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Heat Stress Evaluation of Special Operations Aviation Regiment and Air Warrior Concept 1 and 3 Aviator Ensembles in a UH-60 Simulator

By

Matthew J. Reardon
Lawrence C. Katz
Beth E. Fraser

Aircrew Health and Performance Division

March 1999

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Colonel, MS
Director, Aircrew Health &
Performance Division

JOHN A. CALDWELL, Ph.D.
Chairman, Scientific Review
Committee

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This aviator heat stress study used a mixed between/within test subject design with one environmental condition (hot) and three rotary-wing MOPP4 ensembles (Special Operations Aviation Regiment [SOAR], Air Warrior Concept 1, and Air Warrior Concept 3) encumbered with ballistic protection and over-water survival components. The SOAR ensemble was tested with (SC) and without (SX) microclimate cooling (MCC) consisting of a water-cooled undershirt with portable refrigerator/pump. Air Warrior Concept 1 and Concept 3 aviator MOPP4 ensembles were tested with (AC) and without (AX) MCC, respectively. Physiological and subjective data were obtained to compare thermoregulatory responses and quantitate the benefits of microclimate cooling. Test sessions consisted of a 20-minute treadmill walk in a heated (100°F and 20 percent relative humidity [RH]) environmental chamber to stimulate outdoor preflight activities, followed by three 2-hour sorties in a research UH-60 simulator with cockpit conditions set at 100°F and 50 percent RH (90°F wet-bulb globe temperature [WBGT]). Mean (standard deviation) hours of endurance for the four ensembles were: SC=6.8 +/-0.03, SX=5.30 +/-3.28, AC=6.9 +/-0.05, and AX=4.78 +/-0.64. Endurance was not heat stress limited when microclimate was used.

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Mean core (rectal thermistor) temperatures, in °F, just prior to exiting the simulator, were: SC=99.1, SX=101.0, AC=98.9, and AX=101.5. Similarly, end-session heart rates, in beats per minute, were: SC=69, SX=118, AC=62, and AX=130. The ensembles with MCC (SC and AC) resulted in 6.09°F lower chest and 6.29°F lower arm temperatures. Mean total sweat rates were: SC=199.3, SX=753, AC=203, and AX=764 ml per hour. Mood and symptom responses indicated greater comfort and less stress when MCC was used. There was a time-dependent progression of adverse heat stress symptoms when MCC was not used. Ratings that were higher with MCC were those for perceived energy and boredom. Flight performance was not evaluated since the crews were not UH-60 trained. The results of ranking 27 measurements indicated that ensemble AC had the best heat stress mitigation effects, followed, in order of decreasing heat stress performance, by SC, SX, and AX.

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Introduction

This study was implemented to compare physiological and psychological effects of heat stress exposure on aviators wearing current Special Operations Aviation Regiment (SOAR) and Air Warrior Concepts 1 and 3 encumbered chemical defense level-4 mission oriented protective posture (MOPP4) ensembles. The evaluation was performed at the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, during June 1998 for the Commander, 160th SOAR, and the Air Warrior (AW) project manager operating under the program manager (PM), U.S. Army Aircrew Integrated Systems (ACIS). Funding was provided by the U.S. Army 160th SOAR unit and PM ACIS. The objective of the study was to provide data to the SOAR commander and AW/ACIS PM regarding the differences in mission endurance, physiological strain, and psychological heat stress responses between the different MOPP4 aviator uniforms with and without microclimate cooling.

SOAR units frequently deploy on classified missions to remote, austere environments. Crews may be exposed to hot weather, and missions typically emphasize extensive nap-of-the-earth maneuvering. Since distances to objectives may exceed aircraft fuel capacity, inflight refueling is often part of extended duration flight profiles. SOAR commanders and aircrew are aware that heat stress can limit crew and mission endurance and add to the general stress and discomfort of lengthy flights predisposing to decreased performance and accident risk margins. These factors motivated their effort to evaluate the effectiveness and practicality of liquid microclimate cooling garment systems for reducing heat strain and risks of heat stress-induced mission delays or aborts.

The AW project is a joint Army, Navy, and USMC long-range research and development effort to incrementally develop state-of-the-art rotary-wing combat-capable aircrew ensembles using integrated soldier-system design methods. The primary AW goal is to globally enhance aviator effectiveness and survivability when conducting military operations across conditions spanning a complex spectrum of mission and environment-related performance and survivability risks. New-generation aviator ensemble prototypes are being developed by industry to meet AW design goals of modularity, mission configurablility, protection against chemical agents, integrated advanced life support, and ballistic protection (ATCOM, 1995).

Background

Environmental and mission-related heat stress factors

Aviators can be exposed to substantial heat stress when performing outdoor preflight duties and flying unair-conditioned transport helicopters in hot weather environments. The environmental components of heat stress include elevated ambient temperature, humidity, wind speed, and radiant heat load. These heat stress components are frequently expressed as a composite indicator, or index, such as the wet-bulb globe temperature (WBGT) used by the U.S. military.

Mission factors that aggravate the effects of environmental heat stress include requirements to wear occlusive aviator MOPP ensembles. These ensembles are typically encumbered with additional ballistic protection and survival gear that further retard heat dissipation and sweat evaporation. Mission-oriented sustained operational tempo can cause increased activity levels with persistently elevated metabolic rates and lead to fatigue. Increases in metabolic rates contribute to heat stress, and fatigue impairs preventative behavior such as continuous rehydration. Aircraft configurations (e.g., doors and windows closed) may also enhance thermal stress in crew compartments via greenhouse effects.

Individual aircrew factors such as illness, fever, medications (particularly those with anticholinergic properties), and dehydration can also significantly reduce thermoregulatory capabilities and lower the threshold and rate of progression of heat strain and heat illness. Such effects increase the likelihood of performance decrements, failure to complete missions, and occurrence of heat illness.

Numerous field studies have documented dramatic increases in helicopter cockpit temperatures during sunny hot weather. Breckenridge and Levell (1970), for example, measured WBGT readings within the closed cockpit of a parked AH-1G attack helicopter fully exposed to summertime solar radiation at an airfield near Savannah, Georgia. They found that cockpit WBGT typically was greater than 104°F and dry-bulb air temperatures up to 132 °F. Froom et al. (1991) demonstrated that, 1 hour after moving into full sunlight, cockpit WBGT in a Bell 212 helicopter was 13°F (7.2°C) greater than ambient WBGT. Likewise, Thornton and Guardiani (1992) showed that summertime WBGT in the closed cockpit of a hovering UH-60 transport helicopter was approximately 9°F (5°C) higher than at nearby airfields.

High cockpit and cabin temperatures occur because of heat transfer into crew compartments from hot external environments, as well as heat sources from aircraft systems, such as engines, auxiliary power units, and electronic modules. The greenhouse effect exacerbates stress by trapping heat in relatively small, poorly ventilated, crew compartments.

Greenhouse effects occur in enclosures having windows that transmit visible-band solar energy, but are relatively opaque to the longer wavelength infrared (IR) radiation emitted from interior surfaces and crewmembers. Additionally, elevated humidity and carbon dioxide levels in closed crew compartments facilitate cabin air absorption of radiated and transmitted IR energy. The elevated dry bulb temperatures due to IR energy trapped by the air in an aircraft cabin along with the primary heat stress effects of increased humidity from respiration and evaporating sweat contribute to increased cockpit WBGT heat stress index.

Physiological heat stress responses and chemical defense (CD) ensembles

Physiologically, when endogenous or exogenous factors cause net heat storage within body tissue compartments, protective compensatory heat dissipating processes are progressively activated to prevent an increase in core temperature (Epstein, Strochein, and Pandolf, 1987).

Primary thermoregulatory processes include sweating, peripheral vasodilatation, increased cardiac output, and shunting of blood flow from central visceral organs to the skin. Other heat stress responses are only discernable at cellular and biochemical levels.

The metabolic rate for routine flight maneuvers in military helicopters is in the range of 100-200 watts, falling into the category of light physical work (e.g., Thornton, Brown, and Higenbottom, 1984). Therefore, the contribution of metabolic thermogenesis to rise in core temperature during routine flight is usually relatively minor. However, if cockpit conditions are sufficiently hot, even slight metabolic heat gain can cause aviator core temperature to relentlessly increase to levels that cause discomfort, impair performance, and eventually cause heat illness.

Mission oriented protective posture (MOPP) is a term used with a numerical suffix (0-4) to signify five standard levels of personal protection against chemical and biological (CB) threats. Unit commanders designate appropriate MOPP levels for their units based on intelligence estimates of the nature and immediacy of CB threats. Although MOPP ensembles vary somewhat across the services, typical MOPP components include a chemical agent absorbent over- or undergarment, CB protective mask and impermeable hood, and butyl rubber protective gloves and boots. These components are worn simultaneously to provide level four MOPP (MOPP4) CB protection. Although there has been a continuous improvement in the design and biophysical properties of MOPP4 components, complete MOPP4 ensembles still remain bulky, insulating, impermeable, and encumbering. All these factors can significantly impair thermoregulation as well as performance (e.g., Lussier and Fallesen, 1987; Gonzalez, 1988; Taylor and Orlansky, 1993; Muza, Bandaret, and Forte, 1995; and Ramsey, 1995).

Low water vapor permeability for CD ensembles signifies reduced maximum rates of evaporative skin cooling. When ambient temperatures exceed body temperature, sweat evaporation is the only effective method of dissipating body heat (Sawka and Wenger, 1988). Complete evaporation of 1 liter of sweat provides 580 kcal of surface cooling. However, effective sweat rates, as determined by the rate of evaporation of sweat from a uniform, determines the evaporative cooling power available to the individual. It is apparent, therefore, that actual and effective sweating rates may differ considerably.

In heat stress conditions, low water vapor permeability causes the air layer between the skin and inner surface of a CD ensemble to rapidly saturate with sweat vapor. As this occurs, the net evaporation of sweat decreases and approaches zero. The unevaporated sweat is then either absorbed into the flight uniform and overgarments and accumulates in dependent parts such as boots, gloves, and mask. Since the unevaporated sweat cannot be used for cooling, it only contributes, in a deleterious manner, to dehydration.

Methods and procedures

Study design

The original scheme was to conduct this study using a repeated measures design. However, test subject availability and funding limitations resulted in a mixed (between and within test subjects) and incomplete factorial implementation. There was one environmental condition, and, as indicated in figure 1, a MOPP4 ensemble factor with three levels (SOAR, AW Concept 1, and AW Concept 3), and a microclimate cooling (MCC) factor with two levels (with and without). The order of testing is depicted in figure 2. Data were obtained to characterize the physiologic and subjective heat stress responses for the different factor levels.

	SOAR	AW Concept 1	AW Concept 3
With MCC	+	*	+
Without MCC	+	+	*

	SOAR	AW
With MCC	+	+
Without MCC	+	+

+: tested *: not tested

Figure 1. Collapsing the 2 AW Concept ensembles into a composite AW level because of incomplete factorial implementation.

	Tues, 6/16	Wed, 6/17	Thurs, 6/18	Fri, 6/19	Sat , 6/20	Sun, 6/21
Crew	2	1	2	1	2	1
TS 1		SC		AC		SX
TS 2		SC		AX		SX
TS 3	SX		SC		AC	
TS 4	SX		SC		AX	

Legend:

TS	Test Subject
SC	SOAR-specific MOPP4 with MCC
SX	SOAR-specific MOPP4 without MCC
AC	AW MOPP4 Concept3 with MCC
AX	AW MOPP4 Concept1 without MCC

Figure 2. Order of testing by crew, test subject, and ensemble.

Four volunteer aviators were tested as two 2-man crews. Each crew participated in three heat stress exposure sessions during one week of testing. The limited number of available test subjects did not permit full counterbalancing with respect to order of factor levels. The two crews were tested in SOAR-specific MOPP4 without MCC and in SOAR MOPP4 with MCC. There were also two sessions wherein one crewmember wore the Air Warrior Concept 1 MOPP4 ensemble without MCC and the other crewmember wore Air Warrior Concept 3 MOPP4 ensemble with MCC.

Sequence of test session events

Prior to study participation, the volunteer crews received a detailed briefing regarding the study and were informed of their right to withdraw at any time, at their discretion, without penalties. The volunteers read and signed the approved informed consent and then were medically screened for evidence of disqualifying conditions (e.g., significant medical conditions, history of heat stroke or recurrent heat illness of lesser severity, and use of prescription medication) or indicators of excess cardiovascular, musculoskeletal, or other health risks.

Test subjects arrived at USAARL each day during the test week at approximately 0700, self-inserted a rectal thermistor, had skin temperature sensors and electrocardiogram (ECG) leads applied, and then donned the designated MOPP4 aviator ensemble (Appendix A). They subsequently entered an environmental chamber for a 20-minute treadmill walk at a 3 mph pace and 0 percent grade. This was done (per Thornton et al.,1992 and Reardon, et al., 1996 and 1997) to approximate the metabolic heat generated during an actual UH-60 preflight inspection.

According to the 160th SOAR pilots, they do not usually perform preflight inspections in MOPP4. In such circumstances, preflight checks on their aircraft are done by off-duty pilots or others specifically assigned to do so. However, in most other Army aviation units, flight crews are responsible for preflighting their own aircraft regardless of the required MOPP level. Therefore, the simulated preflight treadmill walk was retained in the study design for generalizability of results, as well as to maintain data comparability with the previous heat stress studies that used this method.

After completing the 20-minute simulated preflight inspection on the treadmill, crews walked a short distance in their ensemble to the USAARL UH-60 simulator. Throughout each test session, core temperature and heart rate were monitored every 10 minutes to verify adherence to physiological limits as approved in the research protocol (core temperature limit of 102.56 °F, or 39.2 °C, and heart rate not to exceed 90 percent of age-adjusted predicted maximum). Pre- and post-test weights and fluid intake and output were obtained to determine mean sweat rates and dehydration levels.

Each UH-60 simulator session consisted of three consecutive 2-hour sorties (air assault (AA), medical evacuation (MEDEVAC), and repeat of the AA. Since flight performance was not evaluated, crewmembers were allowed to self-regulated their time on the controls. A 10-minute simulated hot refueling break was allowed between sorties. This time was used for equipment adjustment, water resupply, and use of the bathroom as needed. Except for the latter, the crew stayed in the heated simulator during those 10-minute segments. During the sorties, the study technician in the simulator and data acquisition systems collected physiological data. When subjective or objective evidence suggested that physical or subjective tolerance limits were about to be reached, the crew was instructed to make a simulated landing. The affected crewmember(s) was then expeditiously assisted out of the simulator for supervised cooling and recovery.

Environmental conditions

The pilots in this study were tested only in the hot condition as defined in Reardon et al. (1997). This consisted of 100 °F (dry-bulb) and 20 percent relative humidity (RH) in the environmental chamber for the 20 minute simulated outdoor preflight, and 100 °F and 50 percent RH (resulting in a WBGT of 90 °F) in the UH-60 simulator. The WBGT value in the simulator included the radiant black-globe effects from three sets of heat lamps situated above each pilot's helmet. Lamp rheostats were set at 50 percent per Thornton et al. (1992).

Aviator ensembles

Annotated photographs of the U.S. Army SOAR and AW Concepts 1 and 3 rotary-wing ensembles, as well as average component and total weights as tested in this study, are provided in Appendix B. The complete SOAR-specific ensembles with and without the MCC undershirt weighed 38.84 and 40.52 pounds, respectively. The AW Concept 1 ensemble, which did not include MCC, weighed 49.15 pounds. Likewise, the total weight for the AW Concept 3 aviator ensemble with MCC undershirt was 51.97 pounds.

Microclimate cooling system

The microclimate (personal) cooling device used in this study (see Appendix C for detailed description) was the Portable Vapor-Compression Cooling System (PVCS). The PVCS consisted of a relatively compact upper refrigeration/pump unit weighing about 10 pounds and a lower lithium sulfur-dioxide battery module having a weight of about 11 pounds. The refrigeration/pump circulated water cooled with a vapor compression refrigerant. Water lines from the cooling unit to the plastic tubing in the cooling shirt were insulated with rubber foam collars, except close to the refrigeration/pump unit and garment connection, where the lines were exposed to ambient conditions.

Specified operational duration with the battery module was approximately 4 hours. The refrigeration/pump module had a 24-volt connector for use in the simulator; obviating the need for the battery module during that portion of the test sessions. The listed heat extraction rate for the MCC in battery mode was 300 watts.

Although a complete PVCS ensemble includes shirt, pant, and hood heat transfer garments, the crews in this study used only the cooling undershirt (see Appendix C). The pilots wore the cooling undershirt over a standard cotton military T-shirt for comfort.

USAARL's UH-60 research helicopter simulator

Capabilities and data acquisition

The current USAARL UH-60 research simulator has a hydraulic motion base that provides 6 degrees freedom of motion. This allows generation of acceleration cues in lateral, longitudinal, and vertical directions with pitch, roll, and yaw over a 60-degree range. The simulator has a three-channel, four-window, digital image generator (DIG).

The UH-60 research simulator was equipped with an environmental control unit (ECU) that maintained target dry-bulb temperature and RH in the cockpit during the study. The ECU was capable of controlling cockpit conditions within a range of 68-105 °F (± 3 °F) and 50-90 percent RH (± 3 percent).

A physiological data acquisition system in the simulator captured physiological data from crewmembers (USAARL, 1991). This also allowed continuous monitoring of core temperature and heart rate to ensure compliance with approved protocol limits for physiological parameters.

