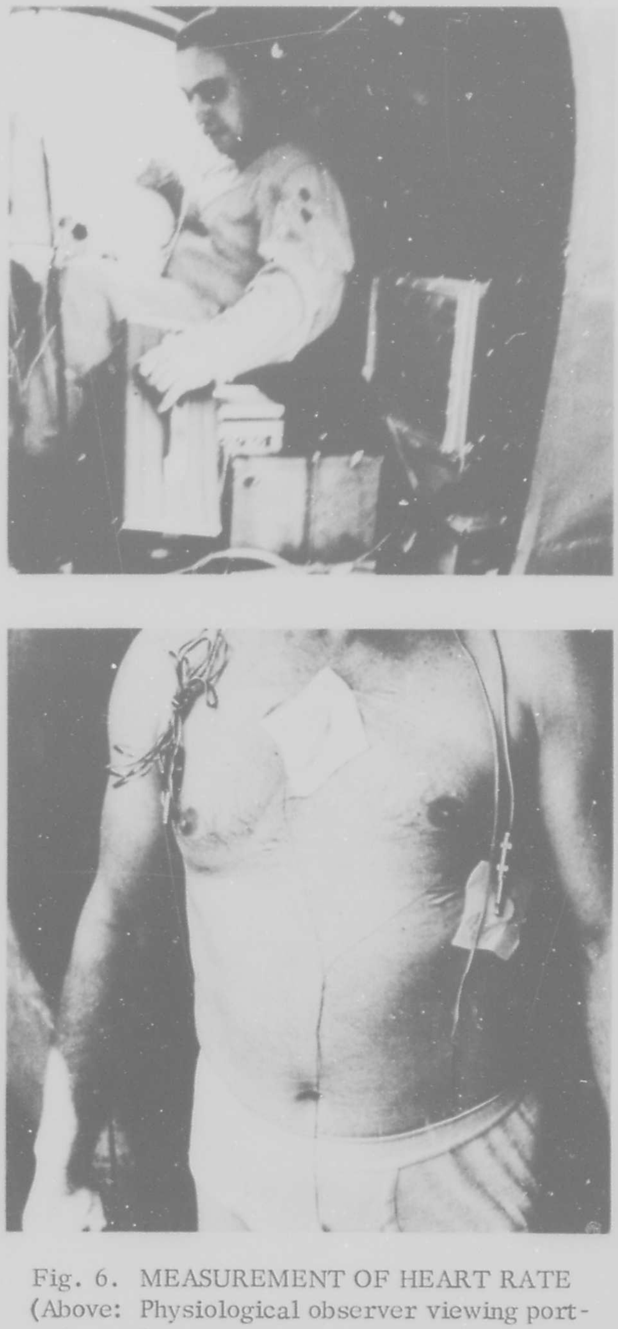


Fig. 6. MEASUREMENT OF HEART RATE
(Above: Physiological observer viewing portable oscilloscope. Below: Mounting of skin thermisters for measurement of heart rate.)

Body-Core Temperature

A rectal thermister probe worn by the pilot during each flight was wired to the temperature display at the physiological observer's station (Fig. 3) to enable inflight body-core temperature measurements every five minutes.

Skin Temperature

One skin-temperature sensor was worn on the inboard position of the upper thigh of the pilot during each flight. Studies by Teichner (11) indicated that one sensor placed in this position could provide an overall assessment of mean body surface temperature. A wire from the sensor was connected to the temperature display at the physiological observer's station (Fig. 3) to enable inflight readouts every five minutes.

Weight Loss

The pilot-subjects were weighed nude just before and after each flight to determine possible weight losses due to perspiration. The scale was accurate to the nearest five grams (approximately .01 lb.).

Airborne Environmental Measures

Wet bulb (WB), Dry Bulb (DB) and Globe Temperature (GT) thermisters were positioned in the cockpit just forward of the pilot (Fig. 2). Additional DB sensors were mounted at the crown of the cockpit, shaded from the sun, and at two locations on the physiological observer's seat (passenger compartment).

A Wet Bulb Globe Temperature (WBGT) Index was used as the overall measure of the total heat stress imposed on the subjects. WBGT Index is computed as follows, as per TB MED 175 (15):

$$\begin{aligned} \text{WBGT} = \; & 0.7 \text{ Wet Bulb Temperature } (^{\circ}\text{F}) \\ & +0.2 \text{ Black Globe Temperature } (^{\circ}\text{F}) \\ & +0.1 \text{ Dry Bulb Temperature } (^{\circ}\text{F}) \end{aligned}$$

Environmental measures were taken simultaneously with physiological measures at least every five minutes of flight.

Ground Meteorological Measures

WB, DB and GT measures were taken on the ground immediately before and after each flight to obtain comparative measures of WBGT for each flight. Measures of WB and DB were also taken periodically with an electric psychrometer as a cross-check on the temperature measures taken for the WBGT Index. Standard Relative Humidity (RH) was computed from the psychrometer data. (A photograph illustrating the temperature stand instrumentation is provided in Appendix I.)

The official DB, Dew Point (DP), wind and cloud cover, as reported by the Fort Rucker (Cairns Field) Flight Meteorological Services, were recorded for each test flight as a cross-reference for measures obtained by the study team.

Appendix J provides a summarized listing of all equipment (including the manufacture and model number) used during the study.

Data Reduction and Analysis

All physiological and psychological performance measures taken on each pilot-subject were obtained simultaneously with the crew-station environmental measures.

A photopanel exposure was made of the flight and engine instruments every second during each 16-minute BRAVO flight pattern. Usually, two or three patterns could be flown during each hour of flight. This data was reduced, recorded and compared to pilot physiological and psychological performance and environmental measures taken approximately every five minutes of flight. Because of the large volume of information generated during the study, a pilot study was initially performed in which different time intervals of collected data were sampled to determine the degree of performance changes and trends during these intervals. Ten-second intervals were selected as optimum for the photopanel data. Extrapolations were made between the five-minute intervals of data collected from the physiological and environmental measures to obtain corresponding information for each ten-second photopanel time frame.

For the purpose of recording and processing the data, this time frame was identified as a "line entry." A line entry represented all inflight performance, physiological and temperature measures recorded at ten-second intervals during each 16-minute BRAVO flight pattern. (Appendix K provides a more detailed description of the data reduction method and form used during the study.)

An equation was devised to represent an overall measure of pilot performance while he was accomplishing his primary task, flying the BRAVO pattern. This performance value could then be compared with the physiological and environmental measures occurring in the same time frame. The following formula was developed for computing the measure of pilot performance (P_1) for each line entry of the flight data:

$$P_1 = 100 - (\text{absolute airspeed error} + \text{absolute altitude error} + \text{absolute heading error} + \text{absolute } \Delta \text{ torque})$$

where 100 = an arbitrary scoring value for perfect performance. The absolute (abs) values were obtained by comparing the following precision-flight requirement values with the actual aircraft values achieved:

Airspeed (A/S) = 80 knots
Altitude (alt) = 800 feet absolute altitude (1100 feet indicated altitude at Fort Rucker, Ala.)
Heading (hdg) = as per the BRAVO flight pattern (Fig. 5)
Torque = the absolute difference of the value of present torque and the previous value of torque for any two sequential time periods. In the special case of the initial value of torque for each pattern, Δ torque was the absolute difference between 50 PSI and the value of torque. The value of 50 was chosen as representative of a realistic power setting for the aircraft and flight conditions. A variation of ± 2 PSI was considered normal for the power/load/airspeed operation of the OH-6A during the BRAVO pattern.

The numerical version of the formula for measurement of performance is as follows:

$$P_1 = 100 - \text{abs}(80\text{-A/S}) - \text{abs}(1100 \text{ alt}) - \text{abs}(\text{hdg error}) - \text{abs}(\Delta \text{ torque}).$$

The term "with limits applied" as used in this report references a variation of the P_1 value which has been computed with the tolerances allowed by the BRAVO pattern performance criterion (Fig. 5). The term "without limits applied" describes the actual performance (P_1), discounting the performance criterion tolerances.

To enable a comparison of the P_1 changes with changes in physiological and environmental variables, the data was organized in a form to enable the analyst to make use of the Ballistic Research Laboratories (BRL) Stepwise Multiple-Regression Computer Program developed by Breaux et al. (1). The candidate model equation used by this program considered all variables to the fifth power and then eliminated those which did not meet the criteria of a .001 level of significance. The candidate model for this experiment was described as:

$$P_2 = V1 + a_1V2 + a_2V2^2 + a_3V2^3 + a_4V2^4 + a_5V2^5 + a_1V3 + a_2V3^2 + a_3V3^3 + a_4V3^4 + a_5V3^5 + \ldots a_nV10^5.$$

where:

Factors	Reference Literature Source of Standards
V1 = Constant	Breaux, Campbell, Torrey (1)
V2 = 73 - Wet-Bulb Temperature Value	AFSCM 80-3 (12)
V3 = 100 - Globe Temperature Value	AFSCM 80-3 (12)
V4 = 90 - Dry-Bulb Temperature Value	AFSCM 80-3 (12)
V5 = 85 - WBGT Index Value	Minard (8), Yaglou (17)
V6 = 98.9 - Rectal-Temperature Value	DuBois (2)
V7 = 94.5 - Skin-Temperature Value	Hall & Klenn (3), DuBois (2)
V8 = Base Heart Rate-Heart Rate Value	Plattner (10)
V9 = 69 - Dew Point Temperature Value	AFSCM 80-3 (12)
V10 = 70 - Relative Humidity Temperature Value	AFSCM 80-3 (12)

(Appendix L provides a more detailed description of the derivation of factors V1 - V10.)

From the candidate model equation, the program derived an equation which provided the above variables (V1 - V10) with the proper exponents and coefficients to best describe (or best fit) the performance shown by the pilots. This program also provided a value for each line entry of performance as given (P_1) and as computed using the equation derived by the program (P_2). The difference between the value of P_1 and P_2 was known as the residual value. Theoretically, the ideal residual equaled zero, thereby substantiating the predicting capability of the derived equation P_2.

Computer analysis runs were made to determine the "best fit" performance equation P_2, both with and without crew performance limits applied for the following conditions: 1) AM flights, 2) PM flights, 3) all flights, and 4) those flights having a WBGT Index higher than 85°F.

The computer was also programmed to provide means, standard deviations, frequency counts and the values of N for other computations which were to be performed manually for the study.

RESULTS AND DISCUSSION

Measures of Pilot Performance With Temperature Changes

Measured data from all flights with a WBGT Index of greater than 85°F were grouped together as "hot" flights and compared with other flights by time periods (Table 1).

TABLE 1

Comparison of Pilot Performance on Hot Flights With Other Flights

Flight Time Periods*	Mean Perf. (P_1) (all subjects)	SD	Total Flights	Total Patterns	Line Entries
Morning	85.94	20.32	4	7	612
Afternoon	87.53	23.10	21	76	4452
Hot	81.196	25.688	6	24	1880
All Flights	87.33	22.785	25	83	5064

*Table 4 provides a summary of crew-station temperatures associated with each flight time period listed in Table 1.

Although no significant difference in performance was found, the trends clearly suggest that when the WBGT Index increases above 85°F, performance decreases and variability increases.

The change in performance with temperature changes was even more apparent when the mean performance flight data of pilots L and C, who completed all required flights, were compared with WBGT Indexes which were either greater or less than 85°F:

$$\text{Mean Performance (WBGT} > 85^{\circ}\text{F, 1695 line entries)} = 80.99$$

$$\text{Mean Performance (WBGT} < 85^{\circ}\text{F, 4159 line entries)} = 89.00$$

All flights were reviewed to determine associated temperatures when pilot performance (P_1) fell below an arbitrary value of 50. Table 2 summarizes mean temperatures from four flight patterns in which the mean low P_1 = 42.44 and the flight having the lowest performance score of 35.83.

TABLE 2

Associated Temperatures When Pilot Performance (P_1) Fell Below 50

P_1 = 42.44	P_1 = 35.83
WB = 76.8	WB = 94.4
GT = 110.4	GT = 118.6
DB = 100.5	DB = 103.1
RT = 99.5	RT = 99.9
WBGT = 85.9	WBGT = 98.1

Of the days in which both AM and PM flights were scheduled and flown by the same pilot, wearing the same clothing/equipment configuration, only one day's matching of flights yielded enough performance data to be reportable -- the rest were incomplete because of weather, inadequate film, flight cancellation, etc. Table 3 summarizes the flight performances versus temperatures for pilot-subject C, wearing the same clothing configuration, flying both an AM and PM flight on 4 September 1966.

