USAARL Report No. 92-32

Effects of Microclimate Cooling on Physiology and Performance While Flying the Uh-60 Helicopter Simulator in NBC Conditions in a Controlled Heat Environment

By

Robert Thornton
J. Lynn Caldwell
Frank Guardiani
Jacquelyn Pearson

Biomedical Applications Research Division

August 1992

United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 70-25 on Use of Volunteers in Research.

Reviewed:

CHARLES A. SALTER
LTC, MS
Director, Biomedical Applications
Research Division

ROGER W. WILEY, O.D., Ph.D.
Chairman, Scientific
Review Committee

Released for publication:

DAVID H. KARNEY
Colonel, MC, SFS
Commanding

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 92-32	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) SGRD-UAB-CB	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 577 Fort Rucker, AL 36362-5292	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21701-5012
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
0602787A	3M162787 A879	BH	169

11. TITLE (Include Security Classification)
Effects of Microclimate Cooling on Physiology and Performance While Flying the UH-60 Helicopter Simulator in NBC Conditions in a Controlled Heat Environment

12. PERSONAL AUTHOR(S)
Robert Thornton, J. Lynn Caldwell, Frank Guardiani, Jackie Pearson

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM May 91 TO May 92	1992 August	240

16. SUPPLEMENTARY NOTATION

17. COSATI CODES FIELD	GROUP	SUB-GROUP
23	01	
23	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
chemical defense, psychological stress, psychological testing psychological performance, heat stress, aircrew protective ensembles, psysiology, helicopter, heart rate, (continued)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The effects of microclimate cooling on aviator performance and physiology in nuclear, biological, and chemical (NBC) individual protective equipment (IPE) were evaluated in the USAARL UH-60 research flight simulator. Sixteen male aviators flew the simulator in two temperature conditions, 95°F and 105°F, both at 50 percent relative humidity (RH). Two thermoelectric conditioning units were used, one providing cooled blown air, the other cooled water to the aviators.

At each temperature, they flew for up to 6 hours in NBC IPE with no cooling, air cooling, and liquid cooling. There was an extra condition at 105°F when vent air with no cooling was blown through the air vest, making a total of seven test conditions.

(continued on back)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center	22b. TELEPHONE (Include Area Code) 205-255-6907 22c. OFFICE SYMBOL SGRD-UAX-SI

Block 18 continued: microclimate cooling sleep

Block 19 continued:

There were significant improvements in flight performance as a result of the cooling, more so at the higher temperature. Also, there were differences between the two cooling systems at 105°F, with the air system producing significantly lower flight error rates.

Survival time was based on the length of time each subject stayed in the condition before reaching physiological withdrawal criteria (rectal temperature of 39°C or heart rate of 150 beats per minute for 15 minutes) or exercising their option to retire early. There were considerable increases in survival time with the use of microclimate cooling. The mean survival time at 95°F was increased to 385 minutes with the liquid system from 285 minutes without cooling. At 105°F to 333 minutes for the air system from 79 minutes with no cooling, the improvement was even more dramatic. There were significant differences between the two cooling systems at 105°F with the air system producing longer survival times.

Rectal temperature, mean skin temperature, and heart rate were monitored and showed significant improvement with both conditioning systems compared with the no cooling conditions. The liquid system produced the most benefit. Dehydration occurred in all conditions, but was significantly reduced by the use of cooling.

Subjective fatigue increased with exposure time in all conditions, with significant benefits apparent from both cooling systems. A performance assessment battery was undertaken before and at regular intervals during flight. The battery showed some improvement in performance in the no cooling condition at 95°F compared with cooling, and worsening performance with increasing time on each test day. On days with extended exposure to hot conditions, subjects suffered a reduction in total rapid eye movement (REM) sleep, with delayed onset of the first REM period.

Table of contents

List of illustrations

List of illustrations (Continued)

List of illustrations (Continued)

<u>List of tables</u>

Preface

This study was conducted under the auspices of the Department of the Army program, the Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat (P^2NBC^2). The study was designed to meet the P^2NBC^2 goals and objectives, and was partly funded by the P^2NBC^2 program.

Acknowledgments

The assistance given by Dr. Heber Jones and Mr. Andy Higden in the design of the flight profile, the data capture, and reduction is gratefully acknowledged. Mr. Al Lewis and Mr. Bob Dillard provided constant help, first in designing and installing the physiological monitoring equipment used in the simulator, and then in trouble-shooting the many teething troubles in using this new system. The study could not have begun without their help. Dr. Sam Shannon provided valuable assistance and tuition with the statistical analysis.

Mr. Pat Heenan of Midwest Research Industries provided invaluable technical assistance with the thermoelectric coolers, visiting Fort Rucker several times, often at short notice. He also helped interpret the cooler performance data.

The work of the UH-60 simulator instructor-operator Mr. Larry Woodrum in training and monitoring the subjects was inestimable. The postflight questionnaire was designed by Dr. Richard Texeira of the Natick Research Development and Engineering Center.

The medical monitor was MAJ John Crowley, ably assisted by LTC Dennis Shanahan, MAJ Bob Weien, and MAJ Jim Bruckart.

A variety of individuals were members of the study team at various times, and they performed most of the daily tasks, including instrumenting and dressing the subjects, monitoring the physiological parameters in the simulator, and collecting and processing data. They were at the front line in interacting with the subjects and maintaining morale. They did an excellent job. They were SSG Nonilon Fallaria, SSG Jose Rosario, SPC Tim Kelbert, SPC Cindy Nelson, SPC Louis Rivera, PFC Shylonda Wallace and Ms. Barbara Bradley. SPC Kelbert's contribution extended to flying in the simulator with the subjects on numerous occasions.

Finally, the subjects themselves must be thanked for their patience and forbearance in what was a long, stressful, and frequently boring experience, which to a man they endured without complaint, and with great professionalism and good humor. They were all a great tribute to their branch.

This page intentionally left blank.

Introduction

United States Army doctrine for the integrated battlefield (AirLand Battle doctrine) depends in large measure upon aviation for support, mobility, and fire power. Current threat information and AirLand Battle doctrine indicate that combined arms crews must be prepared to operate for as long as 72 hours in the presence of a chemical agent threat. Army aviation is at serious risk in the chemical environment since the ability of aviators to control their aircraft may be disrupted. Actual and projected threat estimates increase the battlefield demands on the operational capabilities of new and existing rotorcraft and the pilots who operate them. These demands mandate new approaches to helicopter design and higher levels of technology in new Army aircraft to meet the emerging threat.

The probable outcome of an unprepared crew facing a chemical agent would be the loss of pilots, crew, cargo, passengers, aircraft, and mission failure. Pilots cannot don their chemical protective clothing, the individual protective equipment (IPE) in flight because of limited space, distraction from the flying task, and lack of adequate warning of a chemical threat. It is likely, therefore, that aircrews will be required to wear full IPE, including mask, throughout all flights, whenever there is a significant threat of the use of chemical agents by an enemy.

The conditions experienced by aviators in Operation Desert Shield emphasize the problems of operating in NBC conditions in a hot climate.

The wearing of chemical protective clothing by aircrew increases the thermal stress imposed on them during flight in hot weather conditions. It may add an extra layer to their clothing assembly, increasing the insulation value. It impedes ventilation of the clothing by sealing neck, wrists and ankles, and some components, such as the mask, may be completely impermeable to perspiration. In addition, there may be extra limitations, on pulmonary function caused by increased breathing resistance, ergonomic restrictions caused by increased bulk, manual dexterity reduced by NBC gloves, and vision impaired by the mask because of reduction to the visual fields and imperfect optical materials.

Several studies have examined the physiological penalties on pilots of wearing NBC IPE. Belyavin et al. (1979) performed a laboratory simulation to measure the heat stress of wearing the United Kingdom IPE during helicopter operations at a wet bulb globe temperature (WBGT) index of 28.9°C. They derived a mathematical model which predicted deep body temperature in such conditions would exceed 38°C within 45 minutes of takeoff, and that it would continue to rise at 1°C/hr. A criticism of their study was that the overall rate at which the subjects worked was probably rather high in view of more recent measurements of actual pilot workload both before and during flight (Thornton, Brown, and Higenbottam, 1984).

A USAARL study observed six UH-1 helicopter pilots wearing either the U.S. or U.K. NBC IPE (Knox et al., 1982) during flights with a cockpit WBGT index between 27 and 35°C. They concluded that well acclimatized individuals who were not required to do the preflight safety inspection of their aircraft and were allowed liberal quantities of water, would not experience significant heat strain within 2 hours. Beyond that time three subjects were withdrawn because they reached the maximum heart rate (of 140 beats per minute) imposed for safety reasons while wearing the U.S. ensemble. However, it was observed that these subjects tended to be less fit and overweight.

A study of the U.K. IPE in 1985 (Thornton, Brown, and Redman) came to similar conclusions. They performed a climatic chamber simulation of helicopter operations at a WBGT index of 26°C. No rise in deep body temperature occurred after 2 hours at a work rate equivalent to flying a helicopter, though there was a significant rise at the higher work rate of a helicopter crewchief.

Mitchell et al. (1986) studied the effects of sustained flying operations in the U.S. IPE, with and without microclimate cooling. They found that cooling was not required at a cockpit WBGT index of less than 29°C.

A study of the standard U.S. Navy aircrew NBC ensemble, which is essentially identical to the U.K.'s (Kaufman et al., 1988), resulted in a mean exposure time in IPE of 155 minutes, compared with 219 minutes in standard flying clothing before voluntary or medical withdrawal.

The psychological and performance effects of wearing NBC protective clothing also have been widely studied. Hamilton, Folds, and Simmons (1982) reported that pilots flying in the U.S. IPE made statistically greater heading errors than while wearing their standard flight suit or the U.K. IPE. In a separate study the same year (Hamilton, Simmons and Kimball, 1982), again comparing U.S. and U.K. ensembles, no dramatic effects on psychomotor performance were found, though pilots' abilities to recognize and react to error situations were impaired. This study used elements of the Walter Reed performance assessment battery.

A study of the effects of wearing the U.S. aircrew IPE for 6 hours without the addition of thermal stress, at a WBGT index of

20°C (Hamilton and Zapata, 1983) showed degradation of affect, accuracy and reaction time. This type of laboratory study has received a certain amount of criticism for the lack of relevance to the real situation which the soldier in IPE has to perform, because of the artificial nature of tasks used to simulate field conditions. This adds to the argument for the use of an aircraft simulator for this study (Kobrick and Fine, 1983; Fine and Kobrick, 1987).

A USAARL study which examined both the physiological and performance consequences of flight in NBC IPE was performed in a UH-60 simulator (Thornton et al., 1992). Sixteen male aviators flew the simulator in four test conditions, standard flight suit and cool cockpit, standard flight suit and hot cockpit, NBC IPE and cool cockpit, NBC IPE and hot cockpit. The hot condition had a WBGT of 30.6°C, the cool 17.9°C. Rectal temperature, mean skin temperature, and heart rate were monitored, and showed significant increases for the NBC hot condition compared with the other three. There was a significant degree of dehydration in the hot NBC condition. Seven subjects failed to complete the sortie in the NBC hot condition, with a mean survival time of 298 minutes. All subjects flew for the target 6 hours in the other conditions. Simulator flight performance showed significant impairment in the hot NBC condition. There was little evidence of a reduction in flight performance with time. Six crashes occurred in NBC IPE, and one in the standard flight suit. A performance assessment battery also was undertaken before, and at regular intervals during flight. It showed no effect of condition, though it was sensitive to increasing time on each test day. A subjective questionnaire assessment showed increasing fatigue with time, and that all conditions produced significantly more fatigue than baseline, worse for NBC hot.

In addition to the immediate physiological stress encountered during a mission in which a person is exposed to a high heat environment, residual effects also are seen for several hours after the person is no longer in that environment. One effect of heat is seen on the person's sleep architecture. Research conducted to investigate the effects of passive body heating on sleep has found that slow wave sleep increases and rapid eye movement (REM) sleep decreases in the first half of the night when compared to a baseline sleep period (Bunnell et al., 1988; Di Nisi et al., 1989; Horne and Reid, 1984). These studies also found a decrease in sleep onset latency and an increase in presleep tiredness. These effects were found after as little as 1.5 hours of passive body heating given as early as 5 hours before sleep onset.

With these effects on sleep architecture after relatively short periods of body heating, it seems likely that continuous body heating for as long as 6 hours, as may occur during MOPP IV conditions, would contribute substantially to sleep architecture changes. The assessment of such changes in sleep is necessary in order to determine the extent of physiological effects which occur during high heat conditions. If heat stress increases the need for slow wave sleep, it is possible that a soldier returning from a mission during which heat stress was experienced, may have an increase in fatigue which, in turn, may lead to a decrease in performance. In addition, it was thought helpful to determine if microclimate cooling can alleviate some of these physiological effects of heating, particularly if fatigue is reduced and the increased need for sleep is reduced.

Several studies have demonstrated the value of a variety of microclimate cooling systems in improving the psychological and physiological responses to exercise heat stress with NBC uniforms (Pimental, Sawka, and Tassinari, 1985; Caderette et al., 1986; Caderette et al., 1988; Bomalaski, Chen, and Constable, 1989).

Vallerand et al. (1991) compared the effects on alleviating heat strain of a commercial liquid microclimate cooling system with an air chiller system at 37°C, 50 percent RH. They found significant advantages with the air system in terms of rectal temperature, heart rate, and thermal comfort, which they attributed to the beneficial effects of the greater evaporative cooling produced by the air system.

Bayes, in a detailed report in 1983, reviewed the microclimate cooling options then available for the different Army helicopter types. He concluded liquid based systems were not appropriate because of the weight of refrigeration systems for active units, or the logistic problems of resupplying ice or coolant packs to passive systems.

Thornton (1991) carried out a short subjective assessment of commercially available microclimate cooling systems in conjunction with an Armywide study (Masadi, Finney, and Blackwell, 1991) for possible use by troops involved in Operation Desert Storm.

The aircrew microclimate conditioning system being developed for Army aviation has undergone an operational assessment (Sweitzer, 1989) and human factors engineering assessment which have confirmed its technical feasibility for use in helicopters (U.S. Army HEL Field Office, U.S. Army Aviation Center, 1990).

The objective of the current study was to assess how the deleterious effects on flight performance and physiology of flight operations in NBC IPE can be alleviated by the use of two microclimate cooling systems.

Methods and materials

Simulator

The USAARL UH-60 helicopter simulator is an aeromedical version of the standard UH-60 training simulator with the addition of an environmental control system (ECS) to regulate the cockpit thermal environment by specifying dry bulb temperature (T_{db}) (68-105°F) and relative humidity (RH) (50-90 percent). It also is linked to a real time data acquisition system on a VAX 11/780* computer, which can record and analyze aircraft flight parameters and pilot inputs.

The simulator is mounted on a 60-inch stroke synergistic hydraulic motion system. This provides six degrees of freedom of motion to induce acceleration cues in the lateral, longitudinal, vertical, pitch, roll, and yaw axes over a 60-degree range. The simulator uses actual earth mapping and terrain data as the basis for digital imagery generating visual scenery. Scene viewing is through a three-channel, four-window digital image generator (DIG) system. Three separate video scenes are sent to four cathode ray tube (CRT) displays. Forward looking scenery is split between two front CRTs, with scenery also presented to the left and right side window CRTs.

An on-board biomedical equipment cabinet contains a diagnostic patch panel, the ECS control panel, a 16-channel signal conditioner, and the AC/DC power distribution panels which power the biomedical research data acquisition equipment. The patch panel provides 16 input connections for biomedical signals. These connect to cabinet mounted physiological preamplifiers which can be used to boost the level of the signals.

Environmental conditions

The environmental control of the simulator as originally configured did not allow a truly accurate duplication of conditions in the cockpit of the real UH-60 aircraft due to the lack of a radiant heat source. As part of a separate study (Thornton and Guardiani, 1992) the radiant heat load in the UH-60 aircraft was measured at the head of pilot. This heat load then was simulated in the simulator cockpit using infrared lamps to produce a radiant heat load on the helmet of the subjects of 130 watts per square meter (Wm^{-2}), measured 1.9 m from the simulator floor, and 100 Wm^{-2} over the legs, measured 0.56 m from the floor.

---

*See manufacturers' list, Appendix B.

The environmental conditions chosen were 35°C (95°F), 50 percent RH for one condition (T1), and 41°C (105°F), 50 percent RH for the other (T2). The maximum dry bulb temperature that could be specified was 105°F, and 50 percent the minimum RH. The simulator ECS uses degrees Fahrenheit for its controls and settings, and the conditions therefore will be described in °F in the remainder of this report. All other temperatures are reported in degrees Celsius.

Subjects

Subjects for the study were 19 volunteer male aviators, 13 active Army and 6 national guard. All were between the ages of 21 and 39 and in good health, as determined by a flight surgeon using a self-administered written medical history questionnaire and their medical records. The demographic data are listed in Table 1. Subjects 01 and 02 took part in the dry runs, and most of their results were not pooled with the others, apart from their sleep records. Subject 08 withdrew after 2 days in the study, leaving a total of 16 subjects with usable data.

The original intention was to use two UH-60 pilots for each run of the study. Recruiting difficulties forced a modification. There were several occasions when it was only possible to recruit one aviator for a run. The other subject was substituted by a variety of other researchers and aviators in order to help with navigation, and to assist in trying to maintain the morale of the subject. It also was decided to extend the recruiting process to include all helicopter aviators, even if not UH-60 qualified. There is little in the flight profile flown that is specific to the UH-60, the subjects are not required to start it, and emergency procedures are not included. Their data were analyzed to determine any effect of experience on performance. They are indicated in Table 1 by having no UH-60 flight time.

Apart from age and sex, the only other selection criterion was that subjects should not require visual correction for flight. This was applied because of the difficulties and delay that would have been encountered in providing visual correction for the M43 mask. Recruiting was done by word of mouth, and advertising on posters and in Army aviation publications, and written requests for casual assignment officers. The subjects were briefed verbally and in writing before participation, using the letter at Appendix A. They were asked to refrain from alcohol use for the duration of the study.

Clothing assemblies

The clothing assembly worn is shown in Table 2. The Aircrew Uniform Integrated Battlefield (AUIB) is under development at the Natick Research Development and Engineering Center (NRDEC), Natick, Massachusetts, as a two-piece garment combining both thermal and chemical protection for aviators (Figure 1). It is

Table 1.
Demographic data.

No	Age	Weight (kg)	Height (cm)	Flight hours Total	Flight hours UH-60
03*	33	73.24	178	1700	1350
04*	36	82.48	175	3500	1100
05*	37	86.70	175	8200	0
06*	32	85.08	178	4000	300
07*	25	87.84	175	1100	425
09	35	77.64	175	5500	3000
10	27	83.82	183	700	0
11	30	75.74	168	480	220
12	24	79.08	183	170	80
13	23	64.26	170	170	60
14	26	101.48	180	200	0
15	25	75.48	188	200	0
16	23	92.46	175	170	70
17*	34	85.82	190	1800	300
18	22	87.38	180	183	173
19	28	83.70	178	150	0

* sleep study participants

constructed of sage green 4.5-ounce plain weave Nomex-Kevlar/polytetrafluoroethylene (PTFE) laminated outer shell and charcoal impregnated polyurethane foam/tricot laminated liner. There is a sleeved port in both sides to allow passage of a microclimate cooling hose, and tapes to seal around it. It is worn with the M43E-1 Aircrew Member's Protective Mask (AMPM) (Figure 2), and the survival armor recovery vest (including packets) (SARVIP) (Figure 3).

The M43E-1 mask consists of a bromobutyl facepiece with an integrated butyl hood and skirt. Overpressure is provided within the mask by a blower assembly, a battery-powered motor which blows air to the hood through two standard NBC filters. Some of the air flow is directed over the inside of the lenses to prevent misting, and some over the scalp to provide cooling. It incorporates a microphone and drinking tube.

Table 2.
Clothing assembly.

Undershirt, quarter sleeve, crew neck (air only)
Underpants
Socks
Boots
Flight gloves, summer
Helmet, SPH-4
SARVIP
Body armor
Gloves, chemical protective (outer only) (14 mm)
Overboots, green vinyl
AUIB
M43E-1 mask

Microclimate cooling systems

Two microclimate cooling systems, designated as the aviator microclimate conditioning system (AMCS), have been developed in parallel by Midwest Research Institute (MRI)* under contract to Aviation Systems Command (AVSCOM), St. Louis, Missouri. One is based on air conditioning, the other liquid. The original protocol called for the comparison of the air AMCS with an ice-based cooling vest and this was used for subjects 1 and 2. Renewed interest in liquid cooling during Operation Desert Shield prompted AVSCOM to request a comparison of MRI's liquid and air systems (Appendix C).

Air system

The air cooled version of the AMCS consists of an individual subunit and an aircraft subunit. The individual subunit is the second generation version of a single piece cooling vest, designed by NRDEC, to fit all body sizes, and an airhose interface (Figure 4). It is worn over a tee shirt, immediately

Figure 1. Aircrew Uniform Integrated Battlefield.

Figure 2. M43E-1 Aircrew Member's Protective Mask.

underneath the AUIB. Contaminant-free air is introduced to the vest through the airhose which attaches to a female connector on the side of the vest and has a quick disconnect attachment on the other end to interface with the aircraft subunit hose connector.

The aircraft subunit consists of a filter assembly and a thermoelectric (TE) unit (Figure 5). The dimensions of the TE unit are 450 x 450 x 265 mm, and it weighs 18.21 kg (plus 4.91 kg for the blower), without the filter assembly. The filter assembly provides filtered cabin air for the TE unit, which cools and regulates the air flow. The filter assembly was not used during this simulation because of lack of space in the cockpit and nonavailability of suitable filters. This change to the configuration meant that MRI had to fit a nonstandard blower unit to replace the one incorporated in the filter housing because of the differences in back pressure. The blower was set up by MRI to produce an output of 48 cubic feet per minute (cfm).

Figure 3. Complete NBC IPE.

Figure 4. Air vest.

Figure 5. Air thermoelectric cooler.

One aircraft subunit as designed for the UH-60 will supply four subunits for individuals. The two unused outlets were fitted with a restriction valve to ensure the correct balance of flow rates. The unit was mounted in the cockpit of the simulator, so that it would be working at the elevated environmental conditions.

The cooler supplies air at a flow rate of 5.66 liters per second (12 cfm) for each of four stations, providing a theoretical cooling capability of 250 watts. Subjects were allowed to control their own flow rate, by selecting the high, low, vent, or off setting. This was as the result of a positive decision at the start of the study to use realistic cooler conditions rather than regulating flow rate and temperature to constant values. In practical terms, there will always be some variation from the specified values, especially when several ircrew share the same cooling source.

The vent setting allows the blower fan to be used without thermoelectric cooling, and this was used on one of the test days to simulate cooling failure. The temperature of the conditioned supply was measured for both sides, close to the cooler outlet, using YSI 401 style rectal thermistors*. It also was measured for the air being fed to the cooler from the blower.

The flow rate was measured using a Linear Pneumotach* and Vacumed differential pressure transducer*. Problems were encountered with this system because water droplets and particles of debris in the air stream were deposited on the Pneumotach's membrane, and it eventually was abandoned. The flow rate then was calibrated by MRI at 12 cfm using a Roots meter*. Temperature and flow rates were recorded at 1-minute intervals with a Squirrel 1202/42 data recorder*.

<u>Liquid system</u>

The liquid cooling unit also uses thermoelectric cooling, with a pump to circulate the cooled water. It has similar dimensions to the air system without any filters, and weighs 11.34 kg (dry) (Figure 6). It has a theoretical cooling capacity of 220-250 watts per subject. There is a variable flow control on the unit, which subjects were allowed to adjust to suit their own needs. In both systems, the cooling rate can be adjusted only for both outlets together, with no individual control. Flow rate was measured using a Micro Flow Sensor (Signet Scientific)* and temperature monitored with rectal probes sealed in the coolant tubes, close to the cooler, both recorded at 1-minute intervals. All rectal probes used in monitoring the performance of the coolers were calibrated against a YSI reference probe* before the start and after the conclusion of the study.

The liquid cooler was used in conjunction with the Exotemp* vest and hood. The Exotemp vest is a long-sleeved turtle neck shirt. The garments are made of Nomex fabric and are lined with thin plastic tubing (1/8 inch outside diameter) to carry the coolant (Figure 7). The shirt is available in three sizes, but only the medium was available for the study, and it readily accommodated all subjects. The vest was worn in place of an undershirt. The hood was used to give the subjects the advantage of head cooling, in the knowledge that, in practice, it can be disconnected if not necessary or desired.

