12

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# PERFORMANCE IMPACT OF CURRENT UNITED STATES AND UNITED KINGDOM AIRCREW CHEMICAL DEFENSE ENSEMBLES

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20. ABSTRACT:

Six male volunteers from the graduating entry level flight program at the US Army Aviation Center (USAAVNC), Fort Rucker, Alabama, served as subjects in an investigation of the ability of helicopter pilots to fly while wearing chemical defense (CD) ensembles in hot weather. Each subject flew on three separate days, wearing a different ensemble each day. The ensembles tested were the United States Army Aircrew chemical defense ensemble, the United Kingdom aircrew chemical defense ensemble, and the United States Army standard flight suit uniform. While subjects made statistically larger heading errors while wearing the US chemical defense ensemble, no operationally significant differences in performance were seen. It was also concluded that a pilot's performance was not an indicator of heat stress.

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS



## LIST OF TABLES

# INTRODUCTION

Current military doctrine calls for extensive use of the helicopter for support, mobility, and firepower. Concern has risen recently over the ability of Army aviators to operate safely and successfully should chemical/biological weapons be used. Army aviators are considered to be at serious risk in such a contaminated environment since the presence of even relatively harmless agents, such as tear gas, may render pilots unable to control their aircraft. The nature of the task of flying and the lack of room in the cockpit to don protective clothing, make it imperative that the pilot don a chemical defense (CD) ensemble prior to leaving the ground if there is a threat of encountering a chemically contaminated environment. The CD ensemble in current use is a two-layer, two-piece overgarment with protective hood and mask. It is designed to completely protect the wearer in a chemically contaminated environment. The ability of the pilot to safely and effectively control the aircraft while in CD ensemble is the focus of this research.

CD ensembles may degrade pilot performance in several ways. The pilot may be deprived of normal sensory input (due to changes in visual, auditory, and/or somatosensory cues) in such a way that "normal" flight is not possible. They might cause a loss of manual dexterity to a degree that certain maneuvers, such as nap-of-the-earth (NOE) flight, are unacceptably difficult. CD ensembles may also interfere with physiological mechanisms; e.g., thermoregulation, to such an extent that pilots may not be able to safely and effectively fly for extended periods of time.

The physiological stress imposed by CD ensembles is primarily that of heat stress in that the garments both increase the insulation surrounding the man and decrease the possibility of convective cooling through sweat evaporation. Heat stress has long been known to degrade performance (Poulton 1976, Wing 1965, and Grether 1973). Anyone exposed to high enough ambient temperatures for a long enough period of time will be unable to perform at an adequate level.

The purpose of the present research was to assess pilot performance in a standard flight suit in comparison with the United States (US) CD ensemble and the United kingdom (UK) CD ensemble when worn in a hot environment. It was assumed that there was no difference in the ability of pilots to fly a helicopter while wearing the US CD ensemble (US), the UK CD ensemble (UK), or the standard flight suit (ST); and neither would there be any changes of performance ability over time while wearing the various ensembles.

## METHOD

### SUBJECTS

Six recent male graduates of the entry level rotary wing flight training program at the US Army Aviation Center, Fort Rucker, Alabama, served as subjects for this research. Table 1 shows the age, height, weight, and total flight hours in a UH-1H for each subject. None of the subjects had flown while wearing a CD ensemble although some had worn the US CD ensemble during ground operations. Subjects read and signed privacy act statements and volunteer participation agreements in compliance with the US Army Medical Research and Development Command Regulation 70-25. Examples are presented in Appendix A.

TABLE 1

AGE, HEIGHT, WEIGHT, AND FLIGHT HOURS OF SUBJECTS

| Subject | Age | Height (cm) | Weight (Kg) | Flight hours in UH-1H |
|---|---|---|---|---|
| 817A | 30 | 185.4 | 98.9 | 190 |
| 817B | 23 | 185.4 | 86.2 | 160 |
| 817C | 20 | 182.9 | 65.8 | 200 |
| 817D | 33 | 172.7 | 83.5 | 165 |
| 817E | 26 | 175.3 | 74.4 | 200 |
| 817F | 37 | 185.4 | 88.5 | 180 |

### APPARATUS

A JUH-1H aircraft, modified to allow in-flight data recording, was flown by the subjects except when specifically mentioned. An OH-58 aircraft was used to enhance safety by aiding in maintaining aircraft separation during testing. The second generation Helicopter In-Flight Monitoring System (HIMS-II) was used to collect and record performance data in flight (Figure 1). Appendix B contains a general summary of the hardware and software components of the HIMS-II. Aside from the computer system, HIMS II is similar to the Helicopter In-flight Monitoring System described by Huffman, Hofmann, and Sleeter (1972).

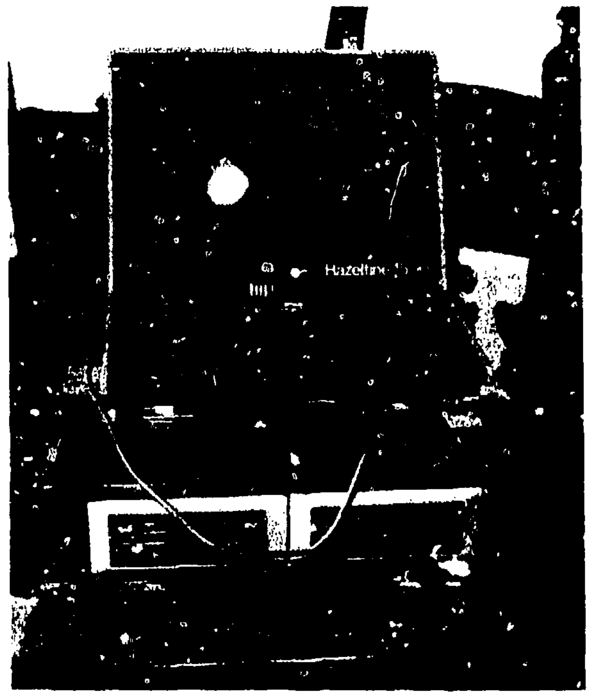

FIGURE 1. Helicopter In-Flight Monitoring System (HIMS II) on Board the JUH-1H Helicopter

## US Aircrew Ensemble

The US Army's current CD ensemble for aviators (Figure 2, p. 8) is a two-layer, two-piece overgarment with butyl rubber boots and gloves. Head/respiratory protection is provided by the M-24 mask and the M-7 hood. This ensemble is designed to be worn as an overgarment to the standard flight uniform. The outer layer is composed of myco fabric treated to repel liquid agents. The inner layer is a charcoal-impregnated foam/nylon tricot laminate which absorbs chemical agents.

