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Heat Stress Evaluation of Air Warrior Block I MOPP0 and MOPP4 Ensembles With and Without Microclimate Cooling

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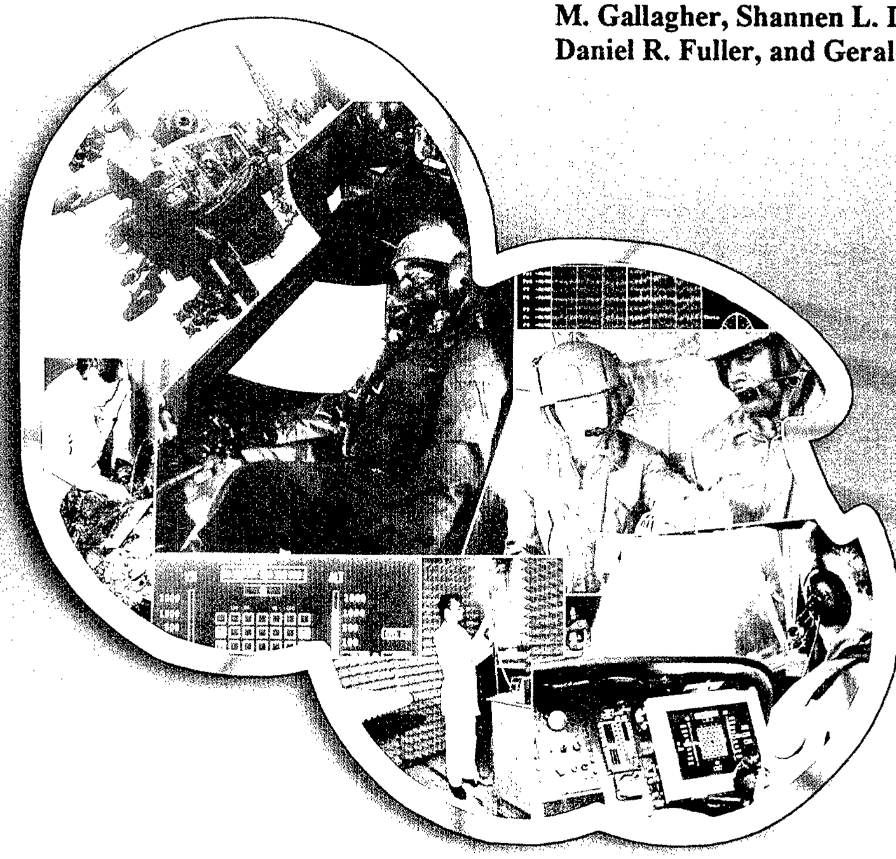

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The current study evaluated the feasibility of a 5-hour flight in MOPP4 with environmental conditions of 100°F and 50% relative humidity. Eight volunteer pilots participated in a within subject, repeated measures design. The test conditions included 70°F without nuclear, biological and chemical (NBC) gear (Cool Standard (CS)), 70°F with NBC gear (Cool MOPP (CM)), and 100°F with NBC gear and microclimate cooling (Hot MOPP (HM)). The test sessions consisted of an initial 20-minute warm up, two flight sorties and an intervening break (without NBC gear removal). Physiological parameters, flight performance, mood, and reaction time were measured during the test sessions. The peak mean core temperature did not exceed 99.8°F. Mean core temperature in the HM condition was about 0.4°F higher than CM and about 0.6°F higher than CS. The absolute increase was quite modest compared to the approved upper limit of 102.5°F. Mean percent dehydration was greatest for the HM condition despite the use of the cooling vest. However, the fluid deficit of approximately 300 cc per hour was a totally compensable rate. The results indicated that the cooling vest was effective in preventing heat stress during an extended rotary-wing mission in a hot, humid condition. However, the cooling vest did not totally prevent sweating and a

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mild degree of dehydration in the hot encumbered condition. Average flight performance scores were reduced in the HM and CM condition primarily by the encumbrance of the MOPP ensemble and only minimally by the heat stress itself.

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Introduction

The current U.S. Army aviator Chemical and Biological (CB) protective clothing ensemble consists of the standard Aircrew Battle Dress Uniform (ABDU) along with the Battle Dress Overgarment (BDO). The BDO is worn over the ABDU to protect against chemical warfare threats. An aviation life support equipment (ALSE) vest and laminated ballistic protection plates are worn over the BDO. When worn together, these components create a bulky ensemble that significantly encumbers the aviator and impairs thermoregulation and heat dissipation. For this reason, the potential adverse effects of the current U.S. Army aviator ensemble in hot weather and nuclear, biological and chemical (NBC) scenarios need to be characterized so that new clothing and individual equipment being developed, under the auspices of the U.S. Army's Air Warrior (AW) program can be designed with properties that reduce any propensities to exacerbate heat stress. This study evaluated the current block 1 AW configuration as part of a higher-level evaluation of aviator-in-the-loop performance and feasibility. A primary objective of Program Manager, Aircrew Integrated Systems (PM ACIS) and the AW program, is to develop new-generation aviator ensembles that will allow aircrew to operate in a combat environment while wearing CB mission oriented protective posture (MOPP4) ensembles for a period of time and at performance levels equal to the average endurance and performance of aircrew unencumbered by such.

Background

Review of thermal biophysics and physiology

Heat stress induces many complex and interrelated compensatory thermoregulatory changes or adaptations which are collectively termed heat strain (Wyndham, 1973). The beneficial effect of heat strain is to dissipate heat energy that accumulates within body compartments (blood, brain, muscle, abdominal organs, etc). It is a basic biophysical principal that core temperature increases in proportion to the amount of heat energy stored within body tissues and fluids. The proportionality constant for this biophysical relationship is the body's average specific heat capacity (3.49 kJ/(kg $^{\circ}$C)). If endogenous or exogenous factors cause heat storage within the body, core temperature increases and compensatory and protective heat dissipating processes are progressively activated. The physiological thermoregulatory processes include sweating, peripheral vasodilatation, increased cardiac output, and shunting of blood flow from visceral organs to the skin and heat producing working muscles. Sweating rate, heart rate, blood pressure, and other physiological measures comprise the readily measured reactions to heat stress, i.e., the clinically detectable components of heat strain. Other heat strain effects such as elaboration of protective heat shock proteins (Schlesinger and Collier, 1991) occur at the cellular and biochemical level and require blood tests or other methods for detection.

Muscle activity and associated metabolic rate is often an important, or even the primary, cause of core temperature elevation. Indeed, a low metabolic rate associated with sedentary activities in an environmentally uncompensable heat stress situation can lead to, perhaps slow but inexorable, elevations in core temperature and eventually, heat illness. If heat accumulation from total metabolic rate and environmental sources equals or exceeds the body's maximum heat dissipating capability, core temperature rises in direct proportion to the duration and intensity of the work rate. In other words, in such circumstances, the steepness of the positive slope of the core temperature profile is a function of the metabolic rate. For these situations, endurance can be extended by minimizing work intensity or by finding ways to improve work efficiency.

Metabolic rates for routine flight maneuvers in military helicopters are rather low (100-200 watts) (Thornton, Brown and Higenbottom, 1984). This is typically categorized as very light to light physical work. Therefore, the contribution of metabolic rate to core temperature elevations in helicopter pilots in hot conditions will be relatively small over a short period of time but, if the ambient or cockpit conditions are sufficiently hot, core temperature may progressively increase to performance degrading or incapacitating levels.

Depending on a variety of factors, thermoregulatory responses to heat stress may have complete, partial, or no beneficial effect. Thermoregulatory effectiveness is a function of the balance between external and internal (metabolic rate) heat gain as well as the capabilities and limitations of the heat strain mechanisms. Completely effective thermoregulatory responses to heat stress will prevent core temperature from rising above normal. Indicators of heat strain in this circumstance will consist of elevated heart rate, increased skin blood flow, and sweating. For the case of compensable heat strain, heat storage occurs initially, but the rate of heat storage is eventually reduced to zero by thermoregulatory mechanisms. This results in a core temperature profile which asymptotically approaches a tolerable, but elevated, steady-state level.

Heat stress may be sufficient to overwhelm an individual's maximum thermoregulatory capabilities (which may be reduced or below average due to dehydration, illness, medications, or other factors). This type of situation indicates the presence of uncompensable heat stress. In such circumstances, core temperature will inexorably rise beyond tolerable limits. Thermoregulatory mechanisms, tasked to their maximum, may delay, but not prevent, this inevitable outcome. Eventually incapacitation will occur due to the adverse effects of increasing heat storage and rising core temperature. If a thermally oppressive environment cannot be avoided by modifying the mission, an effective strategy for maintaining survivability and sustaining performance is the use of macroclimate (air conditioning) or microclimate (personal) cooling systems (MCS).

Available data indicate that the hot environmental condition to be used in this study, i.e., 37.8° C (100° F) and 50% relative humidity (RH), will impose marginally compensable heat stress. That is, it will likely be uncompensable for test subjects with reduced thermoregulatory capabilities. In Thornton et al.'s (1992) heat stress study, the aviators wearing the MOPP4 ABDU while exposed to environmental conditions of 35.0° C (95° F) and 50% RH, reached core temperatures of ≅38° C (100.4° F) by 2 hours into the scenario. At that point, core temperatures diverged. One group of test subjects had a progressive increase in core temperature to ≅39° C (102.2° F) at 4 hours while the others remained at about ≅38° C (100.4° F). Therefore, the heat stress scenario was compensable for some test subjects, while for others it was not.

Variability in heat stress tolerance, for a given scenario, is related to individual differences in factors that affect the efficiency and maximum capabilities of the various heat dissipating mechanisms. Thermoregulatory efficiency is affected by adaptive (or, if training is deficient, maladaptive) behavioral responses, body morphology, condition of skin and sweat glands, cardiovascular conditioning, hydration, fatigue, nutrition, medications, and illnesses. Factors which improve thermoregulatory efficiency decrease core and skin temperature thresholds for initiation of thermoregulatory responses, and increase the sensitivity, or rate of change, of these responses with respect to increases in core temperature.

An effective method for increasing thermoregulatory capacity and efficiency is acclimatization (Wenger, 1988). For scenarios consisting of identical degrees of heat stress, clothing, and metabolic rates, heat stress acclimatization results in earlier onset and more rapid recruitment of thermoregulatory responses. Successful acclimatization results in earlier onset and increased rates of sweating, decreased heart rate, and decreased core temperature for a specific combination of environmental condition, work rate, state of hydration, and type of clothing. Heat acclimatization also results in decreased sweat sodium concentrations (Allan and Wilson, 1971). The numerous beneficial effects of heat acclimatization may effectively convert an uncompensable heat stress situation into one that is at least partially compensable.

The time required to fully acclimate to heat stress when starting from an un-acclimated condition depends on the health and fitness of the individual. Those with high levels of physical fitness can acclimate rapidly (Pandolf, et al., 1988). Three to 5 days of graded intensity exercise in hot conditions will achieve most of the beneficial acclimatization effects. Additional residual benefit continues to occur over the ensuing 1 to 2 weeks. For those whose physical fitness is less than average, acclimatization typically occurs at a more gradual pace over 10 to 14 days. Studies have demonstrated that artificial acclimatization can be as effective physiologically as acclimatizing naturally by training or doing one's usual work outdoors. Two, 50-minute training sessions per day in moderately hot conditions (e.g. 100° F, 20% RH) for 1 to 2 weeks has been found to be sufficient for acclimatizing healthy soldiers. Activity level during acclimatization should be sufficient to elicit sweating and moderate increases in heart rate. If, during acclimatization, signs of excessive heat stress occur, the activity level or environmental conditions should be reduced to be increased again more gradually over the course of several days.

Various studies have demonstrated that military chemical defense (CD) over-garments significantly impair thermoregulation in hot environmental conditions. CB protective ensembles invariably have high insulation values and low water vapor permeability (Gonzalez, 1988). When ambient temperatures are lower than body temperature, the high insulation values cause high resistance to heat transfer from the skin to the clothing's surface where it can then be transferred by convection to the surrounding air or by radiation to cooler objects in the environment. Conversely, when ambient temperatures are higher than body temperature, the high insulation values will initially reduce the rate of heat transfer from the environment to the individual's skin as compared to lighter weight uniforms.

Low water vapor permeability values for CB ensembles such as the BDO indicate the presence of significant resistance to transport of liquid and evaporated sweat through the layers of fabric. This will cause the air layer between the skin and inner surface of a CB ensemble to rapidly become saturated with sweat vapor. As the relative humidity in this air layer increases, its water vapor pressure will equal or exceed the vapor pressure of the film of sweat on the surface of the skin. When this occurs, the net evaporation of sweat decreases and approaches zero. Vigorous sweating continues despite its inability to evaporate. This unused sweat accumulates in the dependent parts of the CB uniform such as boots, gloves, and CB mask. This un-evaporated sweat has not been used for cooling, and in that sense, is wasted fluid.

Complete evaporation of one liter of sweat provides 580 Kcal of surface cooling. When ambient temperatures exceed body temperature, evaporation of sweat is the only effective method of dissipating body heat (Sawka and Wenger, 1988). Effective sweat evaporation rates, as determined by the rate of evaporation of sweat through, or off the outer surface of a uniform determines the evaporative cooling power available to the individual. It is apparent, therefore, that actual and effective sweating rates may differ considerably.

Heat stress and other factors affecting task performance

The effects of heat stress on various types of performance have been investigated in many studies and summarized in various meta-analyses and reviews (e.g., Ramsey, 1995). However, results have been inconsistent, and this has occasionally resulted in confusion with regard to establishing heat stress exposure standards. For example, the National Institute of Occupational Safety and Health (NIOSH) in 1972 promulgated a workplace standard for limiting heat stress exposure for preserving unimpaired mental performance among sedentary workers. As part of this initial standard, NIOSH initially recommended that ambient wet bulb globe temperature (WBGT) not exceed 31° C (87.8° F) in hot workplace environments in order to prevent decrements in mental performance. This particular recommendation was superseded by a 1986 revision of the standard (which favored more general heat stress exposure limits). This revision occurred because, upon review, subject matter experts at NIOSH concluded that the association between heat stress exposure and cognitive performance was not as convincing as originally thought and did not warrant the more stringent and specific limits of the initial version of the standard.

Although the association between heat stress exposure and cognitive performance may be somewhat weak for various reasons (e.g., the difficulty of controlling for the myriad of possible confounders such as skill and training levels, motivational level, effects of other stressors, etc.), studies have consistently demonstrated decrements in performance of other types of tasks, such as tracking, when ambient temperatures exceed 30° C (86° F). Reaction times and vigilance decrements at these and higher temperatures have also been documented but the effects have either been relatively small or inconclusive because of inconsistency across different studies. Heat stress exposure has also been shown to cause significant decrements in performance of complex tasks (Ramsey, 1995).

Fine and Kobrick (1987) showed that sedentary soldiers, in MOPP4 and a 32.8° C (91° F), 61% RH environment, maintained baseline performance on various components of artillery plotting tasks for about 3 hours. After 3 hours, error rates increased linearly for decoding and target-point calculations. In those conditions, task completion rates began to decrease after 4-5 hours. Interestingly, performance in MOPP4 for both temperate and hot conditions and BDUs alone with hot temperature resulted in lower error rates initially than when performing the same tasks in BDUs and temperate conditions. This effect is consistent with the generally observed phenomenon that moderate heat stress can initially improve performance for some types of tasks. This may be due to a test subject behavioral response bias resulting from the obvious inability to blind them to the experimental conditions. Motivational and behavioral overcompensation to readily perceived heat stress conditions are probably volitionally activated thereby causing the paradoxical, early exposure, performance improvements.

Unseen and difficult to measure compensatory factors can be progressively recruited to preserve performance during heat stress exposure. Although performance reserves are being invisibly diminished, there may be few if any observable changes in performance. Therefore, this important effect may remain hidden because there are not adequate methods for assessing reductions in performance potential.

Dehydration can potentially confound the apparent relationship between heat stress exposure and performance. Varying degrees of dehydration may occur during heat stress exposure due to high rates of sweat loss, inadequate self-regulated fluid intake (voluntary dehydration), physical impediments to water intake such as wear of a CB mask, or because sweating rates persistently exceed maximum rates of gastrointestinal water absorption (≅15-20 cc/min). Dehydration has been shown to reduce arithmetic, word recognition, and coding tasks independently of heat stress (Gopinathan, Pichan, and Sharma, 1988). The repeated measures design which we will utilize may not be sufficient to control for the effects of this confounder because the different test conditions are likely to elicit considerable within-test-subject differences in dehydration. Confounding effects from dehydration can be mitigated during the study by encouraging frequent fluid intake. The effects of within-and between-test-subject variances in dehydration on performance and physiological results can be corrected for with covariance or multivariate regression techniques.

Differences between test subjects in skill levels in the measured tasks may also cause spurious heat stress - performance associations. For many types of tasks, high skill levels will typically raise the ambient temperature threshold for the onset of performance decrements (Hancock, 1982). To minimize the confounding effects of differential levels of previous experience or practice, it will be necessary to pretrain test subjects with the task measurement tools to asymptotic performance levels. For this study, the variance in task performance between subjects will be of secondary interest. However, the extent to which differences in skill levels affect performance can be investigated using several approaches such as analysis of covariance or multivariate regression. In this study, the volunteer aviator's number of career UH-60 flight and simulator hours will be used as a surrogate for aviation skill level.

CB ensembles, particularly when worn in a MOPP4 configuration, degrade performance for many types of tasks through a variety of mechanisms (Taylor and Orlansky, 1993). For example, a CB mask may significantly impair visual and auditory acuity. Multiple layers of protective gloves decrease tactility and manual dexterity. CB mask "hot spots" and general discomfort may lead to distraction. Additionally, there is usually an increased general psychological stress that can nonspecifically impair cognitive performance. The factorial design for this study has been specifically selected to enable a statistical evaluation of independent and interaction effects of type of uniform and/or environmental condition on the various measures (i.e., dependent variables).

Effects of heat stress and MOPP ensembles on Army aviators

Hamilton, Simmons and Kimball (1982) conducted an in-flight (UH-1 Army transport helicopter) evaluation of heat tolerance with six Army aviators wearing standard flight suits or CB ensembles. The CB ensemble consisted of a two-piece Nomex flight suit, two-piece charcoal cloth laminated chemical defense over-garment, mask, hood, and rubber gloves, SPH-4 flight helmet, and combat boots. The insulation and permeability values of that ensemble were 2.57 (clo) and 0.29 (i_m), respectively. Mean cockpit WBGT was 29° C (84.2° F) for the test flights. Average in-flight tolerance times were 3.17 hours for the NBC ensemble versus 3.89 hours for the standard Nomex flight uniform without any NBC protective over wear. Mean heat stress tolerance time associated with wear of the NBC ensemble was disproportionately depressed by a subgroup (cluster) of aviators who were heavier (90 vs. 75.3 kg), older (33.5 vs. 23.0 years), and less fit than the subgroup who were able to complete the missions. Among the heat intolerant aviators, core temperature and heart rate increased more rapidly compared to those in the tolerant subgroup. The latter established relatively stable tolerable plateaus for core temperature and heart rate.