Physiological data

Throughout the experiment, deep body temperature, skin temperature, and heart rate were recorded at 0.5-second intervals, on the VAX computer while the subjects were in the simulator, otherwise on a Squirrel 1202/42 data logger at 1-minute intervals. The same data appeared on a meter at the medical observer's position, independent of the VAX system, in case of computer failure. The medical observer took manual recordings at 5-minute intervals to provide data backup, and to ensure adequate monitoring of critical values.

Deep body temperature

Deep body temperature was measured using a rectal thermistor with 1 cm retention ball (YSI 401 style*), inserted by the subjects, 10 cm beyond the anal sphincter. The rectal probes were precalibrated by comparison to a YSI reference probe*. Any which differed by more than 0.2°C over the range 36-40°C were rejected.

Skin temperature

Skin temperature was measured at four sites, chest (T_{chest}), upper arm (T_{arm}), inner thigh (T_{thigh}) and outer calf (T_{leg}), using thermistors (YSI 400 series*) held in position by an elastic harness. Mean skin temperature ($\bar{T}_{sk}$) was calculated after Ramanathan (1964) using the formula:

$$\bar{T}_{sk} = 0.3(T_{chest}) + 0.3(T_{arm}) + 0.2(T_{thigh}) + 0.2(T_{leg})$$

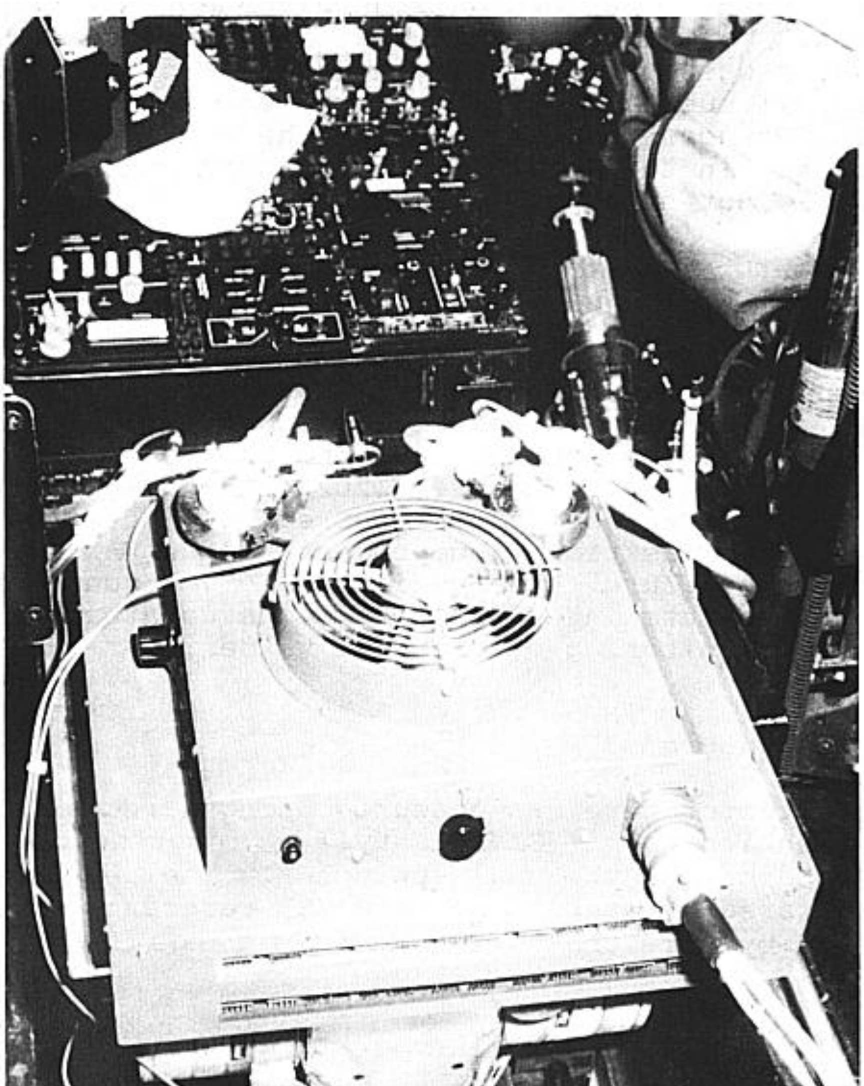

Figure 6. Liquid thermoelectric cooler.

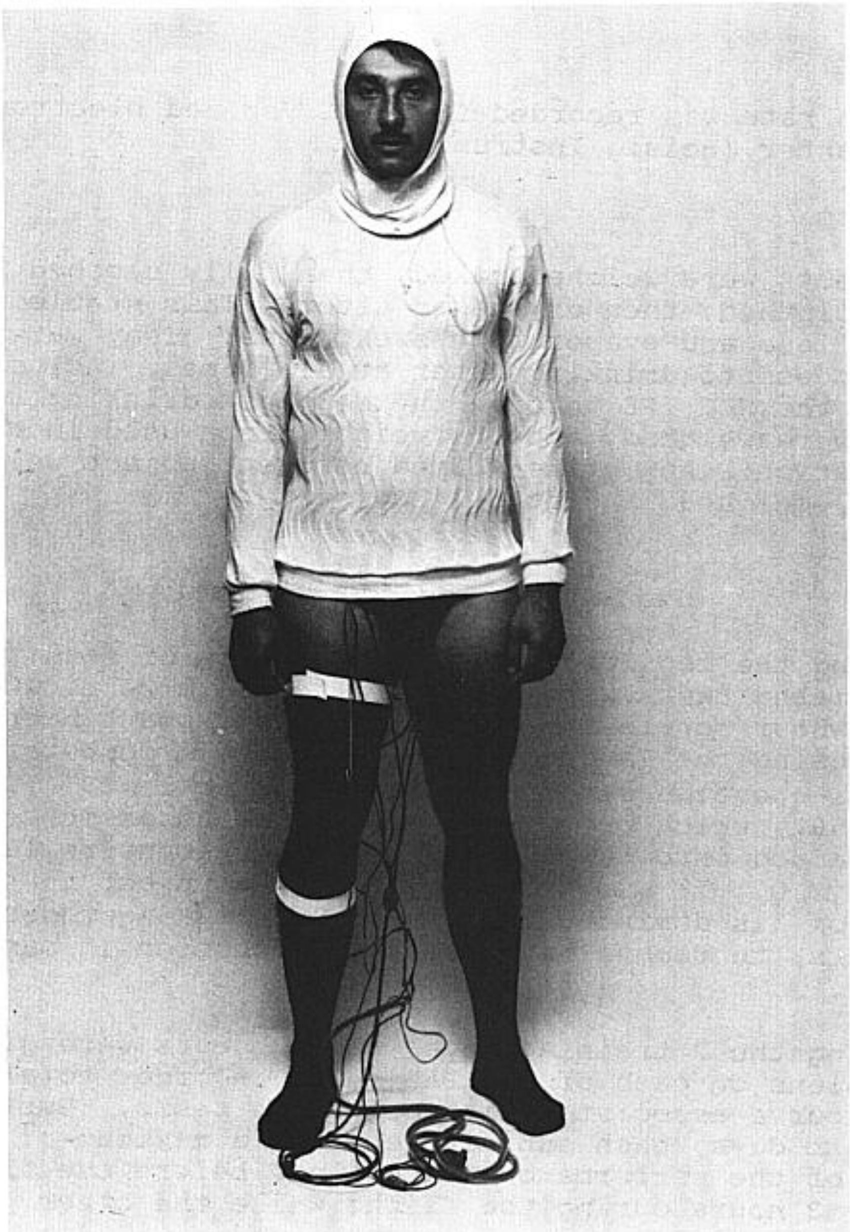

Figure 7. Liquid vest and hood.

This made no allowance for the fact that the chest thermistor in the air system, and both chest and arm thermistors with the liquid vest, are on areas receiving direct cooling. With the small number of sites, it was considered impractical to apply any further weighting on the basis of cooled area, and the limited number (16) of physiological data channels available in the simulator precluded any increase.

Heart rate

Heart rate was recorded from ECG Ver-med electrodes and an R-wave counter (Boisig Instruments*).

Weight loss

Subjects were weighed naked, then fully clothed before each run, and clothed, then dry naked after. This enabled calculation of weight loss and evaporative sweat loss. They were allowed liberal access to drinking water at all times, including during flight in the NBC IPE through the M43 mask drinking tube. Water canteens were weighed, and the weight drank used in the estimate of dehydration. Any urine voided between subject weighings was collected, weighed, and used likewise.

Performance assessment battery

During the copilot's nonhandling phase of each flight, flying-related tasks were minimized to leave 20 minutes available in each 2-hour sortie for performance assessment battery (PAB) testing, using the Paravant RHC-88 hand-held computer*. An additional questionnaire, the 'fatigue checklist,' (Pearson and Byers, 1956), which provided a subjective assessment of fatigue, was programmed into the RHC-88. The questionnaire is reproduced in Appendix D. It was necessary for the subject to remove the gloves from his dominant hand while undertaking these assessments, to remove any effect of reduction in manual dexterity.

During the 2 training days, the subjects were given training four sessions on each of the PAB tests in order to alleviate the learning curve associated with cognitive tests. During the actual test days, each subject received a maximum of four sessions of the performance tests: one before the flight, and one every 2 hours during the flight while the other pilot was flying the simulator.

The RHC-88 has a liquid crystal, dot matrix display with an electroluminescent panel for viewing in poor ambient light conditions. Sixteen lines of text, 42 characters per line, are available on the 5" x 2.75" screen display. The keyboard of the RHC-88 has 52 keys representing a total of 60 characters and functions. After completing each of the tests, the results were stored in the RHC-88 and later uploaded to a standard PC for further analysis.

Seven tests were administered during each of the four sessions. The tests were subject-paced, with a set number of trials administered for each test. The tests are described below (Thorne et al., 1985).

Encode/decode (Griddle)

This test determined a person's reaction time in decoding messages. Two types of questions are presented; encode requires the subject to translate a number into four letters; decode requires the subject to translate four letters into a number. A key is given in the top of the display while the encode or decode pattern is displayed at the bottom of the screen. The subject was to decipher the code and type in his response as quickly as possible.

Six-letter search (MAST-6)

The subject was presented with 6 letters at the top of the screen and a row of 20 letters at the bottom of the screen. The subject was to determine if the top row of letters was in the bottom row of letters. If every letter was displayed in the bottom row in any order, the subject pressed "S." If any letter from the top row was missing in the bottom row, the subject responded by pressing "D."

Logical reasoning

The letter pair "AB" or "BA was presented in the top of the display with a logical statement describing the letters presented in the bottom of the display. The subject was to determine if the statement correctly described the letters. If the statements were the same, the subject responded by pressing the letter "S"; if the statements were different, the subject pressed the letter "D."

Digit recall

Nine digits were displayed in a row on the screen for one second. After a 3-second interval during which the screen was blank, eight of the nine digits were displayed in a different order. The subject was asked to respond by indicating which of the nine digits was missing from the second set of digits.

Serial addition/subtraction

Two numbers were displayed in sequence, followed by either a "+" or a "-" flashed after the numbers. The subject was to perform the indicated operation, either addition or subtraction. If the answer was less than zero, the subject was to add 10 to the number and input the new answer; if the answer was greater than 9, the subject was to subtract 10 from the answer and input the new answer. Each number for input was to be between zero and nine, inclusive.

Matrix I

The subject was presented with an array of 14 asterisks scattered randomly on the display. After a short time, the screen was blanked, then another set of asterisks was displayed. The subject was to determine if the two sets of asterisks were either the same or different and respond by pressing either the "S" or the "D" key, respectively.

Wilkinson four-choice reaction time

The screen displayed four boxes with one of the boxes filled. The subject pressed one of four special buttons on the keyboard corresponding to the placement of the filled box. As soon as the response was made, another box was blackened and the next trial began.

Sleep recordings

Only 8 of the 19 subjects agreed to take part in the sleep component of the study, the remainder opting to go home to their families at night. In order to assess the effect of heat stress on sleep, a polysomnogram was recorded from each of the eight subjects after each day of testing. The subjects were required to sleep in the Laboratory the night of their first training session in order to acclimate to the Laboratory environment. Although electrodes were connected this first night, the data were not analyzed. The night following the training day served as baseline sleep, with the nights after each testing day recorded to measure the effects of heat and cooling on sleep. The subject was released the morning following his last test day.

Each subject had four electroencephalogram (EEG) electrodes attached to his scalp, two electrooculogram (EOG) electrodes attached at the side of each eye, and two electromyogram (EMG) electrodes attached under the chin. Each electrode site was cleaned with acetone in order to reduce impedance. Each EEG electrode was filled with electrode gel and attached to the scalp with collodion. The EOG and EMG electrodes were filled with electrode cream and secured to the skin with surgical tape.

The EEG was recorded from sites C3, C4, O1, and O2, according to the International 10-20 System. Contralateral mastoid sites served as reference. EOGs were recorded from electrodes placed on the outer canthus of each eye, referenced to A1. Submental EMGs were recorded from electrodes attached under the chin. A ground electrode was placed on the forehead at site FpZ. Impedances from the EEG sites were no more than 5000 ohms. The EOG and EMG electrodes were no more than 10,000 ohms. All electrodes were Grass silver cup* electrodes.

After the electrodes were attached, the subject slept in a private, darkened bedroom located in the Biomedical Applications Research Division. An intercom was placed next to the bed in case the subject needed anything during the night. The subjects began electrode hookups at 2100 hours each evening, with lights out between 2200 and 2300 hours, depending upon the subject's normal bedtime. The subject slept through the night, with a technician at the polygraph at all times, and was awakened at 0600 the next morning. The EOG, EMG, and mastoid electrodes were disconnected and the subject allowed to shower and dress before he began the testing sessions for the day.

The polysomnogram was recorded with a Nihon Kohden polygraph*. The time constant for the EEG was set at 0.3 Hz and the low pass filters at 35 Hz, with the 60 Hz notch filter in place. The time constant for the EMG was set at 0.003 Hz and the low pass filter at 120 Hz. For the EOG, the time constant was set at 5.0 Hz and the low pass filter at 15 Hz. The paper speed was set at 10 mm/sec. The data were recorded on paper for future sleep scoring.

Pilot flight performance data

The simulator flight profile has been described in detail elsewhere (Thornton et al., 1992). A deliberate decision was made to use the same flight profile in order to allow comparison of results between the two studies. It was designed to, as far as possible, represent a realistic tactical scenario. Within that, at regular intervals, were embedded maneuvers which had to be flown accurately to allow scoring of performance by measuring deviation from assigned values for various flight parameters. It consisted of 1 hour of tactical low level flight, followed by 1 hour of upper airwork. The automatic flight control system (AFCS) was disabled halfway through the upper airwork to increase pilot workload.

Control of the aircraft alternated between both pilots at specified intervals during flights, to allow assessment of two subjects in each flight. When it was necessary to withdraw one pilot for any reason, it was possible to continue assessing the other using the simulator operator as his copilot.

Aircraft preparation

During field operations of helicopters, the metabolically most demanding activities occur not during flight, but in associated activities on the ground such as preflight inspections and refuelling (Thornton and Brown, 1982). Therefore, to make this study more realistic, an initial metabolic load was devised for the subjects in the form of a simulation of preflight activities. Data were available for the average energy expenditure (370 watts) of preflighting similar sized aircraft, so that it was possible to simulate this activity by exercising to a similar rate of work on a treadmill (4.8 km per hr, 0° slope). While there was no facility available in which this could be done with accurate climatic control, local heating was used in the USAARL cardiopulmonary laboratory, in an attempt to duplicate the simulator conditions as closely as possible. WBGT was recorded during this phase, together with heart rate, and deep body temperature.

Questionnaire

An open-ended self-administered written questionnaire was used at the end of each day to obtain subjective information on any problems encountered, whether or not, and why performance was impaired, and any specific problems with the IPE. Because much of the questionnaire related to specific IPE problems such as comfort, fit, and integration, it was designed by personnel at the Natick RD&E Center, and is included in Appendix E.

Procedure

The timetable for the 2 weeks of the study is at Appendix F, and details the order in which events occurred. It started on the first morning with a briefing for the subjects by the principal investigator, following which they signed the consent forms and completed the initial subject questionnaire to provide the demographic data (Appendix G). The next step was a detailed instruction and practice period on the use of the RHC PAB. The subjects were briefed on the simulator flight profile by the operator/instructor (I/O), which they then flew for the first time, without instrumentation or NBC IPE. After a break for lunch, the RHC PAB training was repeated, followed by a second simulator flight. After completion of the day's training, the subjects were handed over to the night shift. They then were free until required for EEG electrode hookup prior to retiring for the night.

The second day followed a similar pattern of RHC PAB training and flying, this time with the subjects fully instrumented and in IPE. The simulator environmental control system (ECS) was not used during the training days.

For the next 7 days, the timetable was the same on every day. It started with instrumentation and dressing, followed by a baseline PAB. On completion of the PAB, they went straight to the treadmill for 20 minutes, and from there had a short walk inside the building to the simulator. The subjects remained in the simulator for the duration of that day's flying, up to 6 hours. If they needed to urinate during the flight, this was done into a container inside the cockpit in order to maintain constant environmental exposure and monitoring.

Each flight was of 2 hours' duration, and the subjects flew the same flight three times a day, contingent upon remaining within the withdrawal criteria. Individual flights were separated by a 10-minute 'refuelling' period, during which the pilots remained in the cockpit and in full NBC IPE. The flight profile was identical in all sorties and on all days. At the end of the day, the subjects completed the postflight questionnaire, before being handed over to the night shift.

Environmental data

The simulator cockpit dry bulb temperature (T_{db}), wet bulb temperature (T_{wb}), and black globe temperature (T_{bg}) were measured and output to the VAX computer at 1-minute intervals. The WBGT was calculated according to the formula:

$$WBGT = 0.7T_{wb} + 0.1T_{db} + 0.2T_{bg}$$

These data also were recorded on a Reuter Stokes RSS-217 Wibget data logger* as backup. Wibgets also were used to record the environmental data in the room housing the treadmill, and the subjects' bedrooms.

Experimental design

The experimental design is shown in Table 3. It consisted of 2 days training on the experimental flight profile, the first in the standard flight suit, the second in the NBC IPE. Eight hours training has been demonstrated to be more than adequate for this particular flight profile (Thornton et al., 1992).

There were two test environmental conditions, with the simulator ECS set at 95°F, 50 percent RH (T1) and 105°F, 50 percent RH (T2). At each temperature there were three test conditions, no cooling, air cooling and liquid cooling. In addition, at T2 only, there was a fourth test condition in which the air system was used in its vent mode, to simulate failure of the cooling system. The order in which the conditions were administered was randomized, with the restriction that none of the 3 days which resulted in the most heat stress (days 3, 4 and 9 in Table 3) was allowed to fall on consecutive days, to minimize any possible cumulative effects of heat stress or dehydration. The convention for abbreviated names for the conditions used in the remainder of this report is shown in the last column of Table 3.

Table 3.
Experimental design.

Day	Condition	Abbreviation
1	- training, no heat	
2	- training, no heat	
3	- 50 percent RH, 35°C (95°F)	95 nil
4	- 50 percent RH, 41°C (105°F)	105 nil
5	- 50 percent RH, 35°C (95°F) air	95 air
6	- 50 percent RH, 35°C (95°F) liquid	95 liquid
7	- 50 percent RH, 41°C (105°F) air	105 air
8	- 50 percent RH, 41°C (105°F) liquid	105 liquid
9	- 50 percent RH, 41°C air, blower only	105 vent
10	- spare in case of delays	

Data analysis

General

The data have been analyzed in several distinct ways in order to try to allow for the variations in cooler performance discussed below. The first takes all the data in a particular pool, the second selects only data for the subject from each pair receiving better cooling performance, and the third uses data only from subjects 12 onward. The rationale for these approaches is described in the section detailing the results of cooler performance. Which of these analyses were applied for a particular data set is described below.

Flight performance data

The flight profile is divided into nine separate maneuver types. Some of the maneuvers are further subdivided, the hover maneuvers into low or high, and others into whether the AFCS was disabled or not. In most cases, statistically significant differences were found between the subdivisions of the divided maneuvers, necessitating separate analysis, e.g., between hover altitude error for the 40-foot hover, compared with the 10-foot hover. This is discussed further in the results.

Each maneuver is scored for up to five different parameters which vary with the maneuver type. For example, navigation is scored for heading, altitude, slip, and roll while hover turn is scored for altitude only. Some maneuvers are repeated several times in each flight, and the flight is repeated three times per test day. In all, there are 69 separate flight maneuvers per test day with up to 5 relevant parameters each. Table 4 lists the maneuvers, the number of times each is repeated in each of the three flights, and the parameters associated with that maneuver.

Flight performance data were recorded twice a second for 16 parameter channels, and the data were processed to produce a single root mean square (RMS) error value for each channel appropriate to each of the 9 maneuvers. The RMS values were obtained using the squared deviation from the reference value for that particular parameter. These then were summed, and divided by the total number of samples. Finally, the square root was calculated, so that the units for the RMS value corresponded to those of the original parameter. The result thus is similar to the standard deviation, except that it is calculated using differences from the ideal value rather than from the mean.

Plotting the RMS error for maneuver parameters of one type sequentially throughout a test day showed no appreciable increase in error rate with time in almost all cases, as shown in the results section. This was confirmed by statistical analysis, using the methods described below. The mean error rate for each of the 55 maneuver parameter combinations, e.g., hover-heading, hover-altitude, therefore was used in the final data analysis.

Analysis of variance (ANOVA) was undertaken on the RMS error values meaned for all 16 subjects, using the SAS/STAT general linear models (GLM) procedure and Duncan's multiple range test for evaluating posteriori comparisons (Duncan, 1955). Condition and subject number both were included in the model. Repeated measures ANOVA was not appropriate because of the unequal cell size caused by subjects dropping out early on the hotter days. This method also was used to test the relationships between maneuver subdivisions and flights, as described above. The alpha level was set at 0.05 for each comparison.

The performance data were analyzed in a number of different ways in an attempt to allow for the variations in cooler performance described below. Results were analyzed for subjects using the better (right, pilot's) side of the cooler only; analysis was undertaken for subjects 12 onward (8 subjects), to

Table 4.
Flight maneuver types.

Maneuver	Number	Parameters
1 Navigation	4	heading, altitude, slip, roll
2a Hover (10 ft)	1	heading, altitude
2b Hover (40 ft)	1	heading, altitude
3a Hover turn (10 ft)	1	altitude
3b Hover turn (40 ft)	1	altitude
4a Right standard turn (AFCS in)	2	rate of turn, altitude, airspeed, roll, slip
4b Right standard turn (AFCS out)	1	rate of turn, altitude, airspeed, roll, slip
5 Left descending turn	1	rate of turn, altitude, airspeed, roll, slip
6 Descent	3	heading, airspeed, roll, rate of descent, slip
7a Left standard turn (AFCS in)	1	rate of turn, altitude, airspeed, roll, slip
7b Left standard turn (AFCS out)	1	rate of turn, altitude, airspeed, roll, slip
8 Climb	2	heading, airspeed, roll, rate of climb, slip
9a Straight and level (AFCS in)	3	heading, altitude, airspeed, roll, slip
9b Straight and level (AFCS out)	1	heading, altitude, airspeed, roll, climb, slip

allow for the improved performance of the air cooler at that stage; comparisons also were made between the data for pilots and copilots, and between the first and last eight subjects.

The short survival time for the 105 nil condition meant that sufficient data were available for analysis only for the first hour of flight. The upper airwork data therefore do not include this condition. To permit a more accurate analysis of the few 105 nil data available, a separate analysis was performed for the navigation profile for the first run only.

Survival time

The differences in survival times between the various conditions were analyzed by ANOVA, using the Greenhouse-Geisser correction because of the large number of degrees of freedom. The Newman-Keuls test was applied to determine posthoc comparisons (Weiner, 1971). Analyses were performed for all subjects, estimating missing data for the vent conditions for two subjects from the means of the data present, for subjects sitting in the right hand seat (pilots), and for the last six subjects only. Because the air cooler failed completely on the last run at 105°F, the data for the last two subjects were not included in the analysis.