TABLE 3

Comparison of Pilot Performance and Environmental Temperatures for Matched Flights

	AM Flight No. 18			PM Flight No. 20		
	Mean Perf. (P_1)	Perf. Var. (SD)	Mean WBGT	Mean Perf. (P_1)	Perf. Var. (SD)	Mean WBGT
First Flight Pattern	84.54	18.94	78.9	85.42	19.18	82.1
Second Flight Pattern	89.25	12.81	80.8	80.77	22.71	83.2
Total Flight	86.52		79.7	84.05		82.45

Though one sample of data (Table 3) cannot be used to predict, it does relate to other findings (Tables 1, 2 and 6) showing a tendency toward a decrease in performance as temperature increases and an increase in performance variability as temperature increases. (Appendix M provides a comparison of pilot performance during the first and next to last BRAVO patterns flow during afternoon flights.)

Table 4 provides an overall listing of some of the inflight measured performance and temperature data summarized from each flight flown during the study. (Appendix N provides the range of physiological and temperature measures during each flight of the study.)

TABLE 4

Means of Performance and Environmental Measures

Flt. No. and Pilot	Scored Flt. Patterns	Line Entries	Perf# (P_1)	A/S Error# (knots)	Alt. Error# (feet)	Heading Error# (degrees)	Delta Torque# (PSI)	Wet Bulb Temp. °F	Globe Temp. °F	Dry Bulb Temp. °F	WBGT Index °F	Rectal Temp. °F
MORNING FLIGHTS												
1C	1	74	76.77	3.00	1.29	36.98	1.67	67.85	92.43	82.45	74.23	99.23
6L	2	188	79.11	2.62	2.01	31.83	1.42	77.29	99.55	93.13	83.32	99.36
18C	2	180	86.52	2.80	1.88	21.28	2.18	74.72	93.61	86.73	79.70	99.30
21L	2	170	96.88	.66	1.18	7.22	3.03	73.58	94.84	88.88	79.36	98.89
AFTERNOON FLIGHTS												
* 7C	5	366	55.54	4.04	2.06	57.43	1.82	77.53	111.60	100.66	86.65	99.49
* 9L	4	338	93.49	1.72	1.65	11.92	3.16	93.15	110.92	98.71	97.26	99.50
*10C	4	295	75.79	2.84	.55	34.91	2.51	92.36	106.93	97.96	95.83	99.31
*11B	2	185	83.09	1.75	2.82	27.95	1.92	86.98	100.16	97.02	90.62	99.85
*15C	5	375	85.76	2.51	1.94	21.31	2.79	78.05	114.90	101.41	87.75	98.90
*16L	4	321	96.05	2.47	1.60	5.68	3.18	76.29	109.43	100.04	85.30	99.66
2G	2	189	91.31	4.06	2.99	18.80	4.04	69.91	102.69	91.51	78.62	99.69
3C	0	Cancelled because of aircraft malfunction										
4L	2	207	92.40	2.61	3.50	11.63	2.91	73.95	108.91	97.04	83.25	99.62
5C	4	258	61.49	2.74	2.04	55.92	1.64	74.84	103.38	98.54	82.91	99.47
8L	0	Cancelled because of rain										
12L	4	343	91.91	1.81	1.83	14.56	3.45	74.45	109.73	99.18	83.98	99.26
13C	4	334	90.76	2.24	1.46	15.05	2.09	74.40	102.72	99.18	82.54	98.26
14L	3	260	97.52	1.50	1.66	6.05	2.12	74.37	107.86	100.60	83.69	99.72
17C	1	80	76.31	2.78	2.00	31.89	2.71	73.69	96.44	94.85	80.35	99.50
19L	4	309	95.71	2.68	2.20	6.71	4.48	75.63	101.82	92.97	82.60	99.26
20C	2	251	84.05	3.27	2.57	25.74	2.43	74.14	104.98	95.44	82.43	99.22
22L	0	Incomplete performance data because of movie camera malfunction										
23C	3	237	84.14	2.39	1.76	23.87	2.88	73.49	107.93	96.81	82.71	99.04
24L	4	340	97.40	1.00	1.25	4.25	3.61	74.45	111.19	101.73	84.53	99.81
25B	5	373	73.06	1.83	1.46	42.36	1.91	70.68	105.19	98.50	80.37	99.70
26L	4	340	97.38	.62	1.12	4.42	3.59	72.34	100.06	92.05	79.85	99.29
27C	3	266	81.30	3.05	2.73	22.24	2.48	70.19	105.78	94.72	79.76	99.30
28L	4	322	95.70	2.91	1.65	5.24	4.82	71.10	111.02	99.75	81.95	99.43
29B	5	342	77.32	3.03	1.45	34.02	1.76	69.44	99.74	94.49	78.00	99.67

*Indicates Hot Flights, > 85°F WBGT. #With Performance Limits Applied

Correlation (r) of Pilot Performance Factors With Physiological and Environmental Temperatures

Individual pilot performance measured during the study was compared with recorded WBGT Index and physiological measures occurring simultaneously. Tables 5 and 6 summarize the resulting correlation (r) values for each pilot.

Significant differences from zero were determined at the .01 and 0.5 level for each pilot using the means of repeated measures from each flight pattern (Tables 5 and 6).

A search of the literature did not provide a clear basis to make a valid assessment of the importance of physiological correlation values. Low values of r may prove to be quite significant in areas such as rectal temperature where small changes can produce definite physiological changes. The results might be interpreted as trends and many appear to produce the expected results. For example:

1. For all subjects, WBGT appeared to have a positive correlation with heart rate (Table 5). This positive correlation would have been predictable according to results reported by DuBois (2), Hall (3) and others.

2. The negative correlation between performance and WBGT for pilots L and C (Table 6) might be considered a trend since these pilots flew the most flights and, therefore, represented a larger sample of behavior.

3. Three of the four subjects showed a negative correlation between performance and skin temperature (Table 5). The strong r of -.97 for pilot G should not be overinterpreted because it represents only one flight of data.

The Pearson correlation analysis of performance (P_1) and temperatures did not fully substantiate the predictor equation results determined by the stepwise multiple-regression program summarized in Tables 7 and 8. This difference probably occurs because the Pearson is a test of linear relationships, while the multiple-regression program defined a curvilinear relationship between all measures. (Appendix O provides a listing of pre- and post-flight heart rate data.)

Regression Correlation Analysis of Pilot Performance Versus Environmental Factors

Tables 7 and 8 summarize the computer analysis runs which established between all data entry measurement of the study the appropriate "best fit" predictor performance equation (P_2), both with and without crew performance limits applied (described in Method Section).

TABLE 5

Correlations of Pilot Performance and Physiological Measures

Comparative Measures	Pearson Correlation Values (r)# for Mean Flight Pattern Scores			
	Pilot L (n = 41)	Pilot C (n = 35)	Pilot B (n = 12)	Pilot G (n = 2)
Pilot Performance (P_1) vs. Skin Temperature	.5031**	-.0069	-.3467	-.9730
Pilot Performance (P_1) vs. Rectal Temperature	.0783	-.5453**	-.1035	.3145
Pilot Performance (P_1) vs. Heart Rate	-.4503*	.0473	.0124	.3335
WBGT vs. Skin Temperature	.2072	.2520	.2790	-.3887
WBGT vs. Heart Rate	.3640*	.8167**	.9307**	.6856
WBGT vs. Rectal Temperature	.2686	.1588	.8112**	-.3754

#Calculations are based on summaries of data obtained for each flight pattern of all flights (Table 4) for each pilot. Pilot G flew only one flight.

Minus (-) r indicates that as temperature increased, performance decreased.

*Significant at the .05 level.

**Significant at the .01 level.

TABLE 6

Correlations of Pilot-Performance (P_1) Factors and Environmental Temperatures

Measured Condition	Pearson Correlation Values (r) for Mean Flight Pattern Scores		
	Pilot L (n = 41)	Pilot C (n = 35)	Pilot B (n = 12)
Performance vs. Wet Bulb	-.0037	-.1461	.2339
Performance vs. Globe	.2039	.3440*	.0602
Performance vs. Dry Bulb	.2198	-.2273	-.2141
Performance vs. WBGT	-.1394	-.1800	.1867
Sigma Perf. vs. Wet Bulb	.2475	.0439	-.3094
Sigma Perf. vs. Globe	-.2144	-.0946	.2574
Sigma Perf. vs. Dry Bulb	-.2249	.1386	.2220
Sigma Perf. vs. WBGT	.1055	.0128	-.2400
Delta A/S vs. Wet Bulb	.0885	.2010	-.2855
Delta A/S vs. Globe	-.2557	.3103	-.0204
Delta A/S vs. Dry Bulb	-.2521	.0204	-.2726
Delta A/S vs. WBGT	-.0757	.2434	-.2957
Delta Alt. vs. Wet Bulb	.0619	-.4455**	.6364*
Delta Alt. vs. Globe	.2341	.0699	-.2432
Delta Alt. vs. Dry Bulb	.0523	-.3251*	-.0349
Delta Alt. vs. WBGT	.0819	-.3380*	.5699
Heading Err. vs. Wet Bulb	.2263	.1612	-.2398
Heading Err. vs. Globe	-.2629	.1240	.1502
Heading Err. vs. Dry Bulb	-.2528	.2560	.2038
Heading Err. vs. WBGT	.0602	.1800	-.1934
Delta Torque vs. Wet Bulb	-.1794	.2047	.0460
Delta Torque vs. Globe	.3940**	.6706**	.5741
Delta Torque vs. Dry Bulb	.3145	.2549	.6769*
Delta Torque vs. WBGT	.0535	.3321*	.1883

The anticipated correlation (r) relationships at the start of the study were as follows:

Performance:	negative value of r, temperature up, performance down.
S. D. Perf.	positive value of r, temperature up, S. D. Perf. up.
Airspeed:	positive value of r, temperature up, Delta Airspeed up.
Altitude:	positive value of r, temperature up, Delta Altitude up.
Heading Error:	positive value of r, temperature up, Heading Error up.
Delta Torque:	positive value of r, temperature up, Delta Torque up.

Pilot G was not listed because of insufficient data.

*Significant at the .05 level.
**Significant at the .01 level.

TABLE 7

Predictor Performance Equations

Performance Equations Without Performance Limits	Performance Equations With Performance Limits
1. All Flights: $P_2 = 94.218 + 4.118WB + .277WB^2 + .179GT^2$ $+ .011GT^3 + 2.629DB - .171DB^2$ $- .028DB^4 - .454WBGT^2 - .016WBGT^3$ $+ 3.463ST - .353ST^2 - .116ST^3$ $+ .072HR + .009HR^2 + .00007HR^3$ $- 1.572DP - .080DP^2 + .002DP^3$ $+ .391RH$ *Shortened Form: $P_2 = 94.5 + 4.118WB + 2.629DB + 3.463ST$ $- 1.572DP$	1. All Flights: $P_2 = 101.518 + 3.995WB + .272WB^2 - .286GT$ $+ 194GT^2 + .012GT^3 + 2.172DB$ $- .197DB^2 - .026DB^3 - .408WBGT^2$ $- .013WBGT^3 + 3.178ST - .346ST^2$ $- .119ST^3 + .310HR + .010HR^2 - .001HR^3$ $- 1.373DP - .076DP^2 + .002DP^3 + .182RH$ $+ .002RH^3$ *Shortened Form: $P_2 = 101.518 + 3.995WB + 2.172DB + 3.178ST$ $- 1.373DP$
2. Morning Flights (WBGT < 85°F): $P_2 = 76.179 - .375WB^2 + 8.751GT$ $+ 1.673GT^2 + .094GT^3 + 30.763RT$ $- .092DP^2 - 500.571RT^5$ *Shortened Form: $P_2 = 76.179 + 8.751GT + 1.673GT^2$ $+ 30.763RT - 500.571RT^5$	2. Morning Flights (WBGT < 85°F): $P_2 = 77.702 + 9.162GT - 1.681GT^2 - 73.039RT^2$ $- .087DP^2 - .0004RH^3 - 623.55RT^5$ $- .092GT^3$ *Shortened Form: $P_2 = 77.702 + 9.162GT - 1.681GT^2$ $- 73.039RT^2 - 623.55RT^5$
3. Afternoon Flights: $P_2 = 67.025 + .423WB^2 + .006WB^3 - .412GT$ $+ .382GT^2 + .020GT^3 + 2.459DB$ $- .208DB^2 - .031DB^3 + 6.722WBGT$ $- .549WBGT^2 - .027WBGT^3 + 2.955ST$ $- .552ST^2 - .156ST^3 + .247HR$ $+ .011HR^2 - .001HR^3 - 1.758DP$ $+ .00005DP^3 + .0004RH^3$ *Shortened Form: $P_2 = 67.1 + 2.459DB + 6.722WBGT$ $+ 2.955ST - 1.758DP$	3. Afternoon Flights $P_2 = 78.378 + .379WB^2 + .006WB^3 - .479GT$ $+ .353GT^2 + .019GT^3 + 2.528DB$ $- .183DB^2 - .028DB^3 + 5.798WBGT$ $- .485WBGT^2 - .026WBGT^3 + 2.53ST$ $- .528ST^2 - .149ST^3 + .242HR + .010HR^2$ $- .001HR^3 - 1.556DP + .027DP^2$ $+ .0003RH$ *Shortened Form $P_2 = 78.378 + 2.528DB + 5.798WBGT + 2.53ST$ $- 1.556DP$

*Shortened forms of predictor equations are provided for ease of reader interpretation and to highlight the more prominent factors contained in the performance equation. It was derived by arbitrarily dropping all factors with a coefficient of less than 1.0.