## UK Aircrew Ensemble

The UK CD ensemble (Figure 3) consists of the MK-5 aircrew respirator worn under the helmet, power supply system, hood, a one-piece long-limbed coverall, neoprene cowl, and an electrically powered, filtered blower/ventilator. The coverall is to be worn over close-ribbed cotton underclothes because the protective qualities of the suit are degraded by sweat. The neoprene gloves have been cotton flocked on the inside and are worn under standard flight gloves. The standard flight suit and helmet are worn over this ensemble. As is the case with the US CD ensemble, various components of the UK ensemble have been tested (Burden, 1977), but no in-flight pilot performance assessment has been done.

FIGURE 2. United States Army Aircrew Chemical Defense Ensemble.

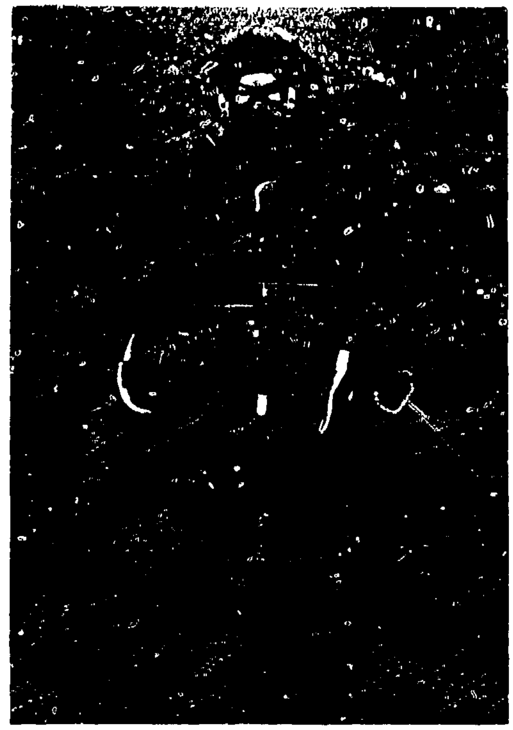

FIGURE 3. United Kingdom Aircrew Chemical Defense Ensemble.

PROCEDURE

Each subject wore each of the three suits (US, UK, and ST), one suit per day over three test days. All permutations of the three suits (3!=6) were used in order to eliminate any statistical artifacts from the order of wear of the suits. Table 2 shows the order in which the suits were worn by each subject. The research took place over a three-week period, testing two subjects per week. Monday, Wednesday, and Friday were flight days, and Tuesday and Thursday were rest days. On Thursday before their test week, each pair of subjects flew the test helicopter and became familiar with the maneuvers to be flown the following week. One subject flew in the morning and the other subject in the afternoon. This was necessary because only one aircraft was available in which performance data could be gathered. Since heat stress was the factor of primary concern, there was originally some concern over differences in temperature during the day. However, it later proved that temperature variation across days was a more important concern than temperature variation during a day. The temperature inside the aircraft was monitored by use of an electronic wet bulb, globe temperature (WBGT) meter. (The WBGT is considered a good measure of temperature in situations where heat stress is a concern since the humidity of the ambient air affects the heat exchange accomplished by sweat evaporation.)

TABLE 2

ORDER OF WEAR OF ENSEMBLES

| Subject | Monday | Wednesday | Friday |
|---|---|---|---|
| 817A | UK | US | ST |
| 817B | ST | UK | US |
| 817C | US | ST | UK |
| 817D | UK* | ST | US |
| 817E | ST | US | UK |
| 817F | US | UK | ** |

* Actually flown on Tuesday because of rain on Monday.
** Not flown due to weather.

## Safety Considerations

The health and safety of the subjects were of utmost concern because wearing the CD ensembles in hot temperatures may produce heat stress. Heat-related injuries can occur in any hot environment where the body cannot adequately cool itself. Examples of heat-related injuries are heat cramps, heat exhaustion, heat pyrexia, and heat stroke. Belyavin, Gibson, Anton, and Truswell (1979) tested aircrews wearing CD ensembles in laboratory conditions simulating helicopter operations with WBGT temperatures of 28.9°C (84.02°F). They reported that core (rectal) temperatures exceeded 38°C (100.4°F) within 45 minutes and continued to rise at a rate of 1°C per hour with no plateau in rise noted. Pandolf and Goldman (1978) noted that core temperatures of 39° to 40°C and/or heart rates of 180 bpm have been used to delimit practical tolerance limits to heat stress. They further argued that a convergence of skin and rectal temperatures appears to be a more practical means of assessing intolerance to heat stress. The following criteria for termination of experimental flight were used in the present study:

1. Subject pilot desired termination.

2. Safety pilot observed mental deterioration or performance deterioration in the subject pilot.

3. Rectal temperature exceeded 38.5°C.

4. Rectal temperature and skin temperature converged to within 0.5°C.

5. Heart rate equaled or exceeded 140 bpm for 10 minutes.

6. Inclement weather, such as rain, high wind, or fog made flight hazardous.

7. Any mechanical difficulties with the aircraft made flight hazardous.

The decision to terminate could be made by any of the following personnel: subject, safety pilot, flight surgeon on duty, or the medical observer on board the aircraft. When a decision to terminate was made, one of two courses of action was undertaken:

a. If the decision to terminate was related to heat stress of the subject, the safety pilot immediately took control of the aircraft and returned to the Highfalls stagefield (the base of operations) where trained medical personnel, including a flight surgeon, were standing by with appropriate medical supplies.

b. If the decision to terminate was related to weather or mechanical malfunctions, the safety pilot immediately took control of the aircraft and either returned to Highfalls or made a precautionary landing, in accordance with standard procedures.

## Flight Profiles

The safety pilot took the aircraft (JUH-1H) aloft and flew to an area where encounters with other aircraft were unlikely. Research team members in an OH-58 aircraft watched for other aircraft while maintaining a safe distance from the JUH-1H being flown by the subject. The subject then took control of the JUH-1H and performed a precision flight profile (heading, altitude, airspeed, and time). After the subject completed this profile, the safety pilot flew the aircraft to Highfalls stagefield where the subject took control of the aircraft and performed a lateral hover and a 50-foot hover.

Following is a description of each maneuver.

Heading, altitude, airspeed, and time (HAAT) maneuver. An iteration of the HAAT maneuver consisted of nine successive trials. At the beginning of each trial, the safety pilot read a set of parameter instructions to the subject. The parameters were: heading, altitude, airspeed, and time. An example of the reading of the parameter instructions is as follows:

"Heading, one-eight-zero degrees; altitude, nine hundred feet; airspeed, eighty knots; time, twenty seconds."