Fatigue checklist

The fatigue checklist was scored using a basic program which converted responses into a score, using the values shown in Table 5. A mean value then was calculated for each of the four administrations of the checklist in each test condition, and used in the analysis. ANOVA was used to analyze the results using the Greenhouse-Geisser correction. The Newman-Keuls test was applied to determine posthoc comparisons.

The data were analyzed first using only subjects who had complete data for sessions one to three (N=6). Difference scores were calculated, that is, the difference between the scores for session two and session one, and between session three and session one. The same analyses were performed after estimating missing data based on the means of the data available. When reporting the results of the analyses, the different methods are only referred to when they produced different results. A separate data set was produced by selecting subjects 12 onwards and analyzed separately.

Table 5.
Fatigue checklist scores.

No	Better than	Same as	Worse than	Statement
1	(3)	(2)	(1)	very lively
2	(1)	(0)	(-1)	extremely tired
3	(2)	(1)	(0)	quite fresh
4	(2)	(1)	(0)	slightly tired
5	(3)	(2)	(1)	extremely lively
6	(2)	(1)	(0)	somewhat fresh
7	(1)	(0)	(-1)	very tired
8	(3)	(2)	(1)	very refreshed
9	(1)	(0)	(-1)	quite tired
10	(1)	(0)	(-1)	ready to drop

Performance assessment battery

The PAB data were analyzed with 3 X 3 analysis of variance (ANOVA) with repeated measures on both factors. Since there were only two subjects in the 105 nil condition to take more than one session of the PAB, those data were not included in the analysis. Three of the four sessions from the 95 nil condition were analyzed since only 7 subjects completed all four sessions.

Sleep

The polysomnograms from nights two through nine were visually scored using the criteria established by Rechtschaffen and Kales (1968). The amount of time spent in each stage of sleep, including movement time, was calculated. Each subject's data were scored by only one person. Reliability among scorers was randomly checked on two records from every subject. Percent agreement among scorers ranged from 93 to 83, with an average of 87.5 percent. Each variable was analyzed using a repeated measures ANOVA. The 105 vent condition was omitted from the analyses since the dry run subjects did not have the same cooling system for this condition. Therefore, the final analysis contained baseline, 95 nil, 95 air, 95 vent, 105 nil, 105 air, and 105 vent conditions.

Physiological data

The physiological data on the VAX were processed by sampling them at 5-minute intervals throughout the flight, first for the pilot, then the copilot, and appending both sets of results into one file. The resulting data file was converted into an SPSS* system file, and the results were plotted using SPSS Graphics*. The data were tested using regression analysis, and plotting the 99 percent predicted confidence intervals. The corresponding treadmill data stored in portable data loggers were converted to Lotus* files for storage, converted to SPSS system files and plotted using SPSS Graphics.

The effects of the exercise period were analyzed by taking the first available simulator value for each variable in each condition and performing ANOVA, using the Greenhouse-Geisser correction whenever sphericity assumptions were violated. The Newman-Keuls test was applied to determine post hoc comparisons.

The weight loss data also were entered into Lotus files for storage and analysis. Water balance was calculated in terms of weight, percentage body weight, and rate of weight change. The latter was done in order to better compare subjects who survived varying periods of time. It was done by dividing the total weight of, for example, dehydration by the time from starting the treadmill work to doffing the uniform. Repeated measures analysis of variance was used to test for differences in fluid balance between conditions. Sweat loss calculations were not corrected for respiratory water loss.

Health and safety of test participants

The subjects participating in this project were all rated military pilots, having passed a recent flight physical. A briefing and questionnaire session was conducted on the first day of the trial. A written self-administered questionnaire was used to elicit personal data, significant medical history, flying experience, and exercise history (Appendix G). At the same time, they were briefed fully on the nature of the trial, both verbally by the principal investigator, and in written format, which they were required to read and sign. The various consent forms are reproduced at Appendix H.

The incentive for the subjects to volunteer was the opportunity to accrue up to 40 simulator flight hours, including the full range of emergencies, which were practiced during the training sessions.

During all testing, both in the simulator and on the treadmill, the subjects were accompanied by a medical observer (researcher) who had a visual display of all physiological parameters, which he recorded manually every 5 minutes. This display was independent of the VAX computer, in case of any malfunction. The medical observer was fully trained in recognizing the signs and symptoms of heat illness, and in initiating emergency treatment.

The medical monitor (physician) remained within the building with a radio while the experiment was in progress, and ensured that the medical observer and primary investigator could contact him immediately at all times.

Before the trial started, all resuscitation equipment was set up in a room adjacent to the simulator bay. The room was equipped with the facility to monitor rectal temperature and ECG, and had ice packs, iced water, and cool drinks on hand. All equipment was checked daily by the medical observers.

A subject could be withdrawn from the experiment by the following personnel:

a. The subject at his request.
b. The medical observer if either of the physiological criteria were exceeded.
c. The medical monitor.
d. The principal investigator.

The physiological criteria for withdrawal were a rectal temperature of 39.5°C, or a heart rate in excess of 149 beats per minute for 15 minutes.

Results

Cooler performance

Liquid cooler

A number of problems were encountered with both cooling systems. The liquid system was the more reliable, with the only significant difficulty being the ease with which the plastic tubes inside the clothing were able to become kinked, reducing the flow rate of the liquid. Careful routing of the hoses through the AUIB, ensuring that the lower border of the vest did not become folded up on itself, helped to minimize the problem. If it occurred in flight, it was very difficult to resolve, given the limitations of space in the simulator. The liquid cooler flow rate was reduced at the request of the subjects on one occasion only, as illustrated in Figure 8. The mean coolant temperatures are shown in Figure 9 for 105°F and Figure 10 for 95°F. Data are missing for the first run as the measuring equipment was not available in time for the start of the study. Data for run 5 for both conditions and run 8 for the 95°F condition were lost due to problems with the data recorder. The data for coolant supplied to nonsubject aviators flying the simulator are not included. Figures 11 and 12 depict the mean difference in temperature between the coolant leaving the cooler and returning to it. Figures 13 and 14 show the mean flow rates.

All the graphs relating to the liquid cooler show a significant difference in flow rate and cooling capacity between the left and right sides, giving more cooling to the right subject (pilot). This was thought to be related to differences in flow resistance between the two sides, down stream of the cooler, which in turn affected flow rate, despite the use of apparently identical fixtures and fittings.

A further problem in analyzing the data is illustrated in Figure 15. This shows the coolant temperature during run 8, and the effect of one subject withdrawing early. The remaining subject, who was already getting water which was some 7°C cooler, then gained a further 3°C of cooling.

MRI performed calculations on the temperature and flow rate data to derive the cooling capacity in watts, by multiplying mass flow rate by specific heat of water by the temperature difference. These are shown in Table 6. They can be compared with a theoretical total capacity for the unit under the same conditions of 248 watts per person at 95°F and 220 watts at 105°F.

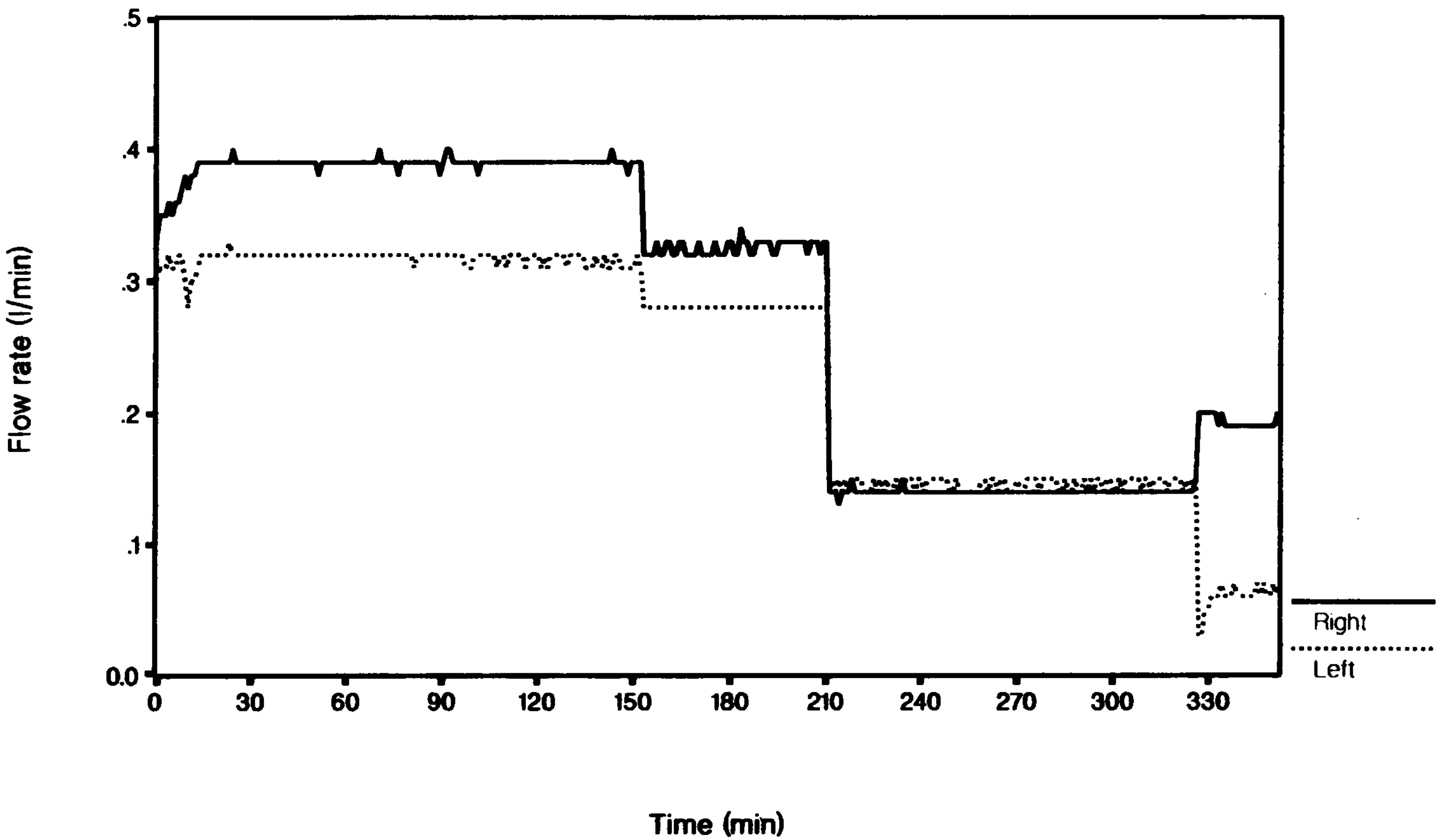

Figure 8. liquid cooler flow rate, run 7, 95°F.

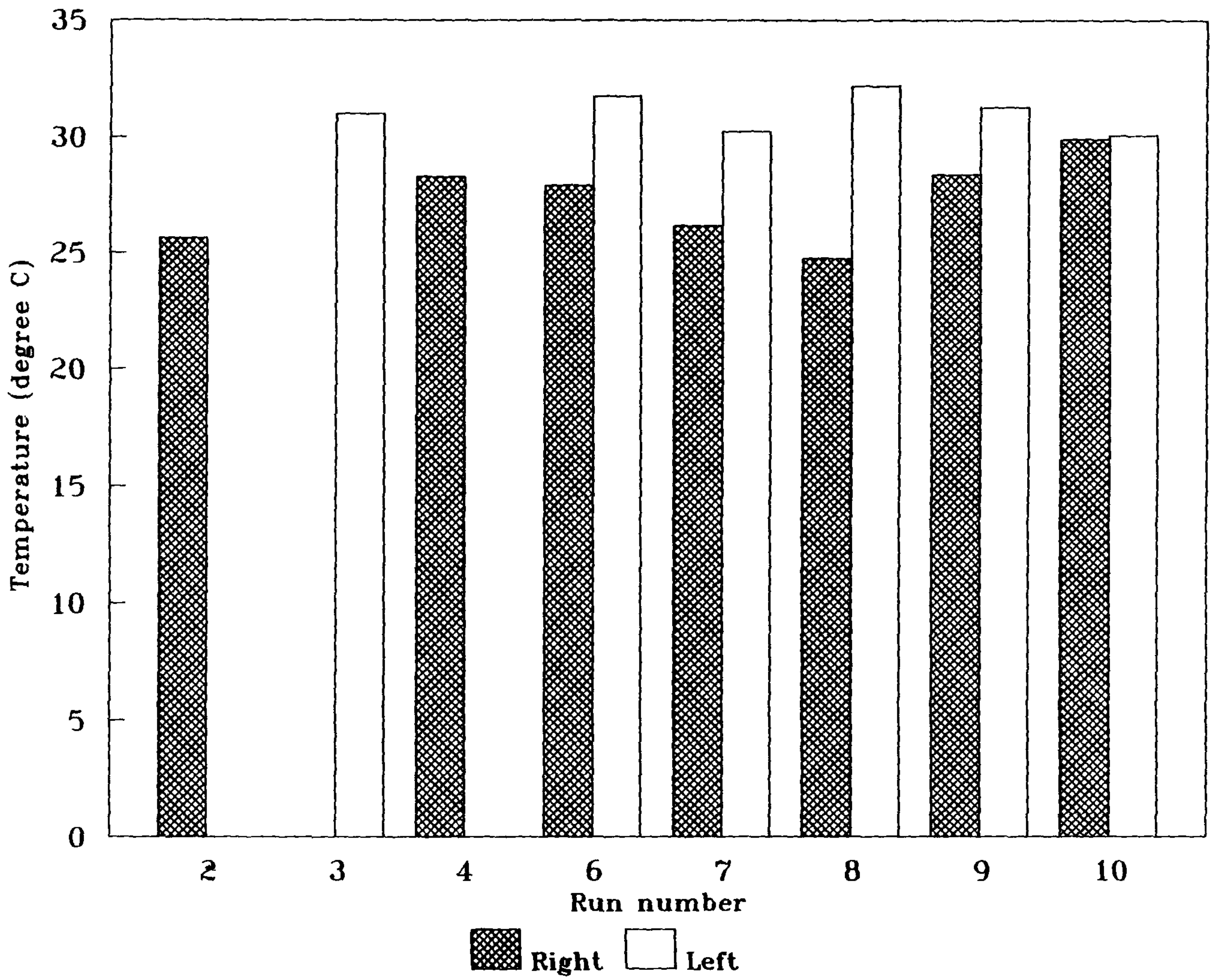

Figure 9. Mean liquid coolant temperature, 105°F.

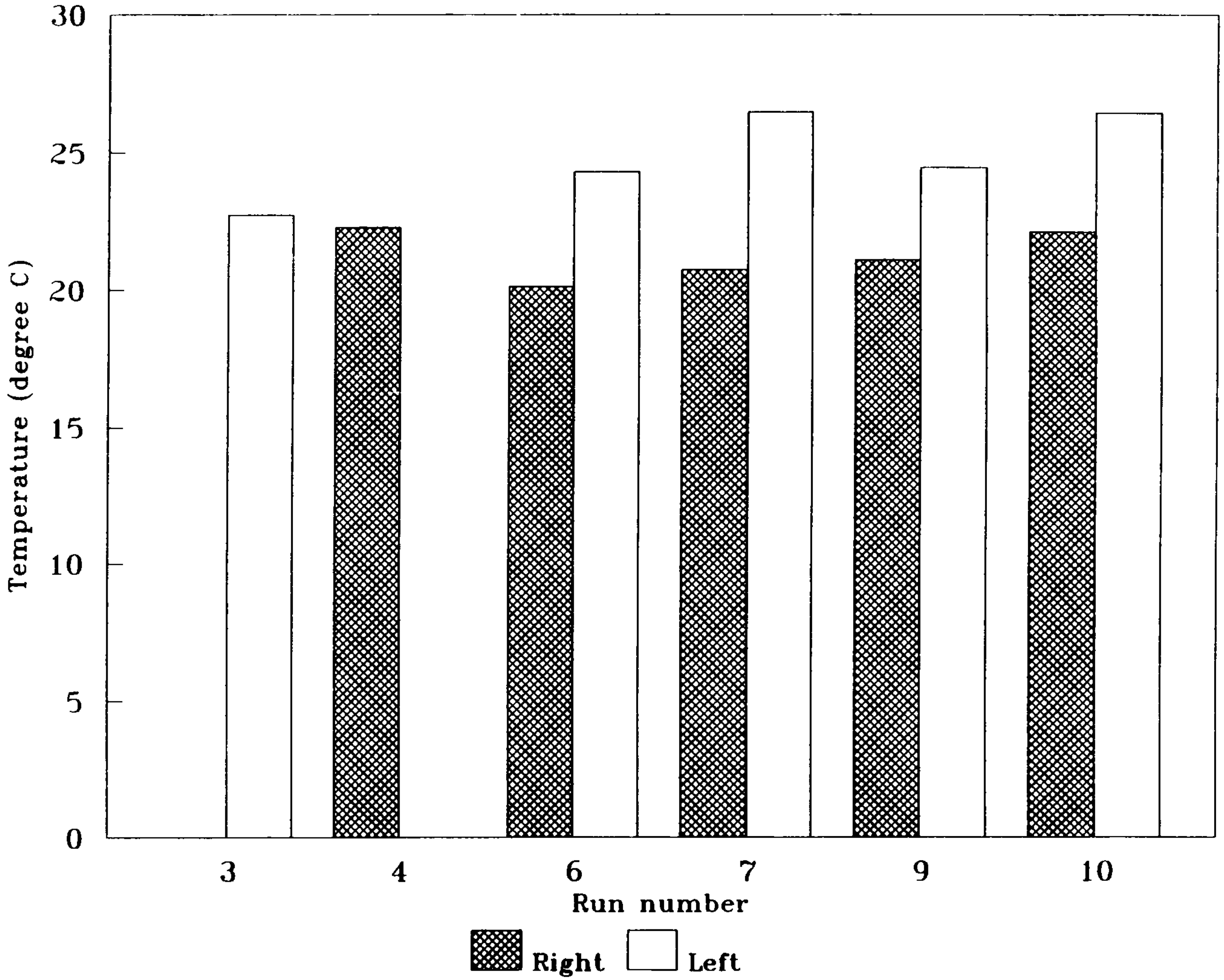

Figure 10. Mean liquid coolant temperature, 95°F.

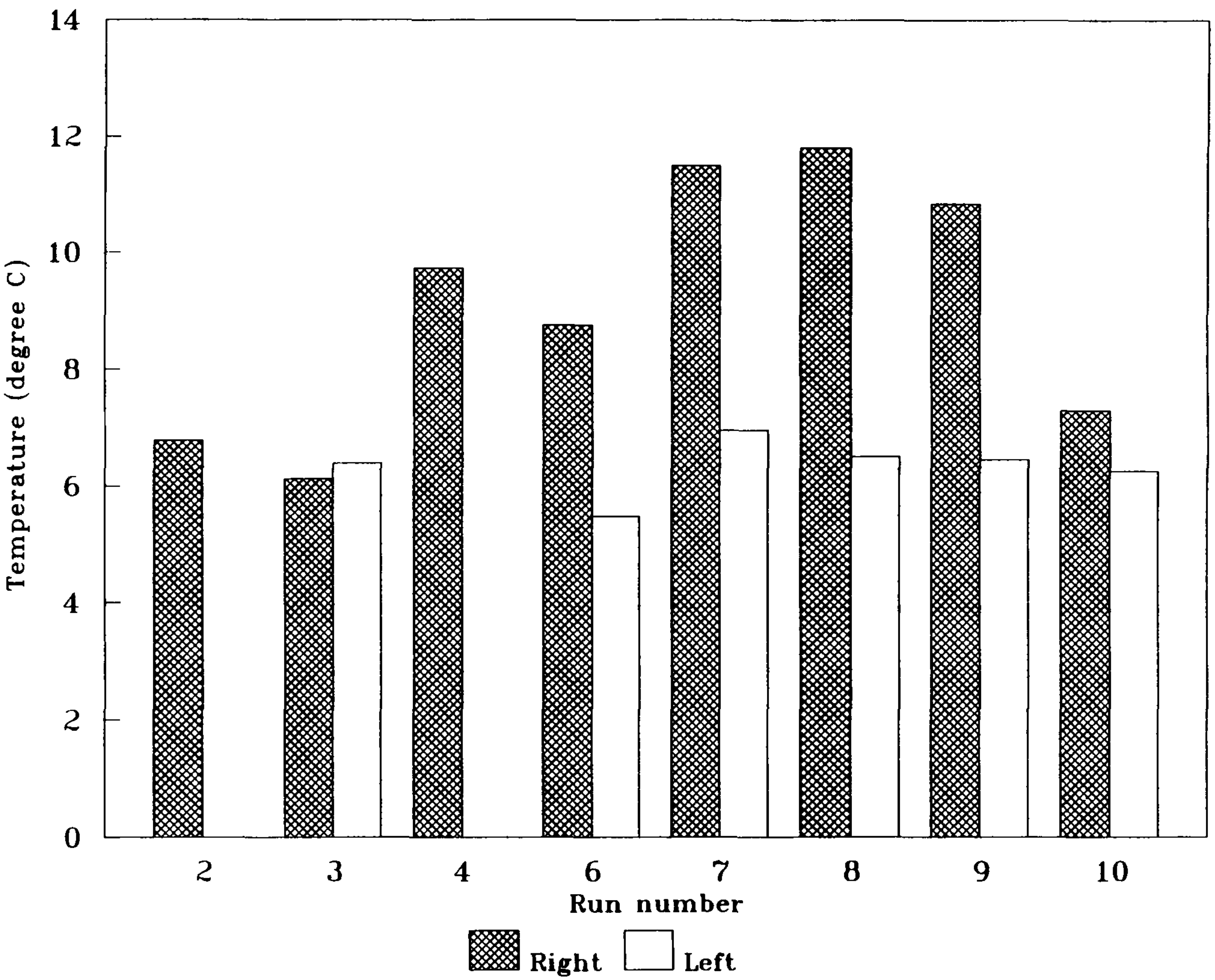

Figure 11. Mean liquid coolant temperature difference, 105°F.

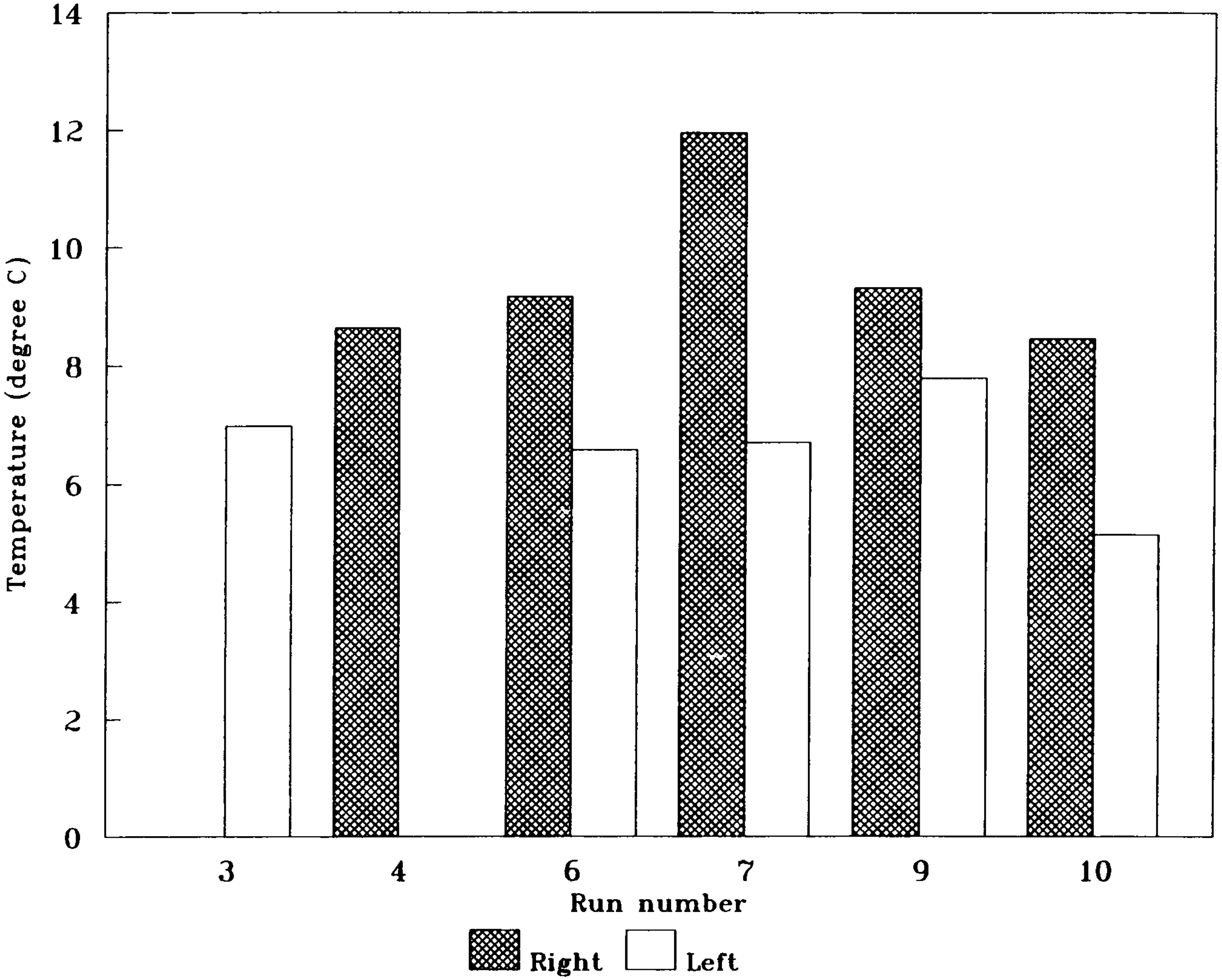

Figure 12. Mean liquid coolant temperature difference, 95°F.