Average sweat loss in that study was 0.95 L (98% evaporated) for those wearing the standard flight uniform and 1.29 L (only 36% evaporated) for those wearing the NBC ensemble. Therefore, the greater water vapor impermeability and absorptivity of the NBC uniform prevented the use of 270 Kcal worth of evaporative cooling from sweat that was not able to evaporate through the ensemble.

The UH-1 root mean square (RMS) in-flight performance errors for the flight conditions involving wear of the standard uniform versus the NBC ensemble are summarized in table 1 below (Hamilton, Simmons, and Kimball, 1982).

Table 1.
Flight performance errors for standard uniform versus the NBC ensemble.

Performance Parameter	Standard Flight Uniform	NBC Ensemble
Heading error (degrees)	1.63	2.02
Airspeed error (knots)	1.83	2.19
Time to complete maneuvers error (secs)	0.93	1.08
Straight flight heading error (degrees)	1.47	1.58
Straight flight airspeed error (knots)	1.27	1.86
Time for one parameter change (secs)	63.92	53.50
Time for two parameter changes (secs)	75.80	63.63
Time for three parameter changes (secs)	81.50	85.75

None of the differences in flight performance errors taken individually reached statistical significance at the p=0.05 level. There does seem to be a trend (6/8 test subjects), however, of somewhat worse performance when flying in the NBC ensemble. It was not possible to discern whether flight performance errors would have been operationally significant during actual military scenarios. Based on their findings, the authors concluded that the quality of the pilot's performance is probably not a reliable indicator that the pilot is approaching physiological overload.

The UH-1 heat stress study demonstrated that cockpit heat stress exposure for pilots wearing a CB ensemble initially was associated with slightly improved cognitive function and psychological condition (Hamilton, Simmons, and Kimball, 1982). Further increase in heat stress, however, caused a reduction in cognitive and psychological performance back to control levels. Target detection response times and errors initially decreased with increased levels of heat stress. However, with more lengthy heat stress exposure, this pattern reversed and response times for a logical reasoning task decreased and errors increased. It is not unreasonable to speculate that these results might be predictive for difficulties with operationally related tasks such as target detection and problem solving that might occur due to a combination of heat stress and the additional mental stress associated with a high work load, rapidly evolving, emergency situation.

Answers to the mood-state questionnaire administered during the UH-1 in-flight heat stress study did not reveal significant correlations with heat stress levels. The authors noted a "dissociation between level of cognitive function and reported mood." In that study, self-reported mood states were not, on average, a sensitive indicator of heat stress related cognitive or mood impairment. An implication of that finding is that medical personnel should not place much reliance on lack of self-reported symptoms alone to rule out heat stress or heat illness.

Thornton et al. (1992) evaluated the effects of heat stress on aviators wearing the Aircrew Uniform Integrated Battlefield (AUIB) MOPP4 ensemble. Nineteen aviators between 21 and 39 years of age were tested. The study was conducted using both temperate and hot cockpit conditions. The temperate condition had a dry bulb temperature of 21° C (70° F) with 50% RH resulting in a WBGT of 16.8° C (62.2 ° F). The hot condition had a dry bulb temperature of 35° C (95° F) with 50% RH resulting in a WBGT of 29.4° C (84.9° F). Each 6-hour flight profile in the U.S. Army Aeromedical Research Laboratory's (USAARL) UH-60 simulator was preceded by a 20 minute walk on a treadmill (≅ 375 Watt metabolic rate) in a heated room to simulate the thermogenic effect of a routine UH-60 preflight inspection.

When the study volunteers wore the MOPP4 AUIB in the hot condition, mean heat stress tolerance time was 298 minutes (almost 5 hours). One test subject withdrew after only 1 hour. Fifty percent of the test subjects were able to complete the entire 6 hour flight scenario. The subjects with shorter tolerance times tended to be heavier, older, and had greater rates of sweating and dehydration. However, increased sweating rates while wearing the occlusive AUIB MOPP4 ensemble did not provide a thermoregulatory advantage since most of the additional sweat could not evaporate and therefore contributed to dehydration but not cooling. The increased sweating rate was not matched with proportionally increased water intake. Dehydration can reduce tolerance time by causing reduced cardiovascular reserve and fatigue.

Rectal temperature increased significantly (1.8° C or 3.4° F) and heart rate rose consistently above 100 beats per minute only during the MOPP4 AUIB-hot conditions. Mean skin temperature in the MOPP4 AUIB-hot condition rose almost 2° C. Lesser elevations in skin temperature were noted for the MOPP4 AUIB in cool and MOPP0 standard flight uniform in hot conditions, in that order. Sweating rates varied from 90 cc/hr in the standard-cool condition to 600 cc/hr in the MOPP4 AUIB-hot condition. By the end of the MOPP4 AUIB-hot scenario, the test subjects had accumulated, on average, a 1 to 1.5 liter fluid-intake deficit.

Flight performance data in Thornton's study revealed significant differences across the four test conditions in only 46% of the combinations of measured navigational parameters and maneuver type. The most consistent differences in flight parameter RMS errors across the test conditions occurred with heading, vertical speed, rate of turn, airspeed, roll and altitude, in that order. Differences in RMS slip errors were not consistent across conditions. Maximum RMS errors for heading and altitude were significantly greater for the MOPP4 AUIB-hot condition. Disconnecting the automatic flight control system (AFCS) had an independent effect of increasing flight parameter errors except for roll error, which was paradoxically reduced.

The general effect of heat stress while wearing the MOPP4 AUIB was a statistically significant increase in RMS error for some flight performance parameters. In an absolute sense, however, the RMS errors were not very large. It was proposed that maximum, rather than RMS, flight parameter error might be a more relevant indicator of operationally significant decrements in flight performance such as those (e.g., infrequent but large altitude deviations) that could directly lead to aircraft accidents (e.g., flying into terrain or obstacles). This line of reasoning was reinforced when significant flight incidents were tabulated and analyzed. During the simulator sessions, seven crashes occurred. These were primarily due to the aviators flying into terrain or trees. Six of the seven accidents occurred while wearing the MOPP4 AUIB ensemble. Four of those occurred in the hot condition and two in the temperate condition.

According to questionnaire data, the MOPP4 AUIB-hot condition evoked the greatest temporal progression of fatigue. During testing, a standardized cognitive performance assessment battery (PAB) was repeatedly administered. This battery of cognitive tests consisted of encode/decode, six-letter search, logical reasoning, digit recall, serial addition/subtraction, and Wilkinson four-choice reaction time problems. Results indicated improved performance during hot conditions for most of those tasks, except for reaction times which were somewhat reduced. Analysis of postflight questionnaires regarding the fit and comfort of the flight ensembles indicated that difficulty drinking water and seeing through the M43 CD mask were common problems. Other problems were general encumbrance and restriction of movements due to the thickness of the AUIB MOPP4 ensemble with the Survival Armor Recovery Vest Inserts and Packets (SARVIP) and ballistic protection plates.

The initial AW heat stress study was done by Reardon et al., (1996) as a repeated measures, 2x2 factorial study, using 14 aviators (17 test iterations) and evaluated the effects of the four combinations of unencumbered MOPP0 ABDU and encumbered MOPP4 over ABDU flight ensembles in cool (70° F, 50% RH) and hot (100° F, 50% RH) UH-60 cockpit conditions. Findings from this study included the following:

> The most striking, operationally relevant result was that none of the crews in the encumbered MOPP4-hot condition were able to complete the first of two 2-hour sorties. In that study, the encumbered MOPP4 aviator uniform in hot conditions decreased average mission endurance from the fully completed mission time of 309 (range: 347-288) minutes to 107 (152-40) minutes. The reduced endurance was attributed to rapid increases in core temperature (0.73 °F/hr compared to 0.27 °F/hr for the MOPP0-cool condition), progressive physical discomfort, and psychological stress and adversely affected mood as reflected in questionnaire responses. Calculated total body heat storage based on core temperature changes for the encumbered MOPP4-hot condition was 1445 watts compared to 627 watts for the MOPP0-hot condition.
>
> In the encumbered MOPP4-hot condition, heart rate rapidly increased to an average maximum of 142 (170-119) beats per minute (bpm) during the simulated preflight on a treadmill and then remained elevated with an average of 133 (164-102) bpm and average maximum of 143 (170-119) bpm during the simulator sorties. The heart rate in the other hot condition (ABDU MOPP0) rose to moderately high levels with an average maximum of 100 (122-73) bpm during the simulated preflight activities, reduced after the treadmill session was completed,

but then increased again in the simulator to an average maximum of 111 (135-91) bpm.

Heavy sweat rates while in the MOPP4-hot condition (1523 cc/hr compared to 92.2 cc/hr during the MOPP0-cool condition) led to significantly greater amounts of dehydration (2.25% compared to 0.18% during the MOPP0-cool condition) over shorter periods of time. Compared to the least thermally stressful condition (ABDU MOPP0-cool), mean chest temperature was 1.52 °F greater in the encumbered MOPP4-cool condition, 1.85 °F greater in the ABDU MOPP0-hot condition, and 4.68 °F greater in the encumbered MOPP4-hot condition. The overall correlation between chest and core temperatures was 0.82.

The encumbrance and thickness of the ensemble also, depending on seat position, restricted the range of aft cyclic movements. Suggestions from that evaluation included that future rotary-wing aviator flight uniform components be lighter weight and allow greater evaporation of sweat and that methods be sought to improve fit and comfort, particularly for the mask and helmet combination, as well as prevent pressure discomfort over the back due to over water survival components such as life raft. The 11.7 lb ballistic protective plate was considered too heavy and thick, interfering with flight performance. Microclimate cooling was recommended for reducing heat accumulation in the encumbered MOPP4 aviator ensemble for hot weather operations.

When averaged across iterations, flight maneuvers flown with either the automatic flight control system fully engaged (AFCS on) or with the trim and flight stabilization components turned off (AFCS off), the encumbered MOPP4 uniform was associated with reduced ($p<0.05$) averaged composite scores (ACS) for 5 (HOV, HOVT, RSRT, SL, and contour) of 8 (62.5 percent) maneuvers. ACS values were significantly lower for 5 of 29 (17.2 percent) separately scored flight systems parameters. The hot condition, as a main effect, reduced the ACS for only 1 (RSRT) of 8 maneuvers.

For the iterations of the maneuvers flown with AFCS on, the encumbered MOPP4 ensemble was associated with significantly lower ACS for 3 (HOV, HOVT, and contour) of 8 (37.5 percent) maneuvers and 5 of the 29 (17.2 percent) separately scored flight parameters. With AFCS off, the encumbered MOPP4 uniform significantly degraded the composite ACS for 2 (SL and LDT) (50 percent) of 4 maneuvers (SL, RSRT, LCT, and LDT) comprising the set of standard maneuvers that were alternately flown with AFCS off and 5 of 17 (29.4 percent) separately scored flight parameters.

The hot temperature was associated with reduced composite ACS values for 2 (RSRT and LCT) of the 4 flight maneuvers. The encumbered MOPP4 uniform had the most frequent adverse effect on flight performance followed by heat stress with less frequent effects from the combination or interaction of these two factors. There were no statistically significant increases in simulator crashes, main rotor or stabilator strikes, or other recorded incidents for the hot or encumbered MOPP4 conditions. Flight parameter scores were more sensitive in detecting differences in simulator performance across test conditions than root mean square errors or maximum and minimum deviations from target performance values. This study confirmed that heat stress and wearing an encumbered U.S. Army MOPP4 flight uniform significantly reduced endurance and flight performance in a UH-60 simulator.

In that study, test subjects typically were withdrawn for reaching core or heart rate limits. At that point, they were invariably sweating heavily, red-faced from peripheral vasodilatation, and visibly stressed but fully coherent. A few were physically exhausted and needed temporary assistance due to unsteadiness on their feet after exiting the simulator. However, they all fully recovered within 20-30 minutes after cooling with towels soaked in ice water and use of high speed fans. None required intravenous fluids or other medical intervention.

A subsequent heat stress evaluation comparing these results to a U.S. Marine/Navy MOPP4 ensemble was performed in 1997 (Reardon et al., 1998) with the following principal findings:

> This aviator heat stress study used a between test subjects design with one environmental condition (hot) and two current (U.S. Navy/U.S. Marine Corps vs. U.S. Army) rotary-wing MOPP4 ensembles encumbered with additional ballistic protective and over water survival components. Four U.S. Marine Corps (USMC) aviators (2 UH-60 crews) were tested in the hot condition and their physiological, subjective, and flight performance responses compared to those of 14 Army aviators (9 crews) who tested in the same condition in the preceding study. The environmental condition consisted of 100° F (dry bulb) and 20 percent relative humidity (RH) in an environmental chamber where test subjects walked on a treadmill for 20 minutes to simulate preflight outdoor activities, and 100°F and 50 percent RH (90°F wet-bulb globe temperature[WBGT]) in the UH-60 simulator flying the standard heat stress sorties.
>
> Mean crew endurance in the hot condition for the Navy/USMC and Army protective aviator ensembles were 132 and 98 minutes, respectively. Although mean core temperature profiles for the two ensembles were not substantially different, heart rates were lower for the group wearing the Navy/USMC ensemble. In the hot condition, the average sweat rate for the aviators in the Navy/USMC protective ensemble was substantially lower (1033 cc/hr) than for the equivalent Army ensemble (1494 cc/hr).The Navy/USMC ensemble allowed a greater percentage of sweat evaporation (52 ± 2.6 percent SE) than the Army ensemble (27 ± 3.2 percent). Conversely, the percentage of sweat retained in the uniform was greater for the Army (73 ± 3.2 percent) than the Navy/USMC (48 ± 2.6 percent) ensemble. Average composite flight performance scores did not differ substantially across the two ensembles. Likewise there were no significant differences in mean number of potentially dangerous flight incidents (e.g. controlled flight into terrain [CFIT], tail rotor strikes, etc.).

Another AW study, this time using the PVCS microclimate cooling undershirt, was performed in 1998 (Reardon, Katz, and Fraser, 1999). Results included the following:

> This study used a repeated measures design with 1 environmental condition (hot) and 3 ensembles (SOAR, AW 1 and AW 3) encumbered with ballistic protective and over-water survival components. The SOAR ensemble was tested with and without microclimate cooling (chilled water vest with portable chiller/pump), AW Concept 1 and 3 were tested without and with (respectively) microclimate cooling system. Four U.S. Army active duty aviators tested the three ensembles in the hot condition which consisted of 100° F (dry bulb) and 20 percent relative humidity (RH) in an environmental chamber where the aviators walked on a treadmill for 20 minutes to simulate preflight outdoor activities, and 100° F and 50 percent RH (90° F WBGT) in a research UH-60 simulator where crews attempted to fly three successive2-hour sorties.
>
> Mean endurance in the hot condition without microclimate was 5.2 hours. Endurance was not heat-stress limited (6.8 hours) when microclimate was used. Regression analysis indicated core temperature increased 0.275° F per hour faster when not wearing MCS. Use of MCS significantly reduced mean heart rate and evaporated sweat losses. Water intake was also less. MCS, however, seemed to increase urine output slightly.

Current study questions

This study examined the following principal hypothesis: compared to the Basic Combat or MOPP4 AW ensemble in the 70°F condition, use of the MCS with the MOPP4 AW ensemble in 100°F will result in similar mission endurance and flight performance as well as similar, core temperature and heart rate profiles, subjective mood and symptom ratings assessed by questionnaire. Specifically, we compared performance of aviators in Basic Combat uniform to that of AW MOPP4 in a temperate condition to determine effects of encumbrance in the non-heat stressful condition, and the Basic Combat to the AW MOPP4 in a hot condition to determine the effectiveness of the MCS in approaching results in the unencumbered non-heat stress condition.

Methods

General

This research was performed in accordance with a USAARL and U. S. Army Medical Research and Materiel Command (MRMC) approved protocol. It was conducted at USAARL, from 3 to 15 December 2001 using eight UH-60 qualified aviators. The number of test subjects was determined using power calculations. Standard deviations from similar recent studies were used in these calculations. Using a within subject design with an N=8 and 3 treatment conditions, power values for all flight maneuvers using a confidence interval of .05 were > .9. Power of .80 is generally accepted as the benchmark. Thus, it was determined that an N of eight corresponding to four crews was sufficient for detection of differences. Each prospective volunteer was required to have a current DA Form 4186 ("Up Slip") that would not expire during the assigned study period. The DA Form 4186 must have designated either full flying duty (FFD) or duty not involving flying (DNIF) but simulator duty permitted. Prospective test subjects were fully briefed regarding the objectives and design of the study, treatment of the data, potential risks and benefits, safeguards, and oversight by the medical monitor. Volunteers were fully informed that they had the right to withdraw from the study at any time for any reason without penalty. Prior to participation, volunteers were medically cleared by the study's physician investigator. All test subjects completed the study without significant or reportable adverse effects and were medically cleared to return to their units by the physician investigator.

Volunteer test subjects

The eight UH-60 pilots who served as volunteer test subjects were paired into four crews. Each crew participated in the three test conditions in a repeated measures, counterbalanced design. The test condition designators included CS for cool-standard meaning 70°F and MOPP0 Air Warrior aviator ensemble without the microclimate cooling unit (MCU) vest, CM for cool-MOPP consisting of 70°F and the provided

MOPP4 Air Warrior ensemble with the MCU vest but not actually turned on, and HM for hot-MOPP consisting of 100°F and the provided MOPP4 Air Warrior ensemble with the MCU vest turned on in the simulator. The test sessions consisted of an initial 20-minute block of simulated preflight activities involving ambulation at 3 miles per hour at zero grade on a treadmill in an environmental chamber at the prescribed temperature and 20% relative humidity. Then, the crews walked to the USAARL UH-60 simulator set at the same temperature but 50% humidity as well as overhead heat lamps resulting in a 90°F WBGT. They flew two, 2-hour sorties with an intervening simulated hot refuel break as an opportunity to urinate and adjust ensemble components to relieve hot spots. Measurements and questionnaire responses were obtained in standardized fashion.

Aviator ensembles and study apparatus

Air Warrior configurations

During a test session, the volunteer crews donned one of two different Air Warrior ensemble configurations: basic combat, normal environment (BC-N); MOPP4, normal environment (AW-N); and MOPP4, hot environment (AW-H). The components for each of these are listed in Appendix A. The first was a MOPP0 configuration, that is, no mask and no chemical-biological over garment, whereas the other two were MOPP4 ensemble with CB mask and over garment. Both MOPP4 configurations added a microclimate cooling garment (MCG), however, only the hot condition used the associated MCU. This resulted in the hot configuration being the most encumbering.