TABLE 8

Predictor Performance Equations, Special Conditions

Performance Equations with Performance Limits

4. Hot Flights (WBGT > $85^{\circ}F$):

$$P_2 = 187.828 + .5668GT - 1.590DB + .2043WBGT^2 + 526.03RT + 848.976RT^2 + 439.213RT^3 + 9.7947ST - 5.3511ST^2 - 1.2024ST^3 + 1.5525HR + .0849HR^2 - .0029HR^3 - .2653RH^2 + .0114RH^3$$

*Shortened Form:

$$P_2 = 187.8 - 1.6DB + 526RT + 849RT^2 + 439RT^3 + 9.8ST - 5.4ST^2 - 1.2ST^3 + 1.55HR$$

5. All Flights with RT, ST and HR out:

$$P_2 = 68.338 + .2616WB^2 - 1.0346GT + .1558GT^2 + .0104GT^3 + 2.2592DB - .2091DB^2 - .0295DB^3 + 5.4089WBGT - .4351WBGT^2 - .0153WBGT^3 - 1.043DP - .0432DP^2 + .00099DP^3 + .2777RH$$

*Shortened Form:

$$P_2 = 68.4 - 1.0GT + 2.3DB + 5.4WBGT + 1.0DP$$

*Shortened forms of predictor equations are provided for ease of reader interpretation and to highlight the more prominent factors contained in the performance equation. It was derived by arbitrarily dropping all factors with a coefficient of less than 1.0.

The stepwise multiple-regression solution of the effects of various temperatures upon performance was an attempt to derive a predictor equation for performance based on environmental temperatures. It would have been most satisfying if the solution for each condition of environmental temperatures had provided a linear equation with each variable included; but, in fact, each condition produced a different equation. The equation which applied limits to the performance measures were quite similar to the equations for the same condition without limits, and the similarity served to verify the equations.

Equation 2 for the cool (morning) flights (Table 7) emphasized the importance of the Globe Temperature and Rectal Temperature and assigned lesser significance to Wet-Bulb Temperature and Dew-Point Temperature. The large coefficients assigned to Rectal Temperature represent moderate values when it is considered that these changes were tenths of a degree while, in general, the other values changed by whole degrees during the flight investigated.

The flights which were flown under extremely hot (WBGT Index > 85^{o}F, Equation 4, Table 8) conditions also emphasized Rectal Temperature and added Skin Temperature, Dry-Bulb Temperature and Heart Rate while assigning a lesser significance to Globe Temperature. This equation also considered WBGT Index and Relative Humidity and dropped Wet-Bulb Temperature and Dew-Point Temperature.

The afternoon series of flights (Eq. 3, Table 7), which included the "hot" flights, assigned importance to Dry Bulb Temperature, WBGT Index, Skin Temperature, and Dew Point Temperature. Heart Rate and Relative Humidity were also considered as contributing to the value of performance.

The total solution of all flights (Eq. 1, Fig. 7) listed Wet-Bulb Temperature, Dry-Bulb Temperature, Skin Temperature and Dew Point as the major variables and Globe Temperature, WBGT Index, Heart Rate, and Relative Humidity as contributing variables.

The final equation in this group (Eq. 5, Fig. 8) considered all of the flights' data but did not compute coefficients for the physiological variables (rectal temperature, skin temperature and heart rate). The results were similar to those for the total flights (Eq. 1) with greater importance placed on Globe Temperature and WBGT Index, while Wet-Bulb Temperature was considered less important that it was in the total flight equation.

Effect of Turbulence on Pilot Performance

There was a question of whether the difference in performance between the "cool" and "hot" flights was perhaps due to the turbulence caused by the heating of the ground. Seven of the flights had a notation by the observer that there was moderate turbulence during the flight.* These flights were statistically compared with flights which had no such notation but which had the same pilot and were matched as closely as possible for equal number of line entries and for equal WBGT values (see Table 9 for a summary of the results).

TABLE 9

Comparison of Pilot Performance During Turbulent and Non-Turbulent Flights

Flight	P_1 (Limits Applied)	SD	Line Entries	t
10C*	75.79	24.88	295	3.6888
5C	61.49	39.00	258	
15C*	85.76	18.94	375	11.1826
7C	55.54	32.99	366	
16L*	96.05	4.97	321	5.2246
12L	91.91	9.54	343	
19L*	95.71	5.80	390	-3.2540
26L	97.38	3.38	340	
20C*	84.05	20.22	251	-0.0600
27C	84.19	17.21	266	
23C*	84.14	19.34	237	-0.0216
27C	84.19	17.21	266	
24L*	97.40	3.46	340	-0.2727
14L	97.52	4.07	260	

*Turbulence noted by observer and pilot.

*Standard inflight terminology as used by the joint services and defined in TM 1-300 (15) was used to report the degree of turbulence encountered during each flight. These classifications of turbulence are selected according to the effect of the turbulence on the aircraft.

The negative values of t are the cases in which the performance is better under the "hot" non-turbulent conditions. There was only one case (Flight 19) of seven in which there was an apparent disadvantage due to turbulence. During this flight turbulence was noted as increasing from moderate to "severe." The difference in performance, as tested by the t test was significantly better than chance at the .01 level of confidence.

It can be seen that in both cases performance generally varied more under smooth air conditions than it did under turbulent conditions. One possible reason for the improved performance during turbulence is that more attention is required of the pilot.

Additional experimental evidence of the small effect of light and moderate turbulence upon the performance of experienced pilots in helicopters has been provided in simulator studies by Nicholson, et al. (9), and Hornick and Lefritz (5). The results indicated that pilot performance was not significantly affected by gust loadings to 15K and/or 0.20 RMS G intensities.

Variability of Pilot Performance

The mean performance for each pilot during the entire study was as follows:

TABLE 10

Performance Variability Among Pilots

Pilot	Mean Perf. (P_1) (with limits)	SD	Total Line Entries
L	94.21	9.43	3139
C	78.04	29.49	2716
B	77.82	29.44	900
G	91.43	15.97	189

It can be seen that there were differences in the mean performance of the pilots who flew in this study. This difference was made more pronounced by the methods of scoring performance during the BRAVO precision flight patterns. While all the pilots flew well, it was observed during the flights and in reviewing the scoring, that techniques of flying affect performance. The pilot who used a method averaging out aircraft attitude, heading and altitude changes during the BRAVO flight pattern, scored lower than the ones who corrected immediately to the desired position. This variability seems to fit the normal expected variation of human performance.

Weight Loss

The value of the mean water loss for all pilots in the experiment was 1.216 lbs. per flight with a standard deviation of .7734. The range of these water losses varied from .154 lbs. to 2.464 lbs., of which pilot L had the most variability. Because of human variability in this area, it seemed more meaningful to consider each pilot separately regarding water loss versus performance correlation. Pilot G was not listed because of insufficient data. A summary of these calculations are provided in Table 11.

TABLE 11

Comparison of Pilot Performance and Water Loss

Pilot	Mean Perf. (P_1)	Mean Water Loss	Correlation r	Line Entries
L	94.21	1.408	r = .4232	3139
C	78.04	1.159	r = .1141	2716
B	77.82	1.073	r = -.9926	900

For pilot B, the correlation was nearly perfect, but the sample size was only three flights as compared with 10 and 12 flights for the other pilots.

Interaction of Temperature, Performance and Clothing

Each clothing configuration used by the pilots during the study was compared with their associated performance (P_1) while wearing the clothing. The results are summarized in Table 12.

The performances using clothing configurations A and B, both of which include body armor, are for all purposes identical. The performance using clothing configuration C, which does not include armor, is somewhat lower than the others but not significantly so. Performance wearing clothing configuration D is not a true representation of this configuration as it refers to only one pilot and one flight; hence, even though the performance is better than with any other configuration, it cannot be considered as a preferred configuration without further testing. The pilots' subjective comments regarding the D clothing configuration indicated it was completely unacceptable.

TABLE 12

Comparison of Pilot Performance and Clothing Configurations

Clothing Configuration	No. Flights	Mean Perf. (P_1)	Computer Line Entries
A	8	86.05	2277
B	8	85.88	2183
C	9	82.76	2162
D	1	95.70	322

Target Identification Task

The data was analyzed for variations in pilot performance due to individual differences, clothing differences and fatigue, and differences in environmental temperature. A total of 348 target displays were presented to the pilots during 22 flights providing usable data. Of the 348 target displays, 228 were correctly identified, 89 were incorrectly identified and 31 were not detected. During the 22 flights the pilots flew five flights with A, six with B, ten with C and one with D clothing configurations.

The data were analyzed using WBGT Index as the environmental measure with a mode of 85°F. The flights were broken into two groups, AM and PM. No AM flights had a WBGT greater than 85°. The results showed that there were no significant differences in pilot performances. There was no significant difference between performance during the first part of the flights and performance during the latter part of the flights. There was a trend indicating a difference in performance due to clothing, but this was not significant at the .1 level.

The PM flights show a greater number of errors occurring when armor was worn and the WBGT was greater than 85°. In the cases when no armor was worn, the errors occurring in each temperature zone were approximately equal. The results indicate that trends were present but were not significant at the .1 level.

Reaction/Response Time Measures

Pilot reaction times and response times were measured 30 to 40 times per flight. The range of mean reaction times for all pilots during the study varied from .23 to .63 seconds, with an overall mean of .44 seconds. Response times varied from .41 to 1.21 seconds, with an overall mean of .93 seconds.

Pilot reaction times were taken in a more consistent manner than response time measures; the results contain smaller ranges of values and smaller variability. Only reaction times were therefore considered reliable enough to be reported and are summarized in Table 13.

TABLE 13

Correlation of Reaction Times With Temperature Measures

Measured Condition		Pilots**	
	L (n = 9)	C (n = 9)	B (n = 3)
Reaction Time vs. WBGT (seconds)	.436	.124	.994*
Reaction Time vs. Rectal Temp. (seconds)	.220	.380	.993*

*Significant at the .05 level.
**The n values shown for the pilots represent the means of 234 repeated measures from several flights (Pilot G was not listed because only one flight was available for analysis).

The correlation analysis of the data indicates a trend showing an increase in pilot reaction time as either Rectal Temperature or the WBGT Index increases.

Appendix P provides a summary of mean and range of pilot reaction and response times.

Comparison of Ground and Airborne WBGT

During the earlier portion of the study it was hypothesized that perhaps a fixed relationship (similar to a standard adiabatic lapse rate of temperature) may exist between the WBGT Index measured at ground level and that measured in the aircraft, assuming that the measurements were taken during the same time period and that the aircraft maintained the same airspeed and absolute altitude, and remained within the local area (5-10 miles). It was hoped that if a reasonably constant relationship did exist, then perhaps ground measurement of cockpit WBGT would help schedule the aircraft for the desired above-85°F WBGT flight conditions.

Unfortunately, no constant relationship could be determined between airborne measurements of WBGT and those taken on the ground. In 18 out of 28 cases compared, the airborne measured WBGT was greater than the WBGT measured on the ground during the same time frame. The range of differences between ground WBGT and airborne WBGT was 4.64 to -15.29. The mean difference was -2.4157 and the sigma was 4.56.

Pilot Comments and Observations

All of the pilots expressed a desire for improved ventilation in the crew station.

Figure 7 summarizes the rating scale of pilots' judgments of the crew station environment. Their judgments are compared with the actual WB, DB, GT and WBGT Index, as measured during each flight in which the pilot reported a specific rating scale index. During the study, no attempts were made to inform the pilots of how their subjective ratings of crew station environment compared with the actual measured temperatures.

The pilots' ratings of a "cool" or "warm" environment included very large overlaps and very large ranges of each temperature measured. Some flights were actually hotter than others they rated as "hot" or "very hot." If only mean ($\bar{X}$) temperature values are considered, Figure 7 indicates that pilot ratings tended to parallel actual increases in Globe and Dry-Bulb Temperatures when reporting their estimates of "cool," "warm," "hot" and "very hot." When the environment was judged as "hot," the range of actual temperature was smaller than when the ratings were "cool" or "warm"; however, the number of times "hot" was selected was also less which could account for the smaller range. "Very hot" was selected only once.