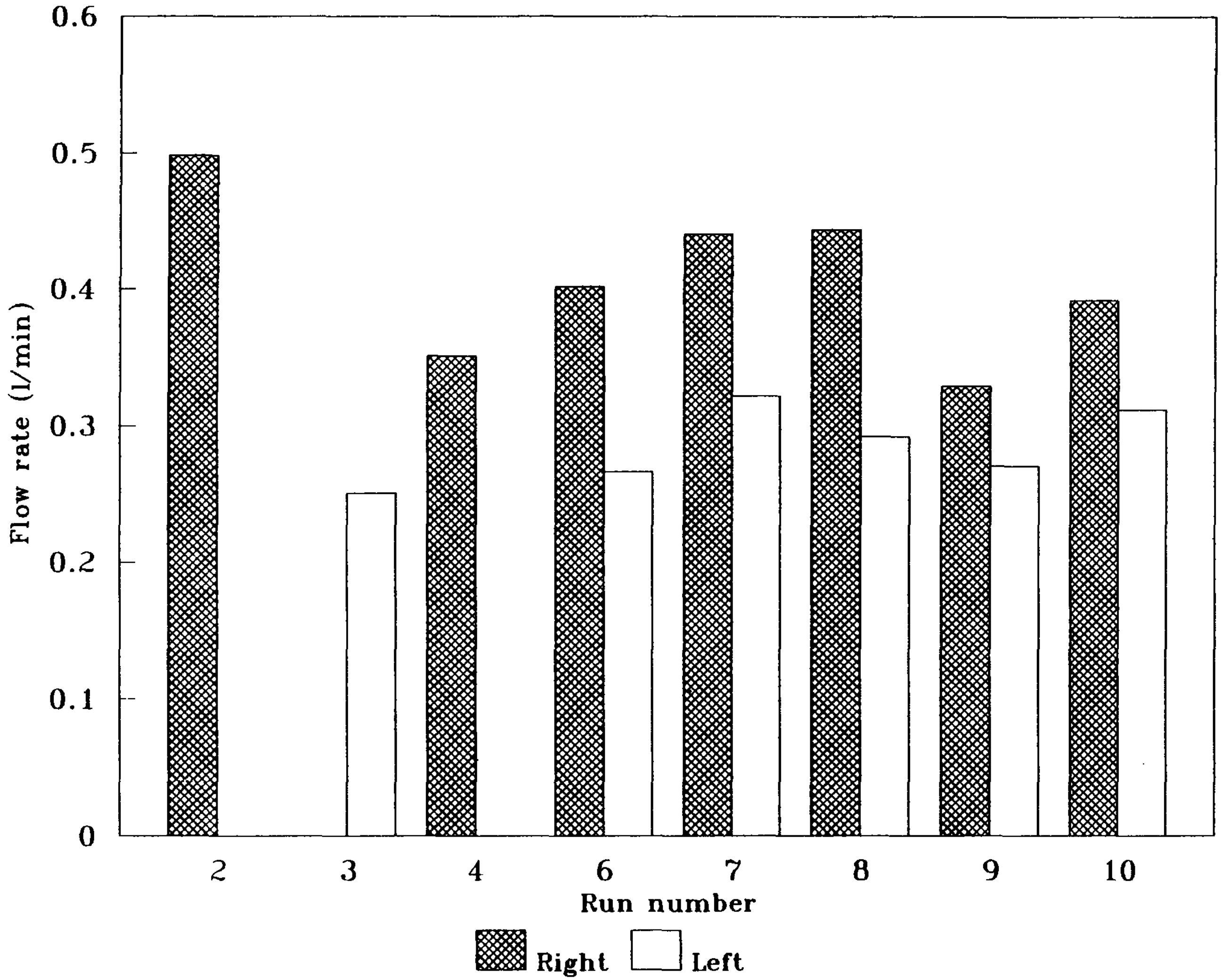

Figure 13. Mean liquid flow rate, 105°F.

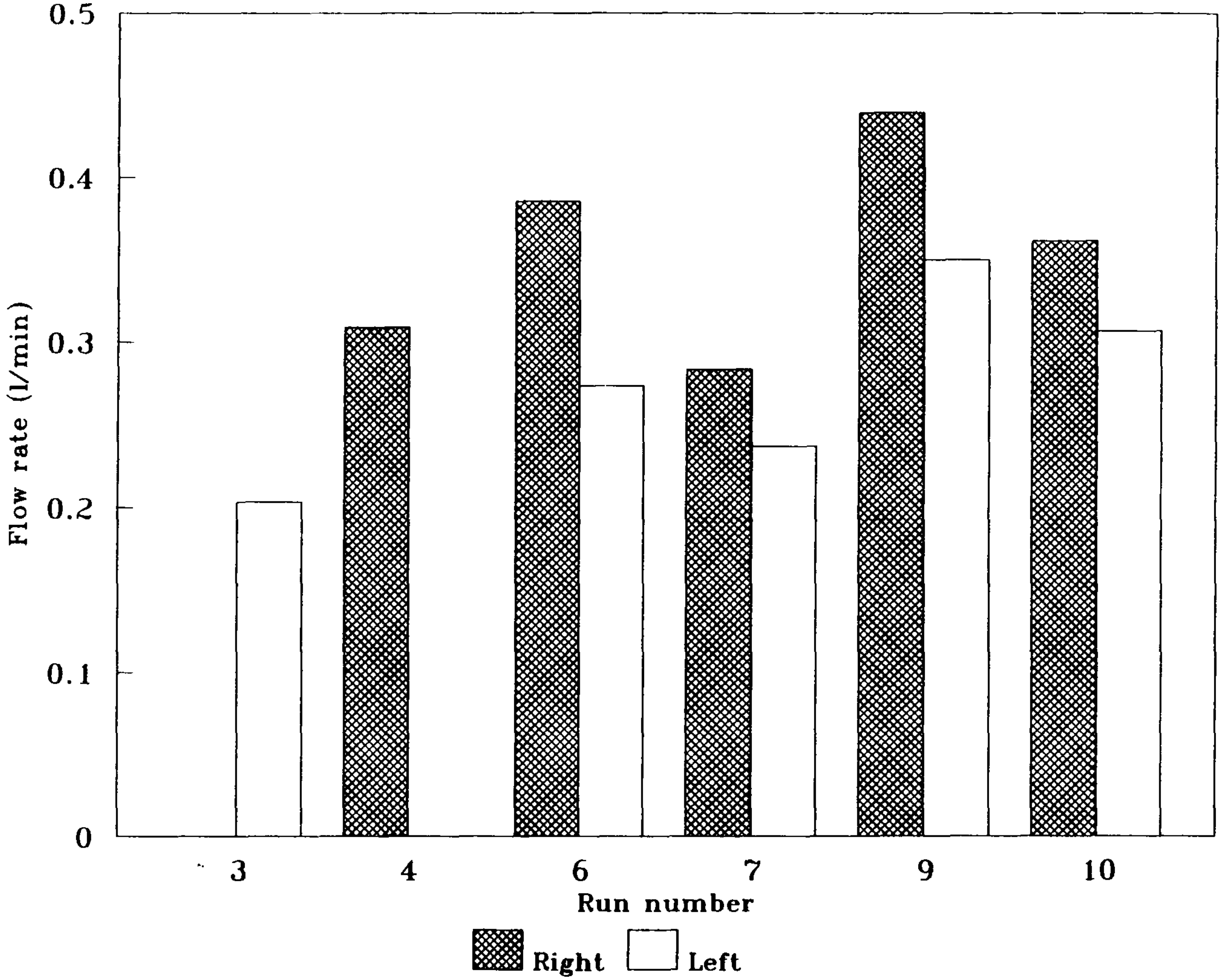

Figure 14. Mean liquid flow rate, 95°F.

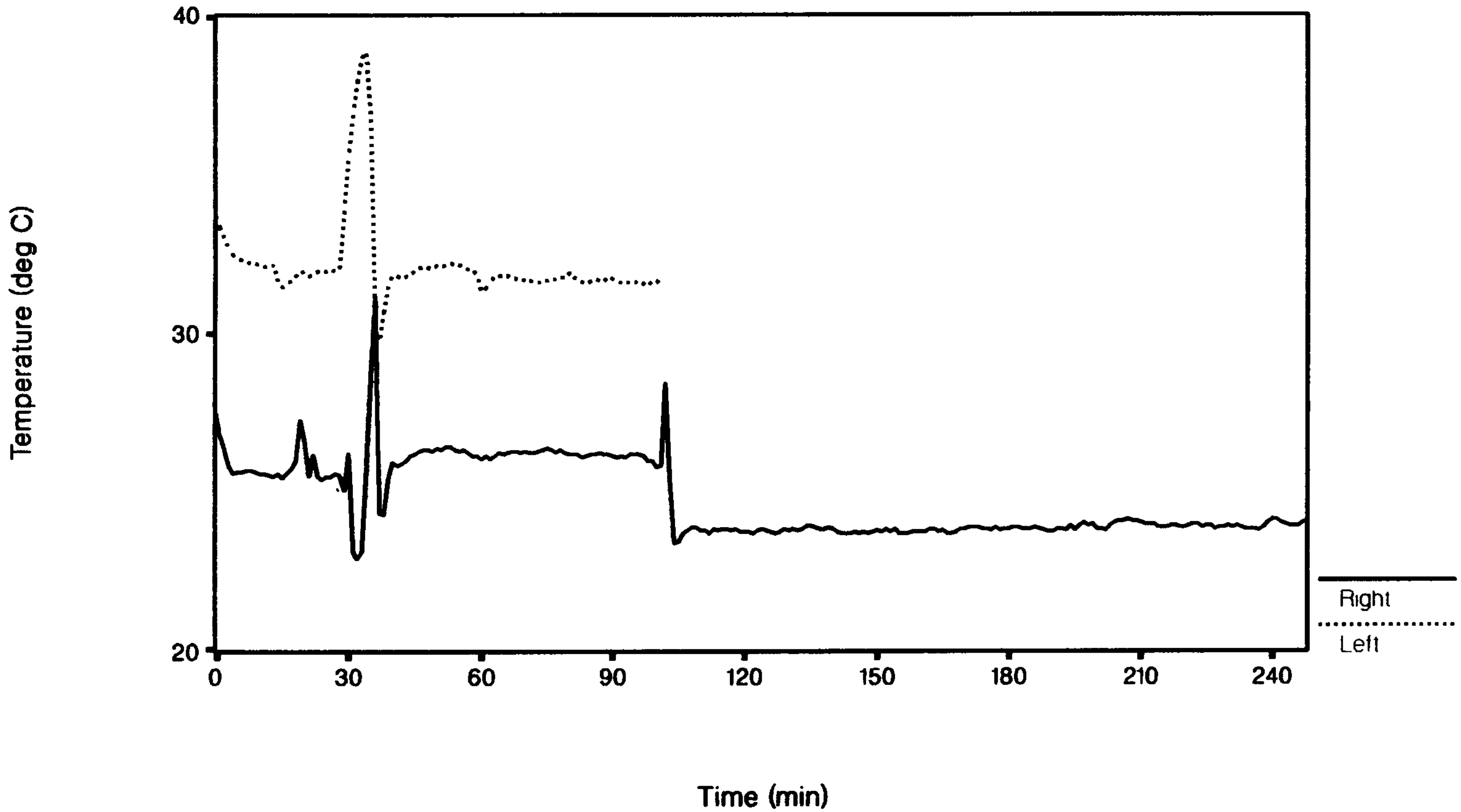

Figure 15. liquid coolant temperature, run 8, 105°F.

Table 6.
liquid cooler performance (watts).

Run	95°F Left	95°F Right	Total	105°F Left	105°F Right	Total
2				164	235	399
3	105	208	313	110	193	303
4	100	185	285	129	237	366
6	125	246	371	101	208	309
7	140	278	418	142	352	494
8	125	304	429	132	343	475
9	193	277	470	127	287	414
10	109	213	322	113	199	312

Air cooler

The air cooler proved much more problematical. The separate blower which was required because the filter box was not used had been supplied with a faulty control card. A new one was obtained by MRI and replaced by USAARL. From the start of the study, there was a big problem with condensation leaking from the unit. Very little water collected from the drainage tubes, despite modification to MRI's instructions. Externally mounted water separators provided by MRI were tried on several runs, but made little, if any difference, to the problem, and were discarded because of the difficulty in supporting them safely. Water tended to collect in all the hoses, sprayed from the reduction valves in the two spare outlets, and seeped from the bottom of the two units. There were no complaints from the subjects about water in the processed air stream. However, water had to be continually mopped from the floor of the simulator to prevent damage. While investigating the condensation problem, MRI also discovered a malfunction in the cooler due to the failure of a redundant fuse (between runs 5 and 6). From the low current consumption, they concluded that the unit was only operating at half its designed efficiency. It was removed to MRI's own facility for repair and testing. Following repair, the power consumption returned to normal levels, but the rate of cooling did not increase. MRI then concluded the problem lay in incorrect setting of the blower flow rate. The rate was measured and found to be 55 cfm instead of the design level of 48 cfm. The dwell time in the cooler would, therefore, be insufficient to provide optimum cooling, although the increased flow rate would compensate for this to some extent by increasing the rate of evaporation of perspiration. This also was corrected (between runs 6 and 7) and improved performance a little.

A further reason for altered performance was due to moving the site of the blowers (between runs 3 and 4). Originally, they were mounted on a platform between the two pilots' seats (Figures 5 and 6). Because of the lack of space, they could not be put into position until after the pilots had taken their seats, making access virtually impossible to the subjects during flight, and emergency extraction of subjects unacceptably delayed. The solution was to build a platform high in the back of the cockpit where the units could be mounted more conveniently (Figures 16 and 17). In the former position, air flow around the coolers was relatively unrestricted. In the latter, some recirculation of the 800 cfm of hot air from the cooler fan into the air inlet ducts on the side of the unit occurred. There also was some ingress of cold air and moisture from the two spare outlets. Air temperatures at the center of the inlet vents on each of the four sides were measured on one occasion for each condition, and are recorded in Table 7, together with the temperature of the hot air being rejected by the cooler fan.

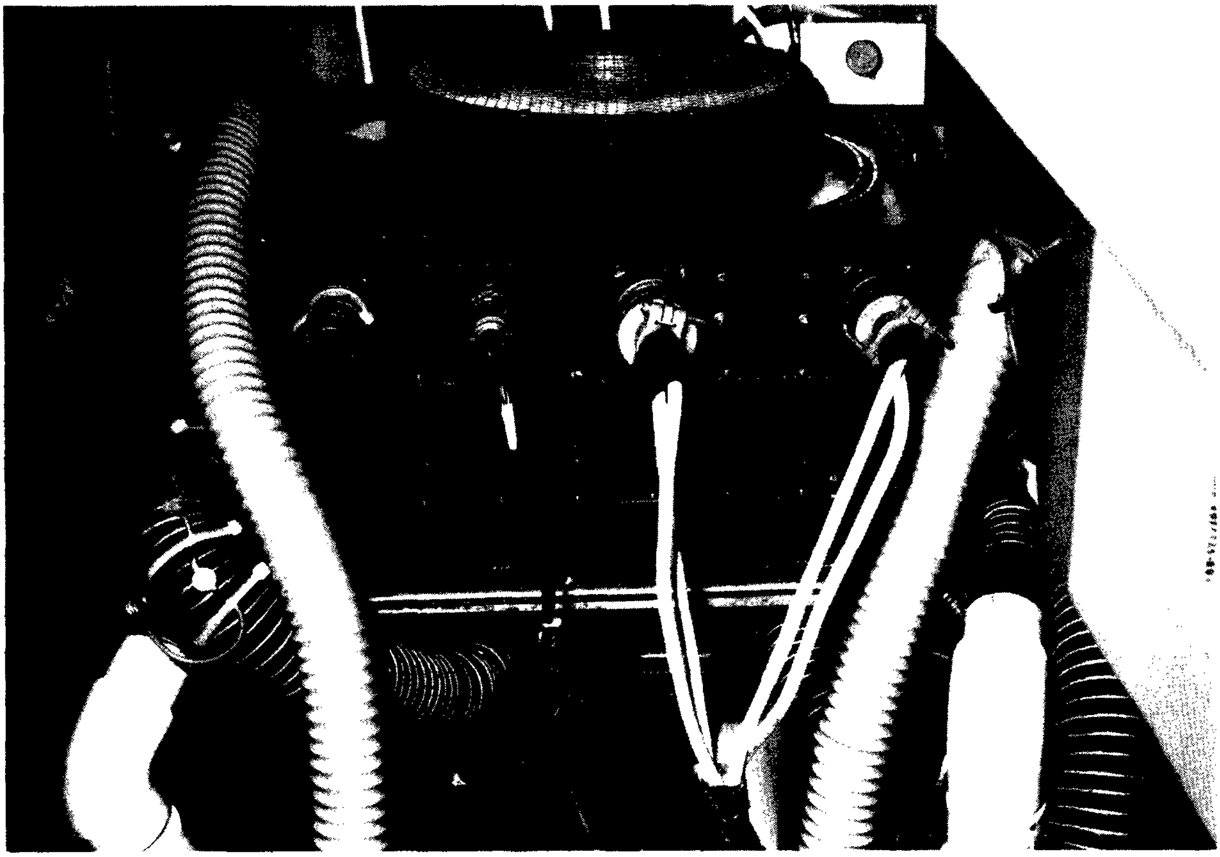

Figure 16. Air cooler mounted on shelf.

Yet another problem which occurred with the air cooler was manifested as intermittent, brief slowing of the cooler fan during the 95°F run for subjects 16 and 17 (run 9). Examination of the unit revealed contamination of the control circuits with water. The unit was dried and cleaned, and precautions were added to further attempt to protect the unit from water ingress.

During the last run of the study (run 10), the cooler blowers failed to operate at the beginning of one of the runs. The condition was changed to one with no cooling to salvage the run. The failure was due to a fault in the blower control circuit in the cooler unit. At the same time, it was discovered that the cooler could not be switched off to allow its use in the vent mode. It too was rectified by bypassing the defective components. The unit finally failed completely after 5 hours of the last air condition.

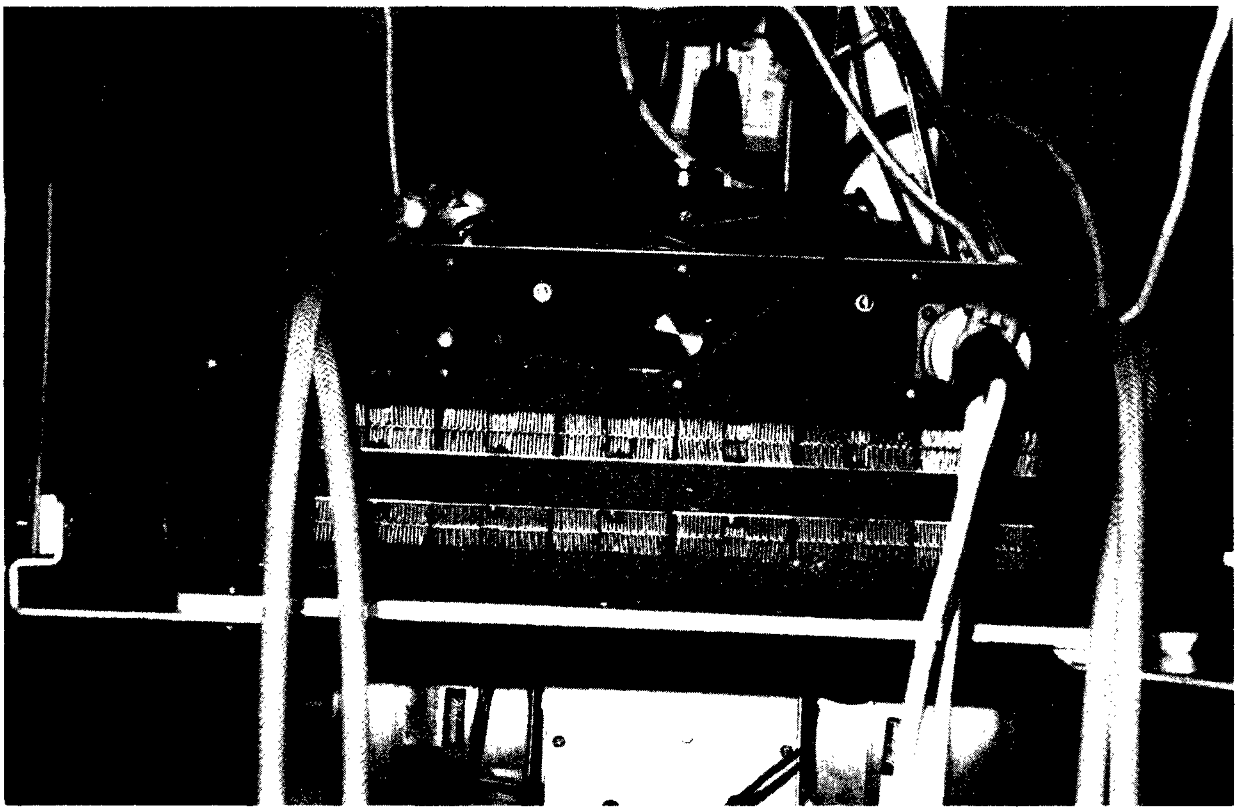

Figure 17. Liquid cooler mounted on shelf.

Table 7.
Cooler inlet and exhaust temperatures
(degrees Centigrade).

	Condition			
Site	105° air	95° air	105° liquid	95° liquid
Inlet 1	38.5	33.8	41.6	35.3
Inlet 2	39.2	32.6	41.7	35.9
Inlet 3	43.2	37.9	41.5	35.4
Inlet 4	42.3	40.8	42.1	36.0
Fan	46.5	40.8	48.5	42.2

In general, MRI personnel were prompt at responding to specific requests for help as problems arose, once their contract was modified by AVSCOM to do so. However, maintenance actions to ensure equipment performance on site proved somewhat deficient. Completion of maintenance was often followed by the discovery of a new problem arising after the MRI personnel had left.

Figures 18 and 19 show the mean coolant air temperature for both conditions. Figures 20 and 21 contain the difference in temperature between the cooled air and the environmental air. Figures 22 and 23 are examples of air temperature from individual runs which demonstrate the degree of variability even within subjects.

The data for the 105 vent run are illustrated in Figures 24 and 25. The difference in temperature between the cooler output air and the environment now is positive, that is, there was up to 6°C of heating in the blower.

Calculations of the actual cooling capacity (watts) of the air unit were more difficult because of the lack of adequate flow rate data. Those in Table 8 were produced by MRI on selected data, by comparing enthalpy at vest inlet and outlet using an assumed flow rate of 12 gpm, a vest efficiency of 63 percent and the measured skin temperatures. The air vest is designed to produce 250 watts at both temperature conditions.