As an additional safety measure, the volunteer aviators were also remotely observed by video cameras during simulator sessions. Two cameras were positioned to monitor the pilots' faces for signs of excessive heat strain and a forward-looking camera fixed to the top of the instrument glare-shield allowed remote monitoring of the view out the left front window. The volunteers were informed about the camera system and provided written recording and photography consent.

Automatic flight control system

Like the actual UH-60 Blackhawk medium transport helicopter, the USAARL UH-60 simulator is equipped with an automatic flight control system (AFCS) which enhances stability and handling qualities (Department of the Army, 1994). The AFCS has four subsystems: The stabilator, the stability augmentation system (SAS), the trim system, and flight path stabilization (FPS). The stabilator, a 14 foot variable angle-of-incidence airfoil, provides control in the pitch axis and a level attitude at a hover. The SAS enhances dynamic stability in all axes, thus preventing "porpoising" in the pitch axis, rolling in the roll axis, and "fishtailing" in the yaw axis. The trim system consists of three trims for pitch, roll, and yaw axes. The trim function provides cyclic (pitch and roll) and pedal (yaw) flight control position reference and control gradient to maintain the cyclic stick and pedals at a desired position.

FPS is also provided for the pitch, roll and yaw axes. FPS provides very low frequency dampening (static stability). FPS functions maintain helicopter pitch attitude/airspeed hold, roll attitude hold, and heading hold and automatic turn coordination.

Flight profiles (sorties)

During test sessions, crews attempted to complete three sequential realistic 2-hour sorties in the heated UH-60 simulator (consistent with USAAC, 1989). These sorties were identical to those described by Reardon et al. (1997 and 1998). The entire simulator mission, or scenario, for each test session consisted of consecutive AA, MEDEVAC, and repeat AA sorties with intervening 10-minute (simulated) hot-refuel breaks which also sufficed for use of latrines and canteen refills.

Every 30 minutes during each test session, the right seat pilot flew a 10-minute set of standard flight maneuvers. Prior to each set of standard maneuvers, the simulator operator initiated simulated IMC conditions. The pilot then ascended to 2,000 feet to start the maneuver set. After the last standard maneuver in each set, the pilot descended out of IMC to resume visual flight rules (VFR) contour and nap-of-the-earth (NOE) flight along the designated path. The sets of standard flight maneuvers were designed to be well integrated into the underlying scenario. The set of standard flight maneuvers was flown 4 times during each 2-hour flight mission or 12 times for the complete 6-hour simulator session. Since flight performance was not evaluated in this study, the set of standard maneuvers were flown merely to keep pilot activity and attention levels consistent with previous similar heat stress evaluations.

Flight performance measurement

Unfortunately, flight performance was not evaluated during this study because the volunteers, although very experienced aviators, were not UH-60 qualified and were not available for sufficient time to train to asymptotic flight performance levels in the UH-60 simulator.

Physiological measurement methods

Heart rate

Heart rate was recorded with a three-lead system using Ver-Med electrodes*. Since the leads were connected to a battery powered R-wave counter, the electrodes were positioned to maximize R-wave tracings. When necessary, a small amount of hair over electrode locations was shaved to obtain sufficient skin-to-electrode contact to reduce the risk of losing heart rate capture from sweating and movement.

Core temperature

Core temperature was measured with a self-inserted YSI 401* rectal thermistor. Prior to use, temperature sensors were calibrated in a stirred water bath with a precision calibrating thermometer.

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* See appendix H, Manufacturers and product information

The rectal thermistor has proven to be quite safe when used by test subjects who are healthy and do not have inflammatory bowel or rectosigmoid diseases or strictures. Prospective volunteers were medically screened to detect criteria precluding use of such thermistors. None of the volunteers had exclusionary conditions and none incurred adverse effects from their use.

Skin temperature

Skin temperature was measured with four YSI 400 series* surface thermistors held in position with collodion and strips of cloth tape. The skin temperature thermistors were placed on the anterior chest, upper lateral arm, lateral thigh, and lateral calf.

Collodion affixed the sensors securely to the skin to prevent sweat-associated separation. The skin was inspected daily to avoid placing these sensors on any lesions and to detect early evidence of irritation or metallic sensitization reactions. After each use, sensors were cleaned and allowed to air dry.

Dehydration

Pre- and post-study session, total undressed and dressed weights were obtained in order to determine the amount of cumulative dehydration and sweating that occurred during each test session.

Prior to starting each test session, the volunteer aviators first urinated and then obtained a nude weight. They self-inserted their individual rectal thermistor. A technician then applied the skin temperature and ECG sensors. Next, test subjects donned the appropriate encumbered MOPP4 ensemble, and a dressed weight was obtained. Before and after each test session, fluids and snack foods were individually weighed. Voided urine was also collected and weights recorded. At the end of each day's test session, a fully clothed weight was again obtained. The ensemble was then removed and a post-session nude weight obtained. Body weight and fluid data were recorded on a form (appendix D) which facilitated subsequent analysis.

Dehydration was calculated by using the term: $100*[(\text{weight}_{\text{sweat loss}} + \text{weight}_{\text{urine output}} - \text{weight}_{\text{water}}) / \text{weight}_{\text{initial nude}}]$. Sweat loss estimate was obtained from the term: $(\text{weight}_{\text{initial nude}} - \text{weight}_{\text{post nude}}) + (\text{weight}_{\text{water}} + \text{weight}_{\text{food}} - \text{weight}_{\text{urine}})$. Total sweat loss minus evaporated sweat permitted assessment of the amount of sweat retained in the ensemble. For each test session, total amounts of sweat, sweat rates, amount of sweat evaporated, and amount retained in the uniform were able to be determined.

Psychological evaluation methods

Mood and symptoms

A 12-question mood and symptoms questionnaire was administered before and approximately every 2 hours after the volunteer pilots began the treadmill session in the environmental chamber (appendix C). Using a 0-10 Likert scale (0=none, 10=maximum), the volunteers assessed their sensation of: headache, nausea, stress, anger, depression, energy, heat stress, thirst, workload, boredom, dizziness, and visual difficulty. Hot spot (pressure point discomfort) locations and intensities were also reported.

Data analysis

The small number of test subjects in this study, as well as the mixed between/within test subject implementation, precluded use of standard parametric statistical analysis. Therefore, comparison of SOAR and AW Concept heat stress results are primarily presented graphically. In subsequent charts and graphs, the 95 percent confidence interval (CI) (mean ± 2 standard errors) for the selected MOPP4 aviator ensemble defines the range within which the mean for other ensemble results must fall to justify a conclusion of no statistically significant difference between responses (see Dawson-Saunders and Trap, 1994, Chapter 7).

Results

Test subjects

Four U.S. Army male warrant officer rotorary-wing aviators voluntarily participated in this study. All completed the study without injury or complications. Mean age was 39.5 years (range: 30-48) with mean weight and height 197 pounds and 72 inches, respectively (Appendix D). They reported an average of 5.6 hours of physical fitness training per week and performed an average of 81 sit-ups and 74 pushups and had a 2 mile run time of 13:54 for their most recent Army physical fitness test. This indicated that the test subjects were in excellent physical condition. The aviators had received an average of 3.25 hours of heat illness prevention training over the past 2 years. Only two of the pilots had worn MOPP4 inflight during the previous year. They were all experienced aviators with pilot qualifications in multiple aircraft and had an average of 3163 total flight hours. However, none had UH-60 flight time. One of the four volunteers had participated in a previous USAARL research study.

Environmental conditions

Time averaged simulator temperature and humidity in the environmental chamber during simulated pre-flight treadmill walks were 100 °F and 20 percent RH. Likewise, these measures in the UH-60 simulator during test sessions were 100 °F and 50 percent RH, respectively. There was tight control of the environmental condition with actual temperature and humidity values deviating negligibly from levels prescribed in the research protocol.

Endurance

Crew endurance was defined as the interval of time from starting the preflight simulation on the treadmill to exiting the simulator due to mission completion, signs or symptoms of worsening heat exhaustion, test subject request to exit, medical monitor directive, or reaching the maximum permissible core temperature (102.5 °F) or heart rate. The pilots were all allowed to continue to their individual heat stress tolerance limits as long as core temperature and heart rate did not exceed prescribed termination thresholds and symptoms were not regarded by the medical monitor as excessive. They were withdrawn individually rather than as crews. The test subjects, however, were generally able to complete test sessions simultaneously as crews when wearing MCC. Endurance with MCC was significantly greater than without MCC since the mean endurances for without MCC fell outside the 95% CI for with MCC means as illustrated in figures 3 and 4 below. The specific endurance times are provided in figure 5.

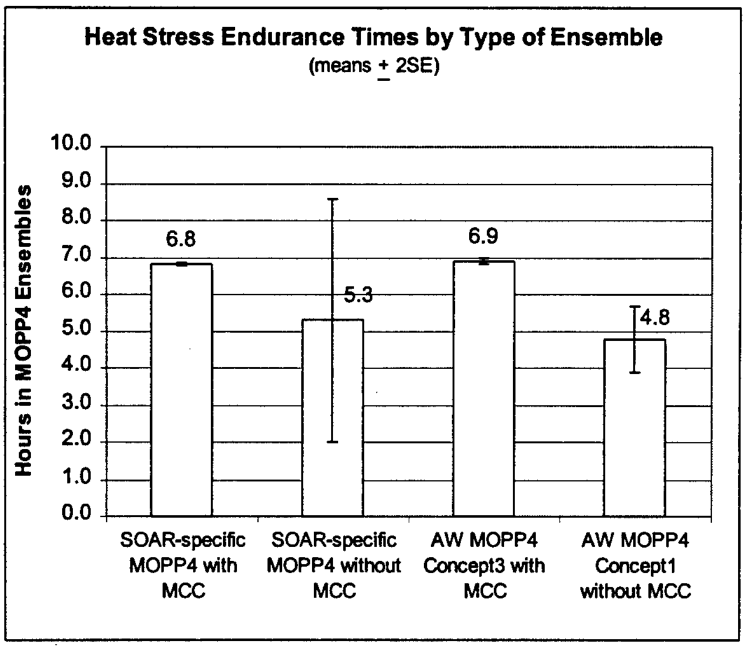

Figure 3. Aviator heat stress endurance by type of MOPP4 ensemble.

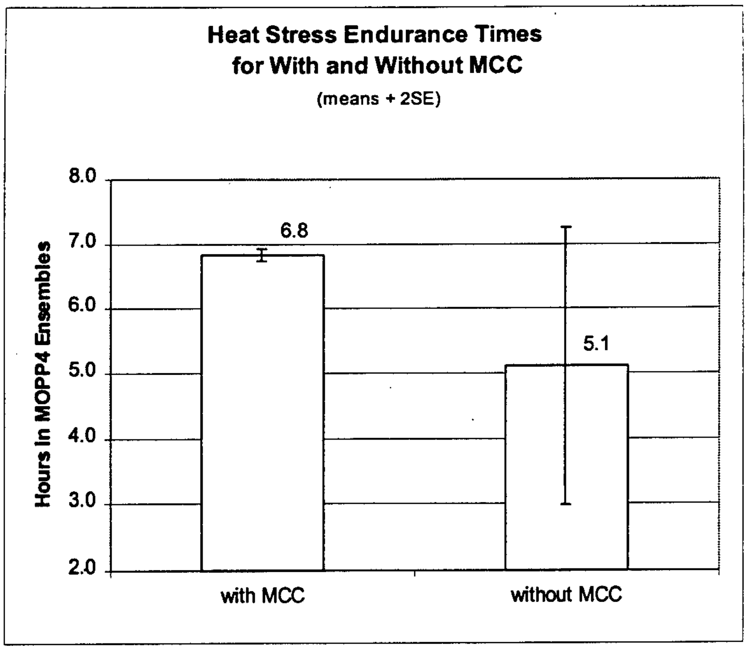

Figure 4. Heat stress endurance by with and without MCC.

	Hours in uniform SC	SX	AC	AX
TS#: 1	6.78	6.72	6.92	NA
2	6.78	6.72	NA	5.00
3	6.82	3.83	NA	4.55
4	6.82	3.92	6.88	NA
AVG -->	6.80	5.30	6.90	4.78
2*SD -->	0.03849	3.281979	0.04714	0.636396
2*SE -->	0.03849	3.281979	0.066667	0.9

	Hours in uniform with MCC	without MCC
	6.8	6.7
	6.8	6.7
	6.8	3.8
	6.8	3.9
	6.9	5.0
	6.9	4.6
AVG -->	6.83	5.12
2*SD -->	0.109545	2.614036
2*SE -->	0.089443	2.134352

NB: Ensembles

SC	SOAR-specific MOPP4 with MCC
SX	SOAR-specific MOPP4 without MCC
AC	AW MOPP4 Concept3 with MCC
AX	AW MOPP4 Concept1 without MCC

Figure 5. Tabulation of endurance times by specific MOPP4 ensemble.

Physiological results

Core temperature

Mean core temperature profiles for the four ensembles, as functions of minutes into test session, are depicted in figure 6 (Appendix E). Figure 7 confirms that use of the MCC garment significantly lowered mean core temperature compared to ensembles without MCC. Figure 8 shows the relative increment in core temperature when not using MCC over the ensembles that included MCC. Note that the ordinate variable is the number of 10-minute increments, not minutes directly. Therefore, when averaged across ensembles with and without MCC, core temperature increased 0.0458 °F per 10 minutes, or 0.2748 °F per hour faster for the two ensembles that did not include MCC. The R^2 value indicates that the regression line accounts for 74% of the variance in core temperature differences. Figure 9 is a chart depicting the relative clustering of endurance and end test session core temperature by ensemble and use of MCC.

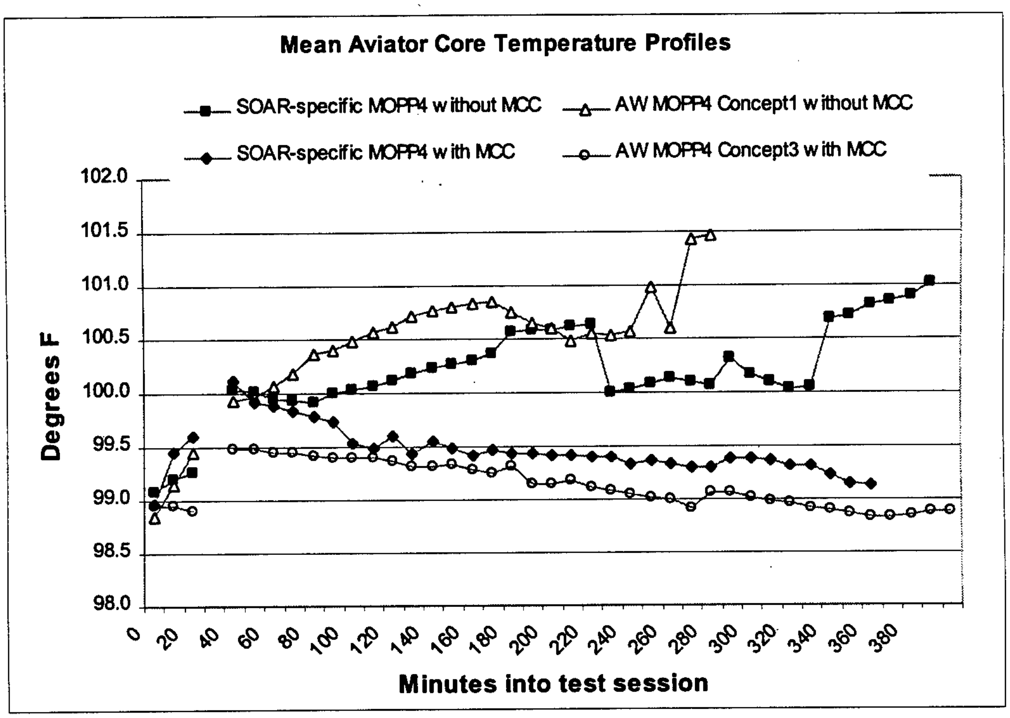

Figure 6. Core (rectal) temperature as functions of time by MOPP4 ensemble. N.B.: data discontinuities between 30-50 minutes were due to treadmill-simulator transitions.

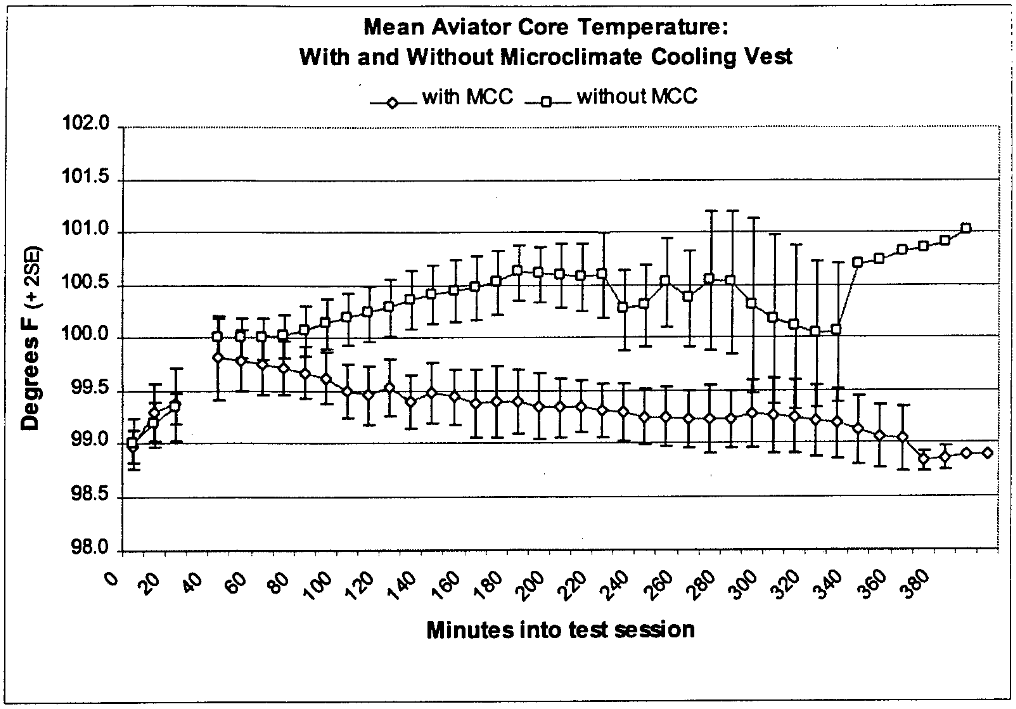

Figure 7. Core temperature as functions of time by with and without MCC.