One conclusion which can be drawn from these data is that pilot judgment of cockpit environmental temperature is inconsistent and appears to be unreliable as a means of assessing actual environment.

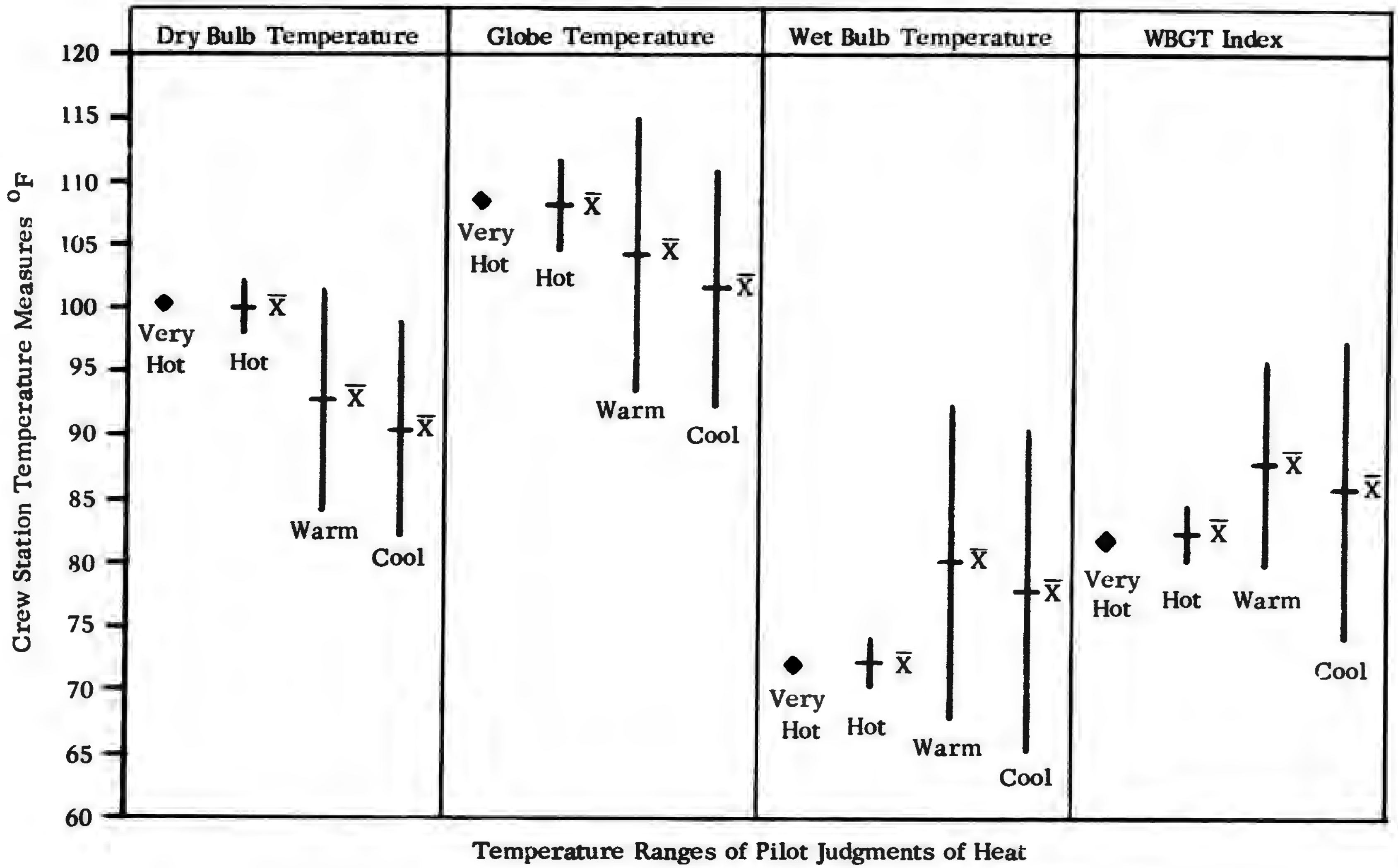


Fig. 7. PILOT JUDGMENTS OF HEAT AS RELATED TO CREW STATION ENVIRONMENTAL TEMPERATURE MEASURES

Detailed pilot comments regarding clothing and survival equipment fit and problem areas are provided in Appendix Q.

Miscellaneous Comments and Data

The following recorded data extracts and comments regarding the crew-station environment are provided for general reader interest:

1. During flight (at 800 ft. absolute altitude), the cockpit WBGT Index frequently rose above 90^{o}F and occasionally reached 95^{o}F and 97^{o}F. The highest recorded WBGT Index was 105.1^{o}F (Flt. 9L: WB 97^{o}F, GT 127.5^{o}F, DB 117^{o}F).

2. DB temperatures taken at the seat reference point (SRP) of the passenger compartment seat measured 110^{o}F-118^{o}F when the cockpit environment measured 102^{o}-103^{o}F. Some of this heat was believed to be radiated heat generated from the engine and transmission.

3. Ground reflected solar radiation appeared to cause rapid increases in overall cockpit DB temperatures when the aircraft was at or passing through 200 ft. absolute altitude. It was not uncommon for the overall cockpit DB temperatures to raise from 90^{o}F to above 110^{o}F within 60 seconds.

4. With the aircraft sitting on the ground with a bright sun and DB of 85^{o}-90^{o}F, cockpit doors and vents closed, the cockpit DB would rise to 155^{o}F, the maximum point on the temperature scale.

5. The old problem of testing enough subjects to provide a representative sample need not be a limitation in an aircraft. During the two-month period of optimum weather for this study 10 to 20 subjects could have been tested, provided a modest increase in the manpower and aircraft resources were made available.

6. If a magnetic tape recording system was substituted for the photopanel technique and many of the manual recording tasks performed by the inflight observers of this study, the data recording and analysis of the flights would have been greatly unburdened and the number of inflight observers could have been reduced.

7. Air velocity measurements of the cockpit taken with a hot-wire anemometer are listed in Table 14.

Appendix R provides a summary of pilot anthropometric and background data.

Appendix S summarizes the official meteorological ground data reported at Cairns Field, Fort Rucker, Alabama, during each flight of the study.

TABLE 14

Cockpit Air Movement Measures

Flight Mode	Vent Settings	Probe Position	Rate of Air Movement, ft/min, at Level of: Head	Hip	Toe	Average Air Movement, Ft/Min
Slow Cruise (80K)	Vents Closed*	R	30	30	35	32
		C	20	25	50	32
		L	25	25	40	30
	Vents Open	R	160	300	45	168
		C	210	150	50	137
		L	480	110	85	225

Probe position: R = 2" to right of body
C = in mid-body plane, 2" in front of body or between legs
L = 2" to left of body

*The vent closed position was used during this study.

SUMMARY AND CONCLUSIONS

The design and development of recent Army aircraft environmental systems have been largely inadequate because of the lack of suitable quantifiable data describing human performance changes under high cabin temperatures. It was the purpose of this study to explore techniques which could provide this quantifiable information and to assess actual pilot performance in a hot environment.

A prototype OH-6A helicopter was instrumented as the test vehicle. Four experienced pilots flew precision air patterns, observed and recorded ground targets, and performed normal flight duties of monitoring flight and engine instruments and other tasks during two-hour flight test periods. Four separate clothing configurations were worn by the pilots during the study.

During each flight two observers simultaneously measured pilot physiological and psychological performance as well as the crew-station environment. The physiological performance was measured by heart rate, skin and rectal temperatures, and perspiration weight loss. Measures of psychological performance were photopanel exposures of the instrument panel during precision flight patterns, response and reaction time measures, ground target identification, and assessments of subjective comments during post-flight debriefings. Both airborne and ground environmental measures of Dry-Bulb, Wet-Bulb and Globe Temperature were taken to determine the Wet-Bulb Globe Temperature (WBGT) Index of heat stress, which provided a base by which pilot performance changes were compared.

A stepwise multiple-regression program, Pearson correlation, analysis of variance and t tests of significance were employed on the data to describe the relationships of temperature changes with pilot performance factors. The following statements generally summarize the results of the study:

1. Pilot performance (P_1) decreased and performance variability (SD) increased above a WBGT Index of 85^oF.

2. The predictor performance equations determined by the multiple-regression program indicated that skin and rectal temperatures were definitely related to pilot performance.

3. Pilots' reaction times increased as either ambient temperatures or rectal temperatures increased.

4. Pilots tended to perform more precisely when they encountered light to moderate aircraft turbulence than they did on non-turbulent flights.

5. Pilot subjective judgments of cabin heat were highly inconsistent with environmental measurements.

6. Weight loss from perspiration appeared to have a positive correlation with performance (P_1).

7. The clothing and equipment configurations worn by the pilots (including body armor) had no significant effect on their performance (P_1).

8. The cabin heat did not significantly affect the pilots' ability to observe ground targets.

9. Large differences in performance (P_1) variability among pilots were due to basic pilot techniques (regardless of experience).

10. No constant relationship could be determined between ground and airborne measures of WBGT.

Limited aircraft and pilot availability allowed only four subjects to be used during the study, of which two completed all required flights. The above results, therefore, should be considered only as trends for the subjects and conditions tested.

The techniques used during this study did successfully measure both a large portion of pilot performance and the cockpit environment. The multiple-regression program enabled comparisons of pilot performance and environmental sub-factors on large volumes of data, which heretofore would have been impossible. Though environmental variables could not be controlled, they could be accounted for, measured and correlated with other variables using the multiple-regression program. It may be hypothesized that if these variables can be accounted for and correlated, then the basic approach of inflight measurement of human performance certainly offers the potential of obtaining realistic assessments of new crew-station designs and may ultimately be the best approach to developing the type of quantified information needed to develop crew station design criteria and standards.

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APPENDIX A

LOH ENVIRONMENTAL STUDY

Pilot Background Information

1. Name ______________________ Army Service Number or Social Security Number ____________

2. Rank/Grade __________

3. Age at last birthday _______

4a. Total flying hours logged (military and civilian) __________

b. Number civilian flying hours logged ________

c. Number military flying hours logged _______

d. Number combat flying hours logged _______

e. Number combat missions flown _________

5a. Number fixed wing hours logged ________

b. Number rotary wing hours logged _______

6. Total number of hours in LOH _________

7. I have flown combat missions in the following theaters/conflicts (circle all applicable answers):

a. Europe

b. No. Africa (WW II)

c. Near East

d. So. Pacific

e. China-Burma-India

f. Korea

g. Malaya

h. Vietnam

i. Laos

j. Congo

k. Philippines (Huk Rebellion)

8. I have been rated as a test pilot in the following military aircraft (list): ____________

____

9. I have been rated as an instructor pilot in the following military aircraft (list): _____

____

____

10. I am currently qualified in the following military aircraft in addition to those already indicated in questions 8 and 9 (list): __________________________

____

____

11. Date of most recent experience in the LOH ________________

12. List the flight clothing you normally wear in rotary winged aircraft during warm weather ____

____

____

13. My current instrument qualification level is __________________________

BODY SIZE INFORMATION

Name ______________________ ASN or SSN ______________________

	Millimeters	Inches
Weight		
Height		
Crotch Height		
Sitting Height		
Knee Height		
Buttock-Knee Length		
Shoulder Breadth		
Hip Breadth, Sitting		
Head Circumference		
Neck Circumference		
Shoulder Circumference		
Chest Circumference		
Waist Circumference		
Hip Circumference		

Civilian Clothing Size

Suit Chest ______________

Suit Length ______________

Waist Size ______________

Inseam Length ______________

Collar Size ______________

Sleeve Length ______________

Size Military Clothing Fitted

Fatigue Shirt ______________

Fatigue Trousers ______________

Flying Suit ______________

Torso Armor ______________

APPENDIX B

CLOTHING/EQUIPMENT FLIGHT CONFIGURATION MODE
(24 Aug 66)

TABLE IB

Description of Personal Flight Clothing and Survival Equipment Configurations Worn by Pilot-Subjects During Environmental Study

Flight Configuration	Equipment/Clothing to be Worn
A	1. Shirt, Man's, Cotton Sateen, O.G. 107 2. Trousers, Man's, Cotton Sateen, O.G. 107 3. Body Armor, Torso, Front 4. Survival/Clothing Equipment listed below.
B	1. Coveralls, Flying, Man's, Nomex, Fire Resistant 2. Body Armor, Torso, Front 3. Survival/Clothing Equipment listed below.
C	1. Coveralls, Flying, Man's, Nomex, Fire Resistant 2. Survival, Clothing Equipment listed below.
D_1	1. Clothing Ventilation System 2. Survival/Clothing Equipment listed below.
D_2	1. Clothing Ventilation System 2. Body Armor, Torso, Front 3. Survival/Clothing Equipment listed below.