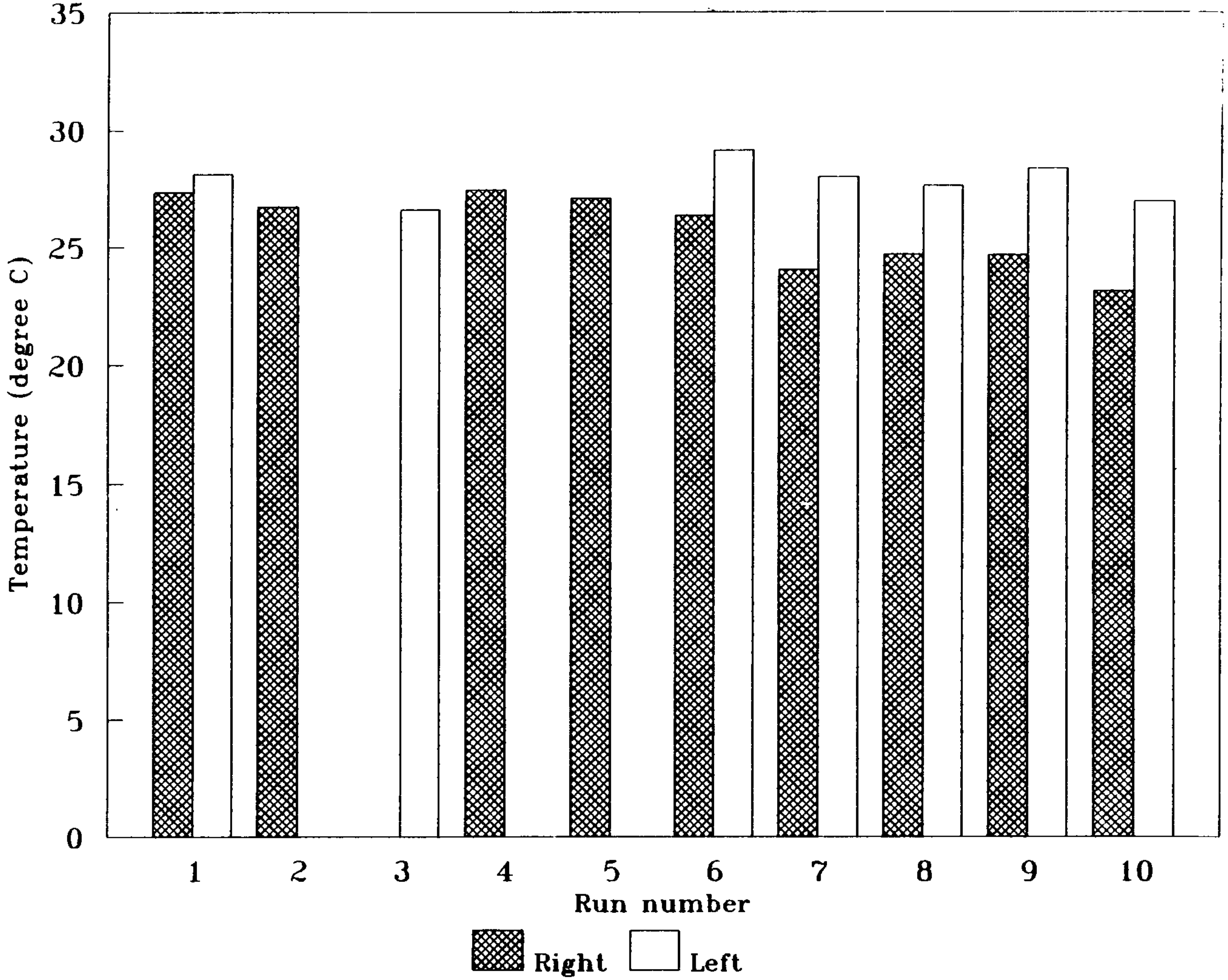

Figure 18. Mean air coolant temperature, 105°F.

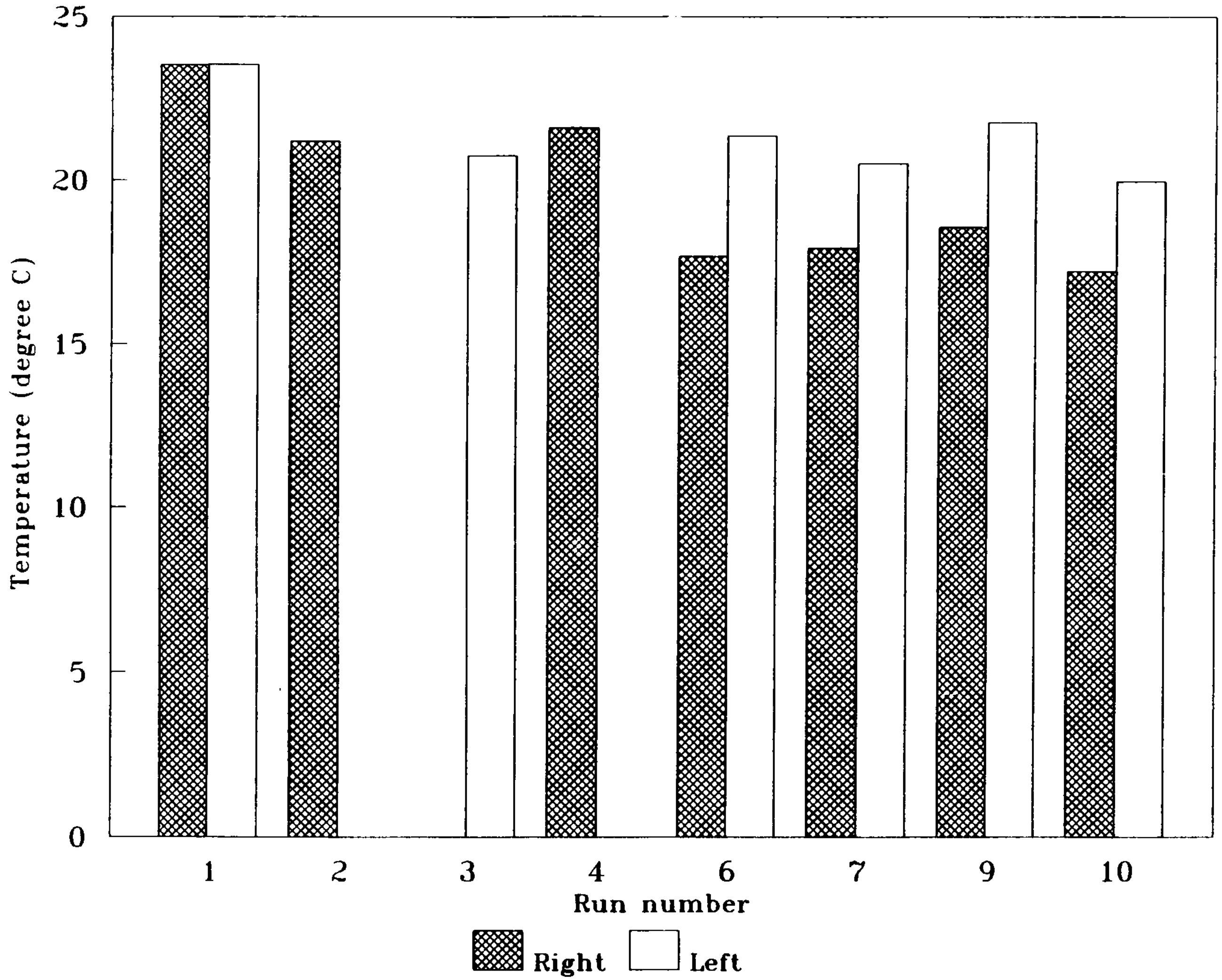

Figure 19. Mean air coolant temperature, 95°F.

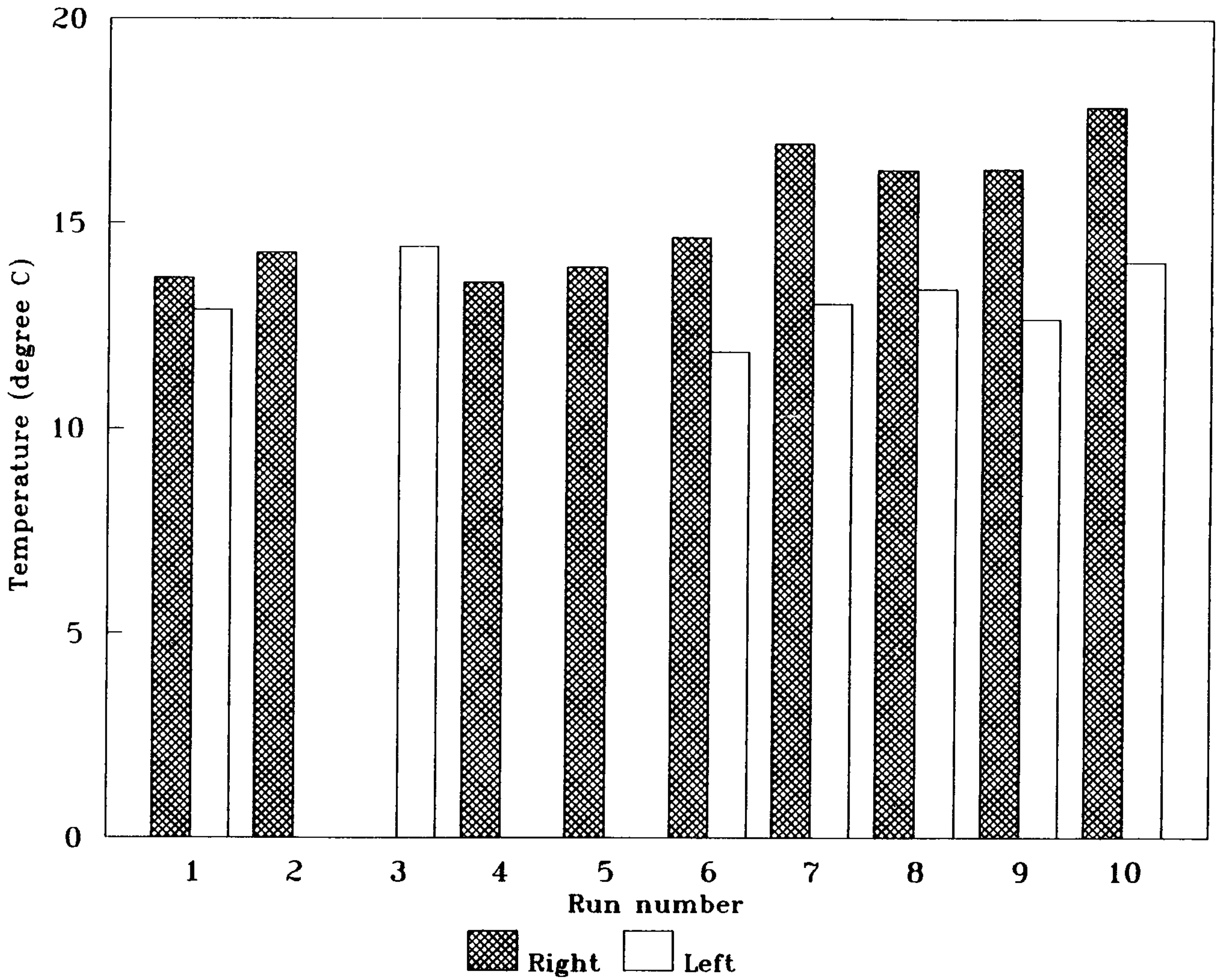

Figure 20. Mean difference between coolant air and environment, 105°F.

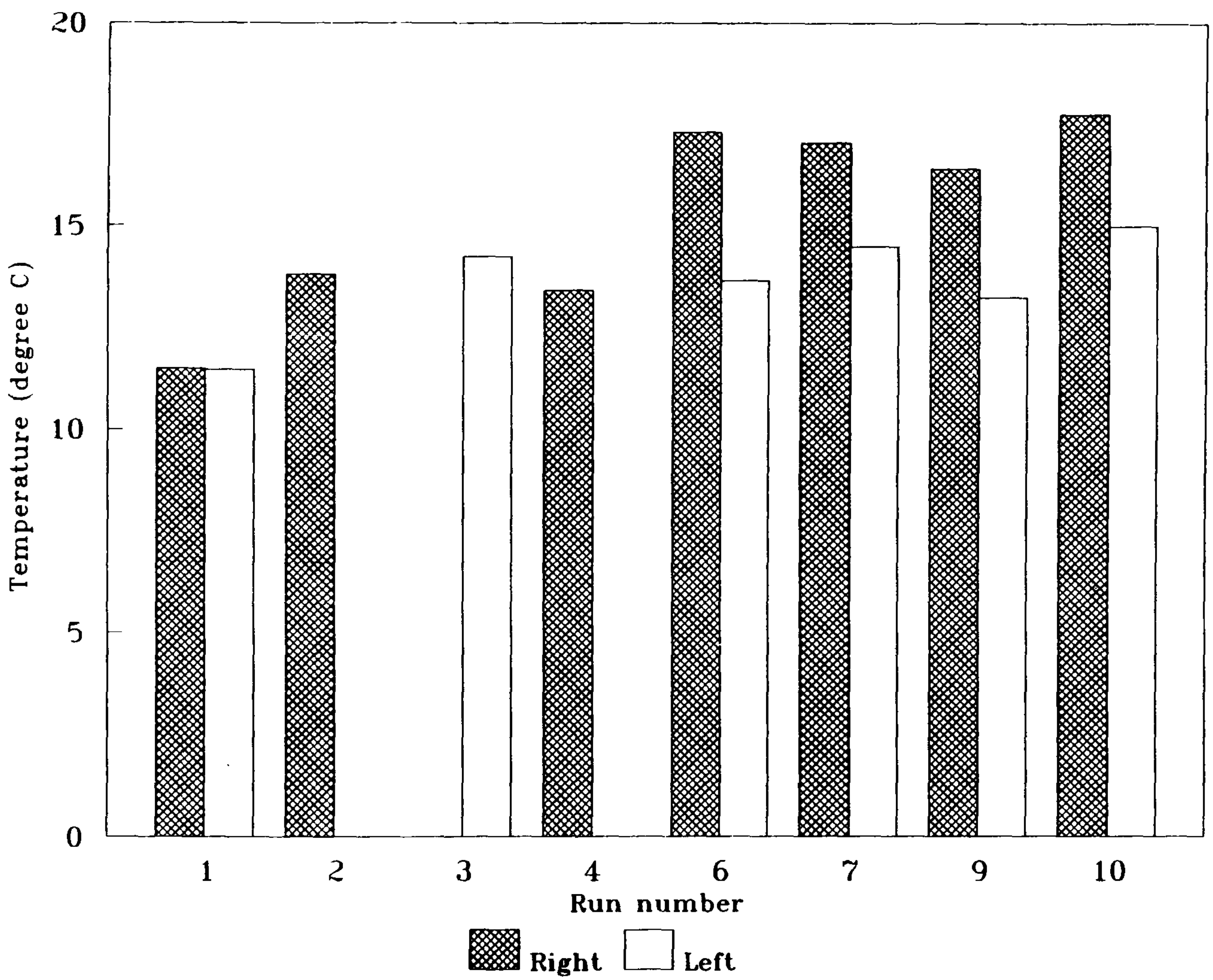

Figure 21. Mean difference between coolant air and environment, 95°F.

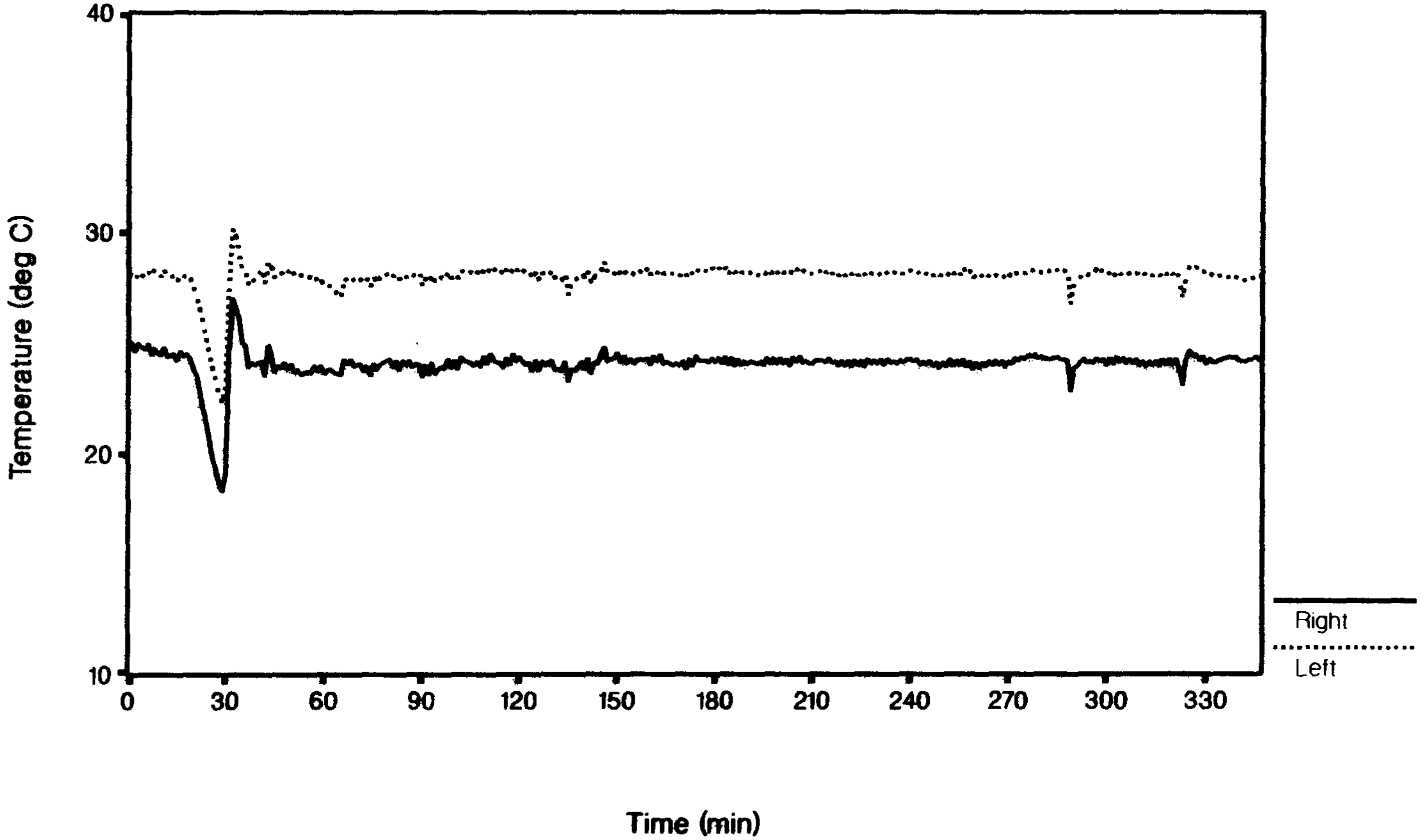

Figure 22. Air coolant temperature, run 7, 105°F.

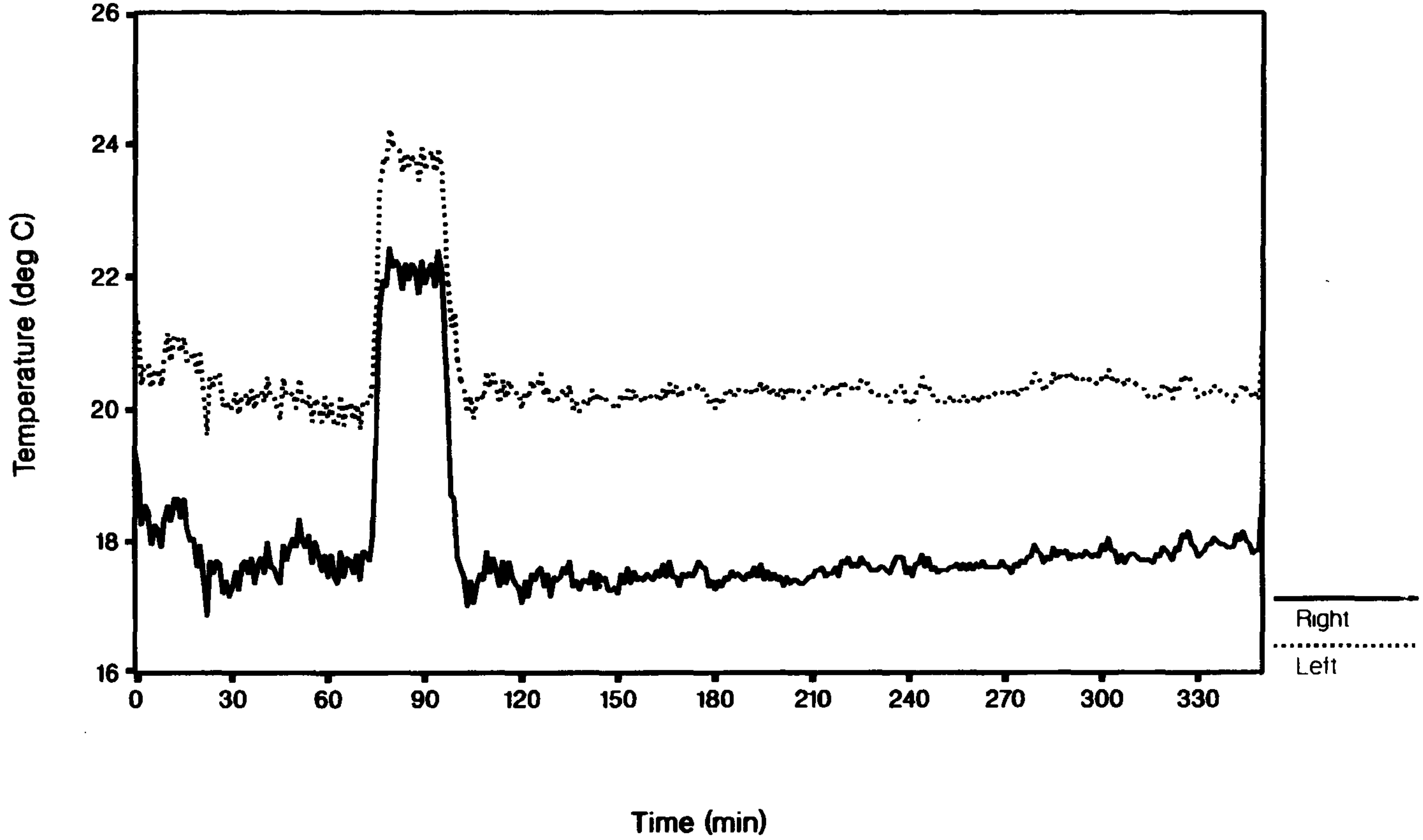

Figure 23. Air coolant temperature, run 7, 95°F.

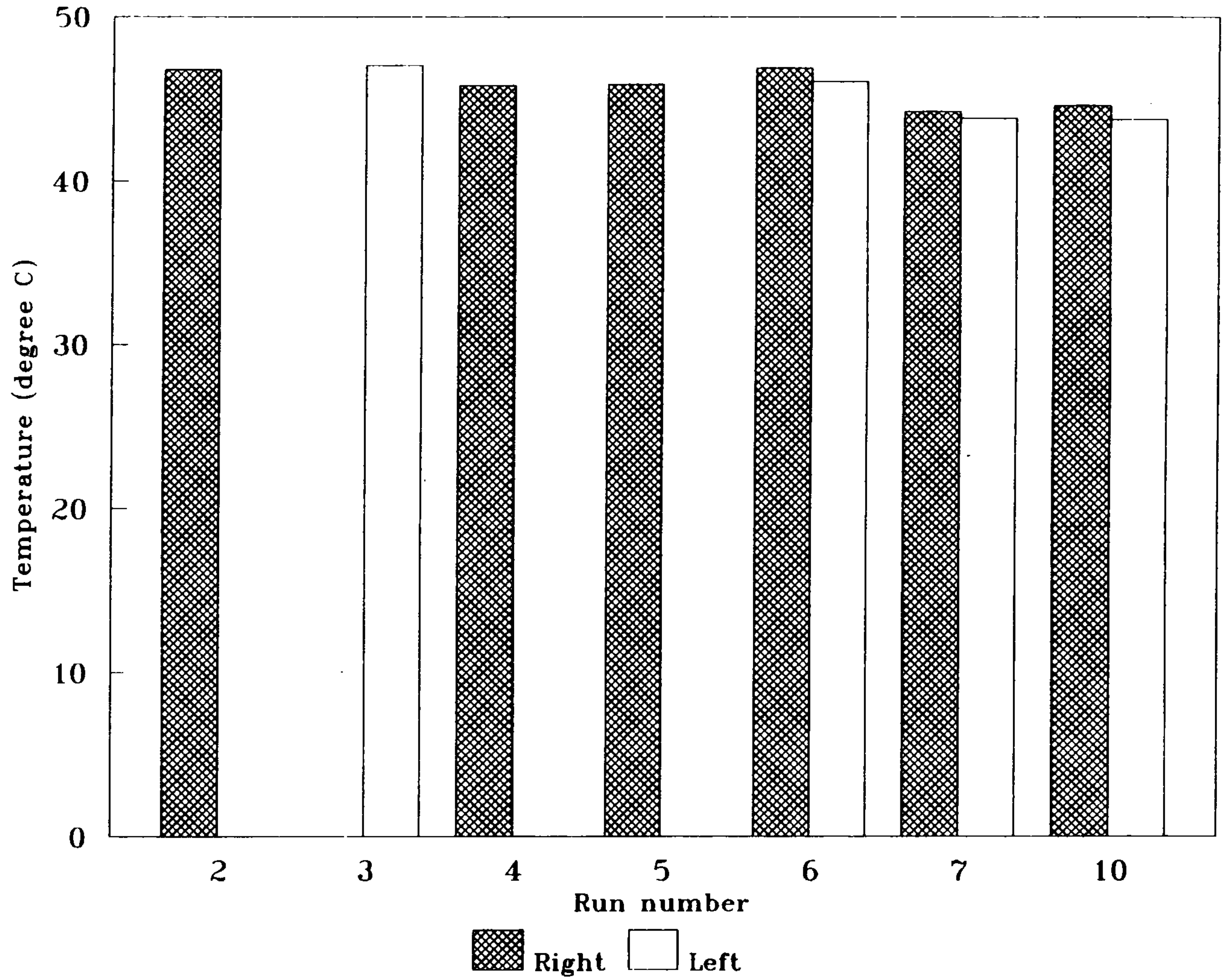

Figure 24. Mean air coolant temperature, 105 vent.