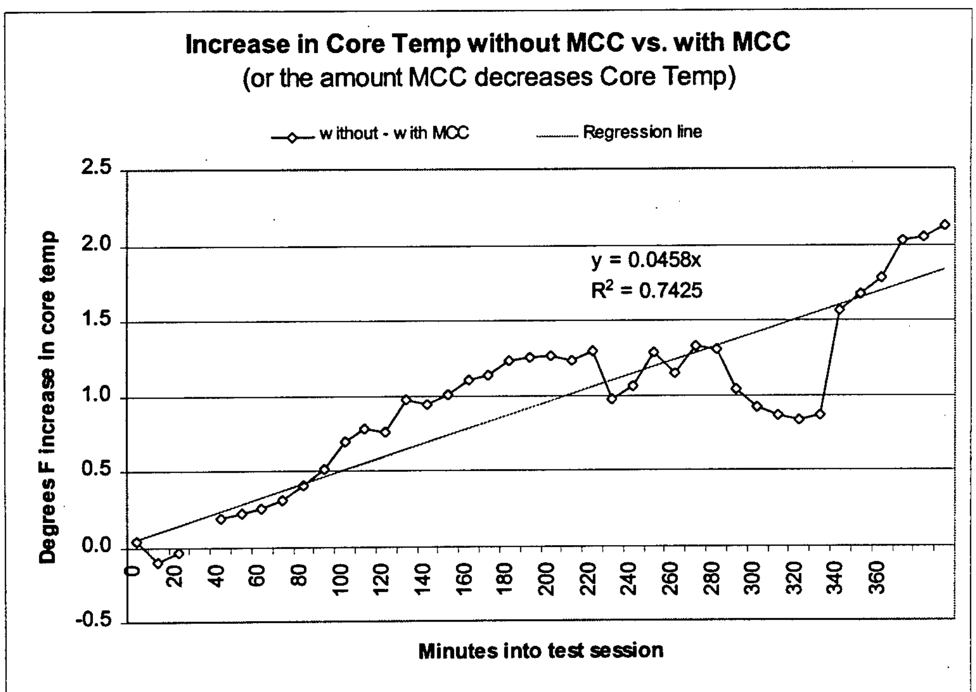

Figure 8. The relative increase in core (rectal) temperature when MCC is not used.

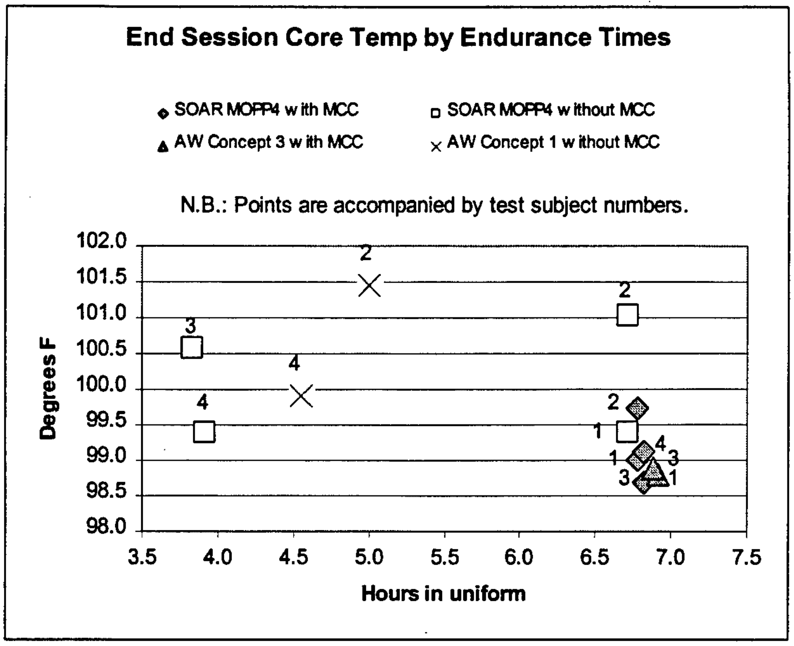

Figure 9. Endurance and end-session core (rectal) temperature by ensemble and test subject. Values in the right lower corner indicate better performance than those in the left upper corner.

Heart rate

Mean heart rate profiles for the four ensembles, as functions of minutes into test session, are depicted in figure 10 (also see Appendix F). Figure 11 confirms that use of the MCC garment significantly lowered mean heart rate response compared to ensembles without MCC. Figure 12 shows the relative increment in heart rate when not using MCC compared to heart rate responses for ensembles that included MCC. Note that the ordinate variable (x) in the regression equation is number of 10-minute increments, not minutes directly. Because of the logarithmic nature of the regression curve, heart rate (y) increases at a rate that is proportional to the inverse of time into test session (9.53.8/x °F per number of 10 minute increments). The R^2 value indicates that the regression line accounts for 54% of the variance in heart rate differences. Figure 13 is a chart depicting the relative clustering of endurance and end test session heart rate by ensemble and use of MCC.

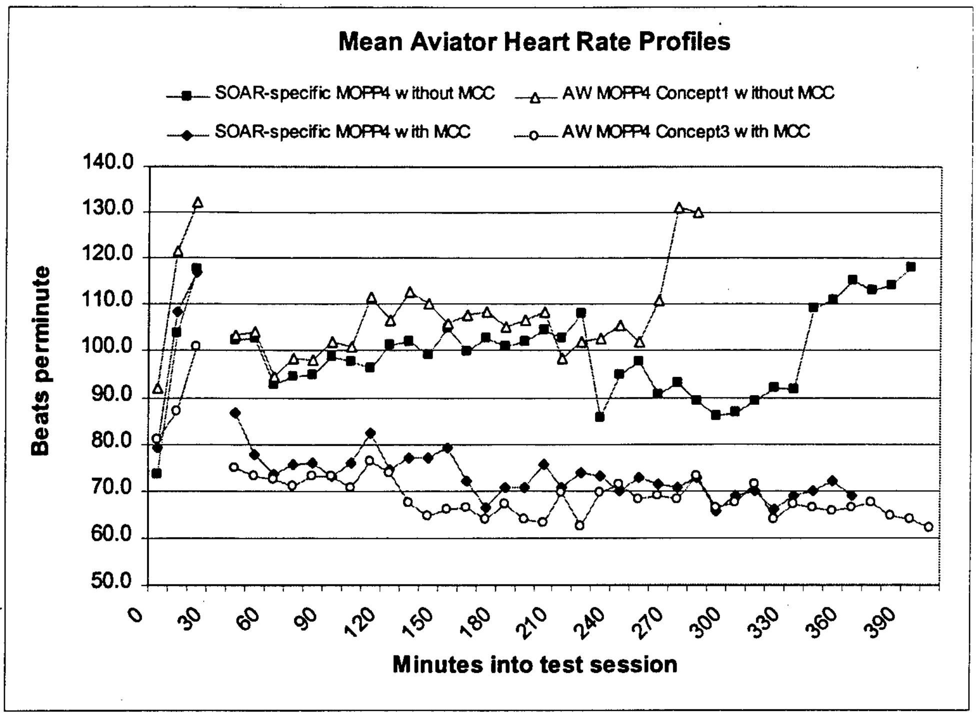

Figure 10. Heart rate as functions of time by MOPP4 ensemble.
N.B.: data discontinuities between 30-50 minutes were due to treadmill-simulator transitions.

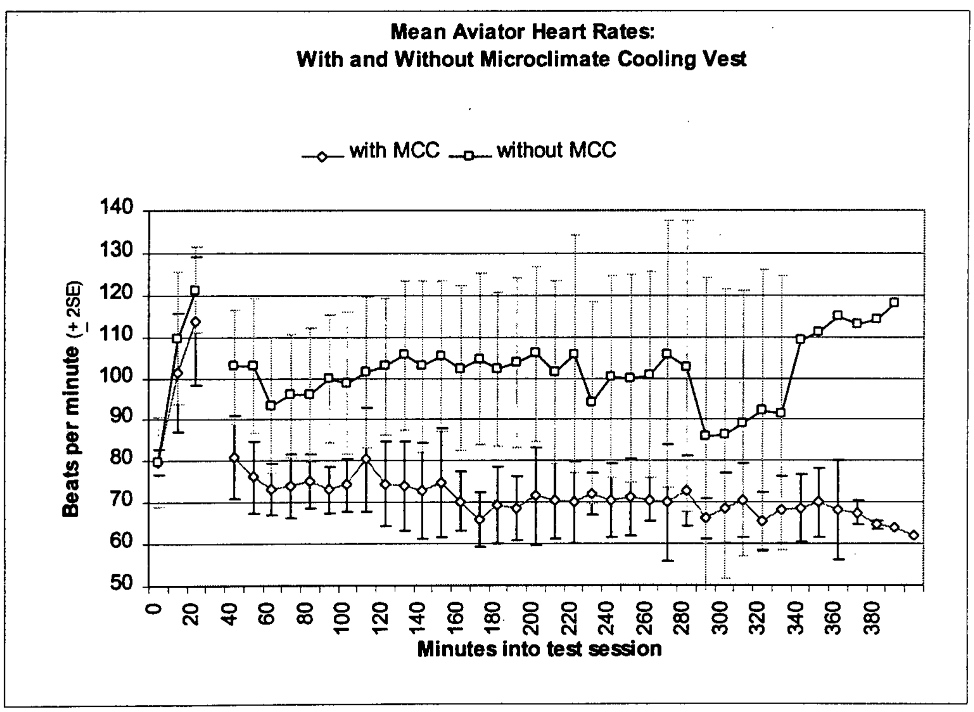

Figure 11. Heart rates as functions of test session duration by with and without MCC.

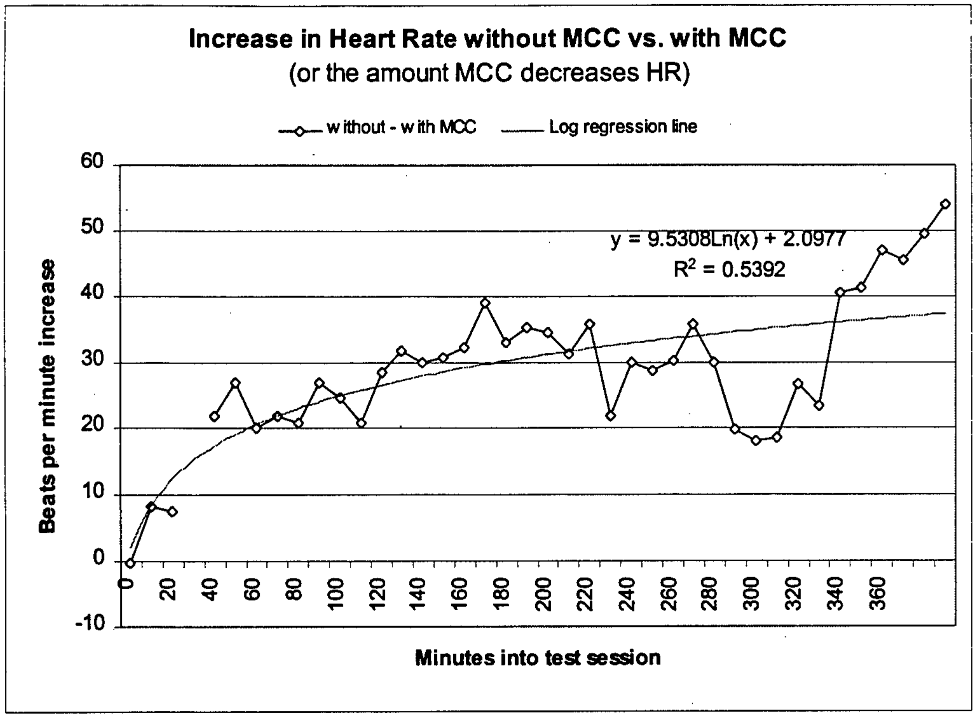

Figure 12. The relative increase in heart rate when MCC was not used.

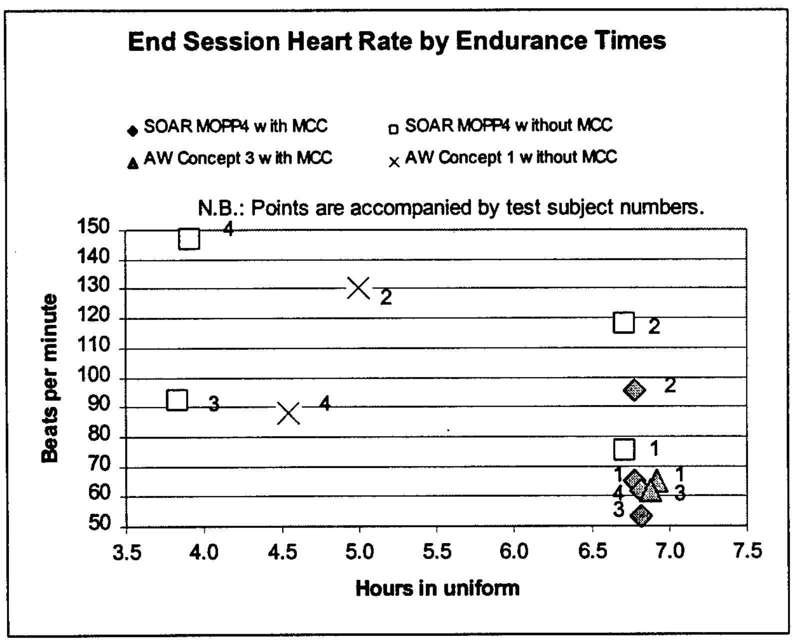

Figure 13. Endurance and end-session heart rate by ensemble and test subject.

Skin temperatures

Mean skin (anterior chest, upper lateral arm, mid lateral thigh, and mid lower calf) temperature responses for the four ensembles are depicted as functions of minutes in the simulator in figure 14. It is visually apparent that use of MCC resulted in lower arm and chest skin temperature but did not have much effect on thigh and calf temperatures.

Skin temperature profiles as functions of time in the simulator are aggregated in figure 15 by with and without microclimate cooling undershirt. These highlight the increased core to skin temperature gradient caused by wearing the MCC under-shirt.

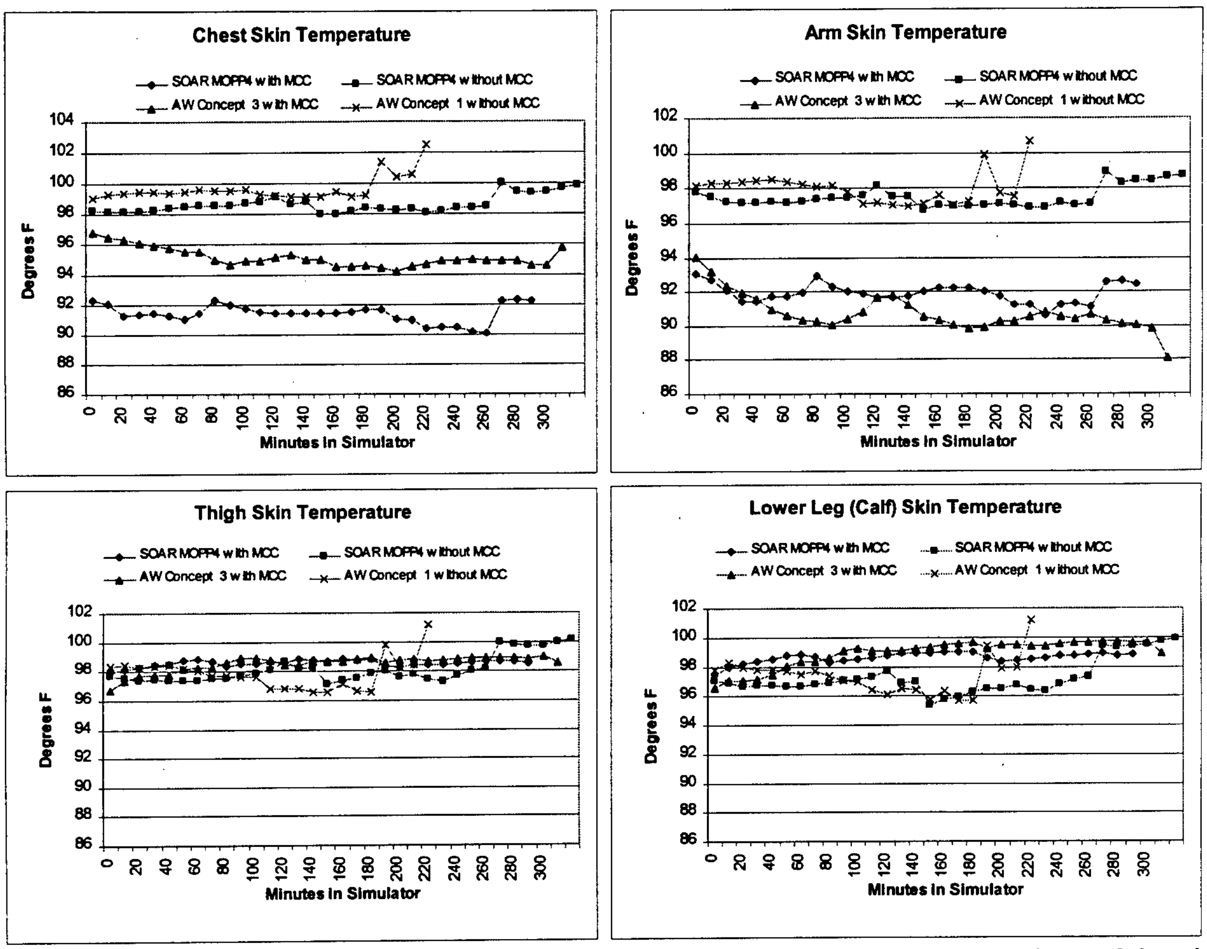

Figure 14. Mean chest, arm, thigh, and lower leg (calf) skin temperatures as functions of time in UH-60 simulator heat stress.