Upon hearing the parameter instructions, the subject could either ask that they be repeated once or acknowledge the instructions by saying "Roger" and proceed to come about to the instructed heading, altitude, and airspeed. Upon complying with the instructions for those three parameters, the subject said "start" and maintained those parameters (straight and level flight) for the instructed time. The subject timed himself. At the end of the time, the subject said "stop" and the next trial began. After completing the ninth trial, the subject returned control of the aircraft to the safety pilot. Appendix C contains the written description of the maneuver which was furnished to the subject ahead of time.

The parameters in the HAAT maneuver were designed to be compatible with aircraft instruments. The heading was always a multiple of 5 degrees, the altitude was always a multiple of 20 feet, and the airspeed was always a multiple of 5 knots. The pattern of parameter changes was important. In trials one, two, and three, the altitude and airspeed were the same while the heading changed each trial. Thus, trials two and three were simple heading changes. In trials four, five, and six, the airspeed remained the same while heading and altitude changed. In trials seven, eight, and nine, all three parameters changed. The instructed time also changed with each trial. The magnitude and direction of change across iterations were identical for each trial. For example, the heading change in trial two (i.e., the difference between the instructed headings in trials one and two) in one iteration might be from 180 degrees to 240 degrees (60-degree turn) and in another iteration might be from 230 degrees to 290 degrees (also a 60-degree turn). The direction of change was always identical. (The altitude change in trial eight was always a 240-foot climb, never a 240-foot descent.) The combination of altitude and airspeed changes was also designed so that one would not aid the other. (Descent was not associated with an increase in airspeed, nor was a climb associated with a decrease in airspeed.) Appendix D contains the instruction sets for two iterations of the HAAT maneuver.

Lateral hover. The lateral hover commenced when the safety pilot placed the aircraft on the southeast corner of the lane at the Highfalls stagefield. The subject then brought the aircraft to a stabilized three-foot hover and hovered laterally around the rectangular runway, keeping the mast of the aircraft over the edge of the runway. At each corner, the subject performed a 450-degree pedal turn around the mast before continuing. The exercise was terminated when the subject completed the rectangular course by returning to the starting point. Each iteration of the lateral hover was flown in the opposite direction of the previous lateral hover.

Fifty-foot hover. Following completion of the lateral hover the subject was to hover the aircraft at a perceived altitude of 50 feet. The aircraft heading during the hover was determined by the winds. At the commencement of the maneuver, the safety pilot turned the nose of the aircraft into the wind, landed the aircraft, and announced the heading to be maintained during the exercise. The subject was directed to bring the aircraft to what he perceived to be a 50-foot hover and maintain the hover and the heading until instructed to land. The subject then took control of the aircraft and rose to a perceived 50 feet and verbally counted down from 5 to 0 when stabilized. After two minutes the safety pilot instructed the subject to land the aircraft.

Summary of flight profiles. The following is a summary of the procedure for the four hours of flight on a test day.

1. Safety pilot takes aircraft aloft and away from traffic.

2. Subject performs HAAT maneuver.

3. Safety pilot takes control of aircraft and returns to Highfalls.

4. Subject performs lateral hover exercise.

5. Subject performs fifty-foot hover.

6. One through five repeats until the one-hour point.

7. At the one-hour point, aircraft lands, subject drinks water ad libitum while seated inside the aircraft.

8. One through five above are repeated until the two-hour point.

9. At the two-hour point, aircraft lands; subject and crew exit aircraft. Subject sits in shade, drinks water ad libitum while the aircraft is refueled (15-20 minutes).

10. One through eight above are repeated until four hours elapse.

## RESULTS

The specific dependent variables analyzed were:

1. Absolute difference between the instructed heading and the observed heading at the start of each trial.

2. Absolute difference between the instructed airspeed and the observed airspeed at the start of each trial.

3. Absolute difference between the instructed time and the observed elapsed time between the start and stop of each trial.

4. The median of heading standard deviations* between the start and stop for each trial.

5. The median of airspeed standard deviations* between the start and stop of each trial.

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* During straight and level flight, pilots' variation from directed parameters (error) could take two forms. The first was the natural error in ability to hold the aircraft precisely on course. The second was an error in remembering what the proper parameter should have been. Mean standard deviation was contaminated by the second kind of error because inappropriate parameters could be off a great deal (e.g. heading may vary 100 degrees) while the first kind of error may vary only a little (e.g. heading error may be only one to two degrees). Rather than deleting data on the basis of presumed error in remembering selected parameters, the median of the standard deviations collected for the nine trials comprising one iteration was used as the measure of central tendency. Comparison of the medians with the standard deviations lead to the conclusion that median was a reasonable measure of central tendency.

6. Elapsed time from acknowledgment of instructions to "start" for trials two, four, and seven.

Variables one through three above are measures of accuracy of compliance with the instructed parameters at the beginning of a trial. Variables four and five are measures of how well the subject maintained instructed straight and level flight. The last variable is a measure of the length of time required to change aircraft parameters--one time each for the one, two, and three parameter change trials.

The actual number of iterations of the HAAT maneuver flown by subjects A through D are presented in Table 3. Data for subjects E and F are not available due to an engine malfunction in the instrumented JUH-1H which necessitated changing to a backup noninstrumented UH-1H. The number of iterations total six if the subject completed all of the programmed flying. If a subject's participation was terminated for any reason (weather or safety), the number of iterations was reduced.

TABLE 3

NUMBER OF ITERATIONS COMPLETED BY EACH SUBJECT
FOR EACH ENSEMBLE

| | Ensemble | | |
|---|---|---|---|
| Subject | ST | US | UK |
| 817A | 6 | 5 (Safety) | 4 (Safety) |
| 817B | 6 | 6 | 6 |
| 817C | 6 | 3 (Weather) | 6 |
| 817D | 6 | 4 (Safety) | 6 |

Subjects completed six iterations in each ensemble unless heat safety criteria (safety) or inclement weather (weather) terminated the testing.

Median errors in heading, airspeed, and timing are presented by subject, suit, and iteration in Tables 4, 5, and 6, respectively. Due to an undetected problem in the altimeter recording circuit, accurate altitude measures were not available. Mean heading errors were 1.63 degrees while wearing the ST suit, 1.78 degrees while in the UK CD ensemble, and 2.02 degrees while in the US CD ensemble. Mean airspeed errors were 1.83 knots in the ST suit, 1.95 knots in the UK CD ensemble, and 2.19 knots in the US CD ensemble. Mean timing errors were .93 second in the ST suit, 1.58 seconds in the UK CD ensemble, and 1.08 seconds in the US CD ensemble. As can be seen, there was a tendency (except in timing) for increased magnitude of error in the UK and US CD ensembles. The largest errors were in the US CD ensemble.