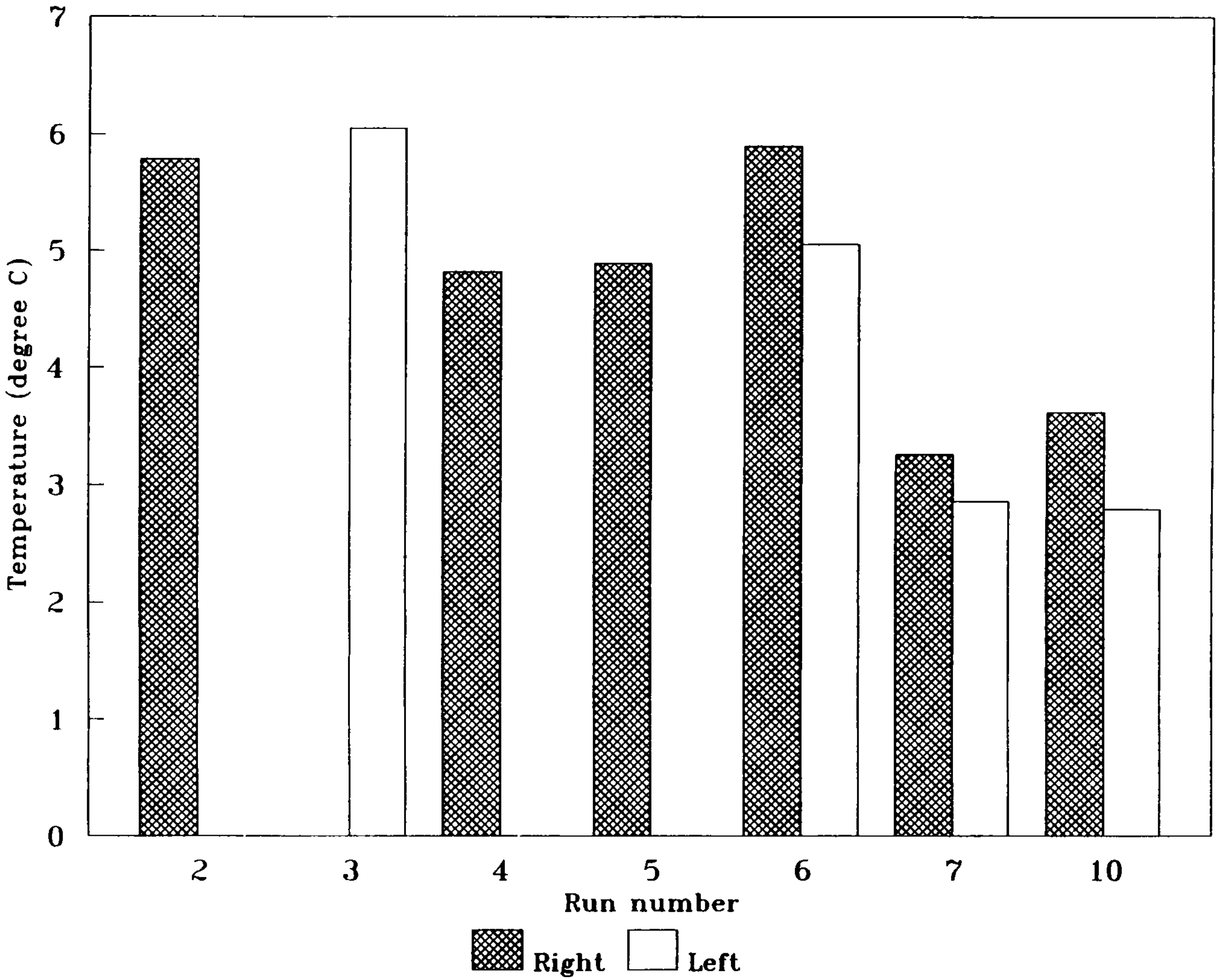

Figure 25. Mean difference between cooler air temperature and environment, 105 vent.

Table 8.
Air cooler performance (watts).

	95°F			105°F		
Run	Left	Right	Total	Left	Right	Total
1	225	231	456	195	179	374
2	293	289	582	194	192	386
3	288	300	588	237	180	417
4	284	251	535	180	196	376
5	185	213	398	142	211	353
6	267	276	543	243	194	437
7				271	202	473

Flight performance

A concern in analyzing the flight data in the Thornton et al., study (1992) was the validity of considering the pilot and copilot as one population for analysis of the flight performance data. They performed the same maneuvers, but after different lengths of exposure to the various conditions, the pilots performing individual maneuvers some 30 minutes before the copilots. The issue was complicated further in this study by the differences in cooler performance between the two sides. The difference in performance was tested by comparing the data for the two groups. There were 17 of 37 maneuver parameters (when collapsed across condition and AFCS) in which there was a significant difference in performance between the pilot and copilot. For 11 of them, the pilot had the better performance, and for 6, the copilot. This reflects the better cooler performance on the pilot's side.

A problem new to the current study was the validity of using pilots not qualified on the UH-60. A separate study is underway to consider this factor in more detail. The current data were compared for the two groups, with five non-UH-60 pilots and 11 UH-60 pilots. The effect of seat position was balanced with three of the five non-UH-60 pilots serving as pilots and two as copilots. There were 15 of 37 maneuver parameters in which the UH-60 pilots performed significantly better, 2 in which the non-UH-60 pilots had lower error scores.

The mean scores for each maneuver parameter also were ranked in the ANOVA by subject. Of the 55 parameters (not collapsed across AFCS), for 21 a non-UH-60 pilot had the worst score, slightly over the one-third that would be expected by chance.

Conversely, non-UH-60 pilots had the best score on only eight occasions. One confounding variable is the experience of the two groups. The average total flight time for the UH-60 pilots is 1707 hours, and for the non-UH-60 pilots 1890 hours. This apparent similarity is, however, disguised by the presence of one very experienced aviator in the non-UH-60 group who had a total of 8200 hours. The next most experienced non-UH-60 pilot had only 700 hours. As most of the statistical comparisons are within subjects, this factor is not considered a problem in this study, but probably would be a concern for studies using intersubject comparisons.

The simulator flight performance results are described separately for each of the nine maneuver types listed in Table 4. In each case, the data used for the analyses are the RMS errors appropriate to that maneuver. The summary statistics for the data are shown in tabular form. Group numbers 2 to 8 refer to the 7 test conditions in the order 95 nil, 95 air, 95 liquid, 105 nil, 105 air, 105 vent, and 105 liquid.

The first two graphs in each case plot RMS error against maneuver number for the four test conditions, the first for the three 95°F conditions, the second for the four 105°F conditions. Points are plotted for each occurrence of the maneuver in a flight for all three flights. For conditions where there are five maneuver parameters, the graph for slip RMS error is omitted from the graphs to save space, though it is still included in the table and discussion.

The third graph is a bar chart of mean RMS error for each of the test conditions. For the upper airwork maneuvers that were performed both with and without the AFCS, these are grouped onto two separate graphs.

The units used in recording the various flight parameters are in Table 9.

Table 9.
Flight parameter units.

Heading	degrees
Rate of turn	degrees per minute
Altitude	feet
Airspeed	knots
Roll	degrees
Rate of climb	feet per minute
Rate of descent	feet per minute
Slip	degrees

A summary of the flight performance data statistics is shown in Table 10. In the table, liquid is abbreviated to liq., vent to ven. The error for the upper airwork maneuvers at 105 nil is not included because so few subjects stayed in the simulator long enough to complete any of the maneuvers. There are 55 combinations of maneuver and parameter, each of which has a mean RMS error score for each of the 7 conditions. The convention used for indicating significant differences between groups is that used by SAS in their multiple comparisons testing, in which the same letter denotes means that are not significantly different. In those lines which contain different letters, the means grouped as A are always higher than those grouped as B, B higher than C, and so on. The alpha value was set at 0.05, and significance levels of <0.01 are indicated by an asterisk. With such a large number of statistical tests the chances of a Type I error are quite large and the more conservative may wish to consider only those cases with the higher significance level.

There are 7 cases in which the performance error was significantly lower for 95 liquid than 95 nil, and 7 in which 95 air produced a better performance. There were no significant differences between the flight performance for the two cooling systems at 95°F.

There are 18 cases in which the error was significantly lower for 105 liquid than 105 vent and 2 in which performance was significantly better for 105 vent. There were 13 cases in which 105 air produced significantly better performance than 105 vent. There were 3 cases at 105°F in which the performance with the liquid system was significantly better than the air system.

To allow for the poorer performance of the air cooler unit in the early stages of the study, a separate comparison was made using only subjects 12 onward. This is summarized in Table 11. There are no differences in flight performance between the cooler systems at 95°F, but at 105°F, there are 11 examples of the air system producing significantly better flight performance than the liquid. A comparison was made of subjects 3-11 with 12-19 without separation for AFCS, (37 maneuver parameters) which showed that the later subjects had significantly better performance on 9 occasions, the earlier subjects on 15. A further confounding effect in addition to cooler performance, is that there were more non-UH-60 pilots in the second group, and this factor appears to have the overriding influence.

Analysis of variance was performed on the data collapsed across condition for the effect of AFCS for those maneuvers that were performed both with and without it, (right standard rate turn, left standard rate turn, and straight and level). There was a significant difference between the 2 measures for 13 of the

Table 10.
Flight performance data statistical summary.

Maneuver	Parameter	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
1 Navigation	Heading*	C	C	BC	BC	AB	A	BC
	Altitude*	B	B	B	A	A	A	A
	Slip	B	B	B	A	B	B	B
	Roll	B	B	B	A	B	B	B
2a Hover (10 ft)	Altitude	BC	BC	C	A	BC	ABC	AB
	Heading	A	A	A	A	A	A	A
2b Hover (40 ft)	Altitude*	B	B	B	AB	B	A	B
	Heading	A	A	A	A	A	A	A
3a Hov turn (10 ft)	Altitude*	B	B	B	A	B	B	B
3b Hov turn (40 ft)	Altitude*	CD	D	D	A	ABC	AB	BCD
4a Right standard rate turn (AFCS in)	Rate of turn	A	AB	B		A	A	A
	Altitude	AB	AB	B		AB	AB	A
	Airspeed	AB	BC	C		AB	AB	A
	Roll	A	A	A		A	A	A
	Slip	BC	AB	BC		ABC	C	A
4b Right standard rate turn (AFCS out)	Rate of turn	B	B	B		B	A	B
	Altitude*	BC	C	C		AB	A	BC
	Airspeed*	B	BC	C		B	A	B
	Roll*	AB	B	B		B	A	B
	Slip	A	A	A		A	A	A
5 Left descending turn (AFCS out)	Rate of turn*	ABC	C	C		BC	A	AB
	Airspeed	A	A	A		A	A	A
	Roll*	AB	B	B		AB	A	A
	Descent Rate	A	A	A		A	A	A
	Slip	A	A	A		A	A	A

*$p<0.01$

(continued)

Table 10 (Continued).
Flight performance data statistical summary.

Maneuver	Parameter	Condition 95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
6 Descent (AFCS out)	Heading*	B	B	AB		A	A	B
	Airspeed*	B	C	C		B	A	B
	Roll*	C	D	D		B	A	CD
	Descent Rate*	B	C	C		B	A	B
	Slip*	C	BC	BC		A	A	AB
7a Left standard rate turn (AFCS in)	Rate of turn	BC	BC	C		ABC	A	AB
	Altitude	AB	B	AB		A	AB	A
	Airspeed	A	A	A		A	A	A
	Roll	AB	AB	B		AB	AB	A
	Slip	A	A	A		A	A	A
7b Left standard rate turn (AFCS out)	Rate of turn*	AB	AB	B		A	A	A
	Altitude	A	A	A		A	A	A
	Airspeed*	B	B	B		B	A	B
	Roll*	ABC	BC	C		AB	ABC	A
	Slip	A	A	A		A	A	A
8 Climb (AFCS in)	Heading	A	A	A		A	A	A
	Airspeed*	AB	C	BC		AB	AB	A
	Roll*	B	B	B		B	A	B
	Climb rate*	B	B	B		AB	A	A
	Slip	A	A	A		A	A	A
9a Straight and level (AFCS in)	Heading	A	A	A		A	A	A
	Altitude	AB	B	B		A	AB	A
	Airspeed*	BC	C	C		AB	BC	A
	Roll	B	B	B		AB	A	B
	Slip*	AB	AB	B		AB	A	B
9b Straight and level (AFCS out)	Heading	AB	C	BC		ABC	A	BC
	Altitude*	AB	C	BC		B	A	B
	Airspeed*	B	B	B		B	A	B
	Roll*	B	C	C		B	A	C
	Slip	BC	C	BC		AB	A	ABC

*$p<0.01$

Table 11.
Flight performance data statistical summary, subjects 12+.

Maneuver	Parameter	Condition 95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
1 Navigation	Heading	A	A	A	A	A	A	A
	Altitude*	BC	C	C	A	B	BC	B
	Slip	BC	C	ABC	A	BC	AB	AB
	Roll	B	AB	AB	AB	AB	AB	A
2a Hover (10 ft)	Altitude	A	A	A	A	A	A	A
	Heading	A	A	A	A	A	A	A
2b Hover (40 ft)	Altitude*	C	BC	C	AB	BC	A	C
	Heading	AB	AB	B	AB	AB	A	A
3a Hov turn (10 ft)	Altitude*	B	B	B	A	B	B	B
3b Hov turn (40 ft)	Altitude*	B	B	B	A	B	B	B
4a Right standard rate turn (AFCS in)	Rate of turn	B	AB	B		AB	A	AB
	Altitude*	B	B	B		B	B	A
	Airspeed*	BC	C	C		BC	B	A
	Roll	B	AB	B		AB	A	AB
	Slip	AB	AB	B		B	B	A
4b Right standard rate turn (AFCS out)	Rate of turn	AB	B	B		B	A	AB
	Altitude	AB	B	B		AB	A	AB
	Airspeed*	AB	BC	C		BC	A	A
	Roll	AB	B	B		B	A	AB
	Slip	B	B	B		B	A	AB
5 Left descending turn (AFCS out)	Rate of turn	A	A	A		A	A	A
	Airspeed	A	A	A		A	A	A
	Roll	A	A	A		A	A	A
	Descent Rate	B	B	B		AB	B	A
	Slip	A	A	A		A	A	A

*$p<0.01$

(continued)

Table 11 (Continued).
Flight performance data statistical summary, subjects 12+.

Maneuver	Parameter	Condition						
		95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
6 Descent (AFCS out)	Heading	B	B	B		AB	A	AB
	Airspeed*	C	C	C		C	A	B
	Roll*	BC	C	BC		B	A	B
	Descent Rate*	B	C	C		BC	A	A
	Slip*	C	BC	ABC		A	A	AB
7a Left standard rate turn (AFCS in)	Rate of turn	AB	AB	B		AB	AB	A
	Altitude	B	B	B		AB	AB	A
	Airspeed	AB	B	AB		AB	AB	A
	Roll*	AB	AB	B		AB	AB	A
	Slip	A	A	A		A	A	A
7b Left standard rate turn (AFCS out)	Rate of turn	B	B	B		AB	A	A
	Altitude	AB	B	B		AB	AB	A
	Airspeed	BC	C	C		ABC	A	AB
	Roll	B	B	B		AB	A	A
	Slip	A	A	A		A	A	A
8 Climb (AFCS in)	Heading	AB	B	AB		B	AB	A
	Airspeed*	BC	C	BC		BC	B	A
	Roll*	BC	C	BC		BC	A	B
	Climb rate*	B	B	B		B	B	A
	Slip	A	A	A		A	A	A
9a Straight and level (AFCS in)	Heading	A	A	A		A	A	A
	Altitude*	B	B	B		B	B	A
	Airspeed*	B	B	B		B	B	A
	Roll	B	B	AB		AB	A	AB
	Slip	A	A	A		A	A	A
9b Straight and level (AFCS out)	Heading	B	B	B		AB	A	AB
	Altitude*	AB	C	BC		BC	A	AB
	Airspeed*	BC	C	BC		BC	A	B
	Roll*	B	B	B		B	A	B
	Slip	C	BC	BC		A	AB	ABC

*p<0.01

15 combinations of maneuver and parameter. For 11 of them, the error was greater without the assistance of the AFCS, but in 2 cases the error was paradoxically greater when the AFCS was used.

The effect of flight number on performance also was tested using ANOVA. Collapsed across condition, there were six cases in which there was a difference between flights. Paradoxically, in all of these cases the worst performance was during the first run. A separate ANOVA was undertaken on the 95 nil and 105 vent data in the assumption that these conditions would produce the greatest effects on performance. For 95 nil, there were only three cases in which there was a significant difference in performance between runs. In two, the performance was worst on the third run, in one on the first. For 105 vent, there were four cases, all with the worst performance on the third run.

Table 12 lists the seven parameters used in scoring, and shows the number of times each gave a positive or negative result, positive indicating that there was a statistically significant difference between two of the conditions, negative indicating no significant difference. This gives a crude indication of the sensitivity of the parameters used in the test.

Table 12.
Summary of Parameter Sensitivity.

Parameter	Positive	Negative
Heading	3	4
Altitude	10	1
Airspeed	7	2
Roll	9	1
Rate of turn	5	0
Vertical speed	3	0
Slip	5	5

Navigation

Navigation was scored for the four relevant parameters of heading, altitude, slip, and roll. Figure 26 shows the RMS error plotted against maneuver number (three runs of four maneuvers) for the 95°F conditions, Figure 27 for the 105°F conditions. The large variability in the 105 vent data is due to the effect of rapid decrease in the number of survivors contributing to the data pool. The data beyond maneuver eight result from an N of one.

Collapsing across condition, there were no significant differences between the three run numbers. When the 95 nil data were examined in isolation, there were still no significant differences between runs. For the 105 vent data, there were no significant differences for heading and altitude, but for slip and roll, the third run produced significantly poorer performance than the other two.

Figure 28 demonstrates the mean of the RMS error for all navigation maneuvers in each condition and each subject. For heading, the error in the 105 vent condition was significantly worse than all others except 105 air. The error for 105 air was significantly greater than all other conditions except 105 vent. The 95 air and 95 liquid runs produced statistically smaller errors than all other conditions. For altitude, the errors for all the 105°F conditions were statistically greater than all the 95°F conditions. For slip and roll, the 105 nil error was significantly greater than all other conditions. The summary statistics are shown in Table 13.

When the data were analyzed for the first run alone to assess the results of the 105 nil condition, the differences between error rates for heading disappeared. For altitude, the 105 nil results were significantly worse than the three 95°F conditions, and the 105 vent error was significantly higher than 95 air. For slip, the error for 105 nil was significantly higher than 95 liquid and 105 vent. For roll, the 105 nil error was significantly greater than 105 vent and the two 95°F cooled conditions.

There were no significant differences between the two cooling systems for the data shown in Figure 28. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems.

Collapsing across condition, the error for pilots was significantly greater than for copilots for altitude and roll. For subjects 12 onward, the error was significantly less than the first 8 subjects for heading, altitude, and slip. The error rate was significantly higher for UH-60 pilots for altitude, for non-UH-60 pilots for slip. There were significant differences between the errors for individual subjects.

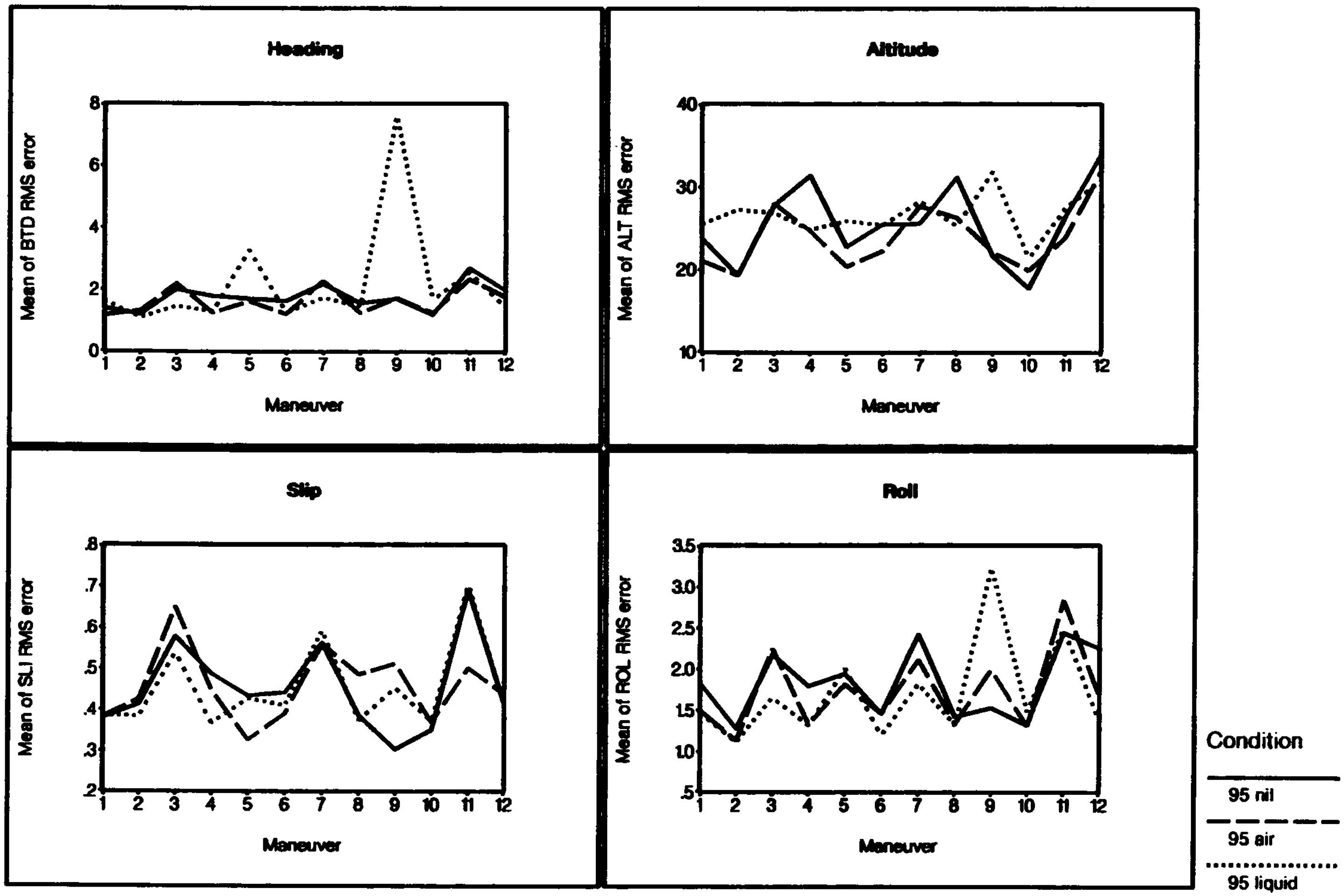

Figure 26. RMS error for navigation against maneuver number, 95°F.