Microclimate cooling garment/vest

The following description of the microclimate cooling garment, which is actually a vest (Figure 1), is provided in the Interface Control Document for the Air Warrior System (PM-ACIS, 7/3/00). Additional summary information for this system is provided in Appendix A. The expected nominal cooling power is 180 watts.

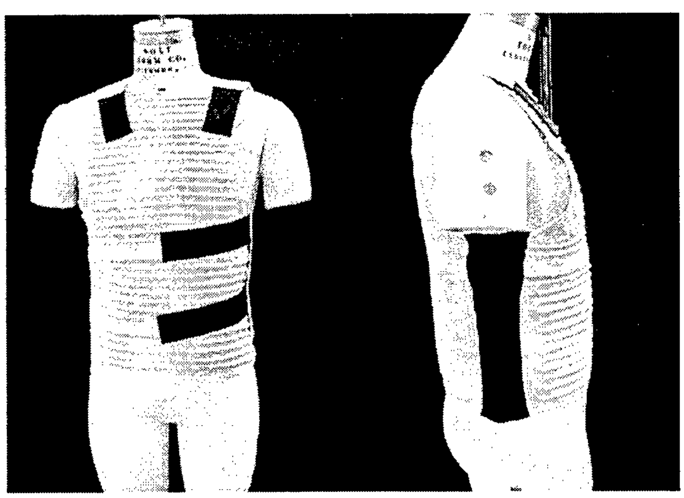


Figure 1. AW water cooled garment/vest.

The selection of the MCG configuration is not trivial. Since the heat from the body is transferred primarily through conduction and convection when the cooling vest is in use, a minimum amount of body surface area must be covered to achieve the heat removal requirements. Of course, user desires such as comfort, bulk, and integration issues must be considered, as well as development and unit costs. Based upon the heat removal parameters stated above, a vest covering the user's torso region is expected to adequately meet these requirements. Historical data indicate that, while heat transfer garments covering just the torso region can remove 180 watts of heat from the torso region, the performance is directly related to fluid flow rate and the temperature of the fluid entering the garment. Therefore, the MCG needs to drive the requirements for these parameters, while, at the same time, not exceeding the performance limitations of the MCU. Thus, the effectiveness of the MCG is dependent on the performance of the MCU.

The current MCG vest consists of approximately 110-130 feet of commercially available 3/32"ID/5/32" OD plasticized PVC tubing laminated between two layers of cotton fabric. The tubing is divided into six parallel circuits, reducing the pressure drop and temperature gradient across the garment and minimizing the likelihood of a complete loss of cooling if a tube becomes kinked or blocked. Each circuit covers a specific region of the body: front upper torso, front lower torso, back upper torso, back lower torso. The amount of tubing in each circuit is approximately evenly divided and is arranged in a horizontal pattern. This arrangement allows for better fit characteristics, especially among females. Both shoulder straps are open to ease donning/doffing procedures. Adjustment and closure is provided by a single strap at each shoulder, as well as two straps on the left side of the MCG. The current requirement specifies that the MCG accommodate at least 95% of the female and 95% of the male general Army population. A formal sizing and fit evaluation has been conducted to verify this requirement and to assess the sizing tariff. A total of three sizes (small, medium, and large) were determined to be necessary to ensure the proper fit across the full range of the specified anthropometric sizes.

UH-60 helicopter simulator

This study utilized the motion-based USAARL UH-60 research simulator. Its hydraulic motion base provides 6 degrees freedom of motion. The forward scenery is displayed by the CRT in each of the front windscreens while the left and right scenery are sent to the CRT in their respective windows.

The UH-60 research simulator is equipped with an environmental control unit (ECU) that can regulate the cockpit thermal conditions to maintain a specified target dry bulb temperature(T_{db}) and relative humidity (RH). The ECU permits setting cockpit environmental conditions within a range of 68-105° F (± 3° F) and 50-90% RH (± 3%).

The flight instruments and controls in the UH-60 simulator are directly linked to a real-time data acquisition system controlled by a DEC VAX 11/780 computer. This 128 channel, automated data acquisition system captures aviator input and aircraft response measurements at a 30 Hertz (Hz) sampling rate. The system allows continuous recording of cockpit instruments such as airspeed, altitude, roll, pitch, and slip. These flight data are then stored as files in the USAARL DEC-VAX computer system. The data are subsequently downloaded and analyzed for objective assessment of flight performance.

The simulator also has an additional data acquisition system for capturing various physiological data that synchronizes with flight performance data. An RS-232 line between the data acquisition box and a continuous display LED device or laptop computer in the observation and control section of the simulator permitted the research team to directly monitor test subject core temperature and heart rate on a real time basis. This facilitated frequent assessments of test subject heat strain and ensured compliance with Human Use core temperature and heart rate limits.

Test subjects were protected from possible electrical shock from current and voltage sources in the data acquisition system by very sensitive (10 micro amp) Patient Isolator circuit breakers (Ohmic Instruments Co., Easton, MD). The data acquisition system also underwent an electrical safety check before and after installation by USAARL's biomedical engineer.

Four continuously recording video cameras (two directly oriented at the crew's faces and two looking over their shoulders) and voice recorders continuously monitored the test subjects when they were in the simulator. The simulator operator could slew these cameras using a control device located in the rear area of the simulator. This allowed close-up, uninterrupted, monitoring of the appearance and responsivity of the test subjects throughout the simulator sessions.

The simulator operator controlled the flight scenarios and was in constant communications with the crew while in the simulator. Next to the operator was a research assistant who had the flight scripts and administered the questionnaires (mood and symptoms and task load) and PVT at the appropriate times. He/she also monitored heart rate and core temperature and was in communications with the medical monitor in the external monitoring room.

Measurement devices

Cockpit WBGT

A calibrated Reuter-Stokes (Ontario, Canada) RSS-217 WIBGET meter was used to measure and record cockpit temperatures (dry bulb, wet bulb and black globe). The main purpose of the WIBGET was to determine accurate WBGT and component temperatures for each simulator session. Only WIBGET meters that had a current calibration were used during the study.

Body core temperature

Core temperature was measured using a rectal probe. The simulator's physiological data acquisition system allowed for real-time monitoring by the assistant in the simulator as well as by the medical monitor in the remote monitoring station or via desktop PC in his/her office. The rectal temperature probes were model YSI 401 thermistors (Yellow Springs Instrument Co., Yellow Springs, OH).

Skin temperature

Skin temperature was measured with YSI 400 series (Yellow Springs Co.) surface thermistors held in position with collodion and tape. They were applied to the anterior chest (T_{chest}), upper arm (T_{arm}), inner thigh (T_{thigh}), and outer calf (T_{calf}). A weighted mean skin temperature(T_{sk}) was be calculated using the following formula (Ramanthan, 1964):

$$T_{sk} = 0.3\ T_{chest} + 0.3\ T_{arm} + 0.2\ T_{thigh} + 0.2\ T_{calf}$$

The sensors were applied to the appropriate locations prior to each session. The skin was inspected daily to avoid placing the sensors on irritated areas and to detect any possible sensitization to the sensors due to immersion in sweat. Sensors were cleaned after each use.

Heart rate

Heart rate was recorded using a three lead system with Ver-Med (Vermont Medical Inc, Bellows Falls, VT) electrodes. The electrodes were placed to maximize the R-wave tracing since the leads were feed into an R-wave counter (Boisig Instruments Inc., Champlain, NY). If necessary, permission was requested to shave a small amount of hair over the preferred electrode locations so that sufficient skin-to-electrode contact could be obtained to maintain a reliable signal for heart rate determination.

Dehydration

Comparisons of pre- and post-study session test subject weights were used to determine the amount of cumulative dehydration and sweating that occurred during each test session. At the beginning of each test session, test subjects urinated and a nude weight was obtained. A technician applied the skin temperature and electrocardiogram (ECG) sensors, and subjects donned the appropriate ensemble. A dressed weight was then obtained. During the tests, water consumption and voided urine was measured and recorded. At the end of each session, a clothed weight was again obtained. The ensemble was then removed, and a final nude weight obtained. These data were recorded on the forms included in Appendix B.

Dehydration was calculated by subtracting post- from pre-session weight. Sweat loss estimate was then obtained from the term: ($weight_{initial}$ - $weight_{after}$)+ ($weight_{water}$ - $weight_{urine}$). The clothed minus nude weights permitted assessment of the amount of sweat retained in the ensemble versus sweat that was evaporated. Comparison of the evaporative cooling potential of the test condition with the cooling power of the evaporated sweat gave an index of the extent to which an ensemble affects the efficiency of sweat production for evaporative cooling.

Tests

Mood evaluation

The Mood and Symptom questionnaire was given approximately every 30 minutes throughout testing. It was used to assess subjective reports of mood, heat stress symptoms, and possible ensemble related problems such as hot spots (Appendix C). A research technician seated in the back of the simulator asked each aviator the 13 questions and recorded the answers at the appropriate times as specified in the flight profiles.

Simulated flight profiles

Studies have indicated that metabolic rate during a helicopter preflight inspection, for a man of average morphology, is approximately 370 watts. This was simulated by preceding each simulator session with a 20 minute walk on a treadmill. During the simulated preflight, test subjects walked at a controlled pace of 4.8 km/hr (3 mph) and 0° grade (equivalent to 350-360 watts of external work). The preflight treadmill ergometer sessions were conducted in an environmental test chamber with temperature and humidity set to 100°F, 20% RH for testing during the hot condition and 70°F, 20% RH for testing during the normal condition, similar to previous thermal stress studies conducted at USAARL (Reardon et. al., 1996; 1997; 1998).

The simulator flight sessions consisted of a maximum of 5 hours of flight time comprised of 2-hour sorties with intervening 10 minute simulated refueling breaks during which the crew exited the simulator to urinate. The two sorties consisted of a 2-hour air-assault (AA) scenario followed by a 2-hour medical evacuation (MEDEVAC) scenario. Any remaining time was spent flying the AA sortie in reverse direction. These sorties, representative of mission types for the UH-60 helicopter (USAAC, 1989), were initially designed by Reardon et al. (1996) as part of the initial AW heat stress evaluation methodology. One aviator from each pair flew the Air Assault profile and the other aviator flew the MEDEVAC profile during all three test sessions.

During the UH-60 simulator sessions, the data acquisition system automatically collected flight performance data at a rate of 2 times per second. Table 2 indicates the flight related parameters which were tracked, along with their units of measurement. The script for the two simulator sorties are included in Appendix D.

Table 2.
Flight parameter units.

Airspeed	Knots
Altitude	Feet
Heading	degrees
Roll	degrees
Slip	degrees
Rate of climb	feet per minute
Rate of decent	feet per minute
Rate of turn	degrees per minute

A 10-minute set of standard flight maneuvers was flown every 30 minutes commencing at time zero in simulated instrument meteorological condition (IMC). The same set of maneuvers was repeated four times at specified locations during each 2-hour flight mission or eight times for the complete mission. The flight maneuvers were integrated into the scenario to minimize risk of simulator sickness from sudden discontinuities in the visual scenery. The purpose of interjecting the set of standard flight maneuvers during the flight session was to provide a systematic method for detecting changes in flight performance as a function of time.

Scores indicating how well the test subjects flew each maneuver were calculated in two steps. First, the scores for mean flight parameter errors for each maneuver were determined using the limits presented in Table 3. These are the score-related deviations from specified target criteria for the standard maneuvers. Second, the scores from each of the relevant error parameters were averaged into a single composite score for each maneuver. Similarly, an average flight performance score was obtained for each set of standard maneuvers and for the entire flight. Flight performance data were automatically scored by custom software on the USAARL simulator systems computer.

Table 3.
Scoring bands for flight performance deviations.

Maximum deviations for scores of:

Measure (units)	100	80	60	40	20	0
Heading (degrees)	1.0	2.0	4.0	8.0	16.0	>16.0
Altitude (feet)	8.8	17.5	35.0	70.0	140.0	>140.0
Airspeed (knots)	1.3	2.5	5.0	10.0	20.0	>20.0
Slip (ball widths)	0.0	0.1	0.2	0.4	0.8	>0.8
Roll (degrees)	0.8	1.5	3.0	6.0	12.0	>12.0
Vert. Speed (ft/m)	10.0	20.0	40.0	80.0	160.0	>160.0
Turn Rate (deg/s)	0.3	0.5	1.0	2.0	4.0	>4.0

Workload ratings

The NASA Task Load Index (TLX) questionnaire was developed by the Human Performance Research Groups at the NASA Ames Research Center (Hart and Staveland, 1988). It required subjective ratings, on a 0 – 10 Likert type scale, for mental demand, physical demand, temporal demand, performance, effort, and frustration level (Appendix E). This questionnaire was given at 30 minute intervals throughout testing. A research technician seated in the back of the simulator asked each aviator the questions and recorded the answers at the appropriate times as specified in the flight profiles.

Data analysis

Analysis consisted of basic descriptive statistics, bivariate correlations, and appropriate one way ANOVAs and associated post hoc methods. Paired t-tests were also used to compare results. The dependent variables (DVs) included physiological responses such as core and skin temperatures, heart rate, level of dehydration, and sweat rate; responses to mood and symptoms, comfort, and workload questionnaires; and composite flight performance scores. The principal independent or experimental variables included three distinct combinations of aviator ensemble (MOPP0, MOPP4 with MCU and MOPP4 without MCU), and environmental condition (cool or hot). Results are presented in descriptive, tabular, and graphical formats. There is one main factor or condition with three levels. These are abbreviated as CS for cool (70° F) condition with the MOPP0 Block I Air Warrior ensemble; CM for cool condition with the MOPP4 Block I Air Warrior Ensemble with the MCC vest but the MCC not turned on, and HM for hot (100° F) condition with the MOPP4 ensemble and functioning MCC system.

Results

Core temperature and heart rate

Mean test subject core temperature as a function of test condition and minutes into the test sessions are provided in Figure 2. These show a rapid increase in core temperature during the simulated preflight treadmill walk in the environmental chamber followed by a progressive decline after entering the simulator. Initial core temperature rise was greatest for the hot-MOPP4 (HM) condition, followed by the cool-MOPP4 (CM) condition and the least for the cool-MOPP0 or cool-standard (CS) condition. The peak mean core temperature did not exceed 99.8°F, and likewise, did not drop below 98°F for any of the test conditions. Mean core temperature in the HM condition was about 0.4°F higher than CM and about 0.6°F higher than CS. But again, the absolute increase was quite modest compared to the approved upper limit on the core temperature of 102.5°F. The three core temperature profiles indicate initial body heat accumulation with subsequent passive or active dissipation. The latter, of course, associated with MCU use in the HM condition.

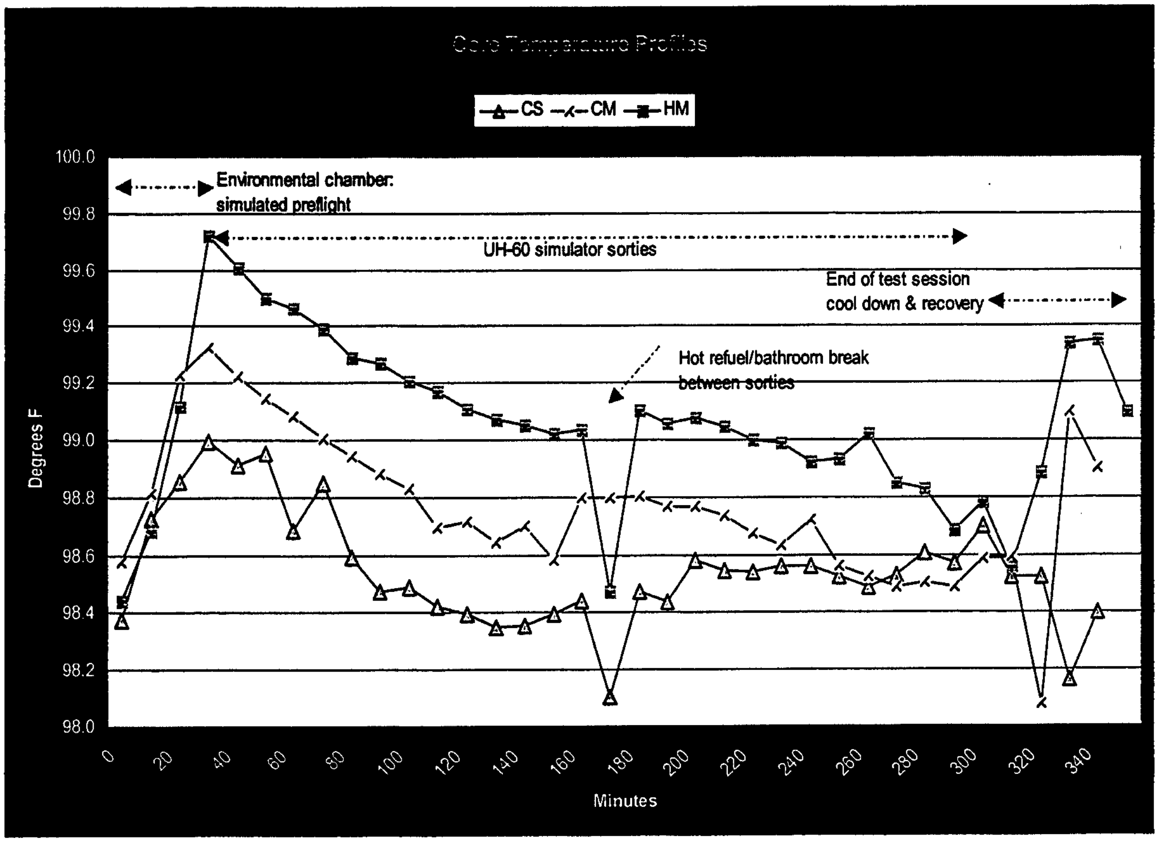


Figure 2. Core temperature responses across sessions.

Tables 4 and 5 show that core temperature rose rapidly for all conditions during the simulated preflight treadmill. However, per repeated measures ANOVA, the rate of increase was statistically greater for the HM versus CS and CM conditions which were not statistically different from each other. These results reflected the excess metabolic heat associated with the greater weight and less favorable heat transfer properties of the HM ensemble and microclimate cooling garment system which was not active during this phase of testing.

Table 4.
Preflight core temperature change (degrees F/hour).

	Mean	Std. Deviation	N
Preflight Core Temp Change - CS	1.20	0.58	7
Preflight Core Temp Change - CM	1.39	1.04	7
Preflight Core Temp Change - HM	2.31	0.75	7

Table 5.
Pairwise comparisons preflight core temperature change (degrees F/hour).