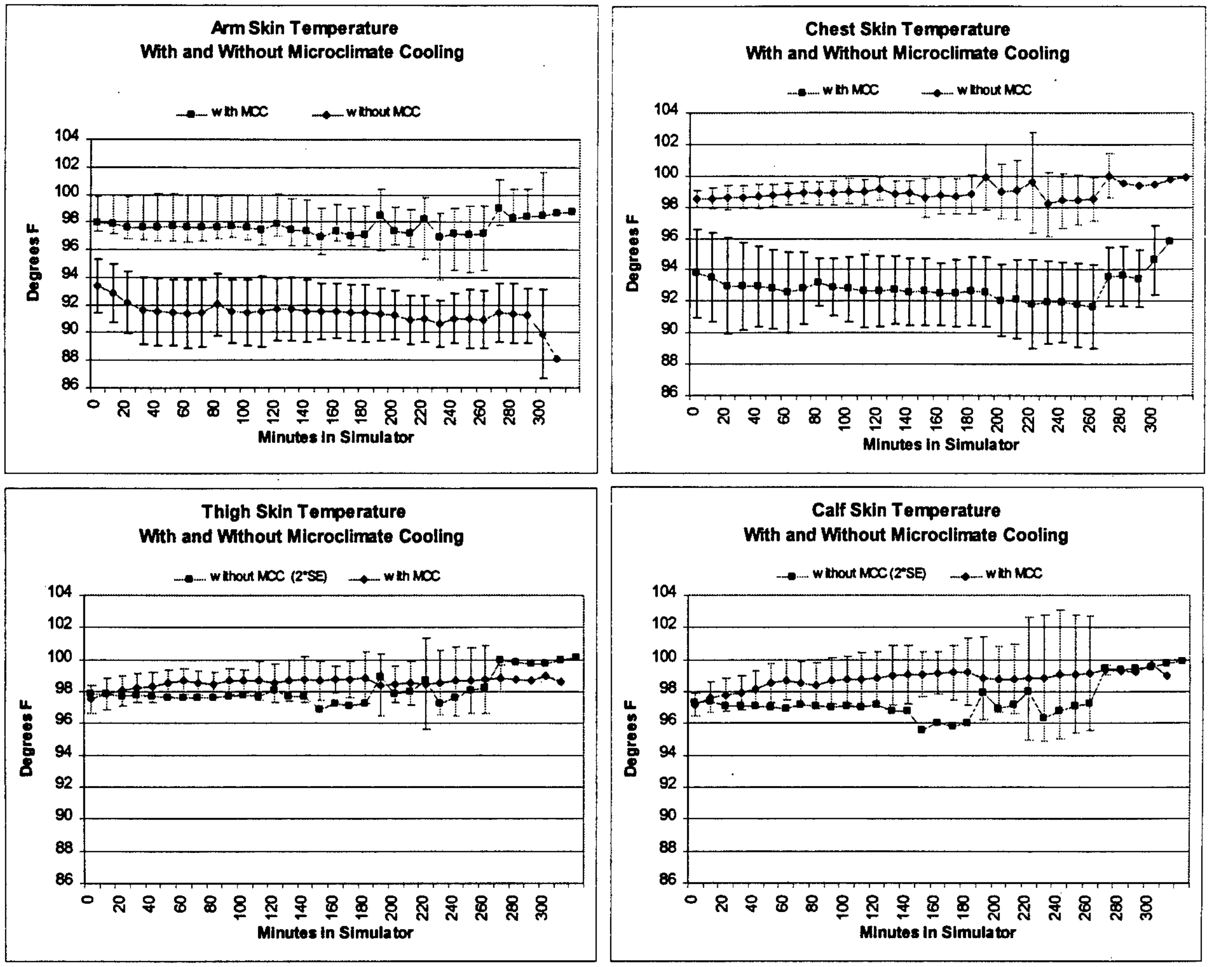

Figure 15. Mean chest, arm, thigh, and lower leg (calf) skin temperature as functions of time in UH-60 simulator heat stress, aggregated by with and without microclimate cooling.

An incidental finding was an apparent trend toward (paradoxically) elevated lower extremity skin temperature when using MCC. This could have been due to a relative decrease in skin bloodflow from MCC-reduced cardiac output from less heat strain. Alternatively, the MCC undershirt might, somehow, have caused or contributed to reduced venous return from the lower extremities. Such mechanisms could reduce vascular convective transfer of heat from the skin of the lower extremities. However, it is also possible that this was a factitious finding due to uncontrolled nonphysiological factors such as differences in seating position that may have preferentially shaded the legs from the heat lamps when aviators used MCC.

Fluid balance and dehydration

Figure 16 shows that use of MCC significantly reduced total and evaporated sweat losses (see also Appendix G). Water intake was concomitantly less in those sessions. MCC, however, seemed to increase urine output slightly. This might have been due to MCC inhibition of upper torso thermoregulatory cutaneous vasodilatation and could be significant for planning inflight urine containment and disposal systems, particularly since use of MCC can result in longer duration missions. Urine output rate of 300 ml/hour for a 6-hour sortie for example, results in a total urine output of close to two liters.

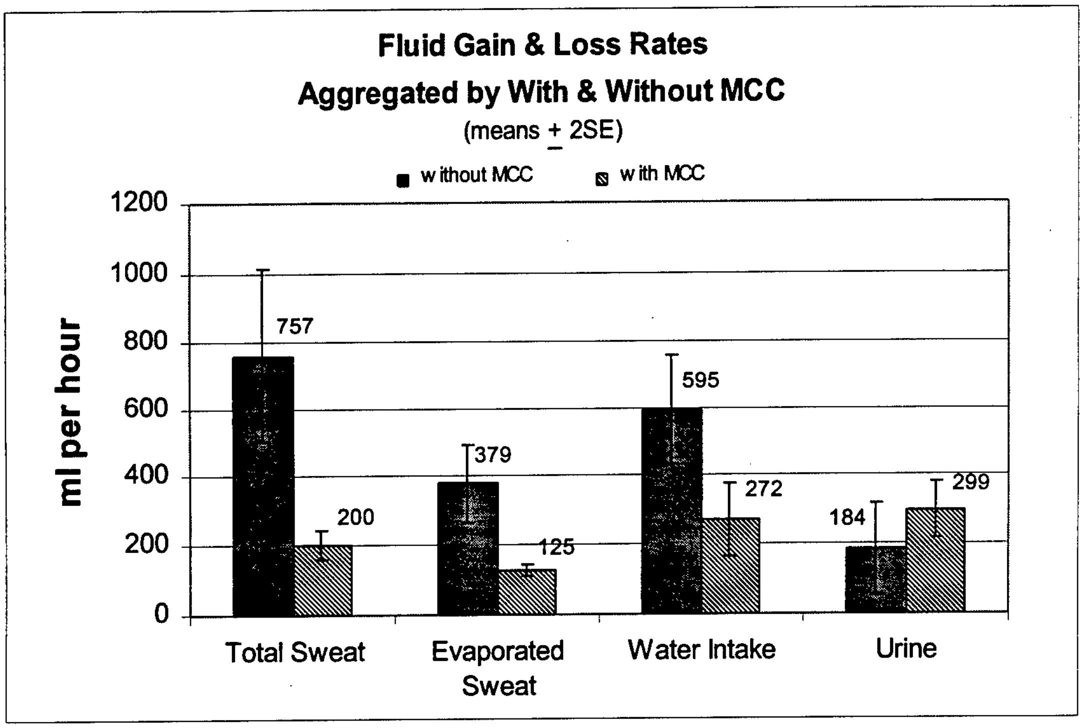

Figure 16. Fluid gain and loss rates (ml/hour) by with and without MCC.

Fluid intake deficit rates were calculated as the difference between fluid loss rates (sweat rate + urine output rate) and fluid intake rate. The results, depicted in figure 17, reveal that the largest fluid intake deficit rates were associated with the AW Concept 1 MOPP4 ensemble without MCC. This occurred for two reasons: the higher sweat rates and greater difficulty imbibing water for the pilots wearing that ensemble. Water intake deficit rates in the other ensembles were comparable, although the lowest deficit rate occurred with the SOAR-specific MOPP4 with MCC.

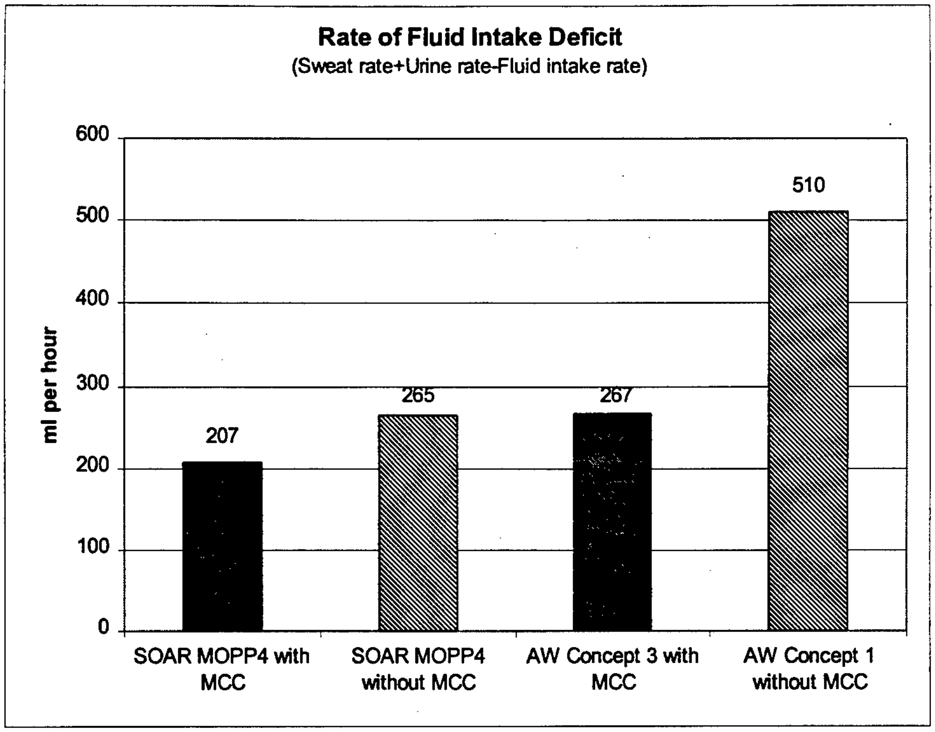

Figure 17. Rate of fluid intake deficit by ensemble.

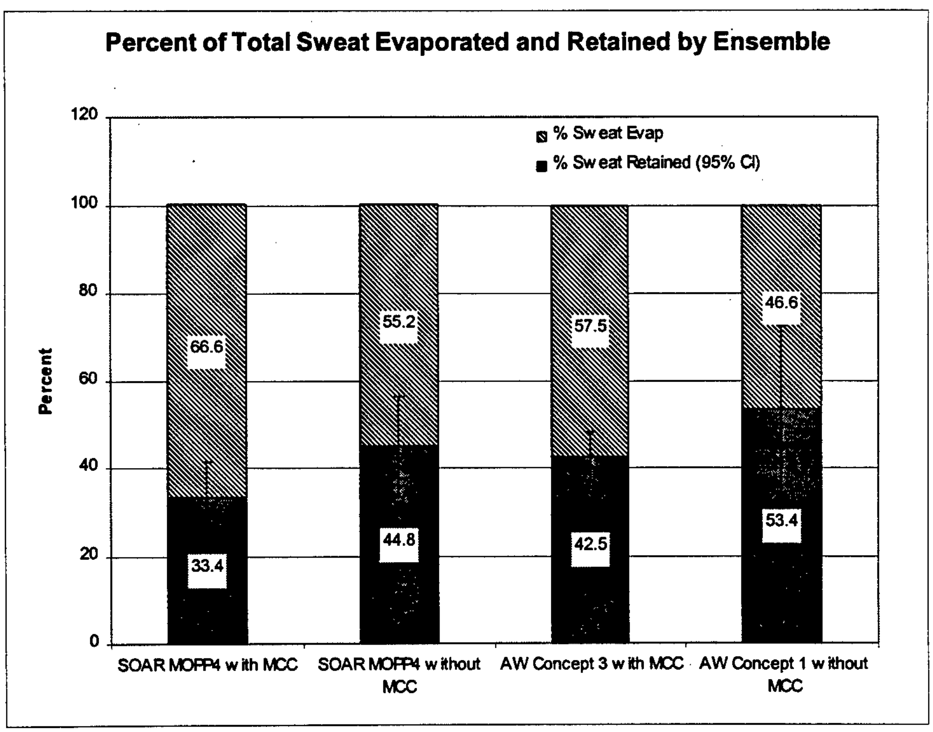

Figure 18. Percent of total sweat evaporated and retained by type of MOPP4 ensemble.

It should be noted, however, that even a seemingly small fluid intake deficit rate of 200 ml/hour could be significant. For example, during a 6-hour sortie, crewmembers would return to base with a 1200 cc water intake deficit. This represents 1.5% dehydration for a 180 pound aviator. Similarly, a fluid intake deficit rate of 500 ml/hour over a 6-hour sortie would mean an end-mission water intake deficit of 3 liters or 3.7% dehydration increment for a 180 pound aviator. If an aviator starts out slightly dehydrated (e.g., 1-1.5%), these additional increments in dehydration could, in themselves, cause symptoms and impair cognitive and physical performance.

Weight and fluid measurements were obtained so that the percent of total sweat that was evaporated versus retained in the uniform could be reported. The results are depicted in figure 18. Use of MCC was associated with a higher percentage of evaporated sweat, or conversely lower percentage of sweat retained. The SOAR-specific ensemble with MCC had the highest percentage of sweat evaporated whereas the AW Concept 1 without MCC had the lowest value.

Percent sweat evaporation results are aggregated by with and without MCC in figure 19 below. Presumably, since the MCC undershirt reduced total sweat rates, a greater percentage evaporated through the garment layers, whereas the higher sweat rates without MCC caused sweat to saturate the garment layers before reaching the outer surface where evaporation could occur.

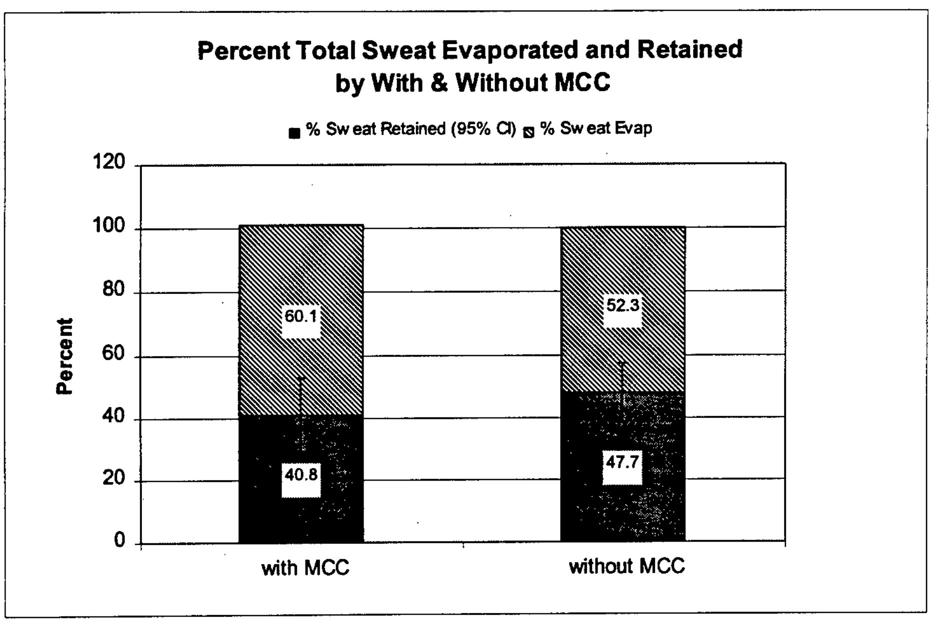

Figure 19. Percent of total sweat evaporated by with and without MCC.

Microclimate cooling system

The water-cooled microclimate system performed well without major mechanical problems during the test week. Cooling power was not directly measured due to lack of sensors to obtain cooling shirt flow rates and coolant temperatures during test sessions. However, analysis of sweat rate differences allowed an indirect estimate of the heat removal rates provided by the cooling undershirt. Cooling power was calculated by the differences between sweat rates (in liters/hr) without and with the MCC shirt multiplied by 0.580 kcal/ml of sweat (the approximate evaporative heat capacity of one ml of sweat). The results are shown in figure 20 below. The estimated cooling power of the MCC undershirt varied from 79.8 to 640 kcal/hr with a mean of 323 kcal/hr.