SURVIVAL EQUIPMENT/CLOTHING CONFIGURATION

1. APH-5 Flying Helmet, OD Finish
2. Glove Set, Flying, without Wool Inserts
3. Boots, Combat, Man's, Black
4. Socks, Man's, Wool, Cushion-sole, One Pair
5. Drawers, Men's, Cotton
6. Undershirt, Man's, Cotton, Quarter-length Sleeves
7. Weapon, Personal, w/Shoulder Holster or Pistol Belt w/Extra Clips (2)
8. Sheath Knife w/Scabbard
9. Thigh Clip Board
10. Survival Kit, Individual
11. Pen Light
12. Pencil
13. Canteen w/Carrier
14. Maps as required

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APPENDIX C

FLIGHT SCHEDULE
(Revision 2, 8 August 1966)

TABLE 1C

Flight Schedule of Clothing Configurations and Pilot-Subjects

Pilot/Subject		Flight Configuration/Condition Mode — Days after Go Ahead																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
I	AM		B					C																	
	PM	A	B	C	A	C	B	C	B	A															
II	AM				B		C																		
	PM	B	C	A	B	A	C	A	C	B															
III	AM			B						C															
	PM	C	A	B	C	B	A	B	A	C															
IV	AM													B		C									
	PM										B	C	A	B	A	C	A	C	B	D_1	D_2				
V	AM											B					C								
	PM										A	B	C	A	C	B	C	B	A	D_2	D_1				

The above flight configuration/condition modes are defined in detail on Table 1 and will be flown in the left to right sequence shown. The subject names are to be assigned.

AM Flights are one-hour duration, to be completed between 0530-0900.
PM Flights are two-hour duration, to be completed between 1000-1600.

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APPENDIX D

FLIGHT LOG: PHYSIOLOGICAL DATA

Flight Date:
Flight Time:
Pilot:

O time =   hrs.

Nude weights:
Before flt.:   Time:
After flt.:   Time:

Observer:

Time	WBGT Index				Body Temp		Time	Heart Rate			
	WB 1	Gl 2	DB 3	Air 4	Rect 1	Skin 2		H	M	S	Pulse

PERFORMANCE OBSERVER

FLIGHT LOG

Flight ________

Date ________

Pilot ____________

Time	Response Time	Dry Bulb	Wet Bulb	Pilot's Temp	Pilot's HB	Ground Target	Remarks

APPENDIX E

MOUNTING OF MOVIE CAMERA ON AIRCRAFT STRUCTURE

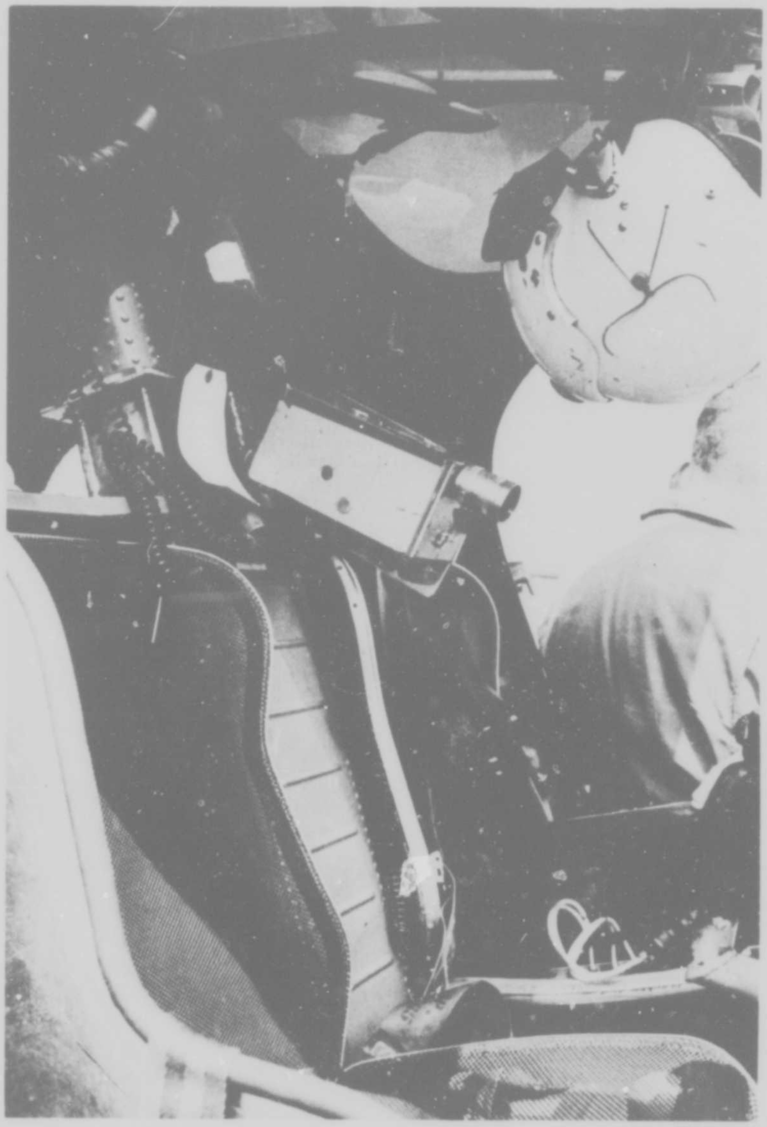

Fig. 1E. MOUNTING OF MOVIE CAMERA ON AIRCRAFT STRUCTURE BETWEEN THE PILOT AND OBSERVER SEATS

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APPENDIX F

AERIAL TARGET CONFIGURATIONS

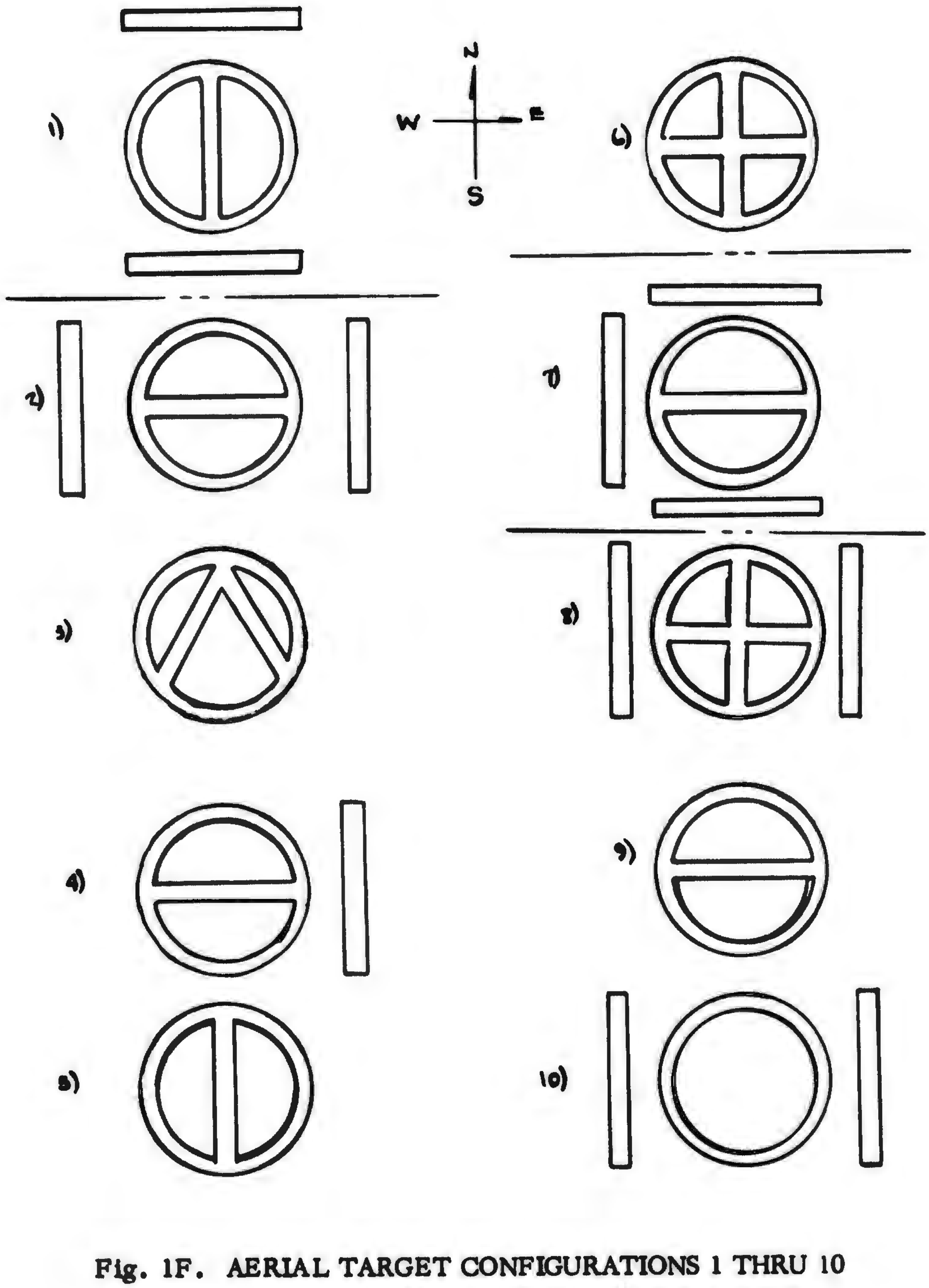

Fig. 1F. AERIAL TARGET CONFIGURATIONS 1 THRU 10

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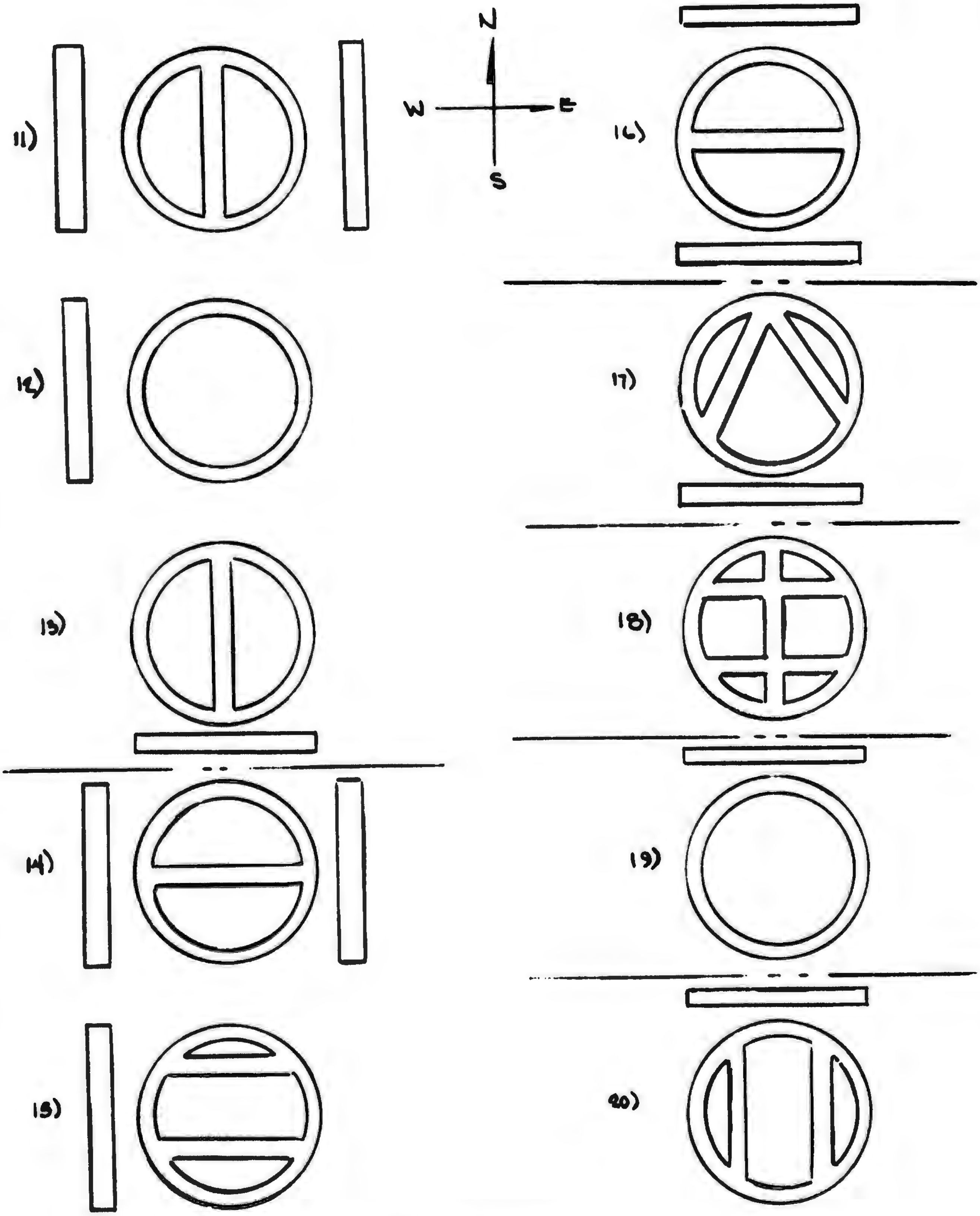