Test Condition	Test Condition	Mean Difference (I-J)	Std. Error	Sig. [a]	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
CS	CM	-.194	.435	1.000	-1.622	1.235
	HM	-1.107	.356	.062	-2.277	6.260E-02
CM	CS	.194	.435	1.000	-1.235	1.622
	HM	-.914 *	.210	.015	-1.605	-.222
HM	CS	1.107	.356	.062	-6.26E-02	2.277
	CM	.914 *	.210	.015	.222	1.605

Based on estimated marginal

*. The mean difference is significant at the .05 level.
a. Adjustment for multiple comparisons: Bonferroni.

Tables 6 and 7 and Figure 3 indicate, however, after entering the simulator, core temperature suddenly stopped rising and actually decreased in an approximately linear manner for all ensembles/conditions. Despite the continuing ambient heat load in the simulator for the HM condition, the MCC system was responsible for a negative core temperature rate that, as indicated in the ANOVA results below, did not differ from core temperature decrease rates in the cooler conditions. This is significant because, as other similar studies have demonstrated, without MCC, the core temperature rate in the simulator for the HM condition would have been positive rather than negative.

Table 6.
Flight core temperature change (degrees F/hour).

	Mean	Std. Deviation	N
Flight Core Temp Change - CS	-.065	.133	8
Flight Core Temp Change - CM	-.165	.106	8
Flight Core Temp Change - HM	-.209	.192	8

Table 7.
Pairwise comparisons flight core temperature change (degrees F/hour).

Test Condition	Test Condition	Mean Difference (I-J)	Std. Error	Sig. [a]	95% Confidence Interval for Difference Lower Bound	Upper Bound
CS	CM	.100 *	.026	.017	.020	.180
	HM	.144	.075	.291	-.091	.379
CM	CS	-.100 *	.026	.017	-.180	-.020
	HM	.044	.061	1.000	-.147	.235
HM	CS	-.144	.075	.291	-.379	.091
	CM	-.044	.061	1.000	-.235	.147

Based on estimated marginal

*. The mean difference is significant at the .05.

a. Adjustment for multiple comparisons: Bonferroni.

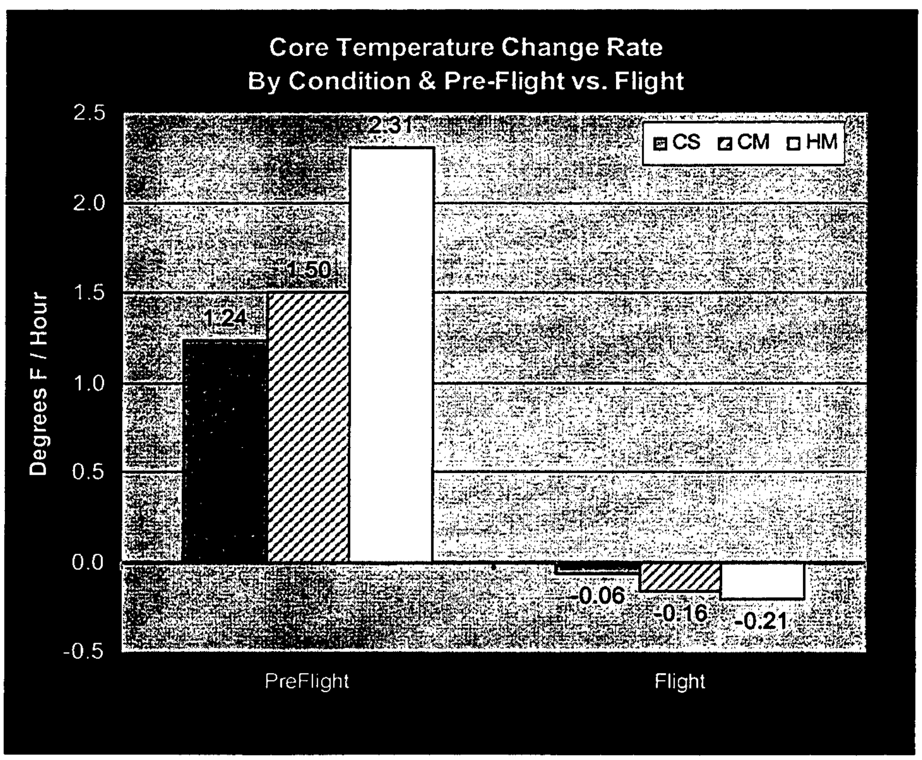


Figure 3. Core temperature change by condition.

The corresponding heart rate profiles for the three different test sessions are included in Figure 4. This shows a rapid spike in heart rate during the treadmill simulated preflight segment in the environmental chamber with a rapid decrease after the test subjects settled into the simulator and a subsequent continuing heart rate decrease during the simulated sorties. As with core temperature, mean heart rate for the HM condition in the simulator remained higher than for the CM condition by about 5 beats per minute. Although heart rate for the CM condition in the simulator was initially somewhat greater than for the CS condition, this difference converged after about 2 hours. Maximum mean heart rate response during the simulated preflight treadmill walk was about 115 beats per minute for both the MOPP4 configurations but less than 100 for the MOPP0 configuration. The heart rate profiles are consistent with a heavier workload during the simulated preflight treadmill walk due to the extra weight of the MOPP4 ensemble in HM and CM configurations and effects of encumbrance and heat stress in the simulator for the CM and HM conditions.

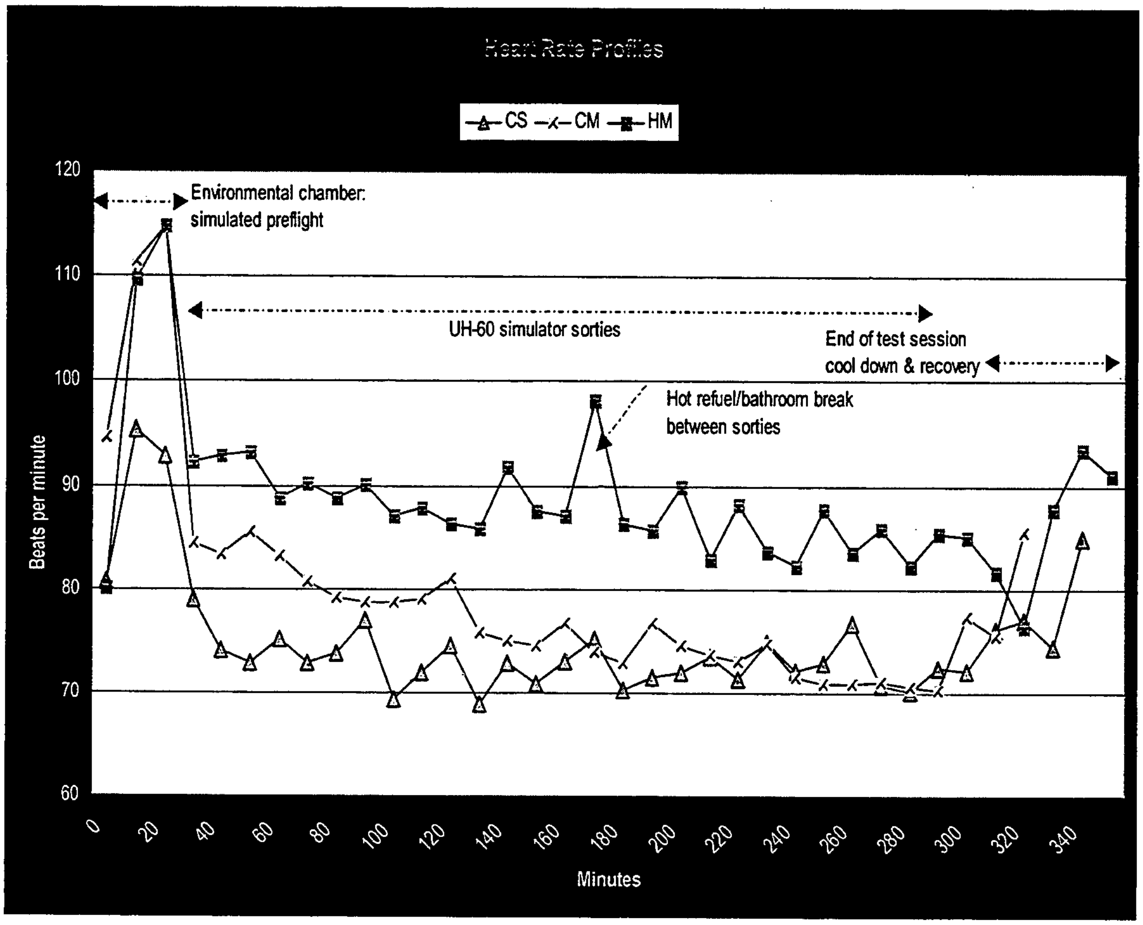


Figure 4. Heart rate response profiles.

Tables 8 and 9 and Figure 5 demonstrate similar patterns for heart rate for the preflight treadmill walk across the three conditions. Again, the preflight heart rate increase rate for the CS condition reflected baseline cardiovascular strain for test subjects in the MOPP0 unencumbered aviator ensemble walking 3 mph at 0% grade in an essentially thermo-neutral environment, therefore, the heart rate increase reflected the baseline mechanical workload. The incremental increase in heart rate slope for the CM condition reflects the additional cardiovascular stress from the greater weight and encumbrance of the MOPP4 ensemble and a modest amount of heat strain due to reduced heat dissipation through the thicker and greater number of clothing and equipment layers. And, the further increase in rate for the HM largely reflects the additional cardiovascular strain from the ambient hot temperature where the MCC system has not yet been turned on.

Table 8.
Preflight heart rate change (BPM/hour).

	Mean	Std. Deviation	N
Preflight Heart Rate Change - CS	23.88	26.85	8
Preflight Heart Rate Change - CM	40.25	33.75	8
Preflight Heart Rate Change - HM	60.50	41.07	8

Table 9.
Pairwise comparisons preflight heart rate change.

Test Condition	Test Condition	Mean Difference (I-J)	Std. Error	Sig. a	95% Confidence Interval for Difference* Lower Bound	95% Confidence Interval for Difference* Upper Bound
CS	CM	-16.38	13.76	.82	-59.41	26.66
	HM	-36.63	20.67	.36	-101.28	28.03
CM	CS	16.38	13.76	.82	-26.66	59.41
	HM	-20.25	17.12	.83	-73.79	33.29
HM	CS	36.63	20.67	.36	-28.03	101.28
	CM	20.25	17.12	.83	-33.29	73.79

Based on estimated marginal

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparison: Bonferroni.

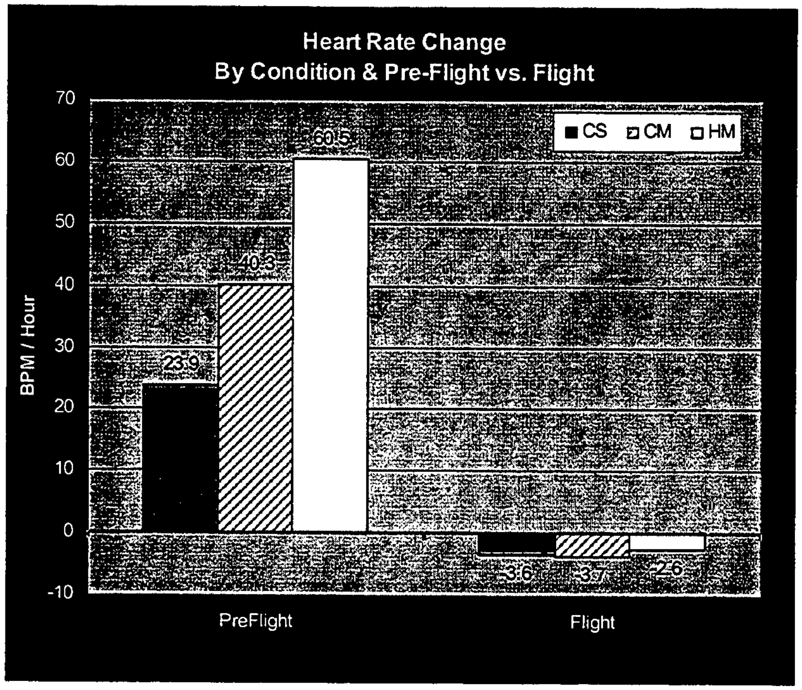


Figure 5. Heart rate change by condition.

Much like core temperature, heart rate in the simulator for all three conditions decreased at the linear rate depicted. The significant point, again, is that were it not for the active MCC in the simulator, one would expect heart rate slope to have been positive in the simulator for the HM condition, although certainly not as much as during the preflight session since the sedentary activity in the simulator resulted in less metabolic heat added to the absorbed ambient heat load.

For heart rate slopes across the different test conditions, repeated measures ANOVA results showed that heart rate increase rates statistically differed across the three conditions (Tables 10 and 11) for the simulated preflight sessions, but not in the simulator. The significant observation for these data is that the active MCC system in the HM condition allowed progressive decrease in heart rate at the same rate as occurred in the cooler conditions rather than incurring an increase as would be expected based on results of previous similar studies.

Table 10.
Flight heart rate change (BPM/hour).

	Mean	Std. Deviation	N
Flight HR Change - CS	-3.561	7.061	8
Flight HR Change - CM	-3.739	5.652	8
Flight HR Change - HM	-2.603	3.382	8

Table 11.
Pairwise comparisons flight heart rate change.

Test Condition	Test Condition	Mean Difference (I-J)	Std. Error	Sig. [a]	95% Confidence Interval for Difference*	
					Lower Bound	Upper Bound
CS	CM	.18	3.28	1.00	-10.07	10.42
	HM	-.96	3.37	1.00	-11.51	9.59
CM	CS	-.18	3.28	1.00	-10.42	10.07
	HM	-1.14	2.63	1.00	-9.36	7.09
HM	CS	.96	3.37	1.00	-9.59	11.51
	CM	1.14	2.63	1.00	-7.09	9.36

Based on estimated marginal means
*. The mean difference is significant at the .05 level.
a. Adjustment for multiple comparisons: Bonferroni.

Dehydration and sweat rates

The next results (Figures 6 and 7, and Tables 12 and 13) summarize the findings for test subject fluid and hydration status for the three test conditions. These reflect the general interest in comparing effects on conditions and ensembles on net fluid balance as reflected in calculated levels of dehydration. This provides an estimate of likelihood of psychophysiological and performance impairment which occurs when dehydration levels exceed 1-2%. Related fluid balance measures, however, such as fluid intake and urine output, are also important for generating operationally feasible fluid intake and voiding recommendations. Although a seemingly mundane issue, it is clear that a full bladder is uncomfortable and can be a significant distracter that must be alleviated with appropriate measures that do not interfere with or delay mission plans. Likewise, lack of realistic voiding measures may lead to self-imposed restriction on fluid intake. Figure 6 shows that mean percent dehydration was greatest for the HM condition despite the use of the cooling vest. This is not entirely unexpected since the vest covered only the thorax, thereby allowing the remainder of surfaces to be directly stimulated to sweat from the local effects on the skin of the hot environmental temperature and relatively high humidity.

The fluid deficit rates were 303, 200, and 132 cc/hr for HM, CM, and CS conditions, respectively. To have remained euhydrated (i.e., zero percent dehydration) the test subjects should have imbibed 650, 435, and 350 cc/hr for the HM, CM, and CS conditions, respectively. These are feasible intake and gastrointestinal absorption rates (15-20 cc/minute or 0.9 –1.2 liters per hour) even with fluid intake largely occurring in the HM and CM conditions via the protective mask drinking tube. As a reminder, in this study, fluid intake was self-regulated by the test subjects.

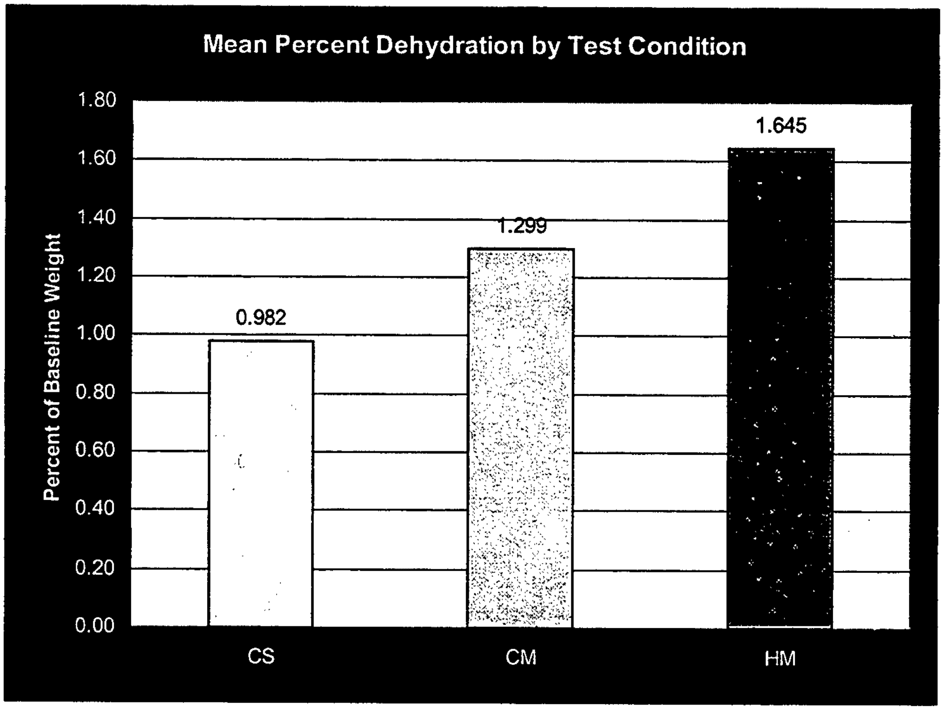


Figure 6. Percent dehydration.

Tables 12 and 13 show the differences in mean end-session dehydration as a percent of initial nude body weight across the three test conditions. Dehydration levels increased from the CS baseline with the additional weight and encumbrance of the MOPP4 ensemble as reflected in the incremental increase for CM and further for HM reflecting the increased sweat losses associated with the environmental heat strain in the HM condition that was not fully negated by the MCC system. It is apparent, based on the core temperature and heart rate data described above, that the MCC system augmented the cooling from evaporated sweat to reduce cardiovascular and thermal strain to that incurred in the cooler conditions.

Table 12.
Percent dehydration.

	Mean	Std. Deviation	N
% Dehydrated - CS	.8738	.2237	6
% Dehydrated - CM	1.2664	.5185	6
% Dehydrated - HM	1.6448	.4366	6

Means from the associated repeated measures ANOVA (Table 12) are slightly different due to case-wise deletion of records because of several missing values due to technical problems during weight and fluid measurements but the pattern is the same, and results confirm that they were all statistically different from each other.

Table 13.
Pairwise comparisons percent dehydration.