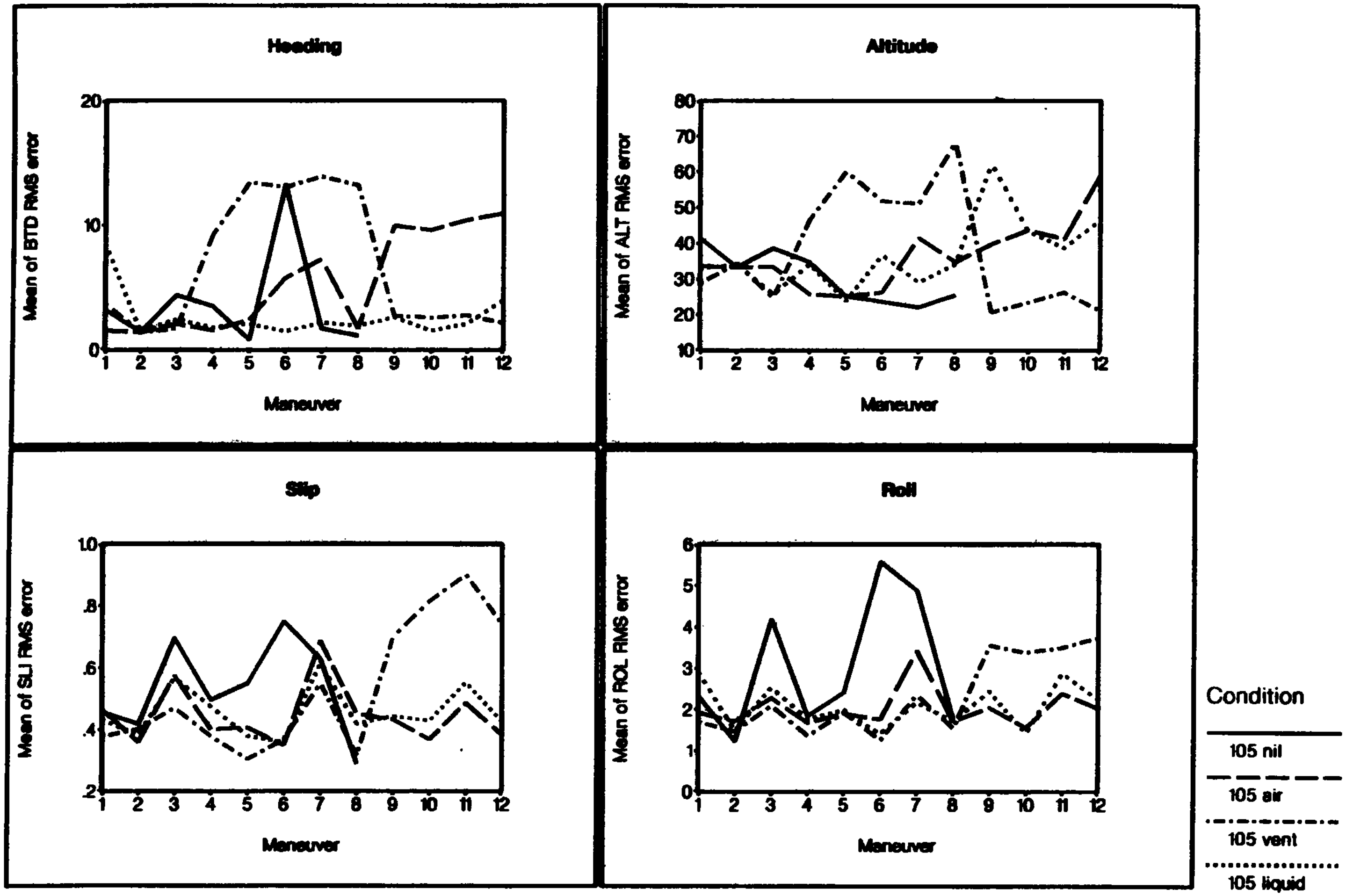

Figure 27. RMS error for navigation against maneuver number, 105°F.

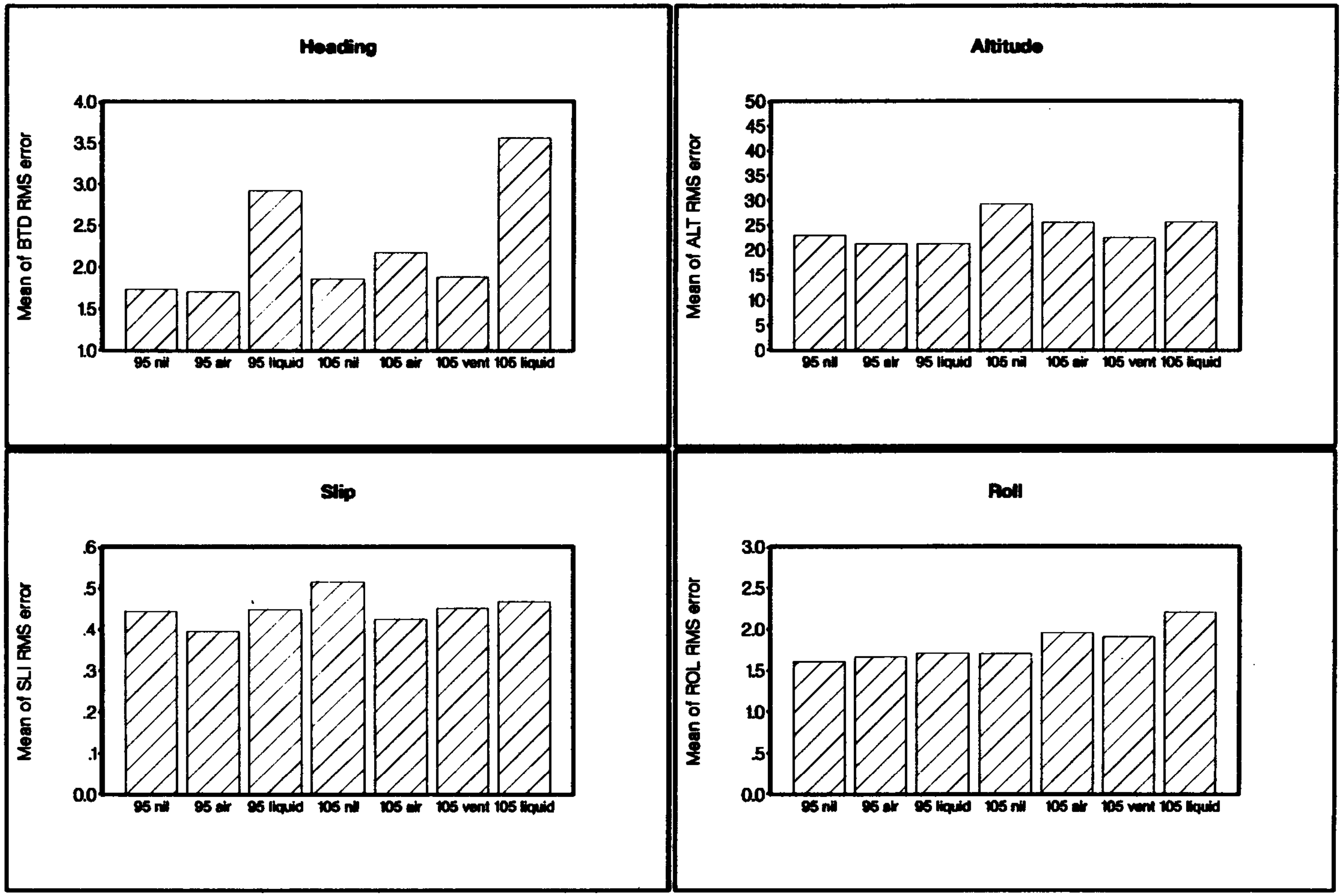

Figure 28. Mean RMS error for navigation.

Table 13.
Summary statistics for navigation RMS error.

Heading

Group	N	Mean	STD	CV
2	166	1.7416265	1.0762270	61.7943642
3	188	1.6083511	1.0846557	67.4389900
4	193	2.2379793	7.0111273	313.2793661
5	64	3.1893750	6.5595746	205.6695929
6	192	5.3720833	19.6944521	366.6073450
7	110	7.7337273	25.8223331	333.8924709
8	168	2.7177381	9.2774472	341.3664910

Altitude

Group	N	Mean	STD	CV
2	166	25.7071084	14.9769401	58.2599171
3	188	23.9343085	14.5409412	60.7535462
4	193	26.7641969	25.4353968	95.0351580
5	64	36.1667188	36.1646889	99.9943875
6	192	36.4200000	51.4902085	141.3789359
7	110	42.7162727	62.8835378	147.2121366
8	168	35.1685119	48.6493366	138.3320872

Roll

Group	N	Mean	STD	CV
2	166	1.8206627	1.2024057	66.0422038
3	188	1.7240426	1.0937277	63.4397153
4	193	1.7154922	1.6058694	93.6098329
5	64	2.4829687	4.0682946	163.8479997
6	192	2.0366146	1.7241857	84.6593992
7	110	1.8320000	1.0851295	59.2319602
8	168	2.0589881	1.8875970	91.6759536

Roll

Group	N	Mean	STD	CV
2	166	0.4566265	0.2291289	50.1786307
3	188	0.4575000	0.2464760	53.8745278
4	193	0.4518653	0.1971586	43.6321574
5	64	0.5195313	0.2222499	42.7789267
6	192	0.4471875	0.2766959	61.8747002
7	110	0.4250909	0.2273693	53.4872084
8	168	0.4550595	0.1910419	41.9817357

Hover

Hover was scored for two relevant parameters, heading and altitude. Figure 29 shows the RMS error plotted against maneuver number (three runs of two maneuvers) for 95°F, Figure 30 for 105°F. The hover turn maneuvers are included in the same figures.

Collapsing across condition and hover height, there were no significant differences between the three run numbers. When the 95 nil data were examined in isolation, there were still no significant differences between runs. For the 105 vent data, there was no significant difference for altitude, but for heading the third run produced significantly poorer performance than the other two.

Figure 31 demonstrates the mean of the RMS error for all hover maneuvers in each condition and each subject, for both low (10 ft) and high (40 ft) hover. For low and high hover, heading, there were no significant differences between conditions. For low hover, altitude, the error for 105 nil was significantly greater than 105 air and all the 95°F conditions. For high hover, altitude, the error for 105 vent was significantly greater than all other conditions except 105 nil. The summary statistics are shown in Table 14.

When the data were analyzed for the first run alone, there remained no difference between error rates for heading. For low hover, altitude, the 105 nil results were significantly worse than all others. For high hover, altitude, the 105 vent errors were significantly greater than the 95 nil.

There were no significant differences between the two cooling systems for the data shown in Figure 31. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems.

Collapsing across condition and hover height, the error for pilots was significantly less than for copilots for altitude. There were no significant differences between subjects 3-11 and subjects 12-19. There were no significant differences between UH-60 and non-UH-60 aviators.

Collapsing across condition to compare the effect of hover height, the error was significantly greater for the high hover for altitude, but for the low hover for heading. There were significant differences between the errors for individual subjects.

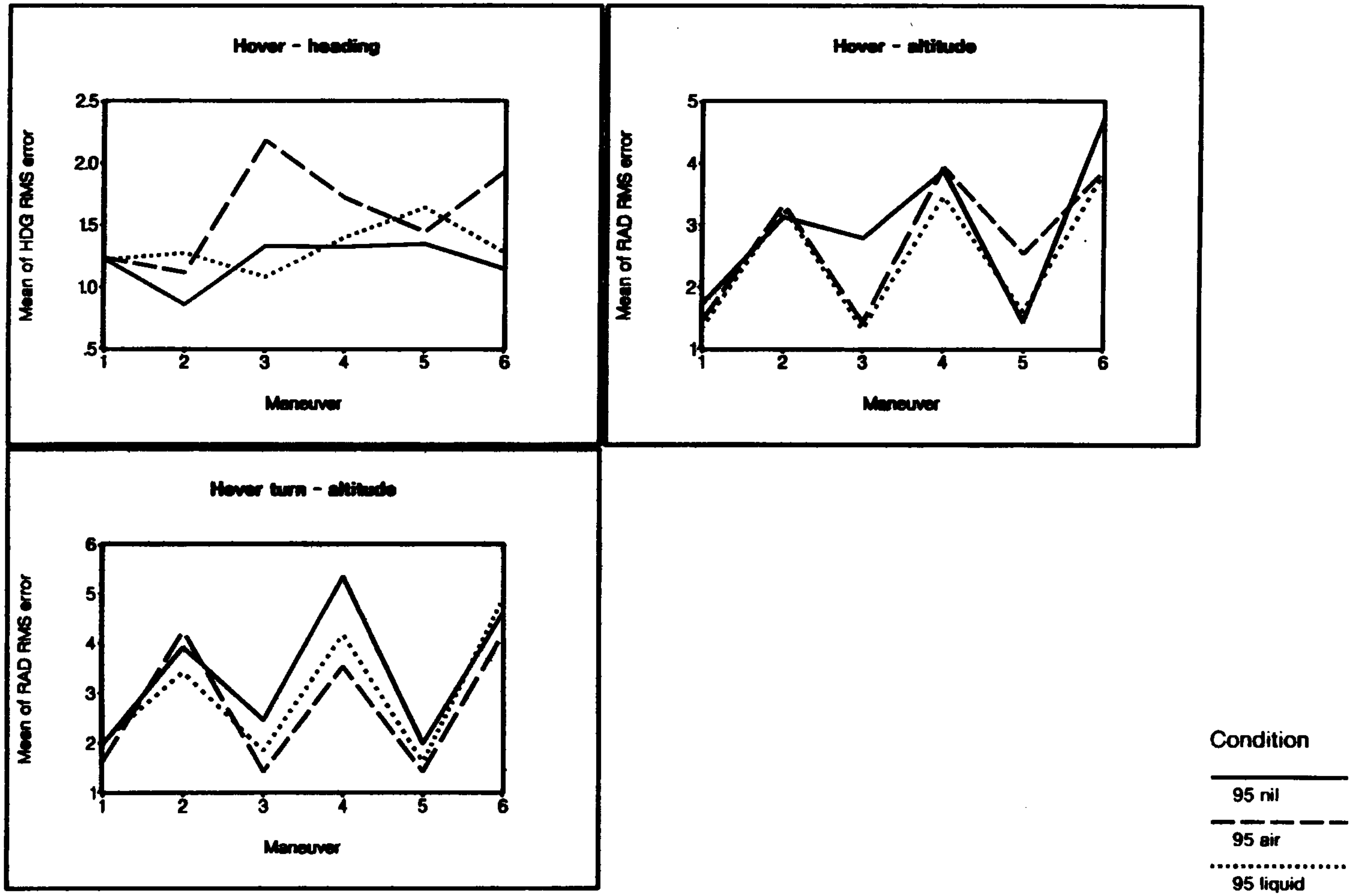

Figure 29. RMS error for hover and hover turn against maneuver number, 95°F.

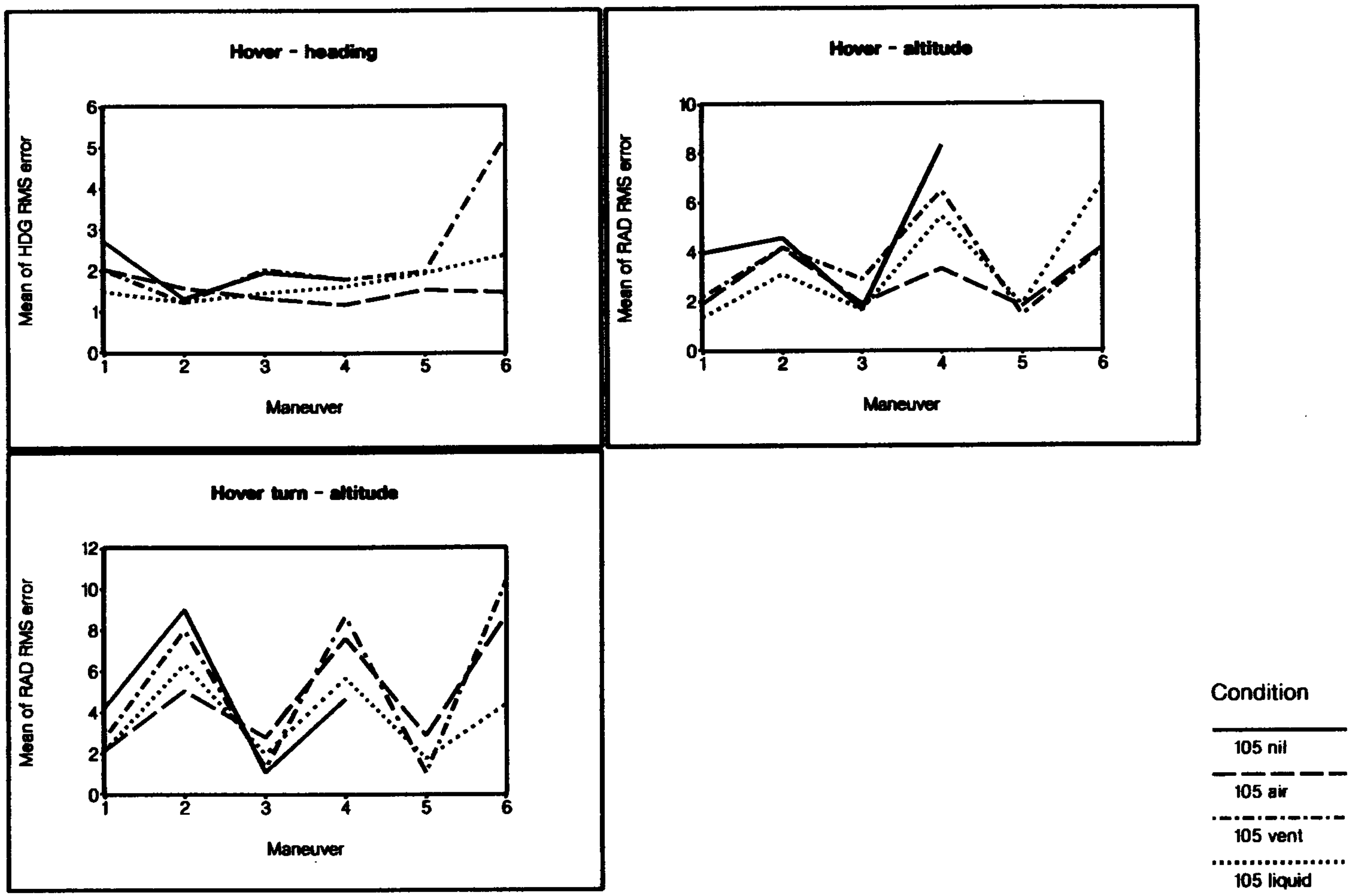

Figure 30. RMS error for hover and hover turn against maneuver number, 105°F.

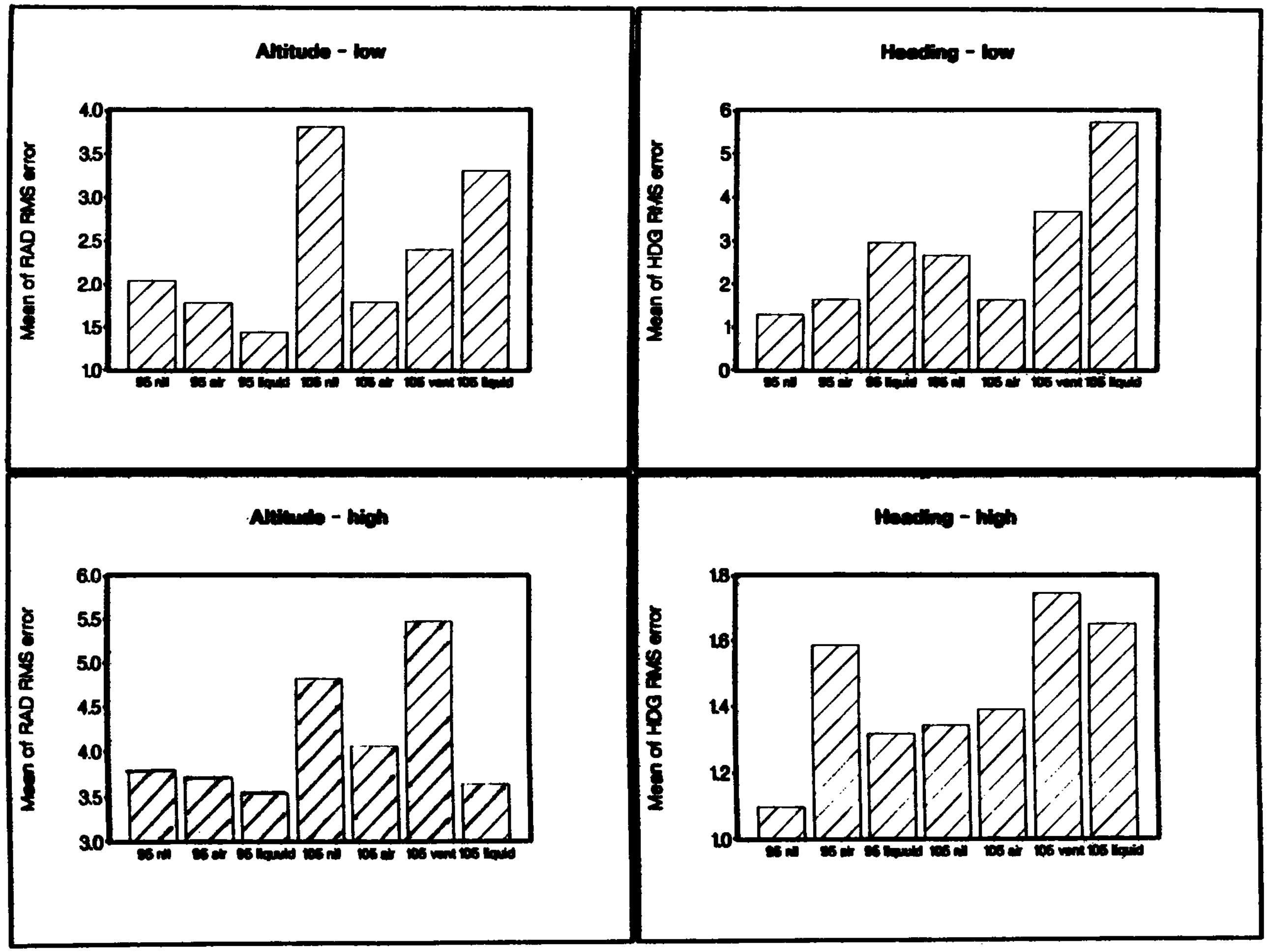

Figure 31. Mean RMS error for hover.

Table 14.
Summary statistics for hover RMS error.

Low hover - heading

Group	N	Mean	STD	CV
2	41	1.2943902	0.7885495	60.9205345
3	45	1.6377778	1.7053017	104.1229016
4	47	2.9595745	11.2922855	381.5509854
5	15	2.6693333	3.2311574	121.0473549
6	50	1.6212000	1.8516596	114.2153739
7	28	3.6625000	9.0704027	247.6560456
8	45	5.7197778	21.0270218	367.6195590

Low hover - altitude

Group	N	Mean	STD	CV
2	41	2.0426829	2.4459467	119.7418669
3	45	1.7831111	2.3013275	129.0624847
4	47	1.4438298	0.7072683	48.9855755
5	15	3.8073333	5.8631494	153.9962197
6	50	1.7860000	1.1082676	62.0530589
7	28	2.3942857	2.7890307	116.4869610
8	45	3.2968889	5.7452581	174.2630173

High hover - heading

Group	N	Mean	STD	CV
2	41	1.0978049	0.6773570	61.7010413
3	45	1.5857778	2.2917565	144.5193957
4	47	1.3161702	0.8393620	63.7730551
5	15	1.3420000	0.7911944	58.9563633
6	46	1.3906522	0.9903678	71.2160709
7	24	1.7450000	2.1777711	124.8006360
8	37	1.6518919	1.6212698	98.1462412

High hover - altitude

Group	N	Mean	STD	CV
2	41	3.7963415	2.2199243	58.4753583
3	45	3.7177778	2.0552426	55.2814811
4	47	3.5368085	2.0719505	58.5824892
5	15	4.8120000	3.9650621	82.3994609
6	46	4.0580435	2.8068786	69.1682720
7	24	5.4720833	5.0491385	92.2708631
8	37	3.6335135	1.7399764	47.8868839

Hover turn

Hover turn was scored for only one parameter, altitude. Figure 29 shows the RMS error plotted against maneuver number (three runs of two maneuvers) for the 95°F conditions, Figure 30 for the 105°F conditions.