TABLE 4

MEDIAN HEADING ERRORS (DEGREES)

| | Subject | Iteration 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| ST Suit | A | 1.5 | 1.4 | 1.3 | 1.7 | 2.1 | 2.5 |
| | B | .8 | 2.3 | .7 | 1.2 | 1.3 | 2.1 |
| | C | 2.3 | 2.0 | 1.2 | 2.0 | .9 | 2.3 |
| | D | 1.4 | 1.4 | 1.4 | 1.5 | 2.1 | 1.8 |
| | Mean for ST suit = 1.63 | | | | | | |
| UK Ensemble | A | .6 | 1.8 | 1.0 | 1.4 | - | - |
| | B | 1.3 | 1.5 | .6 | 1.7 | 1.7 | 1.7 |
| | C | 1.8 | 1.5 | 3.1 | 2.5 | 2.6 | 5.2 |
| | D | 2.5 | 1.0 | 1.1 | 2.3 | 1.2 | 1.1 |
| | Mean for UK ensemble = 1.78 | | | | | | |
| US Ensemble | A | 1.6 | 2.3 | 1.8 | 2.1 | 2.3 | - |
| | B | 1.5 | .8 | 2.6 | 1.3 | 2.7 | 1.1 |
| | C | 3.4 | 2.1 | 1.9 | - | - | - |
| | D | 1.8 | 3.7 | 2.0 | 1.5 | - | - |
| | Mean for US ensemble = 2.02 | | | | | | |

Missing data is due to subject termination (<u>cf.</u> Table 3, p. 13).

TABLE 5

MEDIAN AIRSPEED ERRORS (KNOTS)

| | | Iteration | | | | | |
|---|---|---|---|---|---|---|---|
| | Subject | 1 | 2 | 3 | 4 | 5 | 6 |
| ST Suit | A | 2.0 | 2.3 | 3.0 | 1.7 | 3.7 | 2.6 |
| | B | 1.5 | .9 | 3.0 | .8 | 1.5 | 1.9 |
| | C | 2.1 | 1.4 | .8 | 1.6 | 1.5 | 1.5 |
| | D | 1.1 | 2.6 | 1.9 | 1.2 | 1.2 | 2.1 |
| | Mean for ST suit = 1.83 | | | | | | |
| UK Ensemble | A | 1.5 | 2.5 | 1.9 | 1.2 | - | - |
| | B | 2.4 | 2.2 | 1.0 | 2.2 | 2.4 | 1.9 |
| | C | 1.0 | 1.2 | 1.8 | 3.3 | 1.8 | 1.9 |
| | D | 1.5 | 2.4 | 1.9 | 1.5 | 2.7 | 2.9 |
| | Mean for UK ensemble = 1.95 | | | | | | |
| US Ensemble | A | 3.5 | 2.8 | 1.2 | 2.9 | 2.6 | - |
| | B | 3.5 | 2.3 | 3.0 | 1.2 | 1.8 | 1.2 |
| | C | 1.0 | 2.0 | 1.9 | - | - | - |
| | D | 1.8 | 2.0 | 3.3 | 1.5 | - | - |
| | Mean for US ensemble = 2.19 | | | | | | |

Missing data is due to subject termination (cf. Table 3, p. 13).

TABLE 6

MEDIAN TIMING ERRORS (SECONDS)

| | Subject | Iteration 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| ST Suit | A | 1.0 | .5 | 1.25 | 1.25 | .5 | 1.0 |
| | B | 2.75 | 2.75 | 3.75 | 1.5 | 3.25 | 2.0 |
| | C | 1.5 | 1.25 | .25 | 1.25 | .75 | 1.5 |
| | D | 1.25 | 1.0 | .25 | 1.5 | .5 | 1.0 |
| | Mean for ST suit = .93 | | | | | | |
| UK Ensemble | A | 1.5 | 1.25 | .75 | 1.0 | - | - |
| | B | 1.5 | 7.75 | 1.5 | 1.0 | 1.0 | 1.25 |
| | C | 1.0 | .75 | 1.0 | 2.5 | 2.75 | 1.5 |
| | D | 1.0 | 1.0 | 1.0 | 1.5 | 1.0 | 1.25 |
| | Mean for UK ensemble = 1.58 | | | | | | |
| US Ensemble | A | 1.0 | 1.0 | 1.75 | 1.0 | 1.25 | - |
| | B | 1.75 | 1.0 | 2.0 | 2.0 | 1.25 | 1.25 |
| | C | 1.25 | .5 | .25 | - | - | - |
| | D | .5 | .75 | .25 | .75 | - | - |
| | Mean for US ensemble = 1.08 | | | | | | |

Missing data is due to subject termination (cf. Table 3, p. 13).

The median of standard deviations of heading errors during straight and level flight (from start to stop) for subjects, ensemble, and iterations are presented in Table 7. Mean standard deviation of heading errors was 1.47 degrees for ST suit, 1.44 degrees for the UK CD ensemble, and 1.58 degrees for the US CD ensemble. The standard deviation of errors was slightly larger for the US CD ensemble than for the ST suit or UK CD ensemble.

TABLE 7

MEDIAN HEADING STANDARD DEVIATIONS DURING STRAIGHT AND LEVEL FLIGHT (DEGREES)

| | | Iteration | | | | | |
|---|---|---|---|---|---|---|---|
| | Subject | 1 | 2 | 3 | 4 | 5 | 6 |
| ST Suit | A | 1.4 | 1.2 | 1.8 | 1.6 | 1.3 | 1.9 |
| | B | 1.7 | 1.5 | 1.7 | 1.5 | 1.7 | 1.3 |
| | C | 1.3 | 1.0 | 1.4 | 1.7 | 1.6 | 1.6 |
| | D | 1.5 | 1.5 | 1.2 | 1.4 | 1.4 | 1.1 |
| | Mean for ST suit = 1.47 | | | | | | |
| UK Ensemble | A | 1.3 | 1.7 | 1.4 | 1.7 | - | - |
| | B | 1.6 | 1.4 | .8 | 1.4 | 1.5 | 1.7 |
| | C | 1.5 | 1.6 | 1.4 | 1.8 | 1.2 | 1.8 |
| | D | 1.3 | 1.1 | 1.5 | 1.8 | 1.2 | 1.1 |
| | Mean for UK suit = 1.44 | | | | | | |
| US Ensemble | A | 1.5 | 1.9 | 1.6 | 2.0 | 1.7 | - |
| | B | 1.9 | 1.2 | 1.7 | 1.1 | 1.2 | 1.6 |
| | C | 1.9 | 1.6 | 1.6 | - | - | - |
| | D | 1.2 | 1.8 | 1.5 | 1.6 | - | - |
| | Mean for US suit = 1.58 | | | | | | |

Missing data is due to subject termination (cf. Table 3, p. 13).