Test Condition	Test Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference*	
					Lower Bound	Upper Bound
CS	CM	-.393	.196	.303	-1.084	.299
	HM	-.771 *	.179	.023	-1.402	-.140
CM	CS	.393	.196	.303	-.299	1.084
	HM	-.378 *	.080	.016	-.661	-.096
HM	CS	.771 *	.179	.023	.140	1.402
	CM	.378 *	.080	.016	.096	.661

Based on estimated marginal means

*. The mean difference is significant at the .05

a. Adjustment for multiple comparisons: Bonferroni.

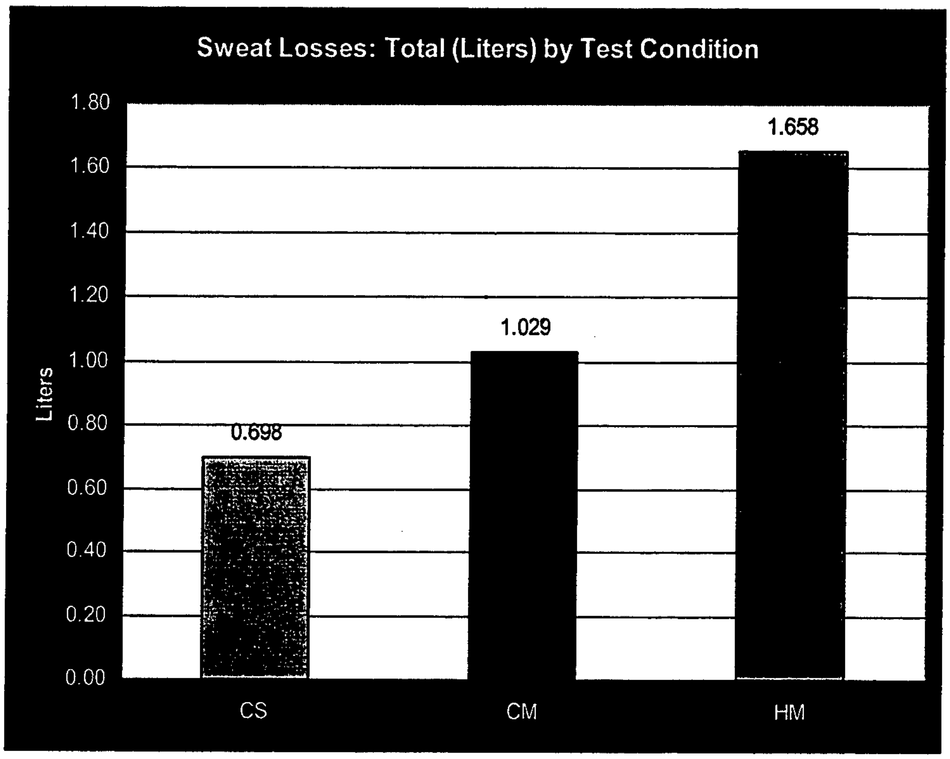


Figure 7. Sweat losses.

The measured sweat losses for each condition are indicated in Figure 7. These correspond closely to the levels of dehydration. It is interesting to note that by comparing values for the CS and CM conditions, it is apparent that the MOPP4 ensemble alone was associated with more than doubling (2.375 times) the sweat loss compared to the MOPP0 ensemble in the 70°F or "cool" temperature condition and was 1.61 times the total sweat loss in the MOPP4 70°F condition. However, when averaged over the approximately 5.5 hour duration of the test sessions, the hourly sweat rates are on the order of 300 cc for the HM condition and less for the other conditions. This compares to maximum possible sweat rates of several liters per hour. Again indicating that incurred heat stress was well within the physiological compensable range.

Mean total fluid intake for the three test conditions are depicted in Figure 8. Total fluid intake of 1.902 liters in the HM condition was 1.64 times or 64% greater than for the baseline CS condition and 1.567 or 57% greater that the CM condition.

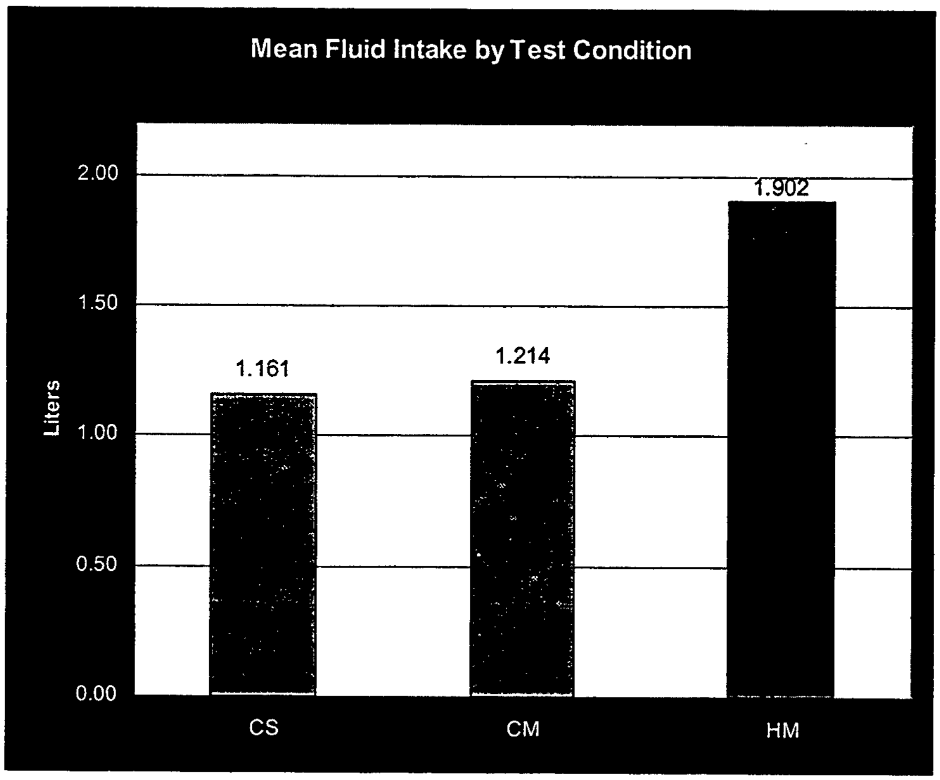


Figure 8. Mean total fluid intake by test conditions.

Figure 9 shows that mean total urine output across the three conditions did not differ. Although the urine output was moderate, it was sufficient to potentially require the need for a brief stop or in-flight voiding to relieve this potential distracter.

Figure 10 summarizes the fluid intake and output rates in milliliters per hour. Note that many of these rates are substantially less than previous similar studies that included test session in the hot condition without MCC.

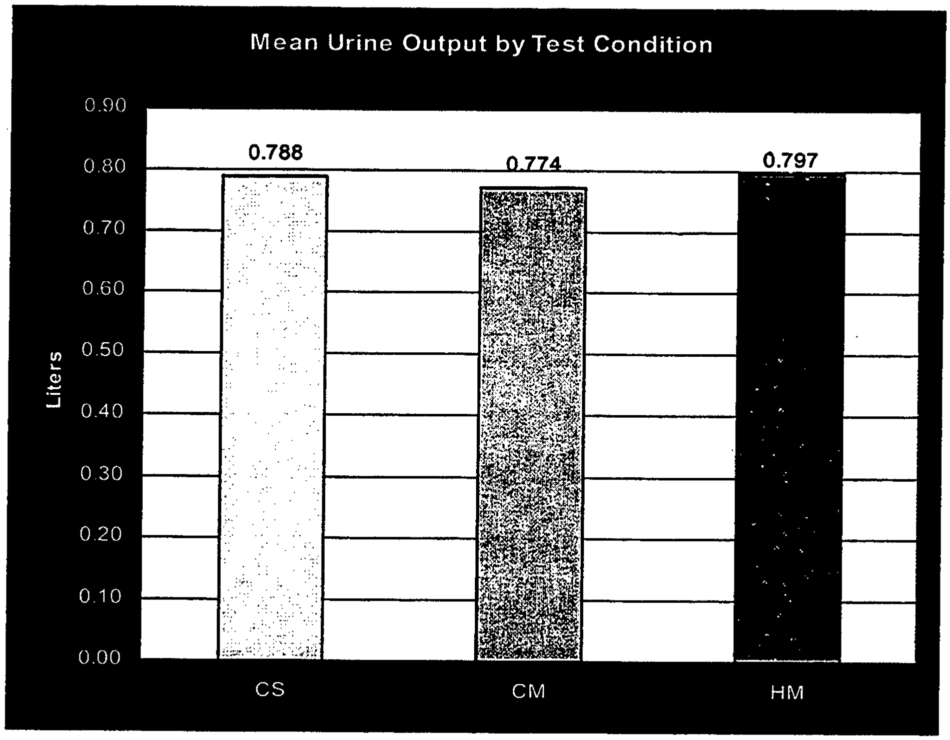


Figure 9. Mean total urine output by test condition.

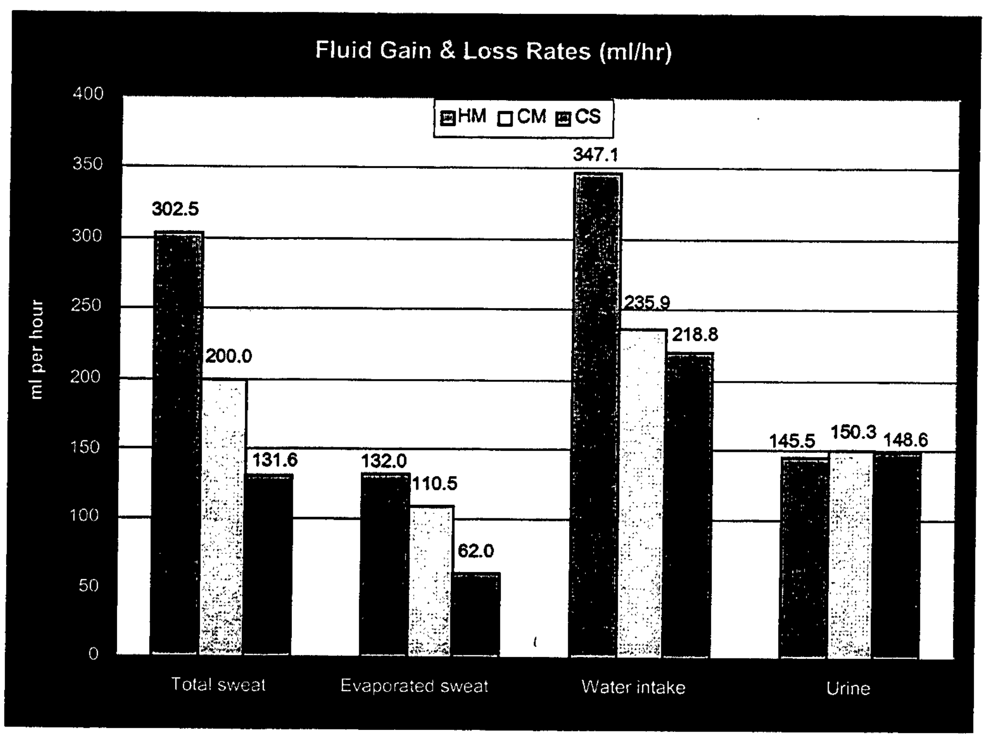


Figure 10. Summary of fluid gain and loss rates.

Total fluid deficits in liters for the duration of each condition are shown in Figure 11. It is obvious that the mean fluid losses follow the same pattern and relative differences across test conditions as the total sweat losses. From these data, the estimated amount of total fluid intake to maintain euhydration (i.e., zero percent dehydration) would have been the sum of fluid deficit and actual fluid intake or 1.859, 2.243, and 3.559 liters for the CS, CM, and HM conditions, respectively. This is equivalent to fluid intake rates of 0.350, 0.436, and 0.650 liters per hour necessary to maintain euhydration.

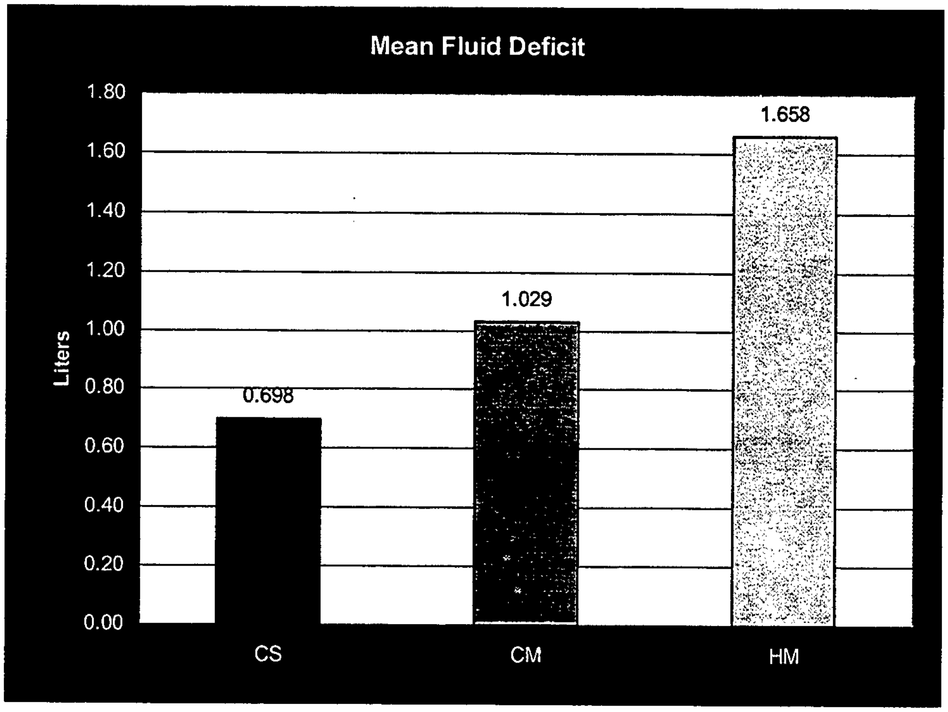


Figure 11. Mean overall fluid deficits.

Since the principle role of sweat is to cool the body surface, it is important to consider the proportion of sweat that is evaporated versus retained in the uniform. The latter occurs when sweat is trapped in the layers of clothing, either due to thickness and absorbency or pools within dependent impermeable ensemble components such a butyl rubber overboots, gloves, and mask. Unevaporated sweat contributes to dehydration without the benefit of cooling. Figure 12 shows the relative proportion of sweat evaporated versus retained. The proportion of retained sweat was greater for the MOPP4 condition.

Figure 13 shows estimated total cooling from sweat evaporation, the additional cooling from the MCC system in the HM condition, as well as unrealized or potential cooling from unevaporated sweat. Total heat extraction or cooling for the MCC system significantly augmented the cooling from evaporated sweat and more than fully compensated for the lost cooling from unevaporated sweat.

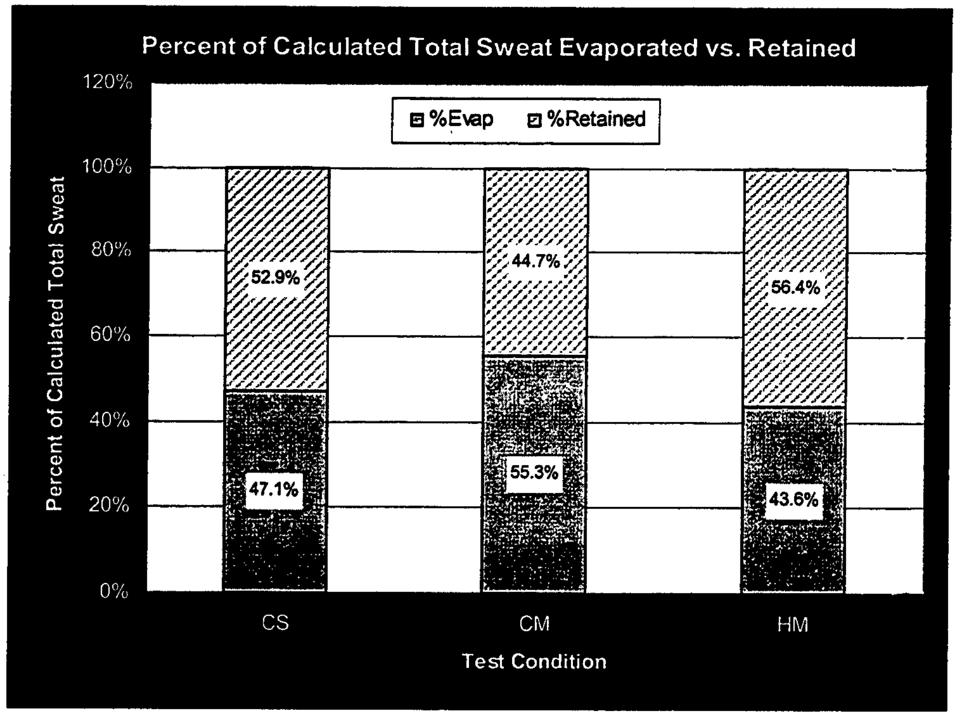


Figure 12. Percent of total sweat evaporated vs. retained in ensemble.

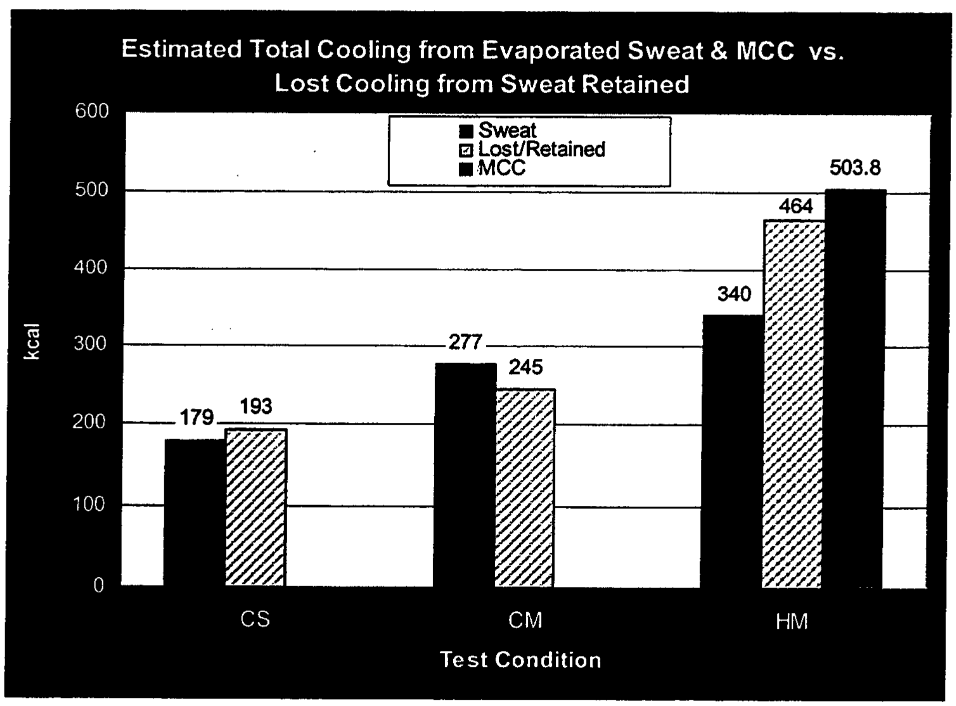


Figure 13. Cooling from sweat and MCC system and lost cooling from retained sweat.