Fig. 2F. AERIAL TARGET CONFIGURATIONS 11 THRU 20

APPENDIX G

AERIAL TARGET SEQUENCE LOG

Pattern Set	Target Order												Flight Data Date, Time, Pilot, Target Operator, Location, Pattern Set Order.
A	5	15	7	18	13	9	10	4	6	20	11	3	Date:
B	7	16	10	12	20	9	15	18	2	17	8	1	Pilot:
C	8	18	9	6	12	19	2	16	20	7	5	13	Flight: AM PM
D	2	17	18	5	12	7	3	14	11	6	10	13	Target Operators:
E	4	8	13	15	20	5	8	18	16	11	19	7	Time Check:
F	6	7	18	4	9	12	11	20	13	10	17	14	Flight Start:
G	4	16	17	6	13	10	19	3	14	1	7	20	Flight Stop:
													Pattern Set Order:

NOTES:

Target No.	Time Start	Time Stop	Target No.	Time Start	Time Stop	Target No.	Time Start	Time Stop	Target No.	Time Start	Time Stop

APPENDIX H

PILOT QUESTION CARDS

CARD 1

Flight Configuration Codes:

a b c d

At what slant range could you detect the target?

2	3	4	5	6	7

Thousands of feet

At what slant range could you identify the target pattern?

2	3	4	5	6	7

Thousands of feet

CARD 2

Flight Configuration Codes:

a b c d

Criticisms of the aircraft cockpit environment.

Suggestions for improvement of the aircraft cockpit environment.

How would you rate the cockpit atmospheric environment on this flight?

1	2	3	4	5
Cool Comfortable	Warm	Hot Tolerable	Very Hot Uncomfortable	Extremely Hot Miserable

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CARD 6

Flight Configuration Codes:

a

Were the fatigues comfortable?

Did they interfere with activities? Which activities?

Do you prefer the fatigues rather than the flight suit for hot weather LOH flight?

Why?

CARD 7

Flight Configuration Codes:

d

Did the clothing ventilation system improve your comfort?

Did the clothing ventilation system help or hinder your performance?

How.....in what way?

CARD 3

Flight Configuration Codes:

a b c d

Comments about any of the clothing or personal equipment.

Recommended changes in clothing or personal equipment.

CARD 4

Flight Configuration Codes:

b c d

Was the flight suit comfortable?

Did it interfere with activities? Which activities?

Are you able to use the relief tube with the flight suit on?

Are pockets accessible with full flight equipment on....sidearms, clipboard, hunting knife, etc.?

Are zippers manageable with full flight equipment on?

CARD 5

Flight Configuration Codes:

a b d

Were you comfortable in the body armor?

Did it interfere with your activities? With ingress and/or egress? With use of relief tube? Were all controls and switches accessible?

Was the body armor excessively heavy?

Would you anticipate problems in wearing body armor in combat? In an accident?

Should the body armor be flexible or jointed to ease movement?

Did the body armor fit better with fatigues or with the flight suit?

APPENDIX I

MEASUREMENT OF GROUND LEVEL WET-BULB, DRY-BULB AND GLOBE TEMPERATURES

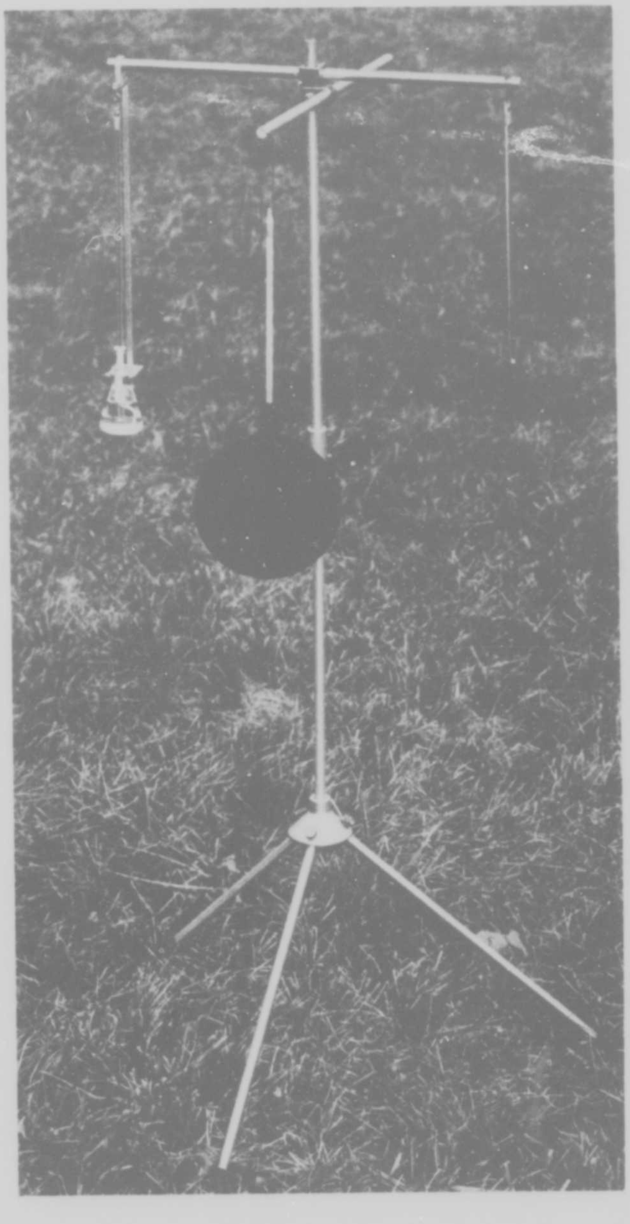

Fig. 1I. TEMPERATURE STAND USED TO MEASURE GROUND LEVEL WET-BULB, DRY-BULB AND GLOBE TEMPERATURES (^{o}F)

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APPENDIX J

EQUIPMENT USED DURING ENVIRONMENTAL STUDY

Item	Manufacturer	Model
1) Timer, Reaction	C.H. Stoelting Co. Chicago, Illinois	1/100 Sec. Increments
2) Running Timer	C.H. Stoelting Co. Chicago, Illinois	1/5 Sec. Increments
3) Camera, Movie 16mm	Vought Camera Co. Los Angeles, Calif.	VDR 4B 228
a. Camera Frame Timer	HEL Design	
b. Film - 16mm, color 100 ft. rolls		
4) Inverter, Sine Wave	Sorenson Division of Raytheon Co.	Q IS28/115-.52
5) Reaction Signal Generator	HEL Design	
6) Reaction Response Switch		
7) Turn and Bank Indicator		
8) Temperature Recorder Tele-Thermometer	Yellow Springs Instrument Co., Inc.	
9) Simulated Seat Armor		
10) Targets	HEL Design	
11) Portable Communications Equipment	Communications Co., Inc. Coral Gables, Florida (FAA Contract FA-WA-4610)	Transceiver UHF, Type TRU-2
12) Thermistor Sensor Probes	Yellow Spring Instrument Co.	Tele-Thermometer
13) Heart Beat Counter	Elgin Watch Co.	Cardid-Counter

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Item	Manufacturer	Model
14) Thermo-Anemometer	Illinois Instrument Co.	
15) EKG Monitoring System		
a. Two silver electrodes		
b. Battery-powered oscilloscope		
c. Electrocardiographic recorder		
d. Portable telemetry unit ("Breadboard")		
16) Scale	Fairbanks-Morse Platform Scale	High Sensitivity
17) Black Globe Copper Sphere	Chicago, Illinois	
18) Aircrew Clothing/Survival Equipment (Detailed description furnished in Appendix B)	Government furnished equipment	

Furnished by USAARL, Fort Rucker, Ala.

APPENDIX K

DATA REDUCTION METHOD AND RECORDING FORM

The bulk of the data used in this experiment was originally recorded by photo-panel coverage of the flight instruments as the pilot flew the precision flight patterns. One picture was taken of the instrument panel for every second of each 16-minute BRAVO pattern flown, and a total of 99 1/2 patterns were flown. Since each picture frame recorded the readings of five instruments, it became apparent that the study was producing more data than was needed to determine significant crew performance differences.

Some way had to be found to simplify the task of reducing the mass of data to usable proportions, so a pilot study was initiated to find the longest time-interval that would still produce valid data. This study was a practical necessity, because when there are thousands of film frames involved, there is a considerable difference in the work required to record the data from every frame (that is, every second of flight) and to record the data from every third, or tenth, frame.

To compare the results of using each of these three intervals -- one, three and 10 seconds -- a statistical analysis was performed for each interval on the data generated by one flight pattern that displayed considerable variability. When standard deviation, mean, and range of pilot corrections to flight path were compared for each interval, it was apparent that the 10-second interval could be used without invalidating the results.

AMXHE-SYS Form 6 was devised to consolidate all the various bits of data available from each measurement taken during the study. Fundamental criterion used during the development of the form was to make sure the data was referenced to a common time line and to arrange the data so it could be readily transcribed to IBM cards. The following instruction sheet with a code description was developed to insert the data into the form.

INSTRUCTIONS: LOH DATA REDUCTION WORK SHEET

Column:	Entries:
Identify	This column always contains 5 characters; the 1st and 2nd are digits designating the flight number, the 3rd designates the costume and is a letter, the 4th is a number indicating which flight pattern is being flown, and the 5th is a letter to identify the pilot.
Date/Hr.	This column always contains five numbers; the 1st indicates the month and the second and third indicate the day of the month of this flight, the fourth and fifth indicate the clock hour of the entires for the line.
Min/Sec	This column always contains four numbers. The first and second indicate the minute and the third and fourth the second of the entries for the line.
A/S	This column always contains 3 numbers: the actual value of the air speed as read from the film strip.
Alt	This column always contains 3 numbers: the actual value <u>in 10's of feet</u> of the altitude as read from the film strip.
Hdg	This column always contains 3 numbers: the actual value of the heading as read from the film strip.
TQ	This column always contains 2 numbers: the actual value of torque as read from the film strip.

<u>WARNING: DO NOT ENTER DECIMAL POINTS!!</u>

WB	This column always contains 3 numbers; these are the Wet Bulb Temperature readings from the PD form.
GT	This column always contains 4 numbers; these are the Globe Temperature readings from the PD form. Note WARNING.
DB	This column contains 4 numbers; these are the Dry Bulb Temperature readings from the PD form. Note WARNING.
AT	This column contains 4 numbers; these are the Air Temperature readings from the PD form. Note WARNING.
RT	This column contains 3 numbers; these are the Rectal Temperature readings from the PD form. Note WARNING.

Column:	Entries:
ST	This column contains 4 numbers: these are the Skin Temperature readings from the PD form. Note WARNING.
HR	This column contains 3 numbers; these are the Heart Rate or Pulse readings from the PD form.
WBG	This column contains 3 numbers; these are the Wet Bulb Ground Temperature from the PD form. Note WARNING.
GTG	This column contains 3 numbers; these are the Globe Ground Temperature from the PD form. Note WARNING.
DBG	This column contains 3 numbers; these are the Dry Bulb Ground Temperature from the PD form. Note WARNING.
ODB	This column contains 3 numbers; these are the Official Dry Bulb Temperature from the PD form. Note WARNING.
ODP	This column contains 3 numbers; these are the Official Dew Point readings from the PD form. Note WARNING.
RH	This column contains 3 numbers; these are the Relative Humidity readings from the PD form. Note WARNING.
RC	This column contains 3 numbers; these are the Conditioned Reaction Time from the RT form. Note WARNING.
RU	This column contains 3 numbers; these are the Unconditioned Reaction Times from the RT form. Note WARNING.

The data from every tenth frame of film were therefore recorded on the AMXHE-SYS Form 6, and the physiological, environmental, meteorological and reaction-time data were added to the form later. Since most of the airborne physiological and environmental data were recorded every five minutes while the film data were entered for every 10 seconds, there were voids in the former data that had to be filled in so the computer could deal with it. The inconsistency was rectified in one of two ways:

1. If the observed data did not change from one five-minute entry to another, they were assumed not to have changed at all during the five-minute interval, so the same data were repeated during each 10-second interval of the five-minute period.