Median standard deviations of airspeed errors during straight and level flight are presented in Table 8. Mean standard deviation of airspeed errors was 1.27 knots in the ST suit, 1.69 knots in the UK CD ensemble, and 1.86 knots in the US CD ensemble. Again, the magnitude of errors was greater in the US CD ensemble.

TABLE 8

MEDIAN AIRSPEED STANDARD DEVIATIONS DURING STRAIGHT AND LEVEL FLIGHT (KNOTS)

| | | Iteration | | | | | |
|---|---|---|---|---|---|---|---|
| | Subject | 1 | 2 | 3 | 4 | 5 | 6 |
| ST Suit | A | 1.8 | 1.6 | 1.5 | 2.1 | 2.1 | 1.8 |
| | B | 1.9 | 1.5 | 2.1 | 1.6 | 1.5 | 1.8 |
| | C | 1.4 | 1.4 | 1.3 | 1.7 | 1.6 | 1.8 |
| | D | 1.4 | 2.0 | 1.9 | 1.9 | 1.6 | 2.3 |
| | Mean for ST suit = 1.27 | | | | | | |
| UK Ensemble | A | 3.1 | 2.0 | 1.9 | 1.6 | - | - |
| | B | 2.0 | 1.1 | 1.2 | 1.7 | 1.8 | 1.5 |
| | C | 1.7 | 2.7 | 1.8 | 1.8 | 1.4 | 2.0 |
| | D | 1.7 | 1.2 | 1.5 | 1.9 | 1.3 | 1.3 |
| | Mean for UK ensemble = 1.69 | | | | | | |
| US Ensemble | A | 1.8 | 2.0 | 2.2 | 2.0 | 2.0 | - |
| | B | 2.1 | 1.5 | 2.4 | 1.4 | 1.9 | 1.6 |
| | C | 1.7 | 2.1 | 1.3 | - | - | - |
| | D | 2.8 | 1.5 | 1.7 | 1.5 | - | - |
| | Mean for US ensemble = 1.86 | | | | | | |

Missing data is due to subject termination (*cf*. Table 3, p. 13).

The time between the acknowledged receipt of instructions ("Roger") to determination that the helicopter was at the desired parameters ("Start") for trials two, four, and seven within separate trials across each of the iterations are presented in Tables 9, 10, and 11 respectively. This is provided to document the duration required to adjust the aircraft when one (trial two), two (trial four), or three (trial seven) parameters are changed (cf. procedure section). Presenting the information across iterations allows fatigue related errors (if present) to be noted. The mean time required to complete any one parameter change was 63.92 seconds in the US ST suit, 69.2 seconds in the UK CD ensemble, and 53.5 seconds in the US CD ensemble. The mean time required to complete two parameter changes was 7[illegible].80 seconds in the US ST suit, 87.81 seconds in the UK CD ensemble, and 63.63 seconds in the US CD ensemble. The mean time required to complete three parameter changes was 81.5 seconds in the US ST suit, 86.05 seconds in the UK CD ensemble, and 85.75

seconds in the US CD ensemble. As expected, the more parameters that were changed, the longer it took to bring the aircraft in line with the new performance criteria.

TABLE 9

TIME FROM "ROGER" TO "START"--TRIAL 2
(SECONDS)

| | Subject | Iteration 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| ST Suit | A | 48.25 | 83.75 | 65.5 | 84.5 | 58.0 | 53.5 |
| | B | 43.75 | 41.25 | 55.75 | 69.75 | 51.25 | 61.5 |
| | C | 75.5 | 54.25 | 64.5 | 109.5 | 94.5 | 81.75 |
| | D | 44.25 | 71.75 | 48.5 | 51.75 | 62.5 | 44.75 |
| | Mean for ST suit = 63.92 | | | | | | |
| UK Ensemble | A | 57.75 | 67.0 | 78.5 | 48.0 | - | - |
| | B | 57.5 | 94.0 | 83.5 | 76.25 | 52.5 | 41.75 |
| | C | 34.0 | 106.75 | 93.75 | 95.75 | 52.8 | * |
| | D | 60.5 | 44.25 | 48.5 | 92.0 | * | 103.75 |
| | Mean for UK ensemble = 69.2 | | | | | | |
| US Ensemble | A | 55.25 | 39.0 | 91.25 | 69.25 | 94.5 | - |
| | B | 42.25 | 42.75 | 42.0 | 71.75 | 36.5 | 73.0 |
| | C | 46.0 | 37.0 | 46.25 | - | - | - |
| | D | 58.0 | 34.25 | 41.5 | 42.5 | - | - |
| | Mean for US ensemble = 53.5 | | | | | | |

* Missing data due to HIMS operator error.
\- Missing data due to subject termination (cf. Table 3, p. 13).

TABLE 10

TIME FROM "ROGER" TO "START"--TRIAL 4
(SECONDS)

| | | Iteration | | | | | |
|---|---|---|---|---|---|---|---|
| | Subject | 1 | 2 | 3 | 4 | 5 | 6 |
| ST Suit | A | 68.75 | 72.5 | * | 94.75 | 72.75 | 125.0 |
| | B | 59.25 | 80.0 | 56.75 | 52.5 | 60.0 | * |
| | C | 75.75 | 107.75 | 97.0 | 85.0 | 86.75 | 38.5 |
| | D | 50.0 | 74.75 | 60.5 | 61.75 | * | 61.75 |
| | | Mean for ST suit = 75.80 | | | | | |
| UK Ensemble | A | 77.25 | 60.0 | 75.25 | 70.0 | - | - |
| | B | 84.[illegible] | * | 55.75 | 77.75 | 69.0 | * |
| | C | 83.75 | 137.0 | 64.25 | 91.5 | 114.25 | 76.0 |
| | D | 74.0 | 195.75 | 94.75 | 69.25 | 89.5 | 76.75 |
| | | Mean for UK ensemble = 87.8[illegible] | | | | | |
| US Ensemble | A | 60.75 | 50.5 | 65.5 | 124.75 | 57.5 | - |
| | B | 75.75 | 59.25 | 58.0 | 44.5 | 55.75 | 56.5 |
| | C | 63.5 | 61.0 | 67.75 | - | - | - |
| | D | 68.0 | 49.25 | 60.5 | 66.5 | - | - |
| | | Mean for US ensemble = 63.63 | | | | | |

* Missing data due to HIMS operator error.