Individual Total Sweat Rate (Ml/hr)	SOAR	SOAR	SOAR	SOAR	AW	AW	AVG	SE	2*SE
with MCC	212.0	280.1	137.6	167.5	221.8	183.9	200.5	20.2	40.4
without MCC	602.1	417.8	721.0	1271.0	556.4	971.4	756.6	127.9	255.8
Estimated Cooling Rate (kcal/hr)	226.3	79.8	338.4	640.0	194.1	456.8	322.6	82.4	164.8

NB:based on 580kcal potential evaporative cooling power per liter of sweat.

Figure 20. Estimated cooling power of the MCC shirt based on sweat rate differences. (AW with and without MCC represent the AW Concept 3 & 1 ensembles, respectively.)

Psychological results

Mood and symptoms

As indicated in figure 21, mean aviator ratings for most mood and symptom questions were significantly lower for the pilots wearing MCC (SC, AC) compared to when they were in the ensembles without MCC (SX, AX). The only ratings that were higher with MCC were those for perceived energy and boredom.

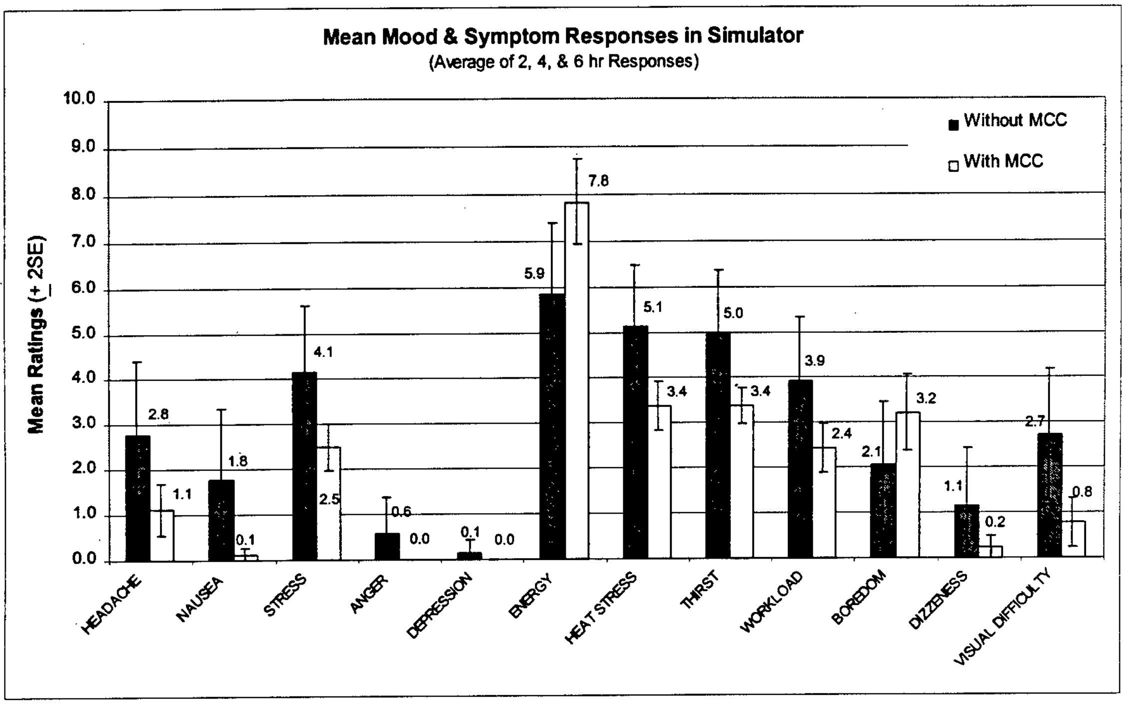

Figure 21. Mood and symptom questionnaire responses by with and without MCC.

Rating the aviator ensembles

An unweighted ranking method was used to objectively compare the heat stress performance of the four MOPP4 aviator ensembles. Mean values for endurance, physiological variables, sweat rate, and mood and symptom questionnaire responses were given integer ratings from 1 to 4 with 1 representing the best performing ensemble and 4 representing the worst performing ensemble. Averages of these MOP-rankings were then obtained for each ensemble. The 27 selected MOP means and rankings are listed in figure 22 and graphically depicted in figures 23 and 24.

	Mean by Type of MOPP4 Aviator Ensemble				Ranking of Means (1=best, 4=worst)			
	SOAR-specific MOPP4 with MCC	SOAR-specific MOPP4 without MCC	AW MOPP4 Concept3 with MCC	AW MOPP4 Concept1 without MCC	SOAR-specific MOPP4 with MCC	SOAR-specific MOPP4 without MCC	AW MOPP4 Concept3 with MCC	AW MOPP4 Concept1 without MCC
Endurance (hours)	6.80	5.30	6.90	4.78	2	3	1	4
End pre-flight HR (bpm)	117	118	101	132	2	3	1	4
End simulator HR (bpm)	69	118	62	130	2	3	1	4
Core temp (simulated pre-flight)	99.6	99.3	98.9	99.5	4	2	1	3
Core temp (UH-60 simulator)	99.1	101.0	98.9	101.5	2	3	1	4
Arm skin temp (UH-60 simulator)	91.9	97.5	90.7	98.0	2	3	1	4
Chest skin temp (UH-60 simulator)	91.4	98.6	95.2	99.7	1	3	2	4
Sweat rate (ml/hr)	199	753	203	764	1	3	2	4
Questionaire responses:								
Headache	1.3	1.6	0.8	5.8	2	3	1	4
Nausea	0.2	1.7	0.0	2.0	2	3	1	4
Stress	2.3	3.2	2.8	6.5	1	3	2	4
Anger	0.0	0	0.0	2.0	1	1	1	2
Depression	0.0	0	0.0	0.5	1	1	1	2
Energy	7.9	6.8	7.7	3.5	1	3	2	4
Heat Stress	3.6	4.4	3.0	7.0	2	3	1	4
Thirst	3.6	4.7	3.0	5.8	2	3	1	4
Workload	2.4	3	2.5	6.3	1	3	2	4
Boredom	2.8	2.1	4.0	2.0	3	2	4	1
Dizziness	0.3	1.3	0.2	0.8	2	4	1	3
Visual Difficulty	0.6	1.5	1.2	5.8	1	3	2	4
Hot Spot Ratings:								
Head	4.2	4.0	3.1	7.6	3	2	1	4
Chest	0.3	0.8	0.0	5.5	2	3	1	4
Back	0.0	0.7	0.0	5.5	1	2	1	3
Buttocks	3.8	4.3	4.3	8.8	1	2	2	3
Arm	0.2	1.1	0.0	4.5	2	3	1	4
Leg	0.4	1.2	2.2	4.3	1	2	3	4
Other	1.6	1.2	1.0	2.5	3	2	1	4

Figure 22. Means and rankings for MOPs by ensemble.

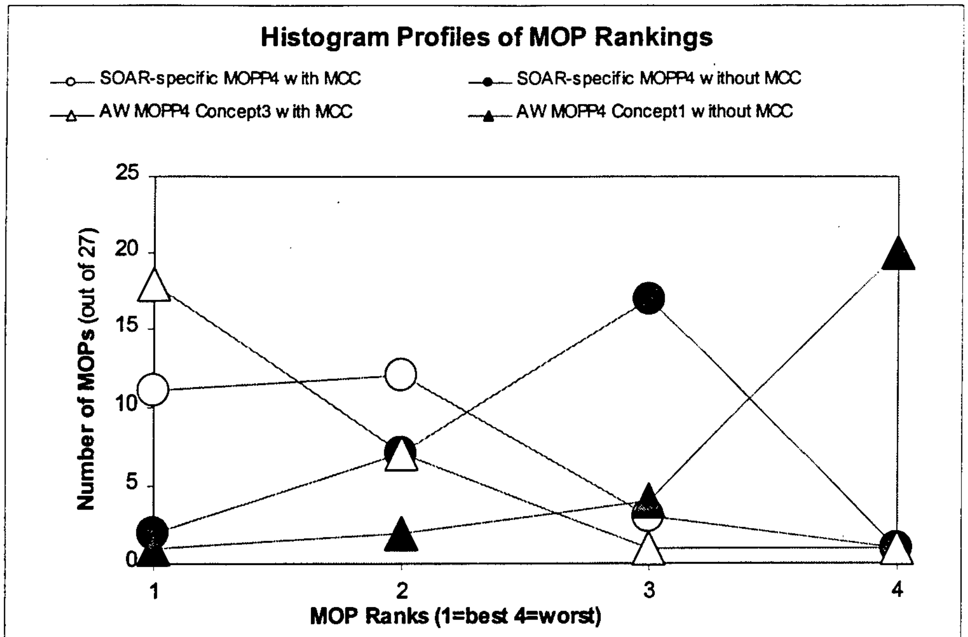

Figure 23. Histogram profiles of MOP rankings by ensemble.

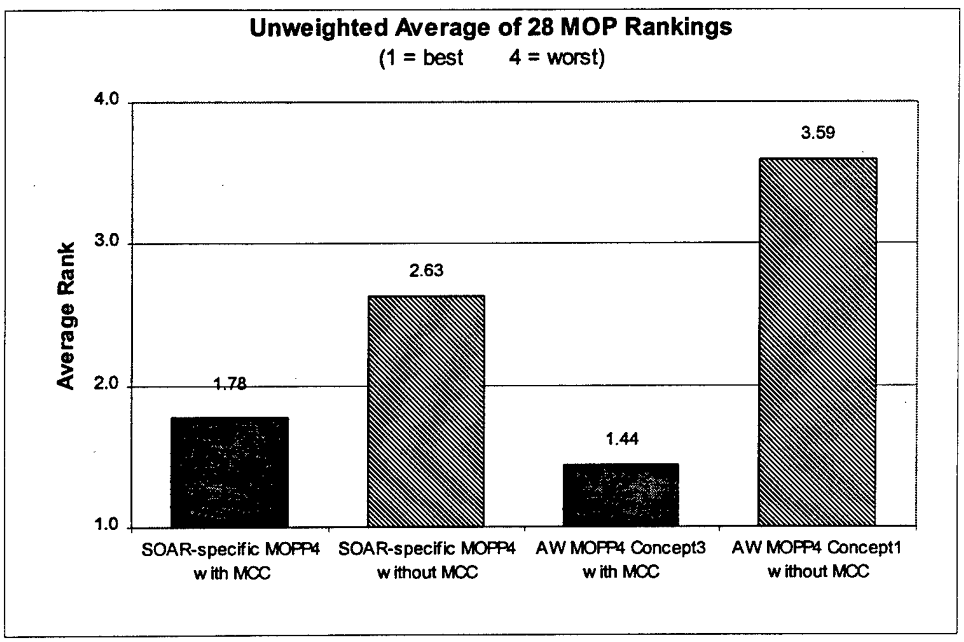

Figure 24. Unweighted average of MOP rankings by ensemble.

Discussion

This study determined physiological, mood, and symptom responses for U.S. Army helicopter pilots exposed to a significant level of heat stress (WBGT = 90 °F) in an environmentally controlled UH-60 simulator while wearing SOAR and Air Warrior MOPP4 aviator ensembles with and without a circulating water cooled undershirt. Results showed that the water-cooled microclimate system prolonged simulator flight times and significantly reduced physiological and psychological indicators of heat strain. The cooling shirt effectively maintained aviator body temperature and heart rate near preexposure baseline levels. Its use also was associated with significantly lower sweat rates and less heat stress-related discomfort. Conversely, a time-dependent progression of adverse heat stress symptoms was noted when MCC was not used.

The results of ranking 27 heat stress performance variables indicated that the Air Warrior Concept 3 MOPP4 ensemble with MCC had the best heat stress mitigation effects followed by (in order of decreasing heat stress performance) the SOAR-specific MOPP4 with MCC, SOAR-specific MOPP4 without MCC, and Air Warrior Concept 1 MOPP4 ensemble without MCC.

Although sweat rates were reduced by the water cooled undershirt, the prolonged mission endurance would necessitate that each aviators start similar real scenarios with 2 – 3 liters of potable water. Likewise, for extended helicopter operations over hot desert areas, crews should ensure that supplementary emergency potable water is onboard and readily accessible in the event a forced landing is required. As a complementary measure, urine containment devices of sufficient capacity (e.g., 2-3 liters per crewmember for a 6-hour mission) should be available to reduce the tendency of crews on extended missions to intentionally restrict water intake to avoid the distracting discomfort of progressively distended bladders.

We also recommend that aircraft microclimate cooling systems include easy-to-use flow-rate and temperature controls as well as a backup system if the primary microclimate cooling system fails. Allowing crewmember cooling rate control is essential since cockpit temperatures can vary considerably over relatively short periods of time due to weather changes, temperature lapse rate associated with climbing to high altitudes, terrain effects, and diurnal changes. It is also reasonable to propose dual-mode MCC systems that could pump warm water to keep crewmembers comfortable when exposed to low ambient temperatures associated with transitioning from day to night or low to high altitude operations.

Finally, microclimate cooling systems should be designed and built for long mean time between failure (MTBF). This is an essential consideration since an MCC system failure effectively results in a passive, thermally occlusive, clothing layer that restricts the effectiveness of physiological heat loss mechanism. Therefore, a nonfunctioning cooling undergarment will exacerbate heat stress.

Conclusions

This comparison of SOAR and AW Concept 1 and 3 aviator MOPP4 ensembles using a realistic, 6-hour, hot weather UH-60 scenario indicated best performance in heat stress by the AW Concept 3 MOPP4 ensemble with MCC. That ensemble performed somewhat better than the SOAR MOPP4 ensemble with MCC. The SOAR MOPP4 ensemble performed better than AW Concept 1 MOPP4 without MCC. However, since the AW Concept 3 ensemble was not tested without MCC it was not possible to determine whether that combination would provide better heat stress tolerance than SOAR MOPP4 without MCC in situations where MCC is not available. Additionally, ensembles rankings could differ if the MOPs were weighted in proportion to actual or perceived differences in importance with respect to operational or managerial factors. Nonetheless, in this study, the beneficial heat stress reduction effects of MCC were unequivocal and consistent with previous research.

Our results indicated that the undershirt MCC system should be effective in reducing heat strain in similar real-world operational heat stress conditions. The composite physiological responses to heat stress and MCC were consistent with previous research. However, the comparative ensemble rankings may not be statistically robust due to the small number of test subjects, mixed-design, limitations that prevented pretest training and acclimatization to the extent desired, and lack of full counterbalancing. If this data is to serve as the basis for important or costly development and acquisition decisions, it may be advisable to verify the stability of the numerical differences between the aviator ensembles with additional evaluations.

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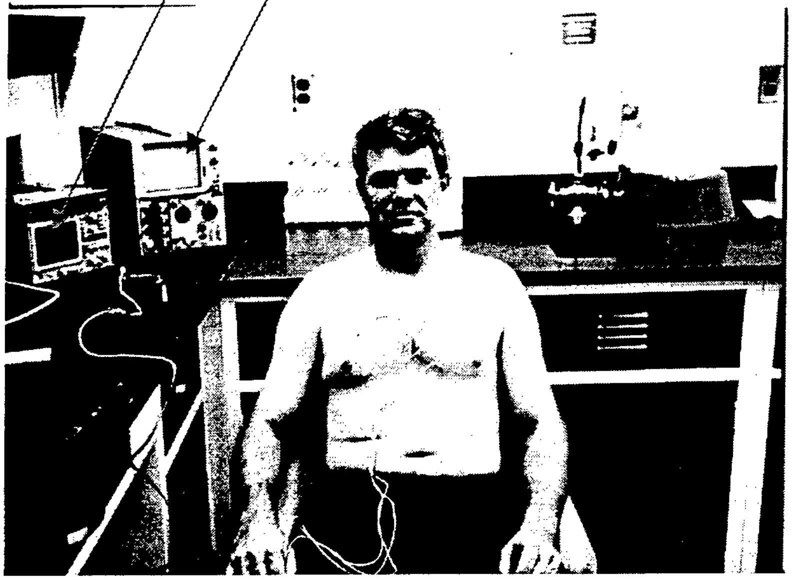
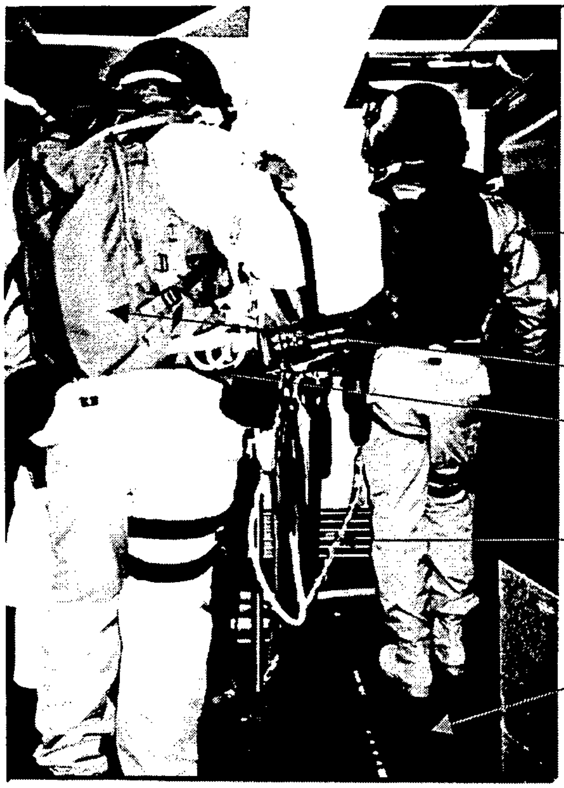
Appendix A.