Skin temperatures

Skin temperature profiles across the three test conditions are illustrated in the following plots (Figures 14 through 17). The expected patterns are generally observed, i.e., chest temperature is highest with lower temperatures as a function of distance from the heart and central vessels in the chest.

Figure 14 clearly demonstrates the progressive decrease in chest surface temperature due to the MCC vest. Chest temperature began to fall slightly below normal, i.e., 97 degrees, beyond 120 minutes into the sorties. This created a favorable core to chest surface temperature gradient for heat dissipation into the circulating coolant in the vest. Figure 15 shows the incremental effect of MOPP4 on heat stress on the arms for the CM condition with additional regional heat stress from the external heat load in the HM condition. Thigh surface temperature was not as affected by MOPP4 as by the heat stressful condition, whereas the lower leg effects mirrored those of the arm as shown in Figure 17.

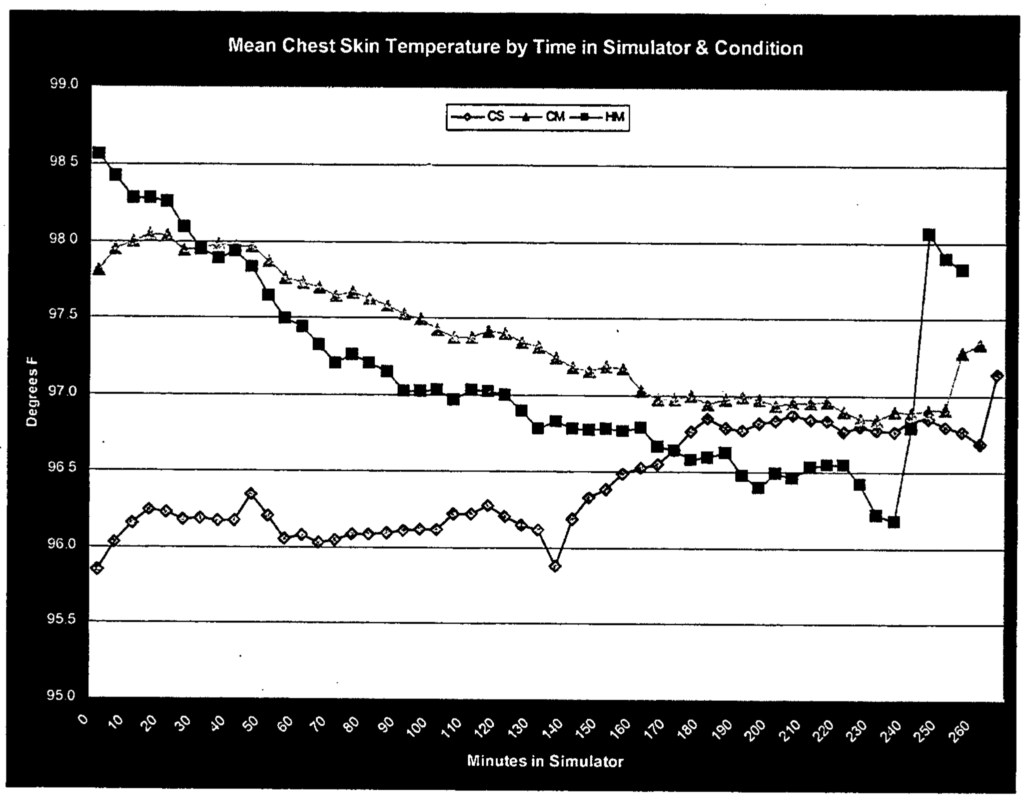


Figure 14. Chest skin temperature by time and condition.

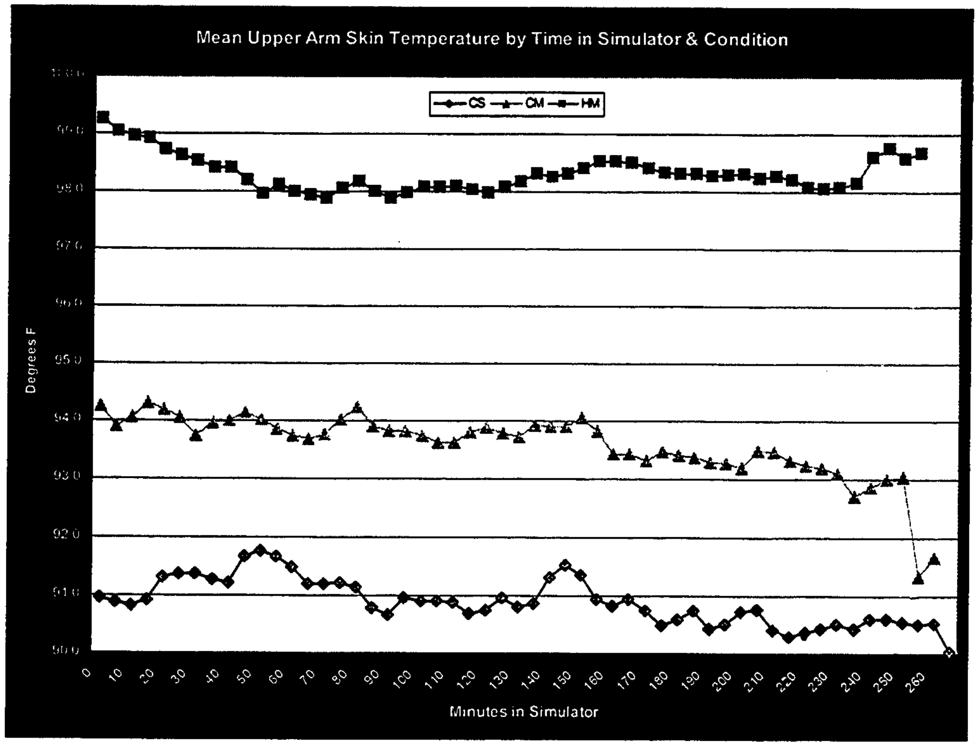


Figure 15. Arm skin temperature by time and condition.

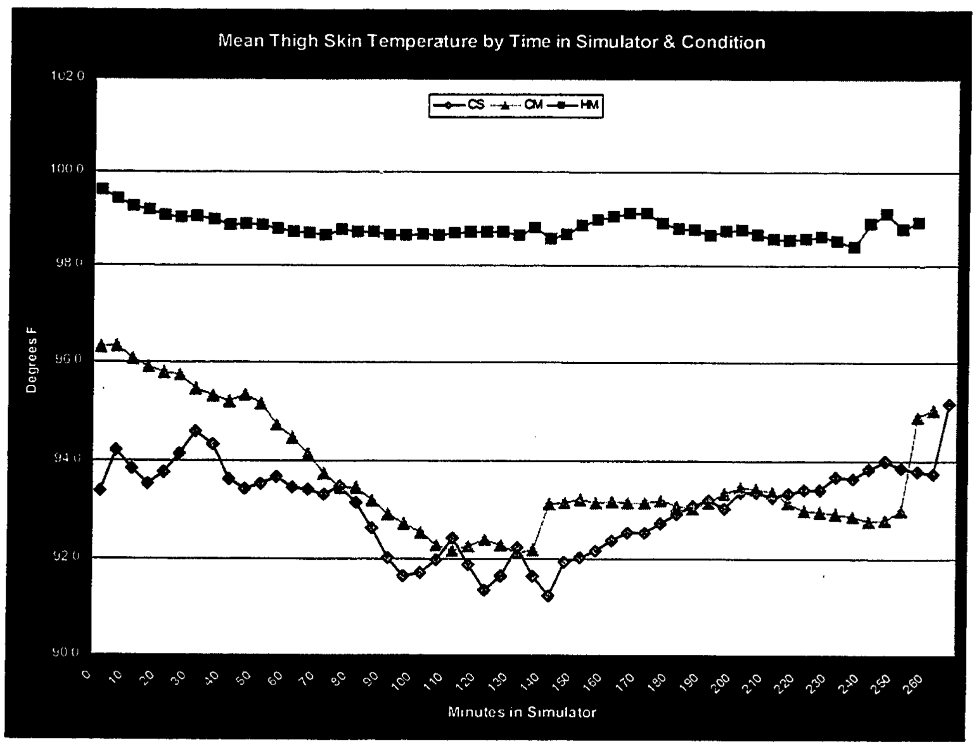


Figure 16. Thigh skin temperature by time and condition.

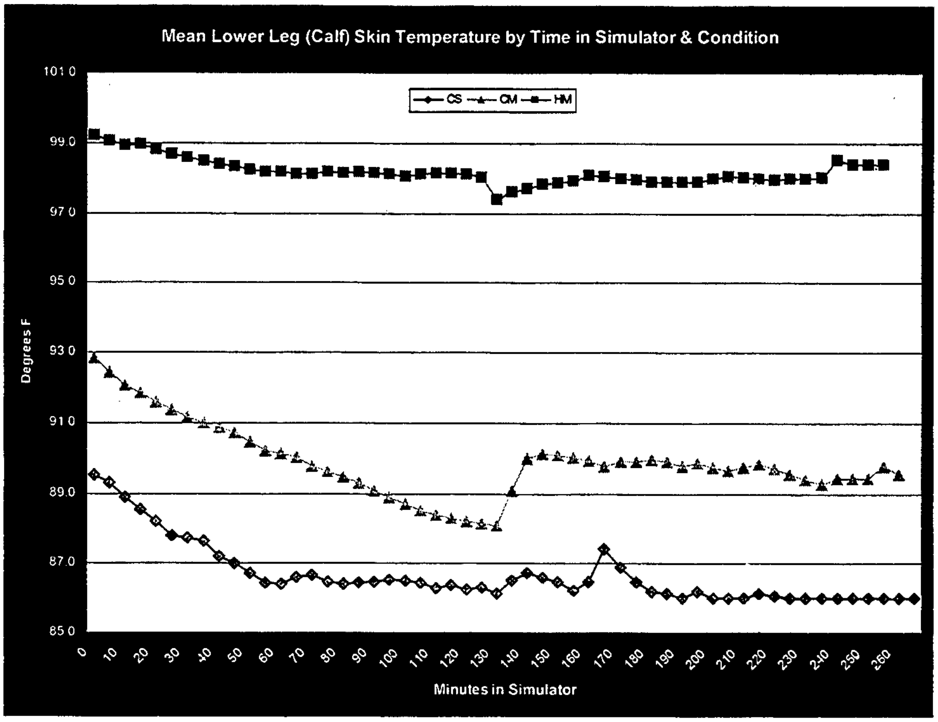


Figure 17. Lower leg skin temperature by time and condition.

Task load responses

Test subjects were also administered a task load questionnaire after each set of standard maneuvers. Response means are depicted in Figure 18 below.

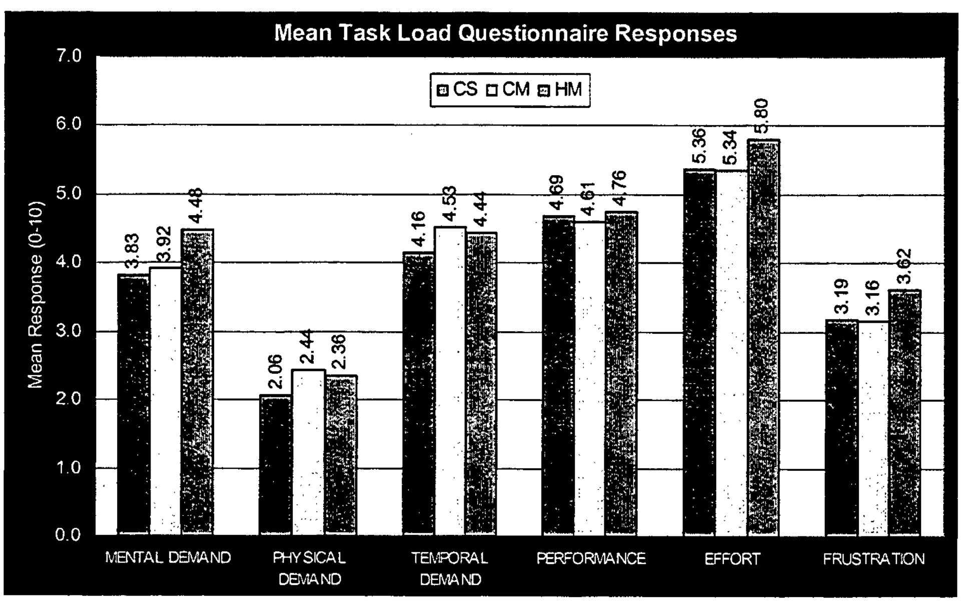
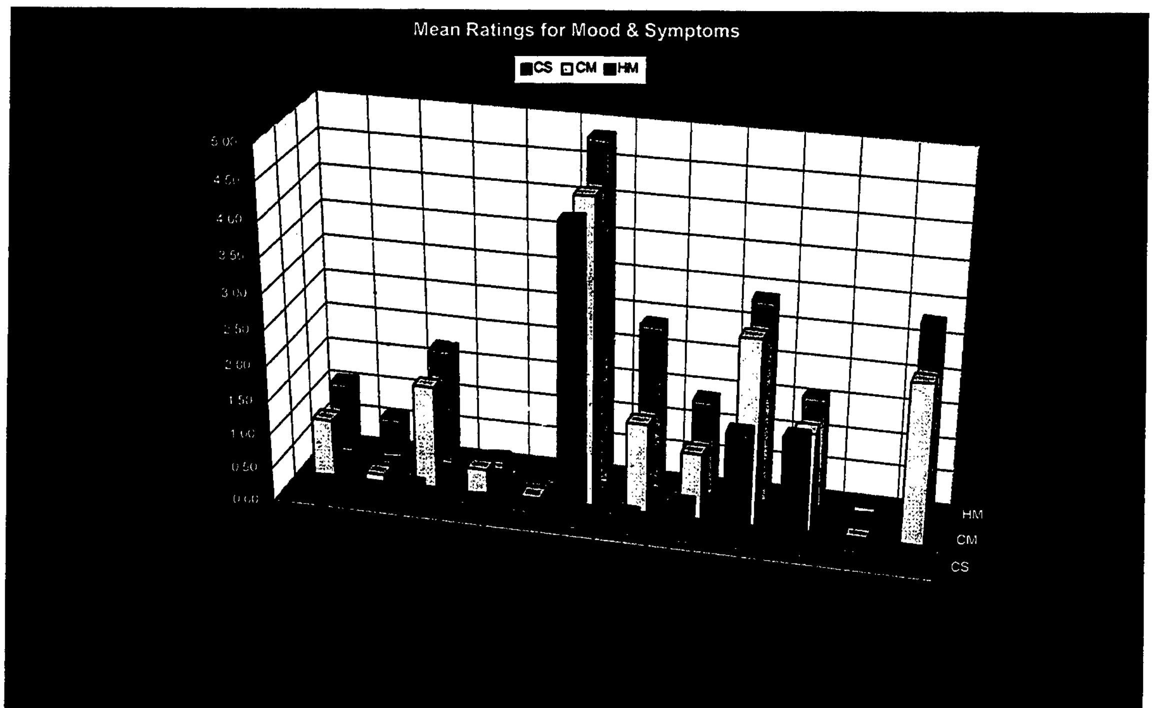


Figure 18. Task load questionnaire responses.

Mean responses on the task load questionnaire were similar across conditions except for increased ratings in the HM condition for mental demand, effort, and frustration. Although subjective flight performance was similar across conditions, composite scores as previously discussed were in fact lower for the CM and HM conditions, indicating that subjective judgment regarding flight performance was inaccurate.

Mood and symptom ratings

Figure 19 summarizes mean ratings for the mood and symptoms questionnaires that were periodically administered to the volunteer aviators during all test sessions. Most notably, ratings were higher for heat stress, total stress, headache, thirst, workload, and visual difficulty for the CM and HM conditions compared to the CS condition.

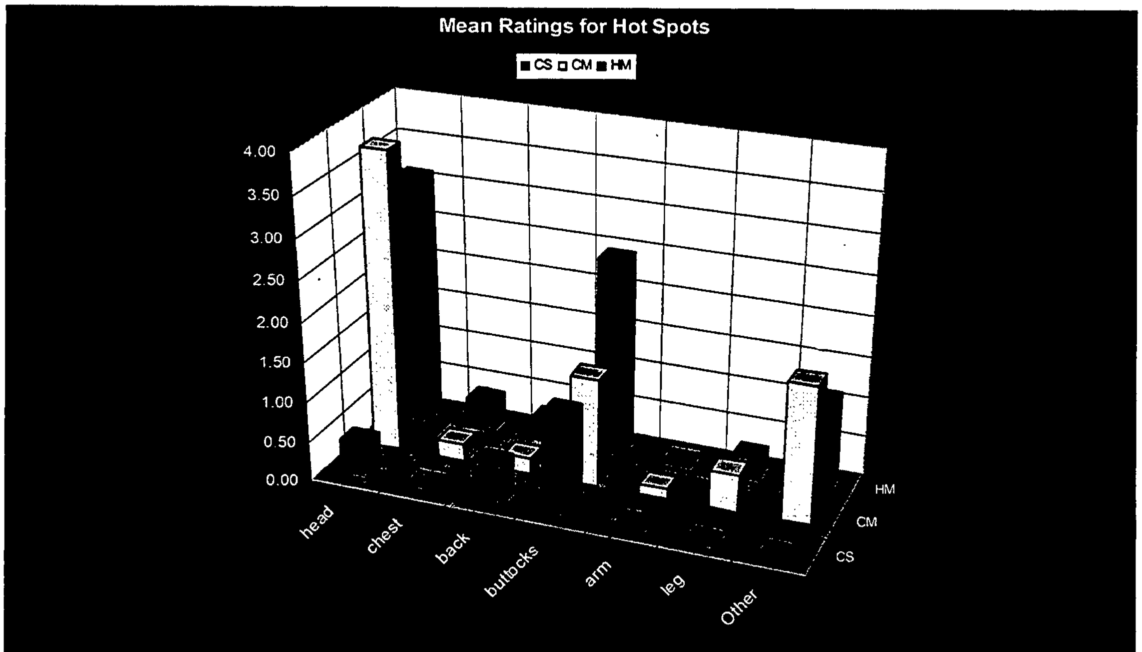


	HEADACHE	NAUSEA	STRESS	ANGER	DEPRESSION	ENERGY	HEAT STRESS	THIRST	WORKLOAD	BOREDOM	DIZZINESS	VISUAL DIFFICULTY
CS	0.17	0.00	0.35	0.02	0.00	4.29	0.30	0.55	1.69	1.71	0.00	0.00
CM	0.84	0.10	1.50	0.35	0.03	4.36	1.32	0.95	2.69	1.45	0.00	2.33
HM	1.05	0.60	1.72	0.15	0.01	4.87	2.39	1.39	2.89	1.61	0.08	2.80

Figure 19. Mood and symptoms ratings.