- Missing data due to subject termination (cf. Table 3, p. 13).

TABLE 11

TIME FROM "ROGER" TO "START"--TRIAL 7
(SECONDS)

| | | Iteration | | | | | |
|---|---|---|---|---|---|---|---|
| | Subject | 1 | 2 | 3 | 4 | 5 | 6 |
| ST Suit | A | 69.75 | 72.0 | 85.0 | 75.25 | 79.5 | 50.25 |
| | B | 94.25 | * | 74.0 | 91.25 | 67.0 | 66.5 |
| | C | 113.5 | 81.0 | 104.25 | * | 95.0 | 103.25 |
| | D | 78.5 | 79.25 | 75.5 | 94.0 | 61.75 | 82.25 |
| | | Mean for ST suit = 81.5 | | | | | |
| UK Ensemble | A | 83.5 | 60.5 | 91.5 | 72.75 | - | - |
| | B | 79.25 | * | 74.75 | 80.75 | 73.5 | 71.5 |
| | C | 101.0 | 99.0 | 93.0 | 95.0 | 83.5 | 65.0 |
| | D | 102.0 | 84.75 | 101.5 | 87.75 | 104.5 | 102.0 |
| | | Mean for UK ensemble = 86.05 | | | | | |
| US Ensemble | A | 80.25 | 64.75 | 96.0 | 88.0 | 115.75 | - |
| | B | 87.5 | 93.75 | 77.75 | 77.5 | 66.25 | 77.0 |
| | C | 93.25 | 97.5 | 92.25 | - | - | - |
| | D | 101.25 | 58.5 | 90.5 | ** | - | - |
| | | Mean for US ensemble = 85.75 | | | | | |

* Missing data due to HIMS operator error.
** Subject D (US) was terminated during the fourth iteration before completing trial seven.
\- Missing data due to subject termination (cf. Table 3, p. 13).

## STATISTICAL ANALYSIS

The data presented were analyzed by means of an ANOVA for a two-factor, repeated measures design (Myers, 1972) to assess suit effect upon performance. Iterations with missing data (i.e., iterations 4-6) were not included in the ANOVA. The only significant comparison was for median heading error at the start of the straight and level flight ($p = .01$). All other comparisons were nonsignificant. The ANOVA for median heading error is given in Table 12. A modified Scheffe's contrast among means (Myers, p. 363) was conducted using the ensemble by subject mean square instead of mean square within. This test indicated that the significance found in the ANOVA of heading errors could not be attributed to any one ensemble. In addition, the means and standard deviations of the distributions were then compared and it was revealed that group distributions largely overlapped and the difference in mean heading error was only .39 degree (standard-US ensemble). Because the pilot's heading indicator was calibrated only to within plus or minus 1 degree, it was concluded that there was no practical effect upon heading error at entry into straight and level flight despite the overall statistical significance of the test.

TABLE 12

MEDIAN HEADING ERROR ANOVA FOR TWO-FACTOR REPEATED MEASURES

| SV | df | SS | MS | F | p |
|---|---|---|---|---|---|
| TOTAL | 35 | 19.28 | | | |
| A (Ensemble) | 2 | 3.34 | 1.67 | 13.68 | <.01 |
| B (Iterations) | 2 | .40 | .20 | .83 | NS |
| S (Subjects) | 3 | 3.47 | 1.15 | | |
| AB | 4 | .47 | .12 | .15 | NS |
| AS | 6 | .73 | .12 | | |
| BS | 6 | 1.46 | .24 | | |
| ABS | 12 | 9.40 | .78 | | |

HEAT STRESSED SUBJECTS

Two subjects were terminated due to exceeding heat safety criteria while wearing the US CD ensemble. Examination of the performance data taken immediately prior to termination revealed satisfactory performance. In fact, the performance immediately before termination was indistinguishable from performance measured earlier in the day. Subject 817A, wearing the US suit, completed five iterations of the HAAT maneuvers before termination. The median heading error for his fifth iteration was 2.3 degrees, which equaled the median heading error for the second iteration and the mean of the medians for the four previous iterations was 1.95 degrees. The median airspeed error for the fifth iteration was 2.6 knots, which was actually less than three of the four previous values. The median timing error for the fifth iteration was 1.25 seconds. The mean of the four previous values was 1.19 seconds. The median standard deviation of heading during straight and level flight for the fifth iteration was 1.7 degrees, less than two of the four previous values. The median airspeed standard deviation for the fifth iteration was 2.0 knots, exactly equal to the mean of the four previous values. The flight was terminated shortly after the completion of the fifth iteration when the subject's heart rate exceeded safety parameters. Subject 817D, wearing the US CD ensemble, had almost completed the fourth iteration of the HAAT maneuver when flight was terminated due to elevated heart rate. Again, examination of the performance data revealed no difference in performance. The median heading error (for the completed trials of the fourth iteration) was 1.5 degrees, the median airspeed error was 1.5 knots, the median timing error was .75 second, the median heading standard deviation was 1.6 degrees, and the median airspeed standard deviation was 1.5 knots.

## DISCUSSION

The finding that there were no practical differences in pilot performance while wearing the standard flight suit, the US CD and UK CD ensembles is significant. In addition to this, it should be noted that performance during normal flight did not serve as a predictor or indicator of heat stress. Although the criteria used for termination were admittedly conservative, subjects experienced heat stress only in the US CD ensemble, and they were able to maintain performance up to the point of reaching termination criterion. Personnel in the decision-making (go/no go) capacity should be aware that pilots may be able to fly satisfactorily up to the point that ensuing effects of heat stress place the pilot, crew, aircraft, cargo, and mission in imminent danger.

Pilot performance is only one of many factors involved in the assessment of aircrew chemical defense ensembles. The psychological impact of the ensembles in a hot environment is another factor for consideration. Readers interested in this topic are referred to Hamilton, Simmons, and Kimball (1982) for an analysis of the psychological impact on these subjects. Another factor while wearing the ensemble is physiological stress. Subjects reached termination criterion only in the US CD ensemble. (Only one subject was terminated in the UK CD ensemble, and this termination was later judged to be inappropriate.) Other factors for consideration include the length of time that the suit may be worn, the impact of the handheld filter/blower unit of the UK ensemble on physical activities such as the preflight check or refueling/rearming, and the methods employed for drinking water in each of the suits.