Study process photos.



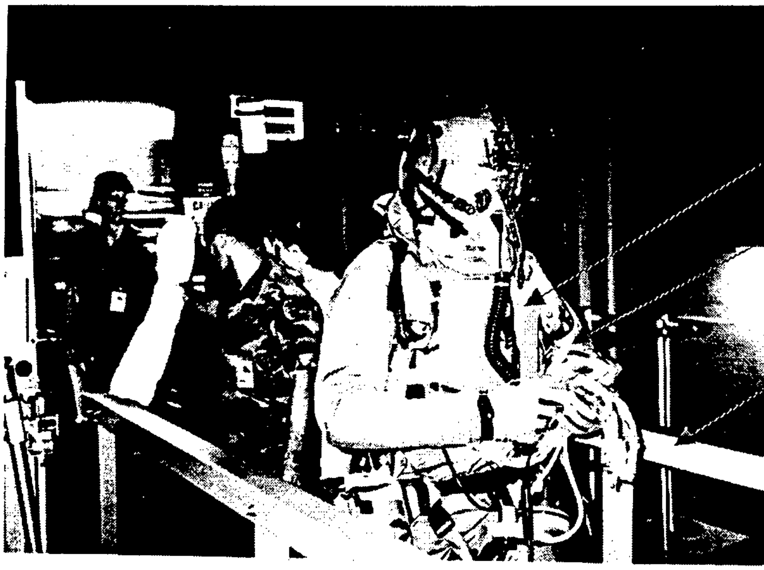
ECG sensors arranged to maximize lead II R-wave amplitude.

Application of skin temperature sensors

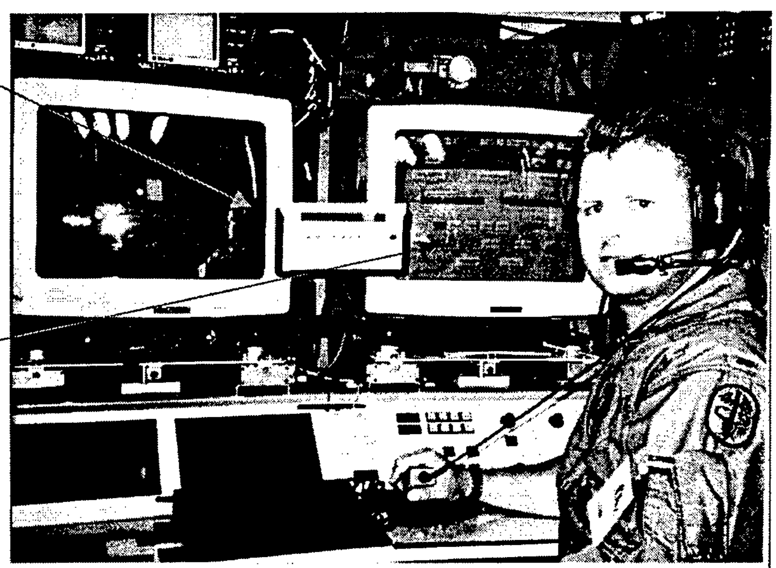


Test subjects on treadmill in environmental chamber

Research assistant, SSG Brock, recording data in the simulator.



Test subject exiting the environmentally controlled UH-60 simulator.



Simulator operator CW2 Swanberg.

Obtaining fully clothed weight after exiting simulator.

Remote test subject monitoring station.

Appendix B.

Tested ensembles with component and total weights.

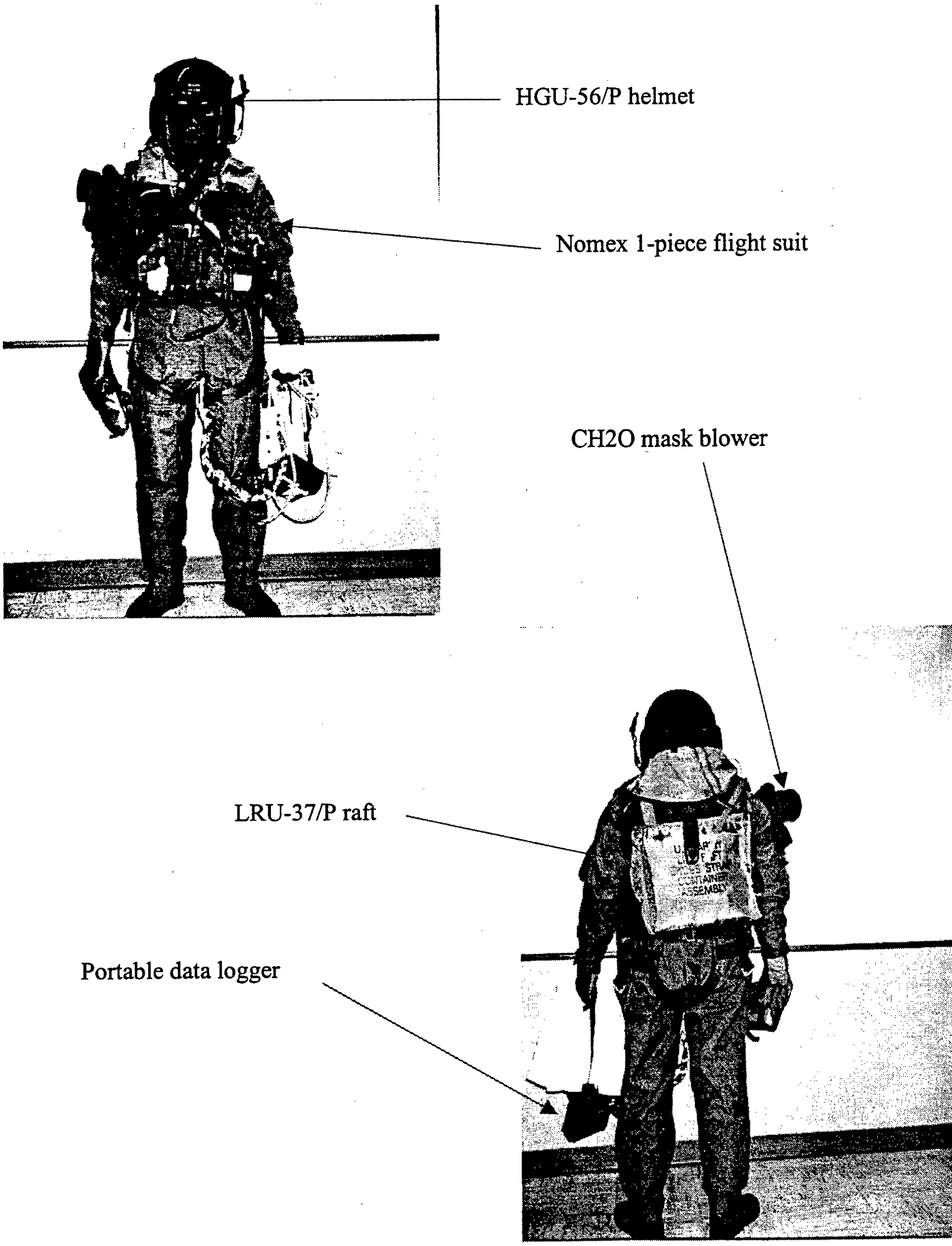
160th SOAR-Specific

Item	Average Weight(kg)
HGU-56/PHelmet	1.626
Communication Earplug	0.010
Flight suit 2pc Nomex	0.930
Combat Boots	1.631
Kneeboard (soft wrap-around type)	0.815
Utility ("bat") belt w/first aid kit	2.813
Soft Body Armor	4.382
Spectra plate	1.482
Chemical vapor protective glove (Gentex 8475-12-330)	0.116
Chemical protective sock	0.134
2-pc chemical protective undergarment	1.526
MBA-19/P AERPS CB mask	0.878
ILC-Dover Blower	0.498
Microclimate Climate Cooling Shirt	0.764
Piggy bac water container	0.813
Total (kg) →	**18.418 kg**

SOAR-specific MOPP4 Aviator Ensemble: Front and Side Views

<u>Air Warrior Concept 1</u>

Item	Weight (kg)
HGU-56/P Helmet	1.626
Communication Earplug	0.010
Flight suit 1pc Nomex	0.872
Combat boots	1.631
Flight gloves GS/FRP2 summer weight	0.088
Survival Harness vest: AirSave w/core survival items	4.404
Ballistic Vest: (std. AirSave, soft body armor)	4.896
Ballistic plate: Spectra plate	1.482
Chemical vapor protective gloves:Paul Boye'	0.088
Chemical protective sock	0.208
2-pc chemical protective undergarment	1.526
M45 CB mask	0.866
CH20 Lightweight motor blower	
Life vest: Low profile flotation	1.278
LRU-37/P Raft	2.310
Heed w/remote mouth piece	1.058
Total (kg) →	**22.343 kg**



Air Warrior Concept I MOPP4 Aviator Ensemble: Front and Back Views

Low profile floatation life vest

Survival vest over ballistic vest and plate

Chemical protective 2-piece undergarment worn as part of AW Concept 1 and SOAR ensembles but <u>not</u> AW Concept 3

Chemical protective socks

Air Warrior Concept I MOPP4 Aviator Ensemble: Additional Views

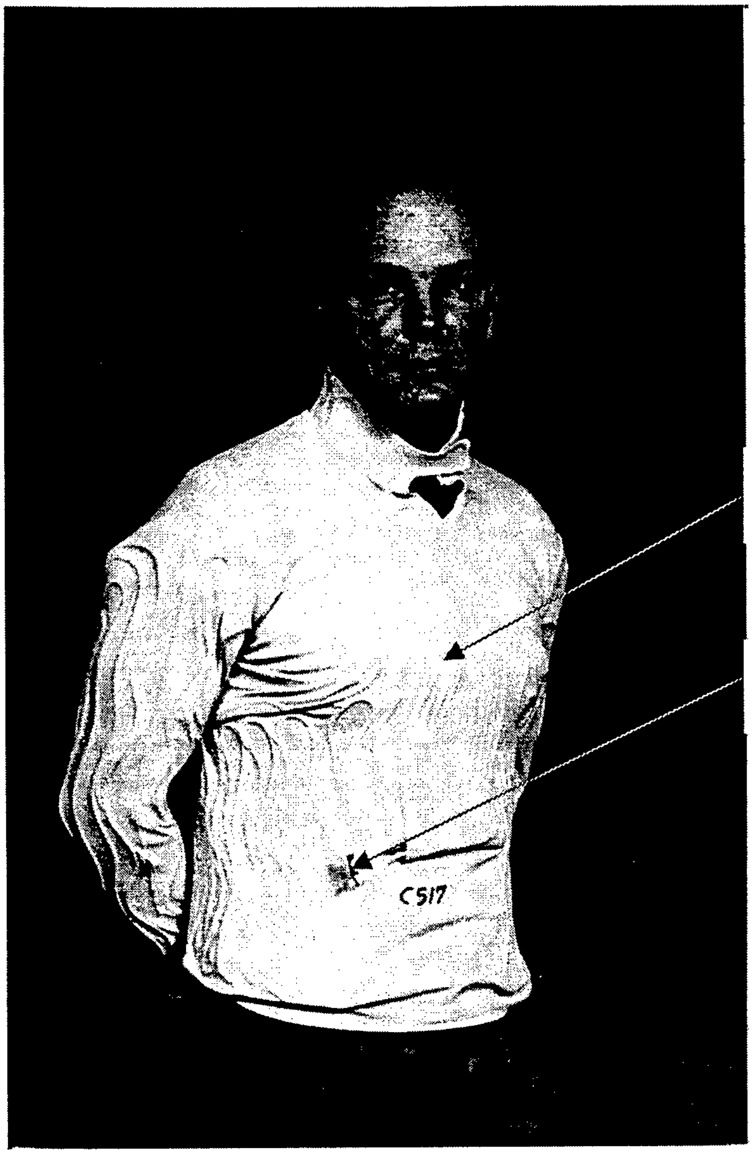
Air Warrior Concept 3

Item	Weight(kg)
HGU-56/P Helmet	1.626
Communication Earplug	0.010
Flight suit: Anti-exposure coveralls CWU-62B/P	1.478
Combat boots	1.631
Survival harness/vest: SEI harness	4.404
Soft Body Armor: BEAU 1	3.868
Ballistic plate: Spectra plate	1.482
Chemical vapor protective gloves	0.118
CB mask	0.894
Blowers	0.488
Life vest: LPU-34/P low profile	1.278
Raft: LRU-18/P-SeaPack	4.436
Heed w/remote mouth piece	1.058
Flight gloves GS/FRP2 summer weight	0.088
Total (kg) →	**22.771 kg**

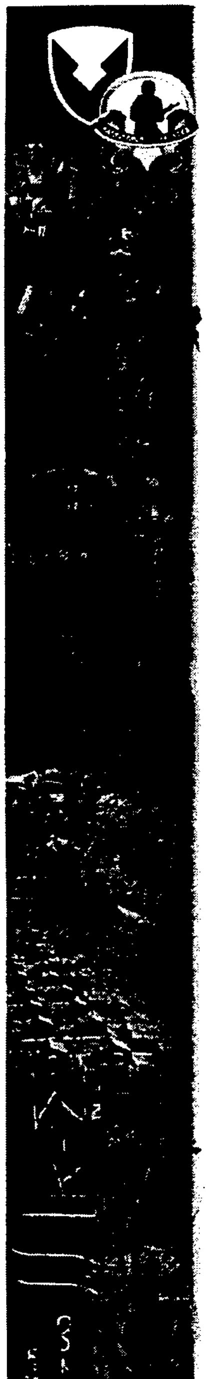
Air Warrior Concept 3 MOPP4 Aviator Ensemble: Frontal Views

Appendix C.

Microclimate cooling system.



Microclimate cooling (PVCS) undershirt



N0025J'10 rev 1-21-98

Portable Vapor-Compression Cooling System

(PVCS)

Overview:

The **Portable Vapor-Compression Cooling System (PVCS)** is a self-contained man-portable microclimate cooling system designed to provide wearers of insulative protective clothing with cooling to reduce the effects of heat stress.

Description:

The PVCS consists of the Refrigeration Unit, Battery Module, Heat Transfer Garment, and accessory tether lines. The Refrigeration Unit chills the coolant and pumps it through the External Coolant Tether Line and into the Heat Transfer Garment. Metabolic heat from the body is transferred to the coolant as it flows through the network of tubing in the Heat Transfer Garment. The coolant then flows back to the Refrigeration Unit where the heat is rejected. The Battery Module can be disconnected and detached from the Refrigeration Unit if a DC power supply is available.

Specifications:

- Cooling capacity (Battery Mode): 1200 Watt-hours (300 Watts cooling rate)
- Comfortable cooling temperature at 65°-70° Fahrenheit
- Four-hour duration on batteries, indefinitely on 24 Volt vehicle power
- Compact size (Refrigeration Unit 416 in^3, Battery Module 450 in^3)
- Full body cooling through liquid cooling shirt, pants, & hood
- Energy efficient (6 Amps max. at 24 Volts)
- Refrigeration Unit Type: Vapor Compression (HFC, R-134a refrigerant)
- Battery Module: four BA5590 lithium sulfur dioxide batteries
- Refrigeration Unit Weight: 10 lbs.
- Battery Module Weight: 11 lbs.
- Heat Transfer Garment (Shirt, pants, & hood) Weight : 6 lbs.

Status:

The PVCS has been successfully field tested with the Self-Contained Toxic Environments Protective Outfit (STEPO) ensemble. It has also been favorably evaluated in heat stress induced physiological studies in climatically controlled chambers.

Point-of-Contact:

Brad Laprise, DSN 256-5440, COMM (508) 233-5440

~~or~~

~~Andy Taylor, DSN 256-4968, COMM (508) 233-4968~~

Appendix D.

Test subject demographics data.

Baseline Test Subject Demographic and Training Data

Test Subject	1	2
Rank	CW4	CW2
Gender	MALE	MALE
Have you ever been a test subject before?	NO	YES
What aircraft are you rated in?	UH-1, OH-58, MH-6	OH-58, CH-47, MH-47, TH-67
Additional aviator qualifications	NONE	NONE
Total flight hours as a pilot	5000	650
UH-60 pilot flight hours	0	0
UH-60 simulator pilot hours	0	0
NBC overgarment and mask past year (hrs)	0	2
NBC overgarment and mask past 5 years (hrs)	3	0
Age	41	30
Height (inches)	70	71
Weight (pounds)	192	186
Most recent PT test	Nov-97	Dec-97
Pushups	73	75
Situps	75	90
Run time	13:40	13:30
How many times per week you do PT?	7	5
Total hrs of physical training per week	9.5	5
Total hrs training in heat casualty over past two years	2	3

Test Subject	3	4
Rank	CW4	CW3
Gender	MALE	MALE
Have you ever been a test subject before?	NO	NO
What aircraft are you rated in?	TH-55, UH-1, OH-58, MH-6, MH-47	MH-47E, UH-1
Additional aviator qualifications	MASTER AVIATOR	IP
Total flight hours as a pilot	4500	2500
UH-60 pilot flight hours	0	0
UH-60 simulator pilot hours	0	0
NBC overgarment and mask past year (hrs)	6	0
NBC overgarment and mask past 5 years (hrs)	30	2
Age	48	39
Height (inches)	73	74
Weight (pounds)	192	219
Most recent PT test		Jun-98
Pushups		73
Situps		78
Run time		14:25
How many times per week you do PT?	5	3
Total hrs of physical training per week	5	3
Total hrs training in heat casualty over past two years	4	4

Appendix E.

Core temperature data.