2. In those cases where the data did change from one five-minute entry to the next, the change was assumed to have occurred linearly and appropriate quantitative graduations were added at each 10-second interval. Appendix L illustrates samples of both types of data entries.

AMXHE-SYS Form 6, 19 Oct 66 (One-Time)

LOH DATA REDUCTION WORK SHEET

SAMPLE

5 Identity	5 Date/Hr.	4 Min/Sec	3 A/S	3 Alt.	3 HDG	2 TO	3 WB	4 GT	4 DB	4 AT	3 RT	4 ST	3 HR	3 WBG	3 GTG	3 DBG	3 ODB	3 ODP	3 RH	3 RC	3 RU	2 HE
24B2 L	90713	24 00	082	106	178	61	748	1142	1022	0964	997	0968	112	225	434	326	927	663	422			02
		24 11	080	110	211	60	748	1141	1022	0965							927	663	421			02
		24 22	081	112	247	60	747	1139	1023	0965							928	662				01
		24 32	082	113	275	43	747	1138	1023	0966												01
		24 39	083	115	294	47	747	1137	1023	0967												03
		24 49	077	116	330	40	746	1135	1024	0967		0968										03
24B2 L	90713	25 00	079	113	357	55	746	1134	1024	0968	997	0967	112	225	434	326	928	662	421			03

APPENDIX L

DERIVATION OF ENVIRONMENTAL AND PILOT PERFORMANCE FACTORS

The standards used for the factors V2, V3 ... V10, were determined as follows:

V1 - a constant, determined by the computer, which allows the equation to "best fit" the data from which equation was generated (1).

V2 - the value of 73° Wet-Bulb Temperature, selected as an upper limit of comfort from the accepted standard of Effective Temperature (ET) (2, Fig. C4-3).

V3 - the value of 100°F Globe Temperature, determined as an approximation of the mean Globe Temperature derived from the initial flight data. This value combined with the values of V2 and V4 gives a WBGT Index of 80°F (12).

V4 - the value of 90°F Dry-Bulb Temperature, selected as an upper limit of comfort from the accepted standard of Effective Temperature (ET) (12, Fig. C4-3).

V5 - the value of 85°F WBGT Index, taken from the studies of Minard (8) and Yaglou (17) as a temperature above which heat stress occurs.

V6 - the value of 98.9°F Rectal Temperature, selected as an approximation from studies of DuBois in which men were tested under various conditions of resting, exercise and environmental conditions. A Rectal Temperature of 98.9°F appeared to be a lower level of comfort with moderate exercise (2).

V7 - the value of 94.5°F Skin Temperature, selected from the work of Hall and Klemm (3) and DuBois (2) as the approximate mean of a range of temperatures at which a sharp increase in insensible weight loss occurs.

V8 - a Heart-Rate standard, since man's heart rate is not constant from day to day. Recent work reported by C. M. Plattner (10) on the measuring of the heart rate of U. S. Navy aviators during combat missions, used a preflight-determined base heart rate for each flight, and that method was used in this experiment.

V9 - the value of 69°F Dew Point, the value which fell beyond the summer comfort zone as given in (12, Fig. C4-4).

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V10 - the value of 70% Relative Humidity, selected as an upper limit of comfort from accepted standard of Effective Temperature (12, Fig. C4-3).

APPENDIX M

COMPARISONS OF THE FIRST AND NEXT TO LAST BRAVO PATTERNS FLOWN DURING AFTERNOON FLIGHTS

Subject	Flight *	P_1	P_{NL}	SD_1	SD_{NL}	$WBGT_1$	$WBGT_{NL}$	$WBGT_M$
C	5	68.73	45.49	42.78	38.21	83.18	82.06	82.95
	7	85.29	56.43	17.66	35.59	85.06	87.12	86.65
	10	89.60	64.32	12.45	32.09	96.52	95.42	95.84
	13	85.13	94.99	24.57	6.23	81.18	83.92	82.54
	15	82.09	79.51	28.35	26.18	87.67	87.14	87.75
L	9	92.31	95.53	10.07	5.93	95.72	98.09	97.06
	12	93.46	93.96	9.03	6.86	83.42	84.71	83.98
	16	96.50	96.42	4.64	5.29	85.45	85.54	85.30
	19	97.48	94.60	4.31	7.97	82.60	83.26	84.87
	24	97.24	97.43	4.08	3.14	84.99	84.82	84.53
	26	95.05	98.12	5.23	2.70	80.77	79.51	79.85
	28	96.17	95.81	4.53	4.61	82.99	81.94	81.95
B	25	85.18	57.71	23.40	36.97	82.05	78.82	80.37
	29	65.67	85.56	37.52	23.53	80.42	76.49	78.00
Mean Values								
$\bar{C}$		82.168	68.148	25.162	27.660	86.722	87.132	87.146
$\bar{L}$		95.459	95.981	5.984	5.214	85.134	85.410	85.363
$\bar{B}$		75.425	71.635	30.460	30.250	81.235	77.655	79.185

Subscript	1	Indicates	First Bravo Pattern Flown
" "	NL	"	Next to Last Bravo Pattern Flown
" "	M	"	Mean for Flight

* Listing of flights was restricted to those having four or more flight patterns.

APPENDIX N

RANGE OF PHYSIOLOGICAL AND TEMPERATURE MEASUREMENT DURING EACH FLIGHT

Flight	WB	GT	DB	RT	ST	Flight HR	Ground BHR	WBGT	DP	RH
01BC	66.6	89.8	80.2	99.0		76	80	73.3		
	72.0	98.2	94.2	99.4		104		79.5		
02AG	68.0	99.4	88.5	99.4	95.0	78	100	76.5		
	77.2	115.4	102.2	100.2	97.6	160		87.3		
03BC	69.2	99.6	91.8	98.7	97.3	92	115	77.6		
	77.2	130.2	104.2	99.2	99.8	120		88.7		
04AL	73.4	107.0	96.0	99.4	95.2	100	108	81.7	63.0	41.0
	76.0	116.5	111.0	99.7	99.0	120		85.6	64.0	46.5
05BC	72.4	100.0	96.0	99.1	95.0		95	81.8	64.0	41.0
	79.8	112.0	102.4	99.5	98.7			89.7	66.0	50.0
06BL	70.0	81.0	77.5	99.2	90.0	116	120	73.0	66.0	74.0
	78.5	108.0	107.0	99.8	94.3	140		90.8	70.0	81.5
07CC	76.0	99.5	96.0	99.4	93.5	84	95	83.6	68.0	47.0
	84.0	120.0	107.5	99.6	97.4	108		91.5	70.0	57.0
08BL	77.2	90.0	95.0	100.4	94.8	124	138	76.5	71.0	79.0
09BL	89.5	106.5	94.5	99.4	94.3	104	120	94.1	66.0	48.5
	97.0	127.5	117.0	99.6	97.2	124		105.1	71.0	65.5
10AC	89.5	97.5	92.5	99.2	93.2	92	100		68.0	52.0
	98.0	112.0	111.0	99.4	98.5	112			70.0	61.0
11CB	84.5	93.5	92.5	99.7	94.0	88	100		68.0	53.0
	90.0	102.5	106.0	99.9	95.8	104			69.0	61.0
12CL	74.0	105.0	95.6	99.5	95.6		125	82.2	64.0	42.5
	84.4	134.2	120.4	99.9	97.4			97.9	66.0	50.0

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Flight	WB	GT	DB	RT	ST	Flight HR	Ground BHR	WBGT	DP	RH
13BC	72.5	98.0	95.5	98.4	94.3	84	130	80.5	65.0	42.5
	82.0	108.0	108.0	99.1	97.5	100		88.2	71.0	67.0
14AL	73.0	98.0	97.5	99.5	96.4	100	130	81.1	63.0	37.5
	82.5	125.0	114.0	99.9	98.2	128		92.8	69.0	55.5
15AC	76.4	105.8	99.0	99.1	96.0		82	86.1	69.0	46.0
	83.8	118.2	118.0	99.2	100.4			94.3	75.0	70.0
16CL	74.8	104.2	96.2	99.5	96.7	100	85	83.2	68.0	44.5
	84.4	128.4	109.0	99.9	97.5	120		91.6	70.0	46.0
17CC	72.5	95.0	95.0	99.5	96.0		93	80.0	69.0	49.0
	84.0	110.0	107.0		97.0			91.5	69.0	52.0
18CC	70.0	89.0	82.0		92.2	80	85	75.0	73.0	77.0
	78.0	98.0	88.0		95.7	88		83.0	75.0	93.5
19BL	75.0	98.0	90.5	99.2	92.6	100	90	81.3	72.0	59.5
	84.5	108.0	108.0	99.4	95.5	120		91.4	74.0	77.0
20CC	72.4	93.0	90.4	99.1	95.9	84	100	80.1	71.0	51.0
	87.8	108.6	102.2	99.4	97.6	104		92.1	75.0	77.0
21CL	73.0	91.8	84.2	98.6	88.7	92	98	77.9	70.0	85.0
	77.0	99.7	93.8	99.1	92.9	108		82.2	73.0	96.5
22CL	72.5	98.0	93.5	99.6	95.5	104	105	80.1	68.0	47.5
	80.0	108.0	103.0	99.9	97.4	120		87.5	72.0	54.0
23AC	71.8	103.8	93.2	99.0	94.1	84	92	81.4	67.0	45.5
	86.0	122.0	116.2	99.3	101.7	120		95.0	74.0	82.0
24BL	72.0	106.0	98.0	99.6	95.1	108	120	82.0	63.0	37.0
	85.0	127.5	126.0	99.9	98.0	124		97.3	67.0	44.0
25AB	69.0	94.2	95.8	99.5	94.7	80	100	78.0	60.0	33.5
	79.8	118.2	112.4	100.1	96.2	104		90.9	65.0	50.0

Flight	WB	GT	DB	RT	ST	Flight HR	Ground BHR	WBGT	DP	RH
26AL	71.0 77.0	93.0 115.5	89.0 106.0	99.2 99.5	94.0 96.8	96 112	100	77.7 85.6	69.0 70.0	54.0 59.0
27CC	69.0 76.0	99.0 126.0	92.0 109.0		92.5 98.1	84 104	95	78.7 88.5	58.0 61.0	40.0 48.5
28DL	69.8 82.0	102.4 120.0	94.4 117.4	99.2 99.8	92.4 97.2	92 112	105	78.8 94.4	61.0 62.0	42.0 45.0
29BB	61.0 72.0	89.0 107.0	89.0 98.0	99.3 99.9	90.9 93.4	84 100	100	72.0 80.4	59.0 63.0	41.5 60.0
ALL	61.0 98.0	81.0 130.2	77.5 120.4	98.4 100.4	88.7 100.4	76 160	80 138	72.0 97.9	60.0 75.0	33.5 96.5

APPENDIX O

PRE- AND POST-FLIGHT HEART RATE DATA SUMMARY

Flight & Pilot-Subject	Date	* Before Flight	*After Flight
1C	18 Aug AM	80	100
2G	18 Aug PM	100	130
3C	18 Aug PM	115	100
4L	27 Aug PM	108	155
5C	27 Aug PM	95	120
6L	28 Aug AM	120	140
7C	28 Aug PM	95	120
8L	28 Aug PM	138	140
9L	31 Aug PM	120	150
10C	31 Aug PM	100	130
11B	31 Aug PM	100	100
12L	1 Sep PM	125	135
13C	1 Sep PM	130	115
14L	2 Sep PM	130	130
15C	3 Sep PM	82	120
16L	3 Sep PM	85	125
17C	3 Sep PM		
18C	4 Sep AM	85	95
19L	4 Sep PM	90	105
20C	4 Sep PM	100	90
21L	6 Sep AM	98	115
22L	6 Sep PM	105	None
23C	7 Sep PM	92	110
24L	7 Sep PM	120	145
25B	7 Sep PM	100	105
26L	8 Sep PM	100	125
27C	9 Sep PM	95	120
28L	9 Sep PM	105	115
29B	9 Sep PM	100	100

* These heart-rate measurements were taken in a hangar dressing room (located approximately 100 yds from the aircraft) immediately before and after each flight. Unfortunately, limited controls were applied in the manner in which these readings were taken; some were taken with the subject in a supine position, others immediately after moderate exercise, some after the subject had been sitting.