## CONCLUSIONS

Within the time and temperature limitations utilized in this study, aviator performance was not significantly degraded by wear of either the UK CD ensemble or US CD ensemble. Within the established limits, subjects aviators were able to satisfactorily control their aircraft during all phases of this investigation. Even those whose participation was terminated because they exceeded safety criteria showed no signs of failure prior to safety pilot intervention. It was therefore concluded that the quality of the pilot's performance is probably not a reliable indicator that the pilot is approaching physiological overload. Psychological changes were not addressed in this report but may be manifested in the pilot's decision making process prior to reaching physiological limits (cf. Hamilton, Simmons, and Kimball, 1982; Wing, 1965). Pilots and commanders are therefore urged to be completely familiar with TB MED 507, Prevention, Treatment, and Control of Heat Injury prior to undertaking flight while in chemical defense ensembles.

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APPENDIX A

CONSENT DOCUMENTS

Privacy Act Statement

The information solicited in this questionnaire will be used for research and statistical analysis of the problem of Army aviator fatigue/stress in wearing chemical defense ensembles. It will be kept confidential and names will not be used in any reports, published or unpublished, of this data. Participants will be identified only by randomly assigned project identification numbers.

Disclosure is voluntary; however, failure to do so will seriously limit the usefulness of other data obtained from the individuals in this project.

I have read and understand the above statement and consent to the use of this information as described.

Signature Date

Volunteer Participation Agreement

I, ____________________________________________, SSN _______________, having attained my eighteenth (18th) birthday, and otherwise having full capacity to consent, do hereby volunteer to participate in a research study entitled: "Physiological Assessment of the Aircrew Chemical Defense Clothing," under the direction of the US Army Aeromedical Research Laboratory.

The implications of my voluntary participation; the nature, duration, and purpose; the methods and means by which it is to be conducted; and the inconveniences and hazards which may reasonably be expected have been explained to me by Francis S. Knox, Ph.D., Principal Investigator, and are set forth on the attachment of this Agreement, which I have initialed. I have been given an opportunity to ask questions concerning this investigational study, and my questions have been answered to my full and complete satisfaction.

I understand that I may at any time during the course of this study revoke my consent and withdraw from the study without prejudice. However, I may be required to undergo further medical examinations, if in the opinion of the attending physician such examinations are necessary for my health or well-being.

______________________________ ______________________

Signature Date

I was present during the explanation referred to above as well as the volunteer's opportunity for questions and hereby witness his signature.

______________________________ ______________________

Signature Date

VOLUNTEER AGREEMENT
(ATTACHMENT)

PURPOSE

You are being asked to participate in a research program entitled: "Physiological Assessment of the Aircrew Chemical Defense Clothing," to assess the biomedical and physiological feasibility of using the United Kingdom (UK) Aircrew Chemical Defense (CD) Ensemble in the US Army aviation environment. Prior to your participating in the study, you will be given a physical examination by a flight surgeon and will be asked to fill out a medical history questionnaire.

PROCEDURE

You will be asked to fly rotary wing aircraft performing the following maneuvers: (1) 50 feet OGE hover, (2) hover course, and (3) instrument flying course. As an experimental subject, you will be asked to fly approximately 4 hours of flight/day with each of two chemical defense ensemble and 4 hours of flight in the standard flight suit. You will be connected via three chest electrodes, five skin temperature electrodes and a flexible rectal thermometer to physiological monitoring equipment which will monitor heart rate, respiratory rate, skin temperature and core temperature. Additionally, your psychomotor coordination and cognitive functioning will be tested intermittently during the course of the experiment.

The aircraft safety pilot will be in standard US flight clothing. A medical observer will be on board during all flights as a member of the research team. A Flight Surgeon will be on call by radio to provide rapid advice to the medical observer and flight crew, if necessary, and at the stagefield with complete resuscitation equipment and an emergency medical team.

RISKS

The medical risks associated with this project are that of heat-related injuries; i.e., heat exhaustion, heat stroke, and heat pyrexia. An explanation of these injuries follows:

Heat Exhaustion

This disorder can be broken down into two areas: a water-deficient heat exhaustion or dehydration and salt-deficient heat exhaustion.

Water-Deficient Heat Exhaustion

It is an effect of excessive exposure to heat and becoming water-depleted due to inadequate replacement of water losses caused by prolonged sweating.

Signs and symptoms: thirst, fatigue, giddiness, oliguria, pyrexia, and in advanced stages, delirium and death.

Salt-Deficient Heat Exhaustion

It is an effect of excessive exposure to heat in which salt depletion occurs due to inadequate replacement of salt lost through prolonged sweating. Signs and symptoms: fatigue, nausea, vomiting, giddiness, muscle cramps, and in late stages, circulatory failure.

Prevention and Treatment

Prevention of heat exhaustion requires an adequate supplv of water easily accessible while working in hot climates or conditions both during and after working hours. The treatment consists essentially of rest in bed in a cool environment with a high intake of fluids. The preferable method of intake is by mouth unless the person is unconscious, then fluid replacement needs to be given intravenously. Also, the person should be kept cool until his thermoregulatory system is back in balance

Heatstroke

A state of thermoregulatory failure with sudden onset following exposure to a hot environment with a high body temperature > 40.6°C (105°F) characterized by an absence of sweating and disturbance of the central nervous system. It is frequently fatal.

Hyperpyrexia

The same symptoms as a heatstroke except the patient is conscious and may be sweating. The rectal temperature will be slightly lower than that of heatstroke. Signs and symptoms: euphoria, headache, dizziness, drowsiness, numbness, restlessness, purposeless movements, incoordinated movements, aggressiveness, mania, suicidal tendencies, mental confusion, and sudden onset of delirium or coma in heatstroke.

The following are some definitions of some terms which we have used above with which you may not be familiar:

Oliguria - Secretion of a diminished amount of urine in relation to the fluid intake.

Pyrexia - A fever, or a febrile condition; abnormal elevation of the body temperature.

Psychomotor - Pertaining to motor effects of cerebral or psychic activity.

Cognitive Functioning (Cognition) - The operation of the mind by which we become aware of objects of thought or perception, including understanding and reasoning.

Mania - Excitement manifested by mental and physical hyperactivity, disorganization of behavior, and elevation of mood.

It is expected that you will experience some degredation of performance due to heat stress. The safety pilot will be instructed to observe your performance and will not allow you to progress to unsafe levels of degredation.

You will be stressed and uncomfortable during this study, but we have established safety limits and the experiment will not be allowed to proceed if any of these limits are reached. By monitoring your heart rate, respiration, skin and rectal temperature and comparing these parameters with established limits, we will be able to terminate the experiment at a point which will minimize the risk to you.