SOAR-specific MOPP4 with MCC

Test date ->	6/17/98	6/17/98	6/18/97	6/18/98			
Ensemble ->	SC	SC	SC	SC			
Minutes/TS# -->	1	2	3	4	Mean	2*SD	2*SE
0	99	99	98.7	99.2	98.98	0.412	0.206
10	99.5	99.6	99.1	99.6	99.45	0.476	0.238
20	99.5	99.7	99.4	99.8	99.60	0.365	0.183
30							
40	100.1	100.2			100.12	0.127	0.090
50	100.0	100.3	99.5	100.0	99.92	0.661	0.330
60	99.9	100.2	99.5	99.9	99.89	0.610	0.305
70	99.9	100.2	99.4	99.9	99.83	0.608	0.304
80	99.9	100.1	99.4	99.8	99.79	0.597	0.298
90	99.8	100.1	99.3	99.7	99.73	0.642	0.321
100	99.2	100.0	99.2	99.6	99.53	0.785	0.392
110	99.1	100.0	99.2	99.6	99.48	0.870	0.435
120	99.9	100.0	99.1	99.5	99.61	0.795	0.397
130	99.2	100.0	99.1	99.5	99.43	0.776	0.388
140	99.8	100.0	99.0	99.4	99.55	0.834	0.417
150	99.7	99.9	99.0	99.4	99.49	0.810	0.405
160	99.3	100.1	98.9	99.4	99.42	1.007	0.503
170	99.4	100.1	98.9	99.5	99.46	1.030	0.515
180	99.4	100.0	98.9	99.4	99.43	0.943	0.472
190	99.4	100.0	98.9	99.4	99.44	0.868	0.434
200	99.3	99.9	99.0	99.4	99.42	0.777	0.388
210	99.4	99.8	99.0	99.5	99.42	0.678	0.339
220	99.4	99.8	99.0	99.4	99.40	0.694	0.347
230	99.4	99.8	98.9	99.4	99.39	0.750	0.375
240	99.2	99.8	98.9	99.4	99.34	0.745	0.373
250	99.4	99.8	98.9	99.3	99.36	0.723	0.361
260	99.3	99.8	98.9	99.3	99.33	0.740	0.370
270	99.3	99.8	98.9	99.3	99.29	0.721	0.361
280	99.3	99.8	98.9	99.3	99.30	0.752	0.376
290	99.3	100.0	98.9	99.3	99.38	0.920	0.460
300	99.4	100.0	98.8	99.3	99.38	0.979	0.490
310	99.4	100.0	98.9	99.2	99.37	0.960	0.480
320	99.3	100.0	98.9	99.2	99.32	0.921	0.461
330	99.2	99.9	98.9	99.2	99.31	0.868	0.434
340	99.2	99.9	98.8	99.1	99.23	0.914	0.457
350	99.0	99.7	98.7	99.1	99.15	0.841	0.420
360	99.0	99.7	98.7	99.1	99.13	0.877	0.439
370							

	SOAR-specific MOPP4 without MCC						
Test date ->	6/16/98	6/16/98	6/21/98	6/21/98			
Ensemble ->	SX	SX	SX	SX	SX	SX	SX
TS# -->	3	4	1	2	Mean	2*SD	2*SE
0	98.7	99.7	98.4	99.5	99.08	1.248	0.624
10	98.9	99.7	98.5	99.7	99.20	1.200	0.600
20	99.3	99.4	98.7	99.7	99.28	0.839	0.419
30							
40	100.0	100.6	99.3	100.2	100.03	1.118	0.559
50	100.0	100.7	99.3	100.1	100.01	1.161	0.581
60	99.9	100.6	99.1	100.1	99.95	1.239	0.619
70	100.0	100.6	99.1	100.1	99.94	1.233	0.616
80	100.0	100.7	99.0	99.9	99.91	1.371	0.686
90	100.0	100.8	99.1	100.1	100.00	1.421	0.711
100	100.1	100.8	99.1	100.1	100.03	1.454	0.727
110	100.1	100.9	99.1	100.2	100.07	1.497	0.749
120	100.1	101.0	99.1	100.3	100.12	1.558	0.779
130	100.2	101.1	99.2	100.3	100.19	1.558	0.779
140	100.2	101.1	99.2	100.4	100.23	1.621	0.811
150	100.2	101.2	99.1	100.5	100.26	1.700	0.850
160	100.3	101.3	99.1	100.5	100.29	1.756	0.878
170	100.3	101.3	99.2	100.6	100.36	1.793	0.897
180	100.4	101.4	99.6	100.9	100.56	1.569	0.785
190	100.4	101.4	99.5	100.9	100.58	1.638	0.819
200	100.5	101.6	99.4	100.9	100.59	1.857	0.928
210	100.6	101.7	99.3	100.9	100.62	1.948	0.974
220		101.8	99.3	100.8	100.63	2.429	1.403
230			99.4	100.6	100.00	1.807	1.278
240			99.4	100.7	100.04	1.884	1.332
250			99.3	100.9	100.08	2.240	1.584
260			99.3	101.0	100.14	2.316	1.638
270			99.3	100.9	100.10	2.367	1.674
280			99.2	100.9	100.07	2.418	1.710
290			99.5	101.1	100.31	2.342	1.656
300			99.4	101.0	100.18	2.266	1.602
310			99.3	100.9	100.10	2.215	1.566
320			99.3	100.7	100.03	1.960	1.386
330			99.4	100.7	100.05	1.858	1.314
340				100.7	100.69		
350				100.7	100.72		
360				100.8	100.81		
370				100.9	100.85		
380				100.9	100.90		
390				101.0	101.01		

AW MOPP4 Concept1 without MCC					
Test date ->	6/19/98	6/20/98			
	AX	AX	AX	AX	AX
TS# -->	2	3	Mean	2*SD	2*SE
0	99.3	98.4	98.85	1.273	0.900
10	99.5	98.8	99.15	0.990	0.700
20	99.6	99.3	99.45		0.300
30					
40	100.1	99.8	99.94	0.331	0.234
50	100.1	99.9	99.97	0.255	0.180
60	100.1	100.0	100.07	0.076	0.054
70	100.2	100.1	100.18	0.178	0.126
80	100.4	100.3	100.37	0.127	0.090
90	100.5	100.3	100.40	0.356	0.252
100	100.6	100.3	100.48	0.382	0.270
110	100.7	100.4	100.56	0.356	0.252
120	100.7	100.5	100.62	0.356	0.252
130	100.9	100.6	100.72	0.382	0.270
140	100.9	100.6	100.76	0.356	0.252
150	101.0	100.6	100.81	0.484	0.342
160	101.0	100.6	100.84	0.585	0.414
170	101.1	100.6	100.85	0.611	0.432
180	101.0	100.5	100.74	0.662	0.468
190	100.9	100.4	100.65	0.713	0.504
200	100.9	100.3	100.60	0.865	0.612
210	100.9	100.1	100.49	1.171	0.828
220	101.0	100.1	100.55	1.196	0.846
230	101.1	100.0	100.54	1.604	1.134
240	101.2	100.0	100.57	1.706	1.206
250	101.2	100.7	100.98	0.764	0.540
260	101.3	99.9	100.60	1.935	1.368
270	101.4		101.43		
280	101.5		101.46		
290					
300					
310					
320					
330					
340					
350					
360					
370					
380					
390					

	AW MOPP4 Concept3 with MCC				
Test date ->	6/19/98	6/20/98			
Ensemble ->	AC	AC	AC	AC	AC
TS# -->	1	4	Mean	2*SD	2*SE
0	99.1	98.8	98.95	0.424	0.300
10	99.1	98.8	98.95	0.424	0.300
20	99.2	98.6	98.9	0.849	0.600
30					
40	99.3	99.7	99.49	0.585	0.414
50	99.3	99.7	99.49	0.535	0.378
60	99.3	99.6	99.45	0.458	0.324
70	99.3	99.6	99.46	0.331	0.234
80	99.3	99.5	99.42	0.229	0.162
90	99.3	99.5	99.40	0.229	0.162
100	99.4	99.4	99.40	0.127	0.090
110	99.4	99.4	99.40	0.076	0.054
120	99.3	99.4	99.37	0.076	0.054
130	99.3	99.4	99.32	0.102	0.072
140	99.3	99.4	99.32	0.153	0.108
150	99.3	99.4	99.33	0.127	0.090
160	99.2	99.4	99.28	0.229	0.162
170	99.2	99.4	99.26	0.280	0.198
180	99.3	99.4	99.31	0.127	0.090
190	99.0	99.3	99.16	0.407	0.288
200	99.0	99.3	99.15	0.382	0.270
210	99.1	99.3	99.18	0.305	0.216
220	99.1	99.2	99.11	0.127	0.090
230	99.1	99.1	99.09	0.102	0.072
240	99.0	99.1	99.05	0.102	0.072
250	99.0	99.1	99.01	0.153	0.108
260	98.9	99.1	99.00	0.204	0.144
270	98.9		98.92		
280	98.9	99.2	99.06	0.382	0.270
290	99.0	99.2	99.06	0.280	0.198
300	98.9	99.1	99.01	0.305	0.216
310	98.9	99.1	98.98	0.305	0.216
320	98.9	99.1	98.96	0.305	0.216
330	98.8	99.0	98.92	0.280	0.198
340	98.8	99.0	98.90	0.229	0.162
350	98.8	98.9	98.86	0.229	0.162
360	98.8	98.9	98.83	0.204	0.144
370	98.8	98.9	98.83	0.127	0.090
380	98.8	98.9	98.85	0.153	0.108
390		98.9	98.89		
		98.9	98.89		

Ensemble TS #	SC 1	SC 2	SC 3	SC 4	AC 1	AC 4	*C Mean	*C 2*SD	*C 2*SE
	With Microclimate Cooling								
0	99	99	98.7	99.2	99.1	98.8	99.0	0.372	0.152
10	99.5	99.6	99.1	99.6	99.1	98.8	99.3	0.662	0.270
20	99.5	99.7	99.4	99.8	99.2	98.6	99.4	0.864	0.353
30									
40	100.1	100.2			99.3	99.7	99.8	0.806	0.403
50	100.0	100.3	99.5	100.0	99.3	99.7	99.8	0.717	0.293
60	99.9	100.2	99.5	99.9	99.3	99.6	99.7	0.691	0.282
70	99.9	100.2	99.4	99.9	99.3	99.6	99.7	0.630	0.257
80	99.9	100.1	99.4	99.8	99.3	99.5	99.7	0.608	0.248
90	99.8	100.1	99.3	99.7	99.3	99.5	99.6	0.608	0.248
100	99.2	100.0	99.2	99.6	99.4	99.4	99.5	0.624	0.255
110	99.1	100.0	99.2	99.6	99.4	99.4	99.5	0.679	0.277
120	99.9	100.0	99.1	99.5	99.3	99.4	99.5	0.666	0.272
130	99.2	100.0	99.1	99.5	99.3	99.4	99.4	0.613	0.250
140	99.8	100.0	99.0	99.4	99.3	99.4	99.5	0.691	0.282
150	99.7	99.9	99.0	99.4	99.3	99.4	99.4	0.651	0.266
160	99.3	100.1	98.9	99.4	99.2	99.4	99.4	0.801	0.327
170	99.4	100.1	98.9	99.5	99.2	99.4	99.4	0.835	0.341
180	99.4	100.0	98.9	99.4	99.3	99.4	99.4	0.743	0.303
190	99.4	100.0	98.9	99.4	99.0	99.3	99.3	0.755	0.308
200	99.3	99.9	99.0	99.4	99.0	99.3	99.3	0.687	0.280
210	99.4	99.8	99.0	99.5	99.1	99.3	99.3	0.600	0.245
220	99.4	99.8	99.0	99.4	99.1	99.2	99.3	0.615	0.251
230	99.4	99.8	98.9	99.4	99.1	99.1	99.3	0.663	0.271
240	99.2	99.8	98.9	99.4	99.0	99.1	99.2	0.651	0.266
250	99.4	99.8	98.9	99.3	99.0	99.1	99.2	0.668	0.273
260	99.3	99.8	98.9	99.3	98.9	99.1	99.2	0.675	0.275
270	99.3	99.8	98.9	99.3	98.9		99.2	0.707	0.316
280	99.3	99.8	98.9	99.3	98.9	99.2	99.2	0.657	0.268
290	99.3	100.0	98.9	99.3	99.0	99.2	99.3	0.797	0.326
300	99.4	100.0	98.8	99.3	98.9	99.1	99.3	0.858	0.350
310	99.4	100.0	98.9	99.2	98.9	99.1	99.2	0.860	0.351
320	99.3	100.0	98.9	99.2	98.9	99.1	99.2	0.818	0.334
330	99.2	99.9	98.9	99.2	98.8	99.0	99.2	0.797	0.325
340	99.2	99.9	98.8	99.1	98.8	99.0	99.1	0.796	0.325
350	99.0	99.7	98.7	99.1	98.8	98.9	99.1	0.723	0.295
360	99.0	99.7	98.7	99.1	98.8	98.9	99.0	0.751	0.307
370					98.8	98.9	98.8	0.127	0.090
380					98.8	98.9	98.9	0.153	0.108
390						98.9	98.9		
						98.9	98.9		

Ensemble TS #	SX 3	SX 4	SX 1	SX 2	AX 2	AX 3	*X Mean	*X 2*SD	*X 2*SE
		Without Microclimate Cooling							
0	98.7	99.7	98.4	99.5	99.3	98.4	99.00	1.145	0.234
10	98.9	99.7	98.5	99.7	99.5	98.8	99.18	1.031	0.210
20	99.3	99.4	98.7	99.7	99.6	99.3	99.33	0.700	0.143
30									
40	100.0	100.6	99.3	100.2	100.1	99.8	100.00	0.883	0.180
50	100.0	100.7	99.3	100.1	100.1	99.9	100.00	0.908	0.185
60	99.9	100.6	99.1	100.1	100.1	100.0	99.99	0.967	0.197
70	100.0	100.6	99.1	100.1	100.2	100.1	100.02	0.989	0.202
80	100.0	100.7	99.0	99.9	100.4	100.3	100.07	1.165	0.238
90	100.0	100.8	99.1	100.1	100.5	100.3	100.13	1.187	0.242
100	100.1	100.8	99.1	100.1	100.6	100.3	100.18	1.230	0.251
110	100.1	100.9	99.1	100.2	100.7	100.4	100.23	1.277	0.261
120	100.1	101.0	99.1	100.3	100.7	100.5	100.29	1.320	0.269
130	100.2	101.1	99.2	100.3	100.9	100.6	100.36	1.335	0.272
140	100.2	101.1	99.2	100.4	100.9	100.6	100.41	1.378	0.281
150	100.2	101.2	99.1	100.5	101.0	100.6	100.44	1.448	0.296
160	100.3	101.3	99.1	100.5	101.0	100.6	100.48	1.496	0.305
170	100.3	101.3	99.2	100.6	101.1	100.6	100.53	1.502	0.307
180	100.4	101.4	99.6	100.9	101.0	100.5	100.62	1.265	0.258
190	100.4	101.4	99.5	100.9	100.9	100.4	100.60	1.310	0.267
200	100.5	101.6	99.4	100.9	100.9	100.3	100.59	1.489	0.304
210	100.6	101.7	99.3	100.9	100.9	100.1	100.58	1.603	0.327
220		101.8	99.3	100.8	101.0	100.1	100.60	1.821	0.407
230			99.4	100.6	101.1	100.0	100.27	1.528	0.382
240			99.4	100.7	101.2	100.0	100.31	1.590	0.398
250			99.3	100.9	101.2	100.7	100.53	1.717	0.429
260			99.3	101.0	101.3	99.9	100.37	1.821	0.455
270			99.3	100.9	101.4		100.54	2.266	0.654
280			99.2	100.9	101.5		100.53	2.349	0.678
290			99.5	101.1			100.31	2.342	0.828
300			99.4	101.0			100.18	2.266	0.801
310			99.3	100.9			100.10	2.215	0.783
320			99.3	100.7			100.03	1.960	0.693
330			99.4	100.7			100.05	1.858	0.657
340				100.7			100.69		
350				100.7			100.72		
360				100.8			100.81		
370				100.9			100.85		
380				100.9			100.90		
390				101.0			101.01		

Appendix F.

Heart rate data.