Hot-spot ratings

Test subjects were periodically administered a short questionnaire regarding hot spots which was intended to mean pressure points or areas of discomfort due to pressure of the helmet or other ensemble components. Mean responses across the test conditions are shown in Figure 20. The high ratings for headache were largely related to hot spots or pressure discomfort points or areas due to mask and helmet fit in the MOPP4 configuration. This was a significant problem for several of the test subjects and required individualized readjustment of their helmets and helmet liners between sorties. The more symptomatic initially had prominent forehead pressure marks that were relieved with helmet refitting. Relatively high hot spot ratings also occurred for the buttocks, even in MOPP0. This was presumably due to the long duration of the simulator sessions exacerbated in the MOPP4 configurations by the greater weight of the additional uniform components. The MCC vest was associated with only minimal chest hot spot ratings indicating that it was well tolerated in that respect.



	head	chest	back	buttocks	arm	leg	Other
CS	0.47	0.05	0.51	1.30	0.04	0.00	0.00
CM	3.75	0.22	0.20	1.35	0.13	0.47	1.73
HM	3.12	0.39	0.28	2.47	0.01	0.27	1.14

Figure 20. Hot-spot ratings.

Cooling vest

Effectiveness ratings

During the HM condition, test subjects also periodically rated the perceived cooling effectiveness of the MCU vest during the simulator sorties. Mean ratings by test subject for that condition are provided in Figure 21. Except for test subjects 3 and 4 (crew 2), ratings were near 8 out of a maximum rating of 10. The mean rating was 7.33, indicating a high level of perceived MCU vest effectiveness correlating with the salutary measured effects on core temperature and heart rate as discussed above.

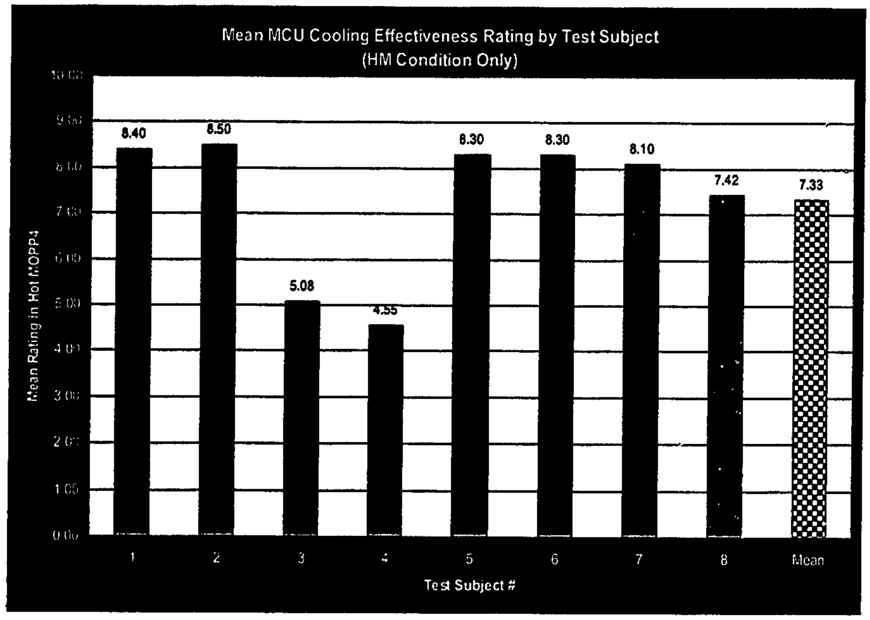


Figure 21. Cooling vest effectiveness ratings.

<u>Cooling vest heat extraction values</u>

Figure 22 shows the corresponding mean cooling rate provided by the cooling vest for the test subjects. The overall mean cooling rate was 134.7 watts. Although not measured, the light physical activity while flying or navigating in the simulator would be expected to generate somewhat less than 100 watts metabolic heat, thereby explaining the effectiveness of the cooling vest in lowering the core temperature.

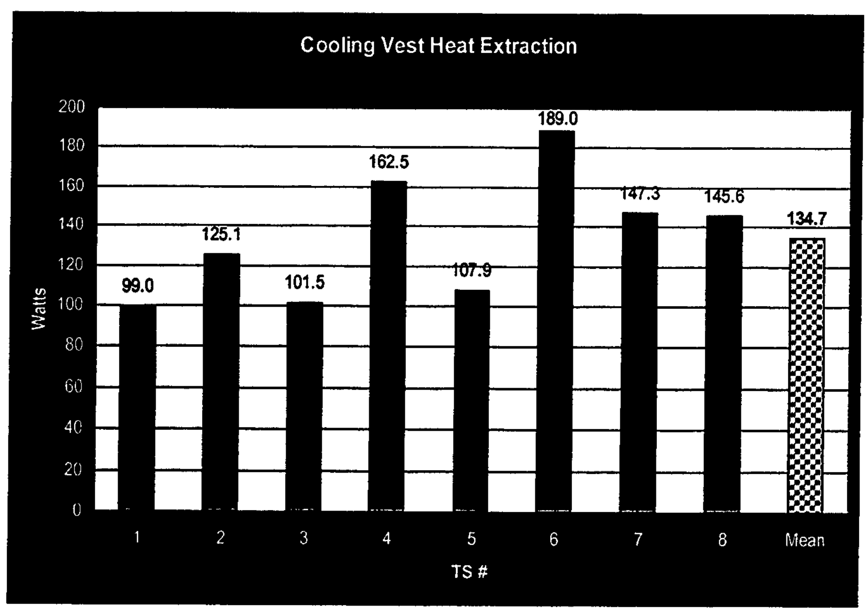


Figure 22. Cooling vest heat extraction by test subject.

Flight performance scores

Effects of the different test conditions on a composite measure of flight performance are indicated in Figure 23 and show a modest decrement due to MOPP4 when comparing CM versus baseline CS configurations. The small incremental decrement between HM and CM is also depicted but was not statistically significant, indicating that flight performance was affected primarily by the MOPP4 encumbrance and that the MCC essentially prevented additional flight performance decrement due to environmental heat stress. Factors associated with the MOPP4 configuration that could have affected flight performance associated with the general encumbrance include reduced agility with the controls and fine control adjustments, increased fatigue and discomfort due the weight and thickness of the ensemble, difficulty maintaining preferred hand and arm position with respect to the cyclic, and impaired fields of view and visual cues due to effects of the protective mask.

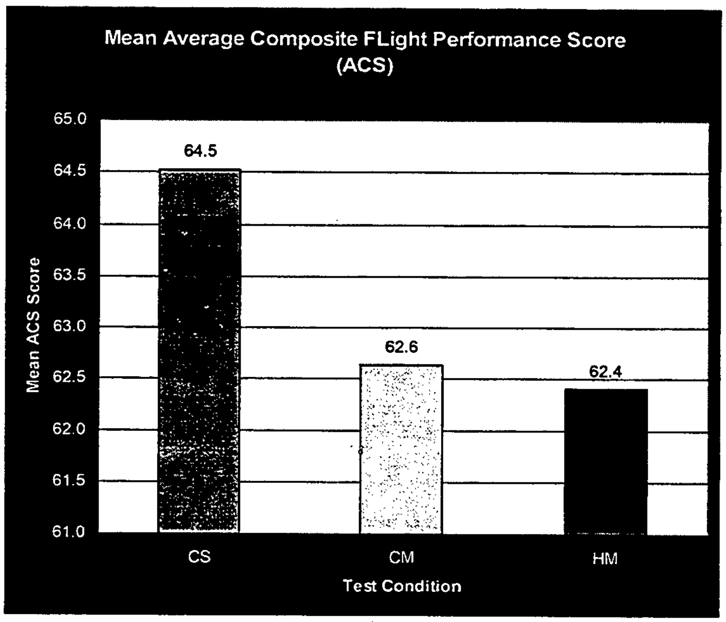


Figure 23. Flight performance scores.

Overall performance rankings

Various measures were aggregated (Table 14) to determine relative performance rankings to compare the overall effect of the three test conditions. The lower the ranking value (1 to 3), the more favorable the response in the sense of less physiological or psychological strain and/or better performance. Paired t-tests indicated that the mutual differences were statistically significant ($p \leq 0.05$), indicating that the test subjects in the CS condition incurred less psycho-physiological strain and had better performance than in the CM and HM conditions. The rankings for the latter two conditions are substantially lower than similar rankings in previous studies for hot-MOPP4 conditions without MCC. These results are depicted in Figure 24.

Table 14.
Overall performance rankings.

		N	Means Test Conditions CS	CM	HM	Pairwise Contrasts p-values CS vs CM	CS vs HM	CM vs HM	Performance Rankings Test Conditions CS	CM	HM
	Endurance**	4	288	279	299	0.269	0.156	0.098	1	1	1
	End Pre-flight HR	7	90.9	117.7	114.7	0.003*	0.056	0.776	1	2	2
	End simulator HR	8	71.0	74.0	85.1	0.493	0.009*	0.006*	1	1	2
	Core temp (simulated pre-flight)	8	99.0	99.3	99.7	0.019*	0.003*	0.075	1	2	2
	Core temp (UhH-60 simulator)	8	98.7	98.6	98.8	0.511	0.721	0.091	1	1	1
Symptoms	Headache	8	0.17	0.84	1.05	0.028*	0.028*	0.605	1	2	2
	Nausea	8	0.00	0.10	0.60	0.180	0.034*	0.042*	1	1	2
	Stress	8	0.35	1.50	1.72	0.008*	0.008*	0.548	1	2	2
	Anger	8	0.02	0.35	0.15	0.292	0.395	0.587	1	1	1
	Depression	8	0.00	0.03	0.01	0.351	0.351	0.651	1	1	1
	Energy	8	4.29	4.36	4.87	0.909	0.351	0.377	1	1	1
	Heat stress	8	0.30	1.32	2.39	0.006*	0.000*	0.045*	1	2	3
	Thirst	8	0.55	0.95	1.39	0.070	0.074	0.367	1	1	1
	Workload	8	1.69	2.69	2.89	0.030*	0.011*	0.592	1	2	2
	Boredom	8	1.71	1.45	1.61	0.592	0.731	0.815	1	1	1
	Dizziness	8	0.00	0.00	0.08	0.282	0.282	0.282	1	1	1
	Visual difficulty	8	0.00	2.33	2.80	0.001*	0.001*	0.529	1	2	2
Hot Spots	Head	8	0.47	3.75	3.12	0.006*	0.005*	0.516	1	2	2
	Chest	8	0.05	0.22	0.39	0.299	0.206	0.594	1	1	1
	Back	8	0.51	0.20	0.28	0.472	0.302	0.705	1	1	1
	Buttocks	8	1.30	1.35	2.47	0.885	0.001*	0.039*	1	1	2
	Arm	8	0.04	0.13	0.01	0.563	0.504	0.397	1	1	1
	Leg	8	0.00	0.47	0.27	0.069	0.032*	0.490	1	2	2
	Other	8	0.00	1.73	1.14	0.019*	0.069	0.295	1	2	2
	% Dehydrated	6	0.87	1.26	1.64	0.101	0.008*	0.005*	1	1	2
	Flight Performance Score (ACS)	8	64.52	62.64	62.41	0.013*	0.044*	0.843	1	2	2
					Mean rankings -->	0.000*	0.000*	0.022*	1.00	1.42	1.62

** mins in sim; all crews completed test sessions as scheduled

* statistically significant difference at $p \leq 0.05$

Rankings: 1=best 3=worst

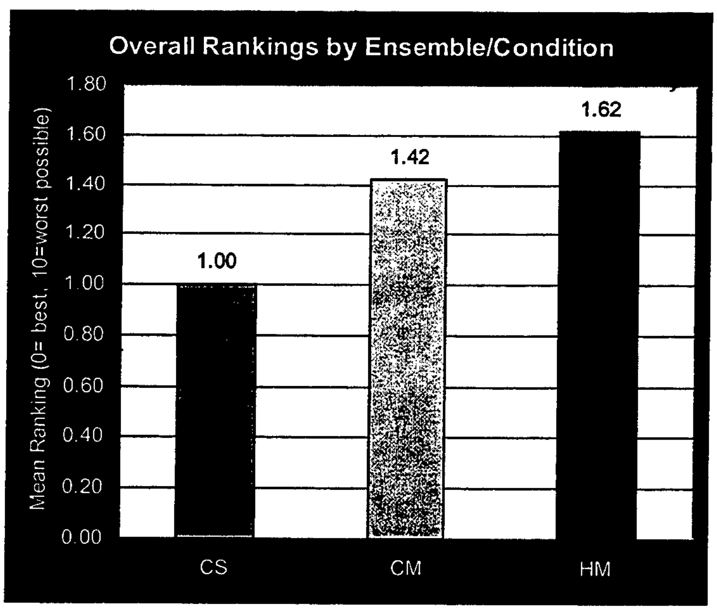


Figure 24. Overall performance (flight, symptoms, comfort, hydration) rankings.

Summary and conclusions

The results from this USAARL UH-60 simulator heat stress study (test and evaluation) indicate that the MCU cooling vest system as installed and worn in the UH-60 simulator was effective in progressively reducing initially elevated core temperature and heart rate in a hot humid condition. The MCU vest was generally given high ratings for cooling effectiveness and did not elicit significant hot-spot ratings indicating a good level of comfort or tolerance. Perhaps the most interesting results were that the MCU vest, although effective in reducing heart rate and core temperature, did not entirely prevent sweating or somewhat greater dehydration compared to the cooler condition, and likewise, did not entirely suppress somewhat elevated heat stress and overall stress ratings in the hot encumbered condition. Additionally, average composite flight performance scores were reduced primarily by the encumbrance of the MOPP4 ensemble but only minimally by the heat stress itself. These results indicate that the MCU vest system is effective in reducing core temperature and heart rate elevated by preflight activities when used in a UH-60 by aviators wearing a MOPP4 ensemble encumbered with ballistic protection and additional survival equipment, keeping them close on several key physiological measures to that experienced in the minimal stress condition (CS).

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Appendix A.

Air warrior ensemble configurations and component descriptions.

The Air warrior system will be used in designated U.S. Army tactical aircraft and during aircraft related ground operations. The selected configuration for any operational mission or activity may be tailored, dependent upon aircraft, aircraft mission, aircrew member duties, and commander's direction. The following test configurations have been compiled to reflect the three most likely operational configurations. These configurations have been defined in the following table:

Basic Configuration – Basic Combat, Normal Temperature(BC-N)
Air Warrior Combat Configuration – Normal Temperature (AW-N)
Air Warrior Combat Configuration – Hot Temperature (AW-H)

Wt.	Component Name	Configurations		
lbs.	Components listed below are planned for inclusion in the Air Warrior BLOCK 1.	**Basic Combat (BC-N)**	**Combat CB (AW-N)**	**Combat CB Hot (AW-H)**
3.5	Modified 2-piece Aircrew Battle Dress Uniform [ABDU], Woodland Camo, w/belt	X	X	X
0.25	Flyer's glove, pair	X	X	X
3.08	HGU56/P - w/clear and dark visors and Communications Ear Plug (CEP)	X	X	X
6.0	9mm Weapon and Pistol Holster with 5 clips	X	X	X
10.9	Primary Survival Gear Carrier (PSGC) with survival gear and attached pouches	X	X	X
3.18	M-45 Protective Mask		X	X
0.58	Blower, M-45 Protective Mask with Mask Blower Pouch (MBP)		X	X
3.75	Modified Chemical Protective Undergarment (CPU)		X	X
0.21	Liquid Chemical Protective Glove, 7 mil butyl rubber		X	X
3.63	Green/Black Vinyl Over boot		X	X
1.75	Survival Radio, PRC 90 or PRC 112	X	X	X
1.45	Survival Knife and knife sheath	X	X	X
13.5	Soft Body Armor (SBA) with Ballistic Plate	X	X	X
1.85	Microclimatic Cooling System [MCS]		X	X

AW is a system combining aircrew mission equipment with personal protective gear and clothing to provide an integrated and tailorable ensemble to enhance the effectiveness and survivability of Army rotary-wing aircrews during flight and dismounted (on ground/in water) operations. The AW is designed to protect the wearer against specific hazards associated with natural and battlefield environments, forced/hard landings, crashes, fire, and threat weapons. The following are the major components that comprise the AW ensemble used in support of the AW Heat Stress Test at USAARL.

1. Modified 2-Piece Aircrew Battle Dress Uniform (ABDU). The Modified 2-Piece ABDU is the standard woodland camouflage Nomex® that is currently in the supply system and fielded to all U.S. Army aviation units. The modification to the ABDU consists of an opening in the right side of the ABDU shirt, approximately 1.5" in length, used for the umbilical pass through for the Microclimate Cooling System (MCS). The opening is held closed by Velcro® when not in use.

2. Flyer's Gloves. The flyer's gloves are the standard GS/FRP-2, MIL-G-81188 fire retardant gloves that are currently in the supply system and fielded to all U.S. Army aviation units. There are no modifications to the gloves.

3. HGU-56/P Flyer's Helmet. The AW flight helmet is the HGU-56P Aircrew Integrated Helmet System (AIHS). The AIHS is a modular helmet system for rotary-wing aircrews. It consists of a basic helmet shell assembly on which devices can be mounted to configure it for a particular type aircraft and mission. It was developed to provide: (1) improved acoustic attenuation to protect the wearer's hearing from high background noise level; (2) head and eye protection against debris or fragmentation spatter, intense sunlight, or laser threats; (3) impact protection; and (4) compatibility with newer generation aircraft.

a. The AIHS incorporates a new injection molded ear-cup design that has superior energy absorption to protect against side impacts. The ear-cup provides improved sound attenuation to protect against hearing loss and improves communications in noisy helicopter environments. The helmet shell is fabricated from an advanced graphite composite for improved weight, tear and impact characteristics. The improved chinstrap and retention system is designed to withstand a 400-lb chinstrap pull. A dual visor module mounts to the outside of the basic helmet and provides clear, sun-shade, or laser protective visors. The helmet provides several functional capabilities through modular adaptation: integral night vision goggle mounting platform for night operations, dual visor assembly for use of helicopter's tracking system and helmet sight systems, compatibility with Army chemical warfare protective masks and hoods, and improved fitting capability (available in six sizes) designed to accommodate the smallest female aviator to the largest male aviator.

b. The AW HGU-56P is modified with the Communications Earplug (CEP), a device used to provide hearing protection and high quality speech communications to the user of the HGU-56P. The CEP unit consists of a pair of elements used to provide a passive noise-attenuating barrier between the users ear and the noise source while providing monaural voice communication signals to each ear. Each element consists of a housing, which contains an earphone transducer and a foam earplug tip. The transducer is directly connected to the communications system through a small, highly flexible coaxial wire. The CEP-helmet interface consists of a coaxial receptacle that is wired to the communications circuit inside the right ear cup.