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APPENDIX P

SUMMARY OF THE MEAN AND RANGE OF REACTION TIME AND RESPONSE TIME FOR ALL PILOTS

Pilot	Reaction Time, Seconds		Response Time	
	Mean	Range	Mean	Range
L	.23	.13 - .35	.41	.22 - .93
C	.56	.16 - 2.69	1.38	.41 - 6.65
B	.37	.23 - .62	.72	.56 - 1.01
G	.63	.35 - .98	1.214	1.01 - 1.5

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APPENDIX Q

PILOT COMMENTS AND OBSERVATIONS

The following comments are summarized from the pilot post-flight recorded interview (a copy of the questions and rating scales are provided in Appendix H):

Nomex Flight Suit - The new Nomex fire-resistant flight suit (Fig. 4C) was preferred over other flight clothing tested by three of the four pilots who used it. The material was found to be cooler and more comfortable than fatigues. One pilot did find the material irritating to his skin; this pilot admitted having very sensitive skin, and his report suggests that there may be individuals who react specifically (in an allergic pattern) to the Nomex material. This person preferred the fatigues over the Nomex flight suit. One subject described the Nomex suit as tending "to pad your body," but allowing freedom of movement. The same subject found the Nomex suit much cooler than the ventilated flight suit (Fig. 4D).

Regarding the detailed design and tailoring of the Nomex suits, the pilots generally agreed that the suits were too loose and baggy, that the flaps over the zippers interfered with operation of the zippers, and that these zipper flaps should be removed. They found the breast pockets inaccessible when they were wearing the armor breast plates. The pilots preferred to use the calf and sleeve pockets during the study. They approved of the tilted sleeve pockets, but regarded the thigh pockets as unnecessary and never used them. They did not like the drawstrings on the pantlegs because they could be accidently caught on controls.

The pilots generally recommended that the Nomex flight suit be retailored to (1) provide a better fit, (2) eliminate unnecessary pockets and all zipper flaps, and (3) replace the drawstrings with velcra pads.

Fatigues - The pilots found the fatigues (Fig. 4A) to bind body movement, comparatively warm, and less comfortable. They indicated that the folds against the legs at boot tops caused discomfort. However, the one pilot who had a problem of mild irritation with the Nomex suit preferred the fatigues.

Ventilated Suit - Because the test flights were concluded earlier than had been anticipated, the pilots tested only one of four ventilated suits originally scheduled for testing; but the one selected was considered by USAARU to be the best overall configuration of the four. It was given one two-hour flight test. The pilot on that flight found the suit (Fig. 4D) very unacceptable in its present configuration for several reasons:

1. When the air flow was turned on, the pilot reported he felt warmer than he did before it was turned on. He felt the ventilation only in certain torso regions, around the kidneys, chest and stomach. He could not feel the moving air reach his arms or legs.

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2. The wire-wound plastic tubing which provided the air to ventilate the suit created pressure points and caused chafing wherever it made contact with the skin. When the pilot removed his suit after the flight, deeply indented corrugated patterns remained clearly apparent in the skin of his back and buttocks.

3. The air inlet was located so inconveniently that the pilot could not connect himself to the ventilation system.

Body/Seat Armor - Surprisingly, three of the pilots did not consider the body-armor chest plate (Figs. 4A and 4B) excessively warm or too heavy. However, the fourth pilot did attribute a headache to the load of the armor support strap pulling on the back of his neck during flight.

The pilots did report the following interference problems as significant:

1. The armor chest plate pressing against the seat belt caused soreness in the abdomen, and one pilot reported that the chest plate dug into his ribs.

2. The chest plate was tight under the left arm when the pistol was carried.

3. One pilot reported some chafing and interference with the circulation of his right arm.

4. The most significant problem reported by all the pilots was that the body armor interfered with body-bending movements. It was impossible for a pilot of normal size to reach the front-center control panel -- but this particular problem will be corrected on the production aircraft where the panel and switches are located closer to the pilot.

The interference with bending movements seriously hindered ingress to and egress from the aircraft, and the seat armor aggravated this problem. For example, to get out of the aircraft, the pilots had to grasp the top of the canopy, pull themselves out and up, with back straight, to clear the cyclic control with the left leg and still get around the seat armor. This maneuver forced them to place their heads dangerously close to the main rotor blades. If the blades were turning, they could easily have suffered fatal head injuries.

5. The seat armor (Fig. 2) restricted the right elbow and seriously limited the right-rear travel of the cyclic control. All the pilots experienced this restriction during takeoff and flare to hover. The body armor also contributed to this restriction because the elbow was pinched between the metal plates of the body armor and the seat armor. One pilot suggested curving the seat armor to fit the door curvature on the right side to give the pilot elbow room inside the armor curve. Another suggested a hinge on the seat armor on the right side to make it easier to get in and out. With the present configuration of the armor, the restriction of the cyclic movement is serious enough to affect the safety of flight.

6. Three of the four pilots agreed that the body armor should be flexible or jointed to ease movement of the body. Two of them felt that the armor would do bodily damage in a crash landing or accident, but one disagreed, saying he thought it would provide protection during an accident.

Shoulder Holster - Two pilots complained that the holster harness had a tendency to slip down the left arm and off the shoulder. Another mentioned the sharp edges of the leather but withdrew this complaint as he became accustomed to the holster.

Crew Station Environment - All of the pilots expressed a desire for improved ventilation in the crew station.

Figure 7 summarizes the rating scale of pilot' judgments of the crew station environment. Their judgments are compared with the actual WB, DB and GT as measured during each flight in which the pilot reported a specific rating scale index. During the study, no attempts were made to inform the pilots of how their subjective ratings of crew station environment compared with the actual measured temperatures.

The pilots' ratings of a comfortable cool or warm environment included very large overlaps and very large ranges of each temperature measured. The environments the pilots rated as cool or warm on some flights were actually hotter than others they rated as hot or very hot. If only mean (X) temperature values are considered, Figure 7 indicates that pilot ratings tended to parallel actual increases in Globe and Dry-Bulb Temperatures when reporting their estimates of cool, warm, hot and very hot. When the environment was judged as hot, the range of actual temperature was smaller than when the ratings were cool or warm; however, the number of times (N) hot was selected was also less, which could account for the smaller range. Very hot was selected only once.

The only conclusion which can be drawn from these data is that pilot judgment of cockpit environmental temperature is inconsistent and appears to be unreliable as a means of assessing actual environment. A larger pilot sample and a more sophisticated test might have changed the overall subjective response, but the results obtained were not surprising. Historically, subject opinion usually has a large variability of responses, regardless of what the opinions are about.

Estimated Detection/Identification Slant Ranges - The pilots' judgments of ranges of detection and identification of the ground targets may be summarized as follows:

1. Detection -- slant range estimates ranged from 3000 feet to four miles; the mean was 3500 feet.

2. Identification -- slant range estimates ranged from 1500 feet to 4000 feet; the mean was 2500 feet.

During the planning for the study, the ground-target slant ranges were calculated to be two to three miles for detection and less than one mile for identification, at 800 feet absolute altitude.

Fig. 1Q. AERIAL VIEW OF TARGET

APPENDIX R

PILOT ANTHROPOMETRIC AND BACKGROUND DATA

Pilot-Subject Background Data

The pilot-subjects participating in this study ranged in age from 40 to 44 years. They were all civilian test pilots employed by the U. S. Army, averaging 8,600 flight hours experience within a group whose range was 6,500 to 13,500 hours. Their rotary wing experience ranged from 3,000 to 6,000 hours, with an individual average of 4,750 hours, which included an average of 40 hours in the OH-6A helicopter.

A comparison of these pilots was made with the current Army aviator population as described by White (1961). The data indicated that they were in the top .8% age group and had attained an experience level reached by only .6% of the total Army aviator population. The following is a description of their physical stature relative to the current Army aviator population.

Physical Measure	Percentile of Pilot-Subject L	C	B	G	Mean of Pilot-Subject Group	Mean Pilot Size
Weight	75	75	10	25	46	166 lbs
Height	25	50	25	5	25	68 inches
Crotch Height	25	25	50	25	30	31 "
Sitting Height	50	95	25	1	42	35 "
Knee Height	25	50	50	25	37	20 "
Buttock-Knee Length	75	50	25	50	50	23.8"
Hip Breadth Sitting	75	90	5	75	61	14.5"
Neck Circumference	75	75	10	50	52	15.2"
Shoulder Circumference	75	50	25	50	50	46.3"
Chest Circumference	95	95	25	95	77	40 "
Waist Circumference	90	95	25	90	75	34.4"
Hip Circumference	75	75	10	50	52	38.5"
Head Circumference	50	95	90	10	51	22.6"
Shoulder Breadth	75	50	50	90	66	18.5"

APPENDIX S

GROUND METEOROLOGICAL DATA REPORTED AT CAIRNS FIELD, FORT RUCKER, ALABAMA, DURING THE STUDY

Flt.No./Date	Time	DB	Dew Pt.	RH	Time of Reading Fort Rucker	
04A/8-27-66	1100-1245	87°F	64	46.5%	1055	05/04
	1.7 hr	88	63	43.5	1157	01/03
		90	63	41.0	1255	36/02
05B/8-27-66	1425-1629	91	64	41.0	1355	029°/04k
	2.1	90	64	42.5	1455	10°/03
		89	64	43.5	1555	13/02
		87	66	50.0	1655	05/03
06B/8-28-66	0648-0750	72	66	81.5	0656	05/04
	1.0	79	70	74.0	0755	08/07
07C/8-28-66	1129-1329	87	70	57.0	1055	07/07
	2.0	89	69	52.0	1158	16/06
		91	68	47.0	1256	05/05
		88	69	53.5	1356	05/04
08B/8-28-66	1430-1442	78	71	79.0	1456	16/13
09B/8-31-66	1011-1214	84	71	65.5	0955	11/06
	2.0	85	70	61.0	1031	17/02
		85	70	61.0	1057	01/01
		89	69	52.0	1155	01/03
		88	66	48.5	1255	02/03
10A/8-31-66	1310-1511	86	70	59.0	1325	06/03
	2.0	85	70	61.0	1355	05/05
		89	69	52.0	1455	06/06
		87	68	53.5	1555	07/06
		87	68	53.0	1600	
11C/8-31-66	1612-1743	81	68	64.5	1655	05/02
	1.5	84	69	61.0	1757	00/00
12C/9-1-66	1030-1221	87	66	50.0	0955	00/00
	1.8	90	64	42.5	1057	00/00
		88	65	46.5	1158	18/02
		90	65	44.0	1258	00/00
13B/9-1-66	1505-1712	90	65	44.0	1500	04/05
	2.1	91	65	42.5	1556	03/05
		89	67	48.5	1655	05/02
		83	71	67.0	1755	00/00

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13. ABSTRACT

The purpose of this study was to measure performance changes which may occur when Army personnel, wearing complete operational/combat flight clothing and equipment, fly a Light Observation Helicopter during periods of high ambient temperature and humidity. Important relationships were found between physiological changes and crew station environment. An equation was developed to quantify a hypothetical relationship between performance, environment and physiological changes.

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Flt.No./Date	Time	DB	Dew Pt.	RH	Time of Reading Fort Rucker	
14A/9-2-66	1511-1706	93	63	37.5	1458	00/00
	1.9	93	65	40.0	1543	17/04
		92	66	42.5	1557	18/04
		90	68	48.5	1655	20/02
		87	69	55.5	1758	23/02
15A/9-3-66	0940-1205	85	74	70.0	0856	36/05
	2.4	89	75	63.5	0955	36/06
		90	71	54.0	1055	10/04
		92	69	47.5	1156	21/08
		93	69	46.0	1258	20/08
16C/9-3-66	1306-1444	93	68	44.5	1355	21/06
	1.6	94	70	46.0	1456	17/08
17C/9-4-66	1525-1615	91	69	49.0	1557	21/07
	.9	89	69	52.0	1655	27/03
18C/9-4-66	0630-0740	75	73	93.5	0557	28/05
	1.2	77	74	90.5	0655	28/05
		83	75	77.0	0756	31/09
19B/9-4-66	0925-1123	82	74	77.0	0857	28/04
	2.0	86	74	68.0	0956	30/02
		87	73	63.5	1055	30/06
		88	72	59.5	1157	31/08
20C/9-4-66	1143-1405	92	71	51.0	1256	23/11
	2.4	89	74	62.0	1357	36/03
		83	75	77.0	1448	11/07
21C/9-6-66	0636-0732	71	70	96.5	0555	00/00
	1.0	73	71	94.0	0655	20/05
		78	73	85.0	0756	33/04
22C/9-6-66	1439-1528	91	68	47.5	1439	33/02
	.8	91	68	47.5	1956	32/02
		91	72	54.0	1556	17/08
23A/9-7-66	0940-1140	80	74	82.0	0857	14/02
	2.0	84	72	67.5	0955	07/04
		87	69	55.5	1056	01/03
		91	67	45.5	1157	09/03

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
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Human Factors Engineering Light Observation Helicopter Pilot Physiological and Psychological Performance Environmental Factors						

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