	SOAR-specific MOPP4 with MCC						
Test date ->	6/17/98	6/17/98	6/18/97	6/18/98			
Ensemble ->	SC	SC	SC	SC			
TS# -->	1	2	3	4	Mean	2*SD	2*SE
0	78	85	80	74	79.3	9.1	4.6
10	92	115	97	130	108.5	34.8	17.4
20	114	116	97	141	117.0	36.3	18.1
30							
40	80	93			86.8	18.2	12.9
50	77	91	60	84	77.9	26.5	13.3
60	75	83	60	76	73.5	19.3	9.7
70	76	90	62	74	75.5	23.1	11.6
80	78	84	62	81	76.1	19.6	9.8
90	77	81	62	72	73.1	16.7	8.3
100	77	89	68	70	76.0	18.8	9.4
110	92	104	63	71	82.3	37.1	18.6
120	74	97	58	70	74.7	32.3	16.1
130	77	98	60	73	77.2	31.7	15.9
140	76	100	63	69	77.0	32.0	16.0
150	79	101	55	82	79.1	37.4	18.7
160	75	83	58	72	72.0	20.7	10.4
170	70	79	55	62	66.5	20.5	10.2
180	73	86	54	69	70.5	26.6	13.3
190	75	83	56	69	70.7	22.5	11.2
200	73	99	61	70	75.7	32.7	16.3
210	71	88	54	69	70.7	28.2	14.1
220	73	91	57	74	73.7	27.4	13.7
230	73	81	66	73	73.3	12.5	6.3
240	64	88	56	71	69.8	27.1	13.6
250	72	93	59	67	72.8	29.0	14.5
260	72	80	65	69	71.4	12.5	6.3
270	72	95	52	63	70.5	36.5	18.2
280	76	87	56	71	72.7	26.0	13.0
290	71	73	56	63	65.8	15.7	7.9
300	71	82	52	71	69.0	24.9	12.5
310	72	88	55	65	70.0	28.0	14.0
320	73	76	52	63	66.2	22.1	11.0
330	70	85	55	65	68.8	25.2	12.6
340	71	86	59	63	69.8	23.7	11.8
350	72	89	63	65	72.1	23.6	11.8
360	65	96	53	62	68.9	37.1	18.5
370							

	SOAR-specific MOPP4 without MCC						
Test date ->	6/16/98	6/16/98	6/21/98	6/21/98			
Ensemble ->	SX	SX	SX	SX	SX	SX	SX
TS# -->	3	4	1	2	Mean	2*SD	2*SE
0	83	64	67	80	73.5	18.8	9.4
10	121	72	104	118	103.8	44.9	22.4
20		128	111	114	117.7	18.1	10.5
30							
40	85.7	122.9	104	97	102.4	31.2	15.6
50	85	130	98	97	102.5	38.5	19.3
60	84.7	116.4	72	98	92.8	38.0	19.0
70	94	119.9	71	93	94.5	40.0	20.0
80	86.9	125.9	78	89	95.0	42.4	21.2
90	93.7	127.8	81	93	98.9	40.3	20.1
100	90.5	128.5	76	96	97.8	44.3	22.2
110	85.7	130	70	99	96.2	51.0	25.5
120	98.2	129	79	98	101.1	41.4	20.7
130	91.9	131	78	107	102.0	45.4	22.7
140	87.9	133	74	102	99.2	50.5	25.3
150	93.7	135	82	109	104.9	45.8	22.9
160	91	126	72	110	99.8	46.8	23.4
170	99.3	134	73	104	102.6	50.0	25.0
180	95.2	129	79	100	100.8	41.7	20.8
190	90.3	136	79	103	102.1	49.3	24.7
200	103.9	143	78	93	104.5	55.6	27.8
210	92.2	145	83	91	102.8	56.9	28.4
220		147	75	102	108.0	72.7	42.0
230			70	101	85.5	43.8	31.0
240			86	104	95.0	25.5	18.0
250			83	112	97.5	41.0	29.0
260			77	104	90.5	38.2	27.0
270			76	110	93.0	48.1	34.0
280			70	108	89.0	53.7	38.0
290			67	105	86.0	53.7	38.0
300			69	104	86.5	49.5	35.0
310			73	105	89.0	45.3	32.0
320			75	109	92.0	48.1	34.0
330			75	108	91.5	46.7	33.0
340				109	109.0		
350				111	111.0		
360				115	115.0		
370				113	113.0		
380				114	114.0		
390				118	118		

AW MOPP4 Concept1 without MCC					
Test date ->	6/19/98	6/20/98			
	AX	AX	AX	AX	AX
TS# -->	2	3	Mean	2*SD	2*SE
0	101	83	92.0	25.5	18.0
10	120	123	121.5	4.2	3.0
20	132		132.0		
30					
40	122	85	103.5	52.3	37.0
50	125	83	104.0	59.4	42.0
60	116	73	94.5	60.8	43.0
70	113	84	98.5	41.0	29.0
80	116	80	98.0	50.9	36.0
90	119	85	102.0	48.1	34.0
100	120	82	101.0	53.7	38.0
110	122	101	111.5	29.7	21.0
120	125	88	106.5	52.3	37.0
130	132	93	112.5	55.2	39.0
140	134	86	110.0	67.9	48.0
150	127	85	106.0	59.4	42.0
160	133	82	107.5	72.1	51.0
170	134	83	108.5	72.1	51.0
180	130	80	105.0	70.7	50.0
190	132	81	106.5	72.1	51.0
200	131	86	108.5	63.6	45.0
210	123	74	98.5	69.3	49.0
220	128	76	102.0	73.5	52.0
230	125	80	102.5	63.6	45.0
240	133	78	105.5	77.8	55.0
250	129	75	102.0	76.4	54.0
260	134	88	111.0	65.1	46.0
270	131		131.0		
280	130		130.0		
290					
300					
310					
320					
330					
340					
350					
360					
370					
380					
390					

	AW MOPP4 Concept3 with MCC				
Test date ->	6/19/98	6/20/98			
Ensemble ->	AC	AC	AC	AC	AC
TS# -->	1	4	Mean	2*SD	2*SE
0	79	83	81.0	5.7	4.0
10	91	83	87.0	11.3	8.0
20	101		101.0		
30					
40	69	81	75.0	17.0	12.0
50	71	75	73.0	5.7	4.0
60	73	72	72.5	1.4	1.0
70	73	69	71.0	5.7	4.0
80	70	76	73.0	8.5	6.0
90	77	69	73.0	11.3	8.0
100	73	68	70.5	7.1	5.0
110	70	83	76.5	18.4	13.0
120	71	77	74.0	8.5	6.0
130	69	66	67.5	4.2	3.0
140	66	63	64.5	4.2	3.0
150	63	69	66.0	8.5	6.0
160	69	64	66.5	7.1	5.0
170	64	64	64.0	0.0	0.0
180	73	61	67.0	17.0	12.0
190	62	66	64.0	5.7	4.0
200	64	62	63.0	2.8	2.0
210	67	72	69.5	7.1	5.0
220	65	60	62.5	7.1	5.0
230	74	65	69.5	12.7	9.0
240	76	67	71.5	12.7	9.0
250	68	68	68.0	0.0	0.0
260	75	63	69.0	17.0	12.0
270	68		68.0		
280	68	78	73.0	14.1	10.0
290	67	66	66.5	1.4	1.0
300	74	61	67.5	18.4	13.0
310	70	73	71.5	4.2	3.0
320	65	63	64.0	2.8	2.0
330	69	65	67.0	5.7	4.0
340	72	61	66.5	15.6	11.0
350	69	62	65.5	9.9	7.0
360	62	71	66.5	12.7	9.0
370	69	66	67.5	4.2	3.0
380	65	64	64.5	1.4	1.0
390		64	64.0		
		62	62.0		

With Microclimate Cooling									
Ensemble TS #	SC 1	SC 2	SC 3	SC 4	AC 1	AC 4	*C Mean	*C 2*SD	*C 2*SE
0	78	85	80	74	79	83	79.8	7.7	3.2
10	92	115	97	130	91	83	101.3	35.3	14.4
20	114	116	97	141	101		113.8	34.5	15.4
30									
40	80.3	93.2			69	81	80.9	19.8	9.9
50	76.5	90.9	60	84	71	75	76.2	21.3	8.7
60	74.8	83	60	76	73	72	73.1	15.0	6.1
70	75.9	90.2	62	74	73	69	74.0	18.7	7.6
80	77.5	84	62	81	70	76	75.1	16.0	6.5
90	77.2	81.3	62	72	77	69	73.1	13.9	5.7
100	77.2	88.8	68	70	73	68	74.2	16.0	6.5
110	91.5	103.5	63	71	70	83	80.3	30.5	12.5
120	74.1	96.6	58	70	71	77	74.5	25.3	10.3
130	77.4	98.2	60	73	69	66	73.9	26.6	10.9
140	76.3	99.5	63	69	66	63	72.8	28.0	11.4
150	79	100.5	55	82	63	69	74.8	32.2	13.1
160	75.2	82.8	58	72	69	64	70.2	17.3	7.1
170	70.2	78.7	55	62	64	64	65.7	16.1	6.6
180	72.5	86.4	54	69	73	61	69.3	22.3	9.1
190	75.2	82.5	56	69	62	66	68.5	18.9	7.7
200	72.8	99	61	70	64	62	71.5	28.5	11.6
210	71.4	88.4	54	69	67	72	70.3	22.1	9.0
220	73.2	90.5	57	74	65	60	70.0	24.3	9.9
230	72.8	81.3	66	73	74	65	72.0	11.9	4.9
240	64.2	87.9	56	71	76	67	70.4	21.8	8.9
250	72.3	93	59	67	68	68	71.2	23.0	9.4
260	71.9	79.8	65	69	75	63	70.6	12.6	5.1
270	72.2	94.9	52	63	68		70.0	31.7	14.2
280	76.4	87.2	56	71	68	78	72.8	21.1	8.6
290	71.2	73	56	63	67	66	66.0	12.2	5.0
300	71	82	52	71	74	61	68.5	21.0	8.6
310	71.7	88.3	55	65	70	73	70.5	21.8	8.9
320	73.2	76.4	52	63	65	63	65.4	17.3	7.1
330	69.9	85.2	55	65	69	65	68.2	19.7	8.1
340	71.3	85.8	59	63	72	61	68.7	19.9	8.1
350	71.5	89	63	65	69	62	69.9	20.0	8.2
360	64.8	95.6	53	62	62	71	68.1	29.4	12.0
370					69	66	67.5	4.2	3.0
380					65	64	64.5	1.4	1.0
390						64	64.0		
						62	62.0		

Ensemble TS #	SX 3	SX 4	SX 1	SX 2	AX 2	AX 3	*X Mean	*X 2*SD	*X 2*SE
		With<u>out</u> Microclimate Cooling							
0	83	64	67	80	101	83	79.7	26.6	10.9
10	121	72	104	118	120	123	109.7	39.3	16.1
20		128	111	114	132		121.3	20.6	10.3
30									
40	85.7	122.9	104	97	122	85	102.8	33.7	13.7
50	85	130	98	97	125	83	103.0	40.0	16.3
60	84.7	116.4	72	98	116	73	93.4	40.1	16.4
70	94	119.9	71	93	113	84	95.8	36.2	14.8
80	86.9	125.9	78	89	116	80	96.0	40.1	16.4
90	93.7	127.8	81	93	119	85	99.9	38.0	15.5
100	90.5	128.5	76	96	120	82	98.8	42.1	17.2
110	85.7	130	70	99	122	101	101.3	44.5	18.2
120	98.2	129	79	98	125	88	102.9	40.1	16.4
130	91.9	131	78	107	132	93	105.5	44.3	18.1
140	87.9	133	74	102	134	86	102.8	50.8	20.7
150	93.7	135	82	109	127	85	105.3	44.3	18.1
160	91	126	72	110	133	82	102.3	49.2	20.1
170	99.3	134	73	104	134	83	104.6	50.8	20.7
180	95.2	129	79	100	130	80	102.2	45.4	18.5
190	90.3	136	79	103	132	81	103.6	50.2	20.5
200	103.9	143	78	93	131	86	105.8	51.8	21.1
210	92.2	145	83	91	123	74	101.4	54.0	22.1
220		147	75	102	128	76	105.6	63.6	28.4
230			70	101	125	80	94.0	48.7	24.4
240			86	104	133	78	100.3	48.8	24.4
250			83	112	129	75	99.8	50.3	25.2
260			77	104	134	88	100.8	49.6	24.8
270			76	110	131		105.7	55.5	32.0
280			70	108	130		102.7	60.7	35.0
290			67	105			86.0	53.7	38.0
300			69	104			86.5	49.5	35.0
310			73	105			89.0	45.3	32.0
320			75	109			92.0	48.1	34.0
330			75	108			91.5	46.7	33.0
340				109			109.0		
350				111			111.0		
360				115			115.0		
370				113			113.0		
380				114			114.0		
390				118			118.0		

Appendix G.

Weight and fluid balance data.

Weight and Fluid Balance							
SOAR-specific w/ cooling (SC)		TS 1	TS 2	TS 3	TS4	AVG	SE
SC	TIME IN UNIFORM (hours)	6.78	6.78	6.82	6.82	6.80	0.010
SC	URINE OUTPUT RATE (ml/hr)	287.2	447.0	166.7	236.5	284.32	59.582
SC	URINE OUTPUT (gms)	1948	3032	1136	1612	1932.00	402.727
SC	FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gm	347	410	90	257	276.13	69.584
SC	FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms)	2356	2782	612	1754	1876.00	471.152
SC	SWEAT LOSS RATE (ml/hr)	212.0	280.1	137.6	167.5	199.31	30.964
SC	TOT SWEAT LOSS (gms)	1438	1900	938	1142	1354.50	208.800
SC	% DEHYDRATION	1.19	2.47	1.67	1.03	1.59	0.324
SC	SWEAT RETAINED RATE (ml/hr)	75.5	122.7	36.4	46.7	70.29	19.316
SC	SWEAT RETAINED (gms)	512	832	248	318	477.50	130.694
SC	SWEAT EVAPORATION RATE (ml/hr)	136.5	157.4	101.2	120.9	129.01	11.913
SC	SWEAT EVAPORATED (gms)	926	1068	690	824	877.00	79.927
SC	% SWEAT EVAPORATED	64	56	74	72	66.58	4.001
SC	% SWEAT RETAINED	36	44	26	28	33.42	4.001
SOAR-specific w/out cooling (SX)		TS 1	TS 2	TS 3	TS4	AVG	SE
SX	TIME IN UNIFORM (hours)	6.72	6.72	3.83	3.92	5.30	0.820
SX	URINE OUTPUT RATE (ml/hr)	254.0	371.9	58.4	33.2	179.38	80.950
SX	URINE OUTPUT (gms)	1706	2498	224	130	1139.50	579.056
SX	FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gm	737	821	385	729	667.78	96.670
SX	FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms)	4952	5512	1474	2854	3698.00	936.377
SX	SWEAT LOSS RATE (ml/hr)	602.1	417.8	721.0	1271.0	752.97	183.594
SX	TOT SWEAT LOSS (gms)	4044	2806	2764	4978	3648.00	533.552
SX	% DEHYDRATION	0.91	-0.24	1.73	2.30	1.18	0.551
SX	SWEAT RETAINED RATE (ml/hr)	306.1	115.5	380.9	608.7	352.80	101.955
SX	SWEAT RETAINED (gms)	2056	776	1460	2384	1669.00	353.804
SX	SWEAT EVAPORATION RATE (ml/hr)	296.0	302.2	340.2	662.3	400.17	87.919
SX	SWEAT EVAPORATED (gms)	1988	2030	1304	2594	1979.00	264.028
SX	% SWEAT EVAPORATED	49	72	47	52	55.20	5.805
SX	% SWEAT RETAINED	51	28	53	48	44.80	5.805

Weight and Fluid Balance							
Air Warrior Concept 3 w/MCC (AC)		**TS 1**			**TS 4**	**AVG**	**SE**
AC	TIME IN UNIFORM (hours)	6.92			6.88	6.90	0.017
AC	URINE OUTPUT RATE (ml/hr)	391.8			262.7	327.24	64.572
AC	URINE OUTPUT (gms)	2710			1808	2259.00	451.000
AC	FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gm	377			149	262.91	114.148
AC	FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms)	2608			1024	1816.00	792.000
AC	SWEAT LOSS RATE (ml/hr)	221.8			183.9	202.85	18.930
AC	TOT SWEAT LOSS (gms)	1534			1266	1400.00	134.000
AC	% DEHYDRATION	1.88			2.06	1.97	0.094
AC	SWEAT RETAINED RATE (ml/hr)	100.6			72.9	86.78	13.848
AC	SWEAT RETAINED (gms)	696			502	599.00	97.000
AC	SWEAT EVAPORATION RATE (ml/hr)	121.2			111.0	116.07	5.082
AC	SWEAT EVAPORATED (gms)	838			764	801.00	26.163
AC	% SWEAT EVAPORATED	55			60	57.49	2.860
AC	% SWEAT RETAINED	45			40	42.51	2.860
Air Warrior Concept 1 w/out MCC (AX)			**TS 2**	**TS 3**		**AVG**	**SE**
AX	TIME IN UNIFORM (hours)		5.00	4.55		4.78	0.159
AX	URINE OUTPUT RATE (ml/hr)		350.8	37.4		194.08	110.817
AX	URINE OUTPUT (gms)		1754	170		962.00	560.029
AX	FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gms)		350	547		448.43	69.881
AX	FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms)		1748	2490		2119.00	262.337
AX	SWEAT LOSS RATE (ml/hr)		556.4	971.4		763.91	146.735
AX	TOT SWEAT LOSS (gms)		2782	4420		3601.00	579.120
AX	% DEHYDRATION		3.23	2.40		2.82	0.295
AX	SWEAT RETAINED RATE (ml/hr)		244.0	611.0		427.49	129.750
AX	SWEAT RETAINED (gms)		1220	2780		2000.00	551.543
AX	SWEAT EVAPORATION RATE (ml/hr)		312.4	360.4		336.42	16.985
AX	SWEAT EVAPORATED (gms)		1562	1640		1601.00	27.577
AX	% SWEAT EVAPORATED		56	37		46.63	9.521
AX	% SWEAT RETAINED		44	63		53.37	9.521

Appendix H.

Manufacturers and product information.

Digital Equipment Corporation 110 Spit Brook Road Nashu, NH 03062-2698	VAX 11/780 Computer
Microsoft Corporation P.O. Box 72368 Roselle, Illinois 66172-9900	Microsoft Office Professional
SPSS, Inc. 444 North Michigan Avenue Chicago, Illinois 60611	SPSS statistical software
Statsoft 2325 East 13th Street Tulsa, Oklahoma 74104	Statistica software
Vermont Medical, Inc. Industrial Park Bellows Falls, Vermont 05101-3122	ECG pads
Yellow Springs Instrument Company P.O. Box 279 Yellow Springs, Ohio 45387	Rectal and skin thermistors