________________ ________________

Initials Date

# APPENDIX B

## HIMS-II

# HIMS-II

HIMS-II is an acronym for the Helicopter In-flight Monitoring System - second generation. It is designed to provide a means for the objective measurement of data which can be used to study the factors affecting the performance of rotary wing aviators and their aircraft. The system can provide continuous sampling of up to 64 measurements of parameters, such as aircraft status, position in space, position of controls, etc.

## HARDWARE

The right chassis of the HIMS-II system contains a 16-bit CPU, a 32K-word memory board, a magnetic tape drive interface board, a 64-channel analog to digital converter, a serial interface card, and a date/time card. The left chassis contains analog filter cards, a radar altimeter isolation amplifier, and a 100 Hz data acquisition clock. All power for the system is derived from the aircraft 28 VDC, either directly or through an inverter and power supplies. The function of these major elements is as follows:

### RIGHT CHASSIS

CPU - executes instruction contained in the memory.

32K Memory - contains program instructions and data.

Tape Interface - provides the means for the CPU to read and write on both tape drives.

A/D Card - provides the means for the CPU to obtain a digital representation of the voltage on each analog input line.

Date/Time Card - provides communication between the CPU and a battery operated clock which keeps track of the date and time of day.

Serial Card - provides communication between the CPU and two devices utilizing the RS-232 data standard. These devices are the CRT terminal and the radar locator readout unit.

### LEFT CHASSIS

Analog Filters - provides conditioning of sensor signals to include anti-alias filtering (5Hz cutoff frequency), buffering, attenuation and offset addition so as to provide output signals between 0 and 5 volts.

Isolation amp - provides isolation for the radar altitude sensor.

100 Hz Clock Card - provides a crystal controlled clock signal which is routed to the CPU external event line and used to precisely time the data acquisition cycle.

## SOFTWARE

The HIMS-II data acquisition program is an interactive command-oriented system with concurrently operating background and foreground processes. Background functions are processed on a time available basis and include operations such as response to operator commands and display of current measurements. The entire foreground system is driven through a crystal-controlled clock which interrupts the background process 100 times per second. The system allows the user to specify the channels to be sampled and sampling rate for each channel. These selections may be recorded on tape and loaded into the system for each operation. The clock interrupt advances a counter for each channel specified for sampling. When one of these counters reaches the sample period designated for that channel, the channel is sampled and its counter reset.

In response to operator command, the system will record the data on tape. This operation is also interrupt-driven and proceeds concurrently with other processes. The time required to complete a normal output buffer transfer is approximately .25 second. The tape interrupt service includes, at the appropriate time, track and drive changes and ejection of full tape cartridges.

## APPENDIX C

## DESCRIPTION OF THE HAAT MANEUVER FURNISHED TO SUBJECTS

## DESCRIPTION OF THE HAAT MANEUVER FURNISHED TO SUBJECTS

You will be instructed to fly a series of maneuvers during which you will be asked to achieve and maintain precise flight parameters. Any deviation from the exact parameter given will be considered an error. The flight parameters are heading, barometric altitude, and airspeed. The instructions will also include a time period for you to maintain the parameters once you have reached them. The instructions will always be given in the following order: heading, altitude, airspeed, and time. If you do not understand say "Repeat," and I will repeat the instructions one time only. After you receive the instructions, acknowledge by saying "Roger." Immediately proceed to follow the instructions. When you have reached the heading, altitude, and airspeed given in the instructions say "Start" and maintain those parameters for the time period given in the instructions. At the end of the time period say "Stop." You will be timed from when you say "Roger" until you stabilize and say "Start." You will also be timed from "Start" to "Stop" to check the accuracy of your timing. Remember that the instructions for heading, altitude, airspeed, and time are intended to be exact and not "school solution." Do not use the heading bug.

# APPENDIX D

## PARAMETER INSTRUCTIONS FOR THE HAAT MANEUVER

PARAMETER INSTRUCTIONS FOR THE HAAT MANEUVER

| Trial | Heading (Degrees) | Altitude (Feet) | Airspeed (Knots) | Time (Seconds) |
|---|---|---|---|---|
| 1 | 180 | 900 | 80 | 15 |
| 2 | 295 | 900 | 80 | 22 |
| 3 | 140 | 900 | 80 | 18 |
| 4 | 355 | 660 | 80 | 25 |
| 5 | 110 | 720 | 80 | 15 |
| 6 | 265 | 1060 | 80 | 23 |
| 7 | 120 | 640 | 65 | 16 |
| 8 | 285 | 900 | 95 | 21 |
| 9 | 035 | 620 | 70 | 19 |
| | | | | |
| 1 | 090 | 1000 | 85 | 16 |
| 2 | 205 | 1000 | 85 | 23 |
| 3 | 050 | 1000 | 85 | 19 |
| 4 | 265 | 760 | 85 | 26 |
| 5 | 020 | 820 | 85 | 16 |
| 6 | 175 | 1160 | 85 | 24 |
| 7 | 030 | 740 | 70 | 17 |
| 8 | 195 | 1000 | 100 | 22 |
| 9 | 305 | 720 | 75 | 20 |

There were eight instruction sets in all, each conforming to the pattern of changes shown above.

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US Air Force Flight Test Center
Technical Library, Stop 238
Edwards AFB, CA 93523 (1)

Command Surgeon
Rapid Deployment Joint Task Force
MacDill AFB, FL 33608 (1)

US Air Force Armament Development
 & Test Center
Technical Library
Eglin AFB, FL 32542 (1)

US Air Force Institue of Technology
 (AFIT/LDE)
Bldg 640, Area B
Wright-Patterson AFB, OH 45433 (1)

US Air Force Aerospace Medical
 Division
School of Aerospace Medicine
Aeromedical Library/TSK-4
Brooks AFB, TX 78235 (1)

Director of Professional Services
Office of The Surgeon General
Department of the Air Force
Washington, DC 20314 (1)

Human Engineering Division
Air Force Aerospace Medical
 Research Laboratory
ATTN: Technical Librarian
Wright-Patterson AFB, OH 45433 (1)

US Navy
Naval Weapons Center
Technical Library Division
Code 2333
China Lake, CA 93555 (1)

US Navy
Naval Aerospace Medical Institute
 Library
Bldg 1953, Code 012
Pensacola, FL 32508 (1)

US Navy
Naval Submarine Medical Research Lab
Medical Library, Naval Submarine Base
Box 900
Groton, CT 06340 (1)

Staff Officer, Aerospace Medicine
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