4. 9mm Weapon, clips, and Pistol Holster. The M9 is a lightweight, Italian manufactured, semiautomatic pistol designed to replace the .45 caliber pistol and .38 caliber revolvers. The M9 has redundant automatic safety features to help prevent unintentional discharges, a 15-round magazine, and may be fired without a magazine inserted. Five 9mm ammunition clips will be a standard part of the AW ensemble. The thigh mounted pistol holster is a lightweight device that is hung from the vest and is composed of a canvas back plate and two Velcro straps. It straps to the wearers leg, adding little weight while comfortably securing the weapon within easy reach.

5. Primary Survival Gear Carrier (PSGC) with survival gear and attached pouches. The vest is made of Raschel knit Fire Retardant treated nylon. It has a total of 12 pockets (8 outside and 4 inside). These pockets accommodate all essential survival, signaling, and communications equipment. For emergency rescue-lift operations, a nylon webbing harness can be attached to the inside of the vest. The cradle fashion design of the harness consists of leg and chest straps for optimum fit and security. Mission essential items include, but are not limited to: compass, mirror, radio, smoke and illumination devices, signal kit, operation manual, and survival packets (medical and basic). Pouches are attached for other ancillary equipment described separately in this list.

6. Air Crew Protective Mask (ACPM) M-45. The current M45 ACPM provides the required chemical/biological (CB) protection and compatibility with rotary-wing aircraft sighting systems and night vision devices. The M45 was recently Type Classified-Standard and will replace the M24 and M49 Protective Mask.

7. Blower, M-45 Protective Mask with Blower Pouch. The motor blower is designed for integration with the M-45 ACPM. The motor blower is a Commercial-Off-the-Shelf (COTS), 2 cubic feet per minute blower, manufactured by 3-M Corp. It attaches directly over the M-45 Inlet filter and provides added CB protection as well as circulating air to enhance comfort and reduce crewmember fatigue. The blower has a pouch to secure it to the crewmember's body.

8. Modified Chemical Protective Undergarments (CPUs). The Modified CPUs are designed to be worn under an aircrew member's flight clothing. The base absorption technology is activated carbon encapsulated in polymer, a new and unique technology that provides uniform carbon distribution and chemical protection. The CPU is designed to be absorbent, durable, air permeable, comfortable, and fire resistant, as required. The modification to the CPU consists of an opening in the right side of the CPU shirt, approximately 1.5" in length, used for the umbilical pass through for the MCS. The opening is held closed by Velcro® when not in use.

9. Liquid Chemical Protective Glove, 7 mil Butyl Rubber. The impermeable 7 mil Butyl Rubber Gloves with cotton knit liners are designed to provide protection to the hands in a chemical threat environment. For maximum durability and/or environmental protection, standard issue hand wear can be worn over the gloves. The outer impermeable butyl gloves are manufactured in right and left hand five fingered configurations and shaped to follow the natural curvature of the hand in a relaxed position while the inner permeable cotton five finger gloves are ambidextrous. The 7 mil Butyl gloves provide 6 hours' protection against a 10 g/m2 liquid chemical challenge after 14 days of wear and resistance to incidental splashing of petroleum, oils and lubricants (POLs).

10. Green/Black Vinyl Over boot. The Over boot is a multipurpose over-boot designed to provide protection from chemical, biological and environmental hazards. Made by injection molding of an elastomer blend, it is designed to provide protection from petroleum, oils, and lubricants and to be flame resistant. The boot incorporates two quick-release side buckles and is designed to be worn over the standard issue combat boot, jungle boot or intermediate cold/wet boot (ICWB).

11. Microclimatic Cooling System (MCS). The MCS is composed of the microclimatic cooling unit (MCU) and the microclimatic cooling garment (MCG). The cooling unit is an aircraft-mounted and aircraft-powered system that chills and circulates coolant to individual crewmembers of the host aircraft to alleviate heat stress. The MCG is an air-cooled vest worn by the crew. Use of the MCS enhances mission performance, and enables the crew to perform normal and extended duration missions, while operating in desert or tropical environments, and while wearing chemical or other protective equipment or gear. The MCS program has completed the EMD phase, including development and operational testing, laboratory environmental stresses testing and physiological testing.

Appendix B.

Weight and fluid balance worksheets.

Today's Date: ____________ Test Subject No.: _____

Uniform: ① AW MOPP0 Basic Combat ② AW MOPP4 Normal Land ③ AW MOPP4 Hot Land

Activity: ① testing

Environmental condition: ① mild (70°F, 50%rh) ② hot (100°F, 50%rh)

➔PRETEST:	➔POSTTEST:
❑ Nude weight _______ kg ❑ Clothed & instrumented weight: _______ kg	❑ Clothed & instrumented weight: _______ kg ❑ Nude weight _______ kg

➔ URINE OUTPUT: (Formula Number 7)

Formula Number	Time of urination	Empty Specimen Container Wgt (kg)	Full Specimen Container Wgt (kg)	Full Wgt - Empty Wgt (kg)
10	After pre-clothed			
	After post-nude			

➔ FLUID INTAKE: (Formula Number 5)

Formula Number	Time of intake	Fluid Container Label Name or #	Initial Wgt (kg)	Final Wgt (kg)	Initial - Final (kg)
	After pre-nude				
8	After pre-clothed				
8					
8					
	After post-clothed				

➔ FOOD INTAKE: (Formula Number 6 and 9)

Type of Food	Initial Wgt (kg)	Final Wgt (kg)	Initial - Final (kg)

Weight and fluid balance worksheets (continued)

Today's Date: ____________ Test Subject No.: _____

Uniform: AW MOPP0 Basic Combat AW MOPP4 Normal Land AW MOPP4 Hot Land

Environmental condition: mild (70° F, 50%rh) hot (100° F, 50%rh)

Fluid intake: Total: _________ kg Between initial and final dressed wgts: _________ kg

Food intake: Total: _________ kg Between initial and final dressed wgts: _________ kg

Urine output: Total: ________ kg Between initial and final dressed wgts: _________ kg

Total sweat loss = $\underset{\text{Nude\_pre}}{\underline{\qquad\qquad}} - \underset{\text{Nude\_post}}{\underline{\qquad\qquad}} + \underset{\text{Fluids\_tot}}{\underline{\qquad\qquad}} + \underset{\text{Food\_tot}}{\underline{\qquad\qquad}} - \underset{\text{Urine\_tot}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad}$ kg

Evaporated sweat = $\underset{\text{Dressed\_pre}}{\underline{\qquad\qquad}} - \underset{\text{Dressed\_post}}{\underline{\qquad\qquad}} + \underset{\text{Fluids\_dressed}}{\underline{\qquad\qquad}} + \underset{\text{Food\_Dressed}}{\underline{\qquad\qquad}} - \underset{\text{Urine\_dressed}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad}$ kg

Sweat retained in uniform = $\underset{\text{Sweat loss}}{\underline{\qquad\qquad}} - \underset{\text{Evaporated sweat}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad}$ kg

% Dehydration = 100* $\left(\underset{\text{Sweat\_tot}}{\underline{\qquad\qquad}} + \underset{\text{Urine\_tot}}{\underline{\qquad\qquad}} - \underset{\text{Fluids\_Dressed}}{\underline{\qquad\qquad}}\right) / \underset{\text{Nude\_pre}}{\underline{\qquad\qquad}} = \underline{\qquad\quad}$ %

Appendix C.

Mood and symptom questionnaire.

Study: ______________________ Condition: ___________

Today's Date:__________ Test Subject No. ____

Instructions: 1. Administer the series of questions at the following times: Just prior to simulated preflight, 15 minutes simulated preflight and at times indicated in flight profile.
2. Alert the test subject with the following : Test subjects name, Mood and symptoms questionnaire.
3. Go through the questions using the same pace, wording, and inflection for each administration.
4. Record results in appropriate locations.

QUESTION	SCALE	RATINGS AT 30 MIN INTERVALS					
	"On a scale of 0 to 10 with respect to the past 5-10 min please rate your sensation of: " (Hrs:mins)--->						
1	headache (0 = none 10 = very severe)						
2	nausea (0 = none 10 = about to vomit)						
3	stress (0 = none 10 = very severe)						
4	anger (0 = none 10 = extremely)						
5	depression (0 = none 10 = extremely)						
6	energy (0 = none 10 = a lot)						
7	heat stress (0 = none 10 = unbearable)						
8	thirst (0 = none 10 = severe)						
9	workload (0 = very light 10 = overwhelming)						
10	boredom (0 = none 10 = totally boring)						
11	dizziness (0 = none 10 = very severe)						
12	visual difficulty (0 = none 10 = can hardly						
13	hot spots (0 = none 10 = severe) location: a) head b) chest c) back d) buttocks e) arm f) leg g) other						
	Technician initials --->						

Appendix D.

Air assault and MEDEVAC sortie scripts.

Air Assault Sortie Script

Time	Man#	Maneuver	Km	Standards	Notes
1	1	Hover		hdg 360° ,10 ft	
2	2	Hover turn (360)		10 ft	
5	3	Contour to wp2	10.9	var AS, const alt	Admin Mood/Symptom
7.5	4	Contour to wp3	10.5	var AS, const alt	
11.5		Arrived at wp3 Ascend to 2k'			Cue Co-pilot to prepare for PVT
12.5	5	S&L		270°,2k', 120kts	Cue Co-pilot to begin PVT
14.5	6	360° RSRT		to hdg 270°,2k',120kts	
15.5	7	S&L		270°,2k',120kts	
16.5	8	L, 180°, SRT		to hdg 090°,2k'-2.5k',120kts	
17.5	9	S&L		090°,2.5k',120kts	
18.5	10	L, 180°, SRT		to hdg 270°,2.5k'-2k',120kts	
19.5	11	S&L		270°,2.0k',120kts	
21.5	12	Descend then go to wp4		270°,2'-1k',120kts	Administer TLX to pilot
25	13	Contour to wp5	13.4	var AS, const alt	Admin TLX to Co-pilot
26	14	NOE to wp6	3.3	var AS, var alt<25	
		Arrived at wp6			
27	15	Hover		hdg 360°, 10 ft	
28	16	Hover turn (360°)		10 ft	
29.8	17	Contour to wp7	5.3	var AS, const alt	Admin Mood/Symptom
33.8		Arrived at wp7 Ascend to 2k'			Cue Co-pilot to prepare for PVT
34.8	18	S&L		270°,2k', 120kts	Cue Co-pilot to begin PVT
36.8	19	360° RSRT		to hdg 270°,2k',120kts	
37.8	20	S&L		270°,2k',120kts	
38.8	21	L, 180°, SRT		to hdg 090°,2k'-2.5k',120kts	
39.8	22	S&L		090°,2.5k',120kts	
40.8	23	L, 180°, SRT		to hdg 270°,2.5k'-2k',120kts	
42.8	24	S&L		270°,2k',120kts	
43.8	25	Descend then go to wp8		270°,2k'-1k',120kts	Administer TLX to Pilot
46.8	26	Contour to wp9	12.5	var AS, const alt	Admin TLX to Co-pilot
49.8	27	Contour to wp10	11.6	var AS, const alt	

53.3	28	Contour to wp11	13	var AS, const alt	Admin Mood/Symptom
57.8	29	Contour to wp12	16	var AS, const alt	
60.3	30	NOE to wp13	8.7	var AS, var alt<25	
62.8	31	Noe to wp6	8	Vas AS Var Alt <25	
		Arrive wp6		hdg 360°, 10 ft	
63.8	32	Hover		Hdg 360°,10 ft	
64.8	33	Hover turn (360°)		10 ft	
66.6	34	Contour to wp7	5.3	var AS, const alt	
70.6		Arrived at wp7 Ascend to 2k'			Cue Co-pilot to prepare for PVT
71.6	35	S&L		270°,2k,120kts	Cue Co-pilot to begin PVT
73.6	36	360° RSRT		270°,2k,120kts	
74.6	37	S&L		270°,2k,120kts	
75.6	38	L 180° SRT		to hdg 090°,2k-2.5k,120kts	
76.6	39	S&L		090°,2.5k,120kts	
77.6	40	L 180° SRT		to hdg 270°,2.5k-2k,120kts	
78.6	41	S&L		270°,2.0k,120kts	
80.6	42	Descend then go to wp8		270°,2-1k,120kts	Administer TLX to pilot
83.6	43	Contour to wp9	12.5	var AS, const alt	Admin TLX to Co-pilot T
86.6	44	Contour to wp10	11.6	var AS, const alt	Admin Mood/Symptom
89.6	45	Contour to wp14	12.2	var AS, const alt	
91.6	46	NOE to wp15	10	var AS, var alt<25	
95.6		Arrive at wp15 Ascend to 2K'			Cue Co-pilot to prepare for PVT
96.6	47	S&L		090°,2k,120kts	Cue Co-pilot to begin PVT
98.6	48	360° RSRT		090°,2k,120kts	
99.6	49	S&L		090°,2k,120kts	
100.6	50	L 180° SRT		to hdg 270°,2k-2.5k,120kts	
101.6	51	S&L		270°,2.5k,120kts	
102.6	52	L 180° SRT		to hdg 090°,2.5k-2k,120kts	
103.6	53	S&L		090°,2.0k,120kts	
105.6	54	Descend then go to wp16		090°,2-1k,120kts	Administer TLX to pilot
108.6	55	Contour to wp1	12.4	var AS, const alt	Admin TLX to Co-
Time	Man	Maneuver	Km	Standards	Notes
		Arrived at wp1			
109.6	56	Hover		hdg 360° ,10 ft	
110.6	57	Hover turn (360°)		10 ft	Admin Mood/Symptom At end of maneuver

MEDEVAC Sortie Script

Time	Man#	Maneuver	Km	Standards	Notes
1	1	Hover	1		10 ft alt, 360°hdg
2	2	Hover turn (360°)	1		
7.3	3	Contour to wp19	5.3	20	var AS, const alt
11.3		Reached wp19 Ascend to 2k'	4		
12.3	4	S&L	1		120kts,2k',180°
14.3	5	RSRT	2		360°
15.3	6	S&L	1		120kts,2k',180°
16.3	7	L, 180°, SRT	1		2.0k_2.5k'
17.3	8	S&L	1		120kts,2.5k',360°
18.3	9	L, 180°, SRT	1		2.5k_2k'
19.3	10	S&L	1		120kts,2.0k',180°
21.3	11	Descend then go to wp20	2		120kts,2.0_1.0k',180°
23.3	12	Contour to wp21	2	8.4	var AS, const alt
26.3	13	Contour to wp22	3	11.8	var AS, var alt<25
30.3	14	NOE to wp23	4	14.8	var AS, var alt<25
34.3		Arrive at wp23 Ascend to 2k'	4		
35.3	15	S&L	1		120kts,2k',270°
37.3	16	RSRT	2		360°
38.3	17	S&L	1		120kts,2k',270°
39.3	18	L, 180°, SRT	1		2.0k_2.5k'
40.3	19	S&L	1		120kts,2.5k',090°
41.3	20	L, 180°, SRT	1		2.5k_2k'
42.3	21	S&L	1		120kts,2.0k',270°
44.3	22	Descend then go to wp24	2		120kts,2.0k',_1.0k',270°
47.3	23	Contour to wp25	3	10.6	var AS, const alt
49.3	24	NOE to wp26	2	10	var AS, var alt<25'
		Arrived at wp26			
50.3	25	Hover	1		10 ft alt, 360° hdg
51.3	26	Hover turn (360°)	1		10 ft alt
53.8	27	Contour to wp27	2.5	9	var AS, const alt
56.8	28	Contour to wp28	3	12.5	var AS, const alt

60.3	29	Contour to wp 29	3.5	13.5	
64.3		Arrived at wp29 Ascend to 2k'	4		
65.3	30	S&L	1		120kts 2k, 090°
67.3	31	RSRT	2		360°
68.3	32	S&L	1		120kts 2k, 090°
69.3	33	L, 180°, SRT	1		2.0k - 2.5k
70.3	34	S&L	1		120kts 2.5k, 270°
71.3	35	L, 180°, SRT	1		2.5k - 2k
72.3	36	S&L	1		120kts 2.0k, 090°
74.3	37	Descend then go to wp 30	2		120kts 2.0 - 1.0K, 090°
75.3	38	Contour to wp31	1	4	Alt, grnd track, roll, trim
79.8	39	NOE to wp32	4.5	16.6	Alt, grnd track, roll, trim
87.3	40	Contour to wp33	7.5	28.2	Alt,grnd track,roll,trim
96.3	41	Contour to wp34	9	33.1	Alt,grnd track,roll ,trim
100.3		Arrive wp 34 Ascend to 2k'	4		Alt, grnd track, roll, trim
101.3	42	S&L	1		AS, alt, trim, roll, hdg
103.3	43	RSRT	2		AS, alt, trim, roll, turn rate
104.3	44	S&L	1		AS, alt, trim, roll, hdg
105.3	45	L, 180°, SRT	1		AS, trim, roll, turn rate, ascent rate
106.3	46	S&L	1		AS, alt, trim, roll, hdg
107.3	47	L, 180°, SRT	1		AS, trim, roll, turn rate, descent rate
108.3	48	S&L	1		AS, alt, trim, roll, hdg
109.3	49	Descend then go to wp35	1		AS, trim, roll, hdg, descent rate
112.3	50	Contour to wp36	3	12.5	Alt, grnd track, roll, trim
116.3	51	NOE to wp18	4	6.5	Alt, grnd track, roll, trim
		Arrived at wp18			None
117.3	52	Hover	1		Alt, drift, hdg
118.3	53	Hover turn (360°)	1		Alt, drift, turn rate

Appendix E.

Task load index questionnaire.

Today's Date:__________ Test Subject No. ______

Instructions: 1. Administer the series of questions as indicated by the flight profiles.
2. Alert test subject "TEST SUBJECT NAME, TLX QUESTIONAIRE."
3. Wait for acknowledgement, then go through the questions using the same pace, wording, and inflection for each administration.
4. Record results in appropriate locations.

QUESTION	SCALE		RATINGS*	
	On a scale of 0 to 10 please assess your experience with respect to the (set of standard maneuvers) the following conditions:		Hrs: Min	Score
1	mental demand	(0 =low 10=high)		
2	physical demand	(0 =low 10=high)		
3	temporal demand	(0=low 10=high)		
4	performance	(0=good 10=poor)		
5	effort	(0=low 10=high)		
6	frustration	(0=low 10=high)		
		Technicians initials--->		

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