Collapsing across condition and hover height, there were no significant differences between the three run numbers. When the 95 nil and 105 vent data were examined in isolation, there were still no significant differences between runs.

Figure 32 demonstrates the mean of the RMS error for hover turn in each condition and each subject, for both low (10 ft) and high (40 ft) hover turns. For low hover turn, altitude, the error for 105 nil was significantly greater than all other conditions. For high hover turn, altitude, the error for 105 nil and 105 vent was significantly greater than the 95°F conditions. The error for 105 air was significantly greater than 95 air and 95 liquid. The summary statistics are shown in Table 15.

When the data were analyzed for the first run alone, 105 nil produced a significantly greater error for low hover turn, altitude, than all other conditions except 105 vent. For high hover turn, altitude, the 105 nil errors were significantly greater than the all the 95°F conditions.

There were no significant differences between the two cooling systems for the data shown in Figure 32. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems.

Collapsing across condition and hover height, the error for pilots was significantly less than for copilots. There were no significant differences between subjects 3-11 and subjects 12-19. UH-60 aviators performed significantly worse than non-UH-60 aviators.

Collapsing across condition, the error for altitude was significantly greater in the high hover than in the low hover. There were significant differences between the errors for individual subjects.

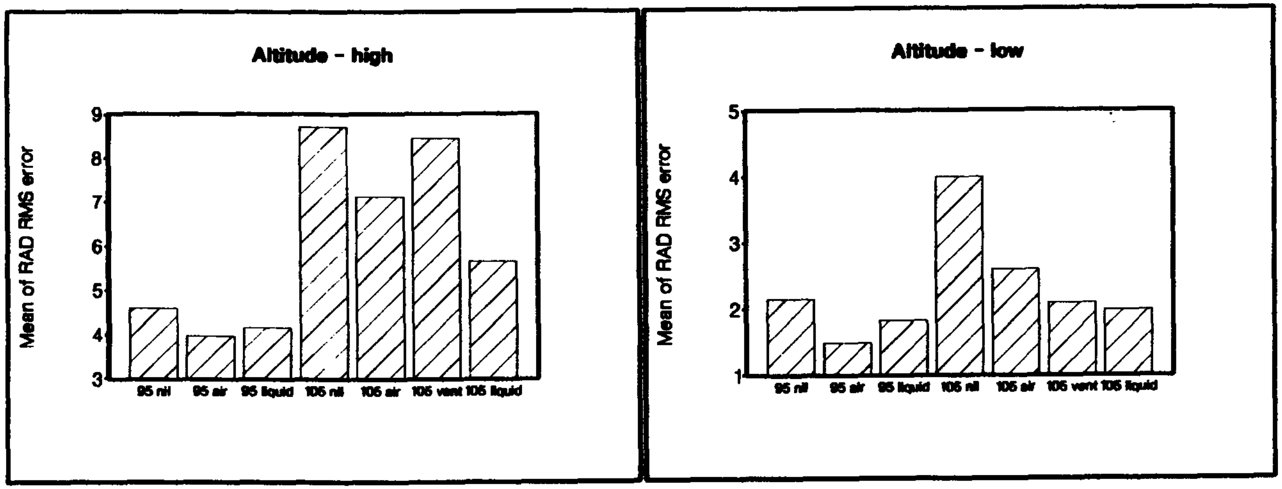

Figure 32. Mean RMS error for hover turn.

Table 15.
Summary statistics for hover turn RMS error.

Group	N	Mean	STD	CV
		Low hover turn - altitude		
2	41	2.1460976	1.7890065	83.3609138
3	45	1.4768889	0.8548919	57.8846433
4	48	1.8214583	1.1691095	64.1853541
5	15	3.9866667	6.2282395	156.2267421
6	48	2.5918750	2.4489083	94.4840424
7	25	2.0784000	2.4446399	117.6212399
8	41	1.9812195	1.6128689	81.4078831
		High hover turn - altitude		
Group	N	Mean	STD	CV
2	40	4.5935000	2.9714449	64.6880356
3	45	3.9762222	2.1885864	55.0418531
4	49	4.1577551	2.0948561	50.3843063
5	15	8.7166667	10.7599772	123.4414211
6	48	7.1237500	7.8838679	110.6701932
7	26	8.4403846	10.2277311	121.1761263
8	41	5.6541463	5.1771020	91.5629286

Right standard rate turn

Right standard rate turn was scored for the five relevant parameters of rate of turn, altitude, airspeed, slip, and roll. Figure 33 shows the RMS error plotted against maneuver number (three runs of three maneuvers) for the 95°F conditions, Figure 34 for the 105°F conditions.

Collapsing across condition and AFCS, there were no significant differences between the three run numbers for four parameters. For airspeed, the error was significantly higher for the first run than the third. When the 95 nil and 105 vent data were examined in isolation, there were no significant differences between runs.

Figure 35 demonstrates the mean of the RMS error for all right standard rate turn maneuvers in each condition and each subject with the AFCS in. For rate of turn, AFCS in, error rate was significantly lower for 95 liquid than for all other conditions except 95 air. For altitude, 95 nil had a significantly lower error than 105 liquid. For airspeed, error rate was significantly lower for 95 liquid than for all other conditions except 95 air, and 95 air was significantly lower than 105 liquid. For slip, 105 liquid had a significantly greater error than 95 nil, 95 liquid. and 105 vent. There were no significant differences between conditions for roll.

Figure 36 shows the same data for AFCS out. For rate of turn, AFCS out, the error for 105 vent was significantly greater than all other conditions. For altitude, the error was significantly greater for 105 vent than all conditions except 105 air. For airspeed, 105 vent was significantly worse than all other conditions and 95 liquid was significantly better than all conditions except 95 air. For roll, the error for 105 vent was significantly worse than all conditions except 95 nil. For slip, there were no differences between conditions. The summary statistics are shown in Table 16.

There were no significant differences between the two cooling systems for the data shown in Figures 36 and 37. When the data were examined for pilots only, there were still no differences between the systems. When the data for subjects 12 onward were analyzed, there were 4 instances out of 10 maneuver parameters when the error for 105 air was significantly lower than 105 liquid.

Collapsing across condition and AFCS, the error for pilots was significantly greater than for copilots for slip and roll, and for copilots for airspeed. For subjects 12 onward, the error was significantly less than the first 8 subjects for roll, and significantly greater for altitude and airspeed. The error rate was significantly higher for non-UH-60 pilots for altitude and airspeed.

Collapsing across condition to determine the effect of the AFCS on performance, the error was significantly worse without the AFCS for airspeed and slip, but significantly better for rate of turn and roll. There were significant differences between the errors for individual subjects.

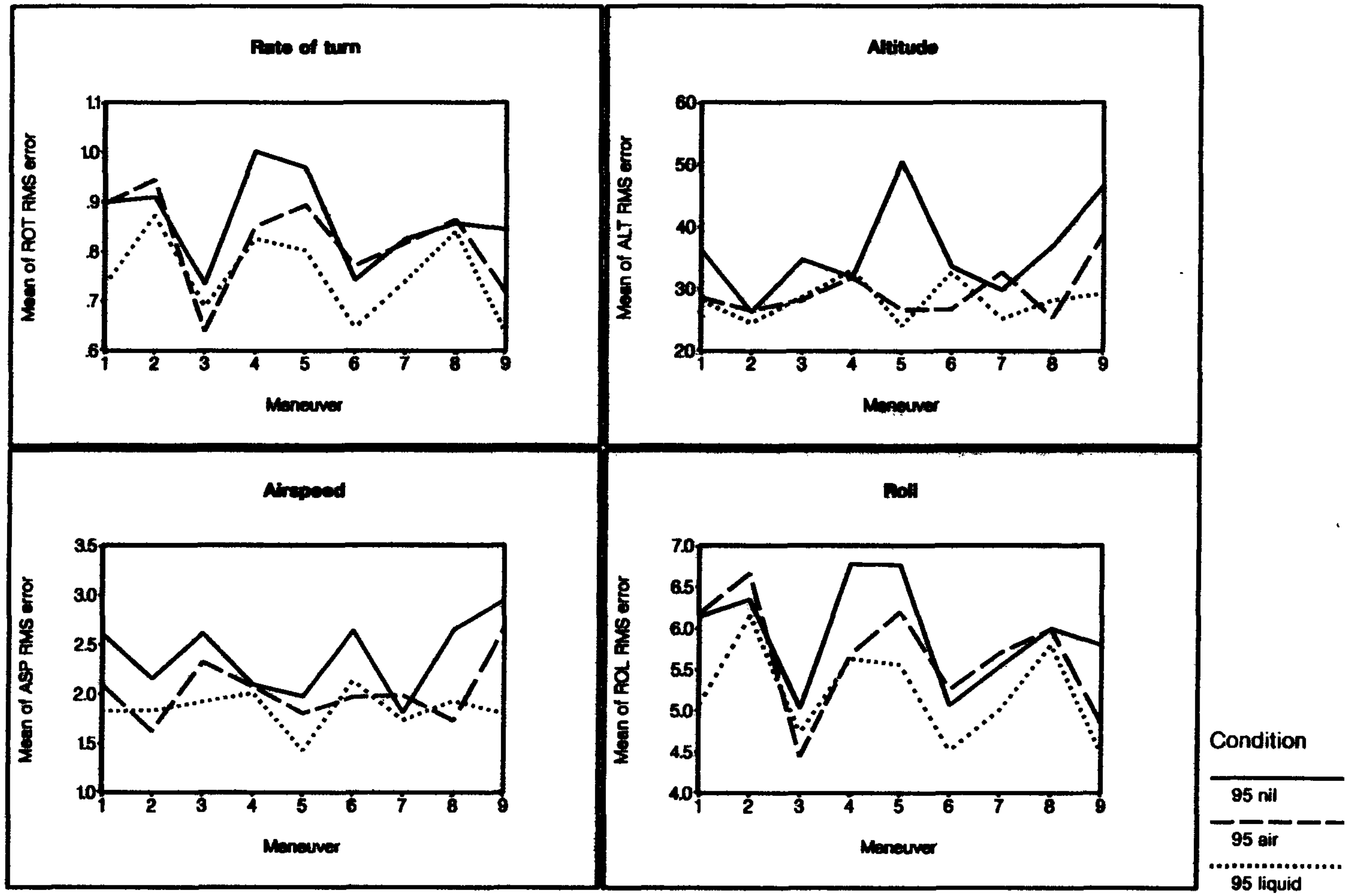

Figure 33. RMS error for right standard rate turn against maneuver number, 95°F.

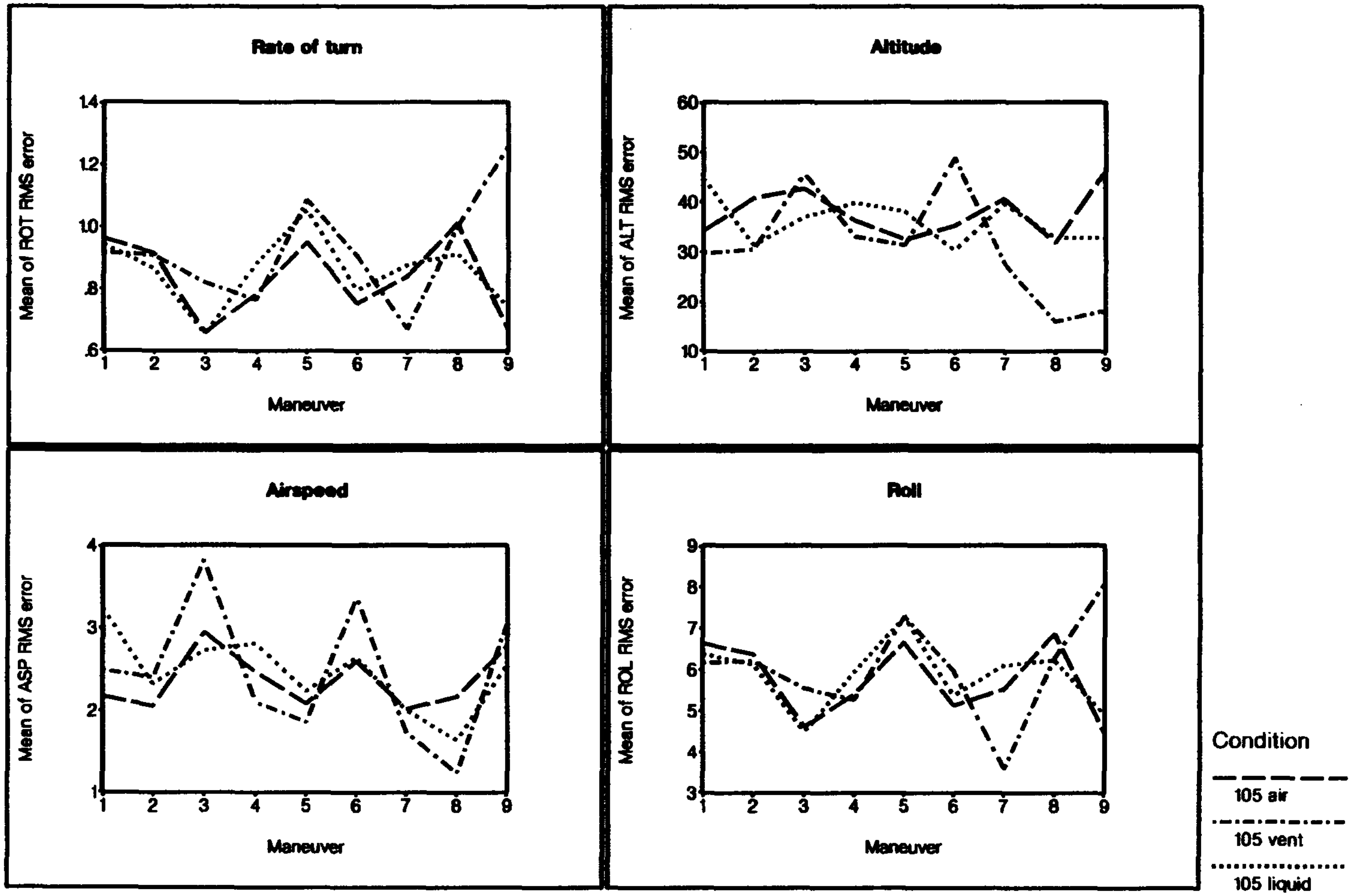

Figure 34. RMS error for right standard rate turn against maneuver number, 105°F.

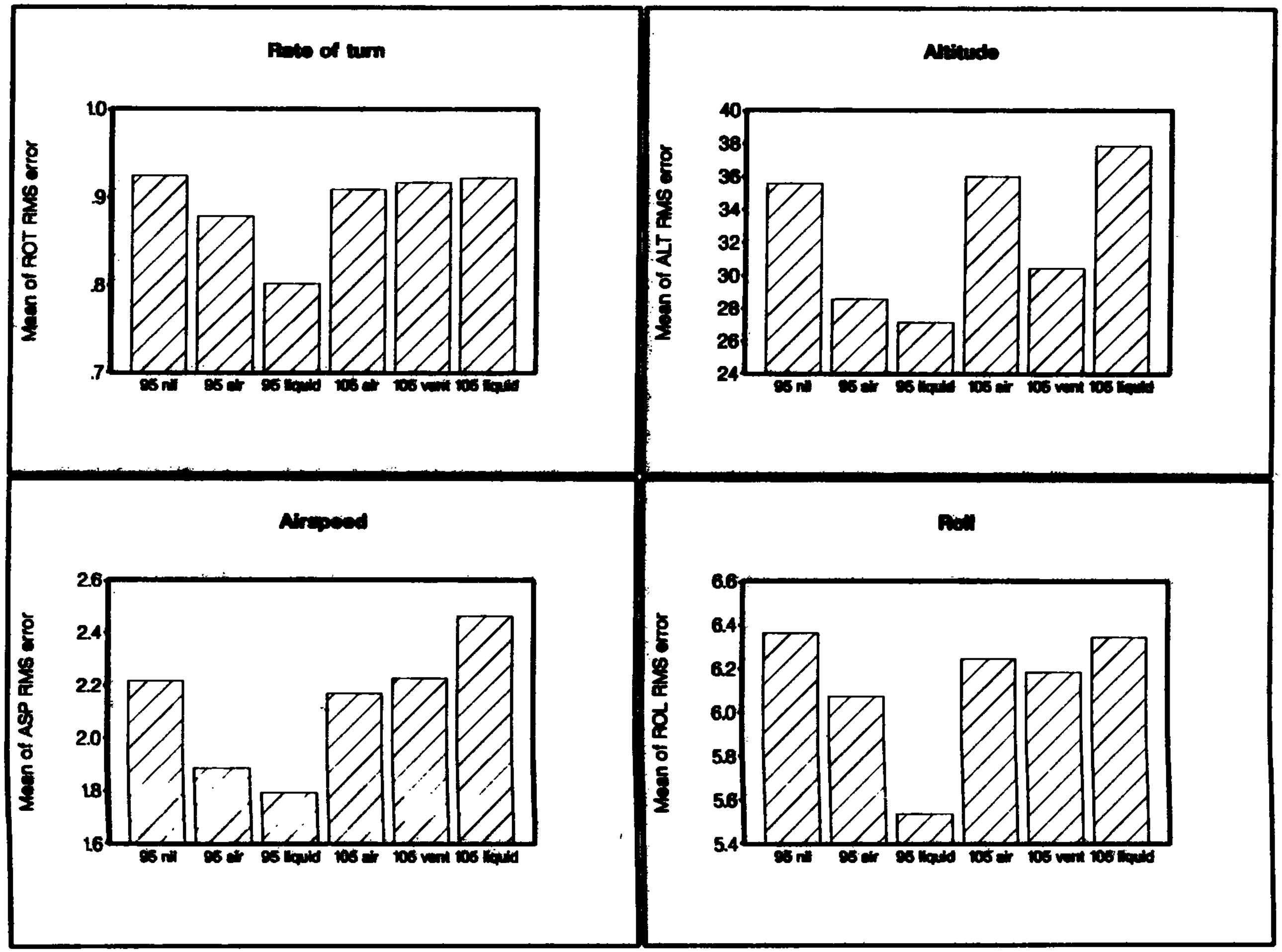

Figure 35. Mean RMS error for right standard rate turn, AFCS in.

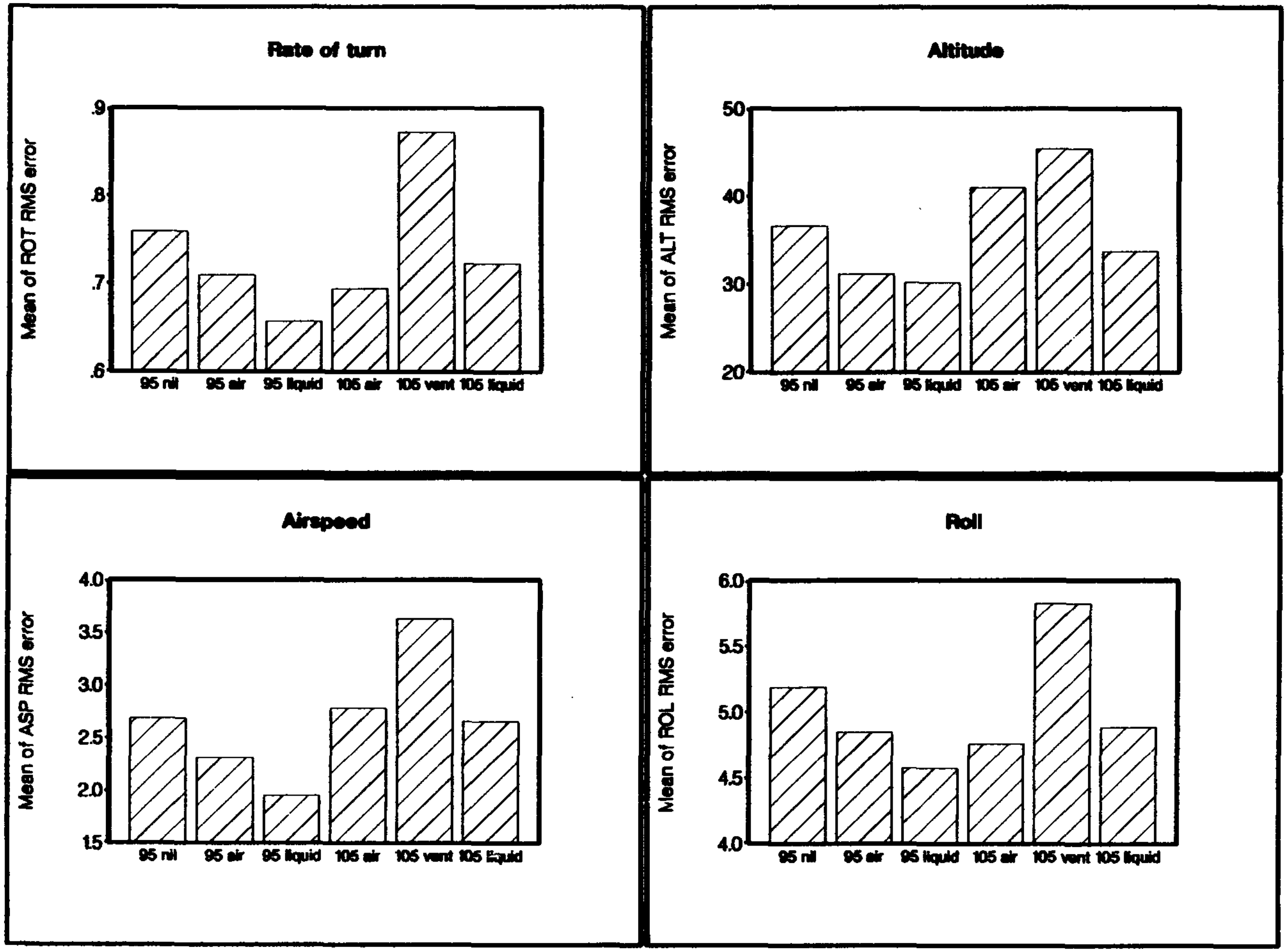

Figure 36. Mean RMS error for right standard rate turn, AFCS out.

Table 16.
Summary statistics for right standard rate turn RMS error.

Rate of turn - AFCS in

Group	N	Mean	STD	CV
2	76	0.9246053	0.4627006	50.0430416
3	94	0.8782979	0.2235425	25.4517906
4	92	0.8017391	0.3238661	40.3954461
6	86	0.9086047	0.3068096	33.7671205
7	41	0.9170732	0.2996101	32.6702516
8	74	0.9222973	0.3231588	35.0384677

Altitude - AFCS in

Group	N	Mean	STD	CV
2	76	35.5802632	48.1643968	135.3682984
3	94	28.5693617	22.7687705	79.6964620
4	92	27.1484783	14.2255808	52.3991830
6	86	36.0100000	19.0812439	52.9887361
7	41	30.4526829	15.3280054	50.3338424
8	74	37.8690541	23.6728920	62.5124988

Airspeed - AFCS in

Group	N	Mean	STD	CV
2	76	2.2181579	1.1345151	51.1467251
3	94	1.8855319	0.8770204	46.5131555
4	92	1.7931522	0.8249461	46.0053606
6	86	2.1704651	1.2463924	57.4251272
7	41	2.2270732	1.2575775	56.4677235
8	74	2.4639189	1.7128274	69.5163851

Roll - AFCS in

Group	N	Mean	STD	CV
2	76	6.3643421	3.0924870	48.5908347
3	94	6.0739362	1.3802175	22.7236096
4	92	5.5377174	2.0999189	37.9202981
6	86	6.2475581	1.9454417	31.1392331
7	41	6.1860976	1.9424390	31.4000711
8	74	6.3455405	2.1087217	33.2315536

Slip - AFCS in

Group	N	Mean	STD	CV
2	76	0.4639474	0.1716903	37.0064079
3	94	0.4974468	0.1570627	31.5737602
4	92	0.4530435	0.1448966	31.9829396
6	86	0.4706977	0.1503470	31.9413043
7	41	0.4268293	0.1461068	34.2307345
8	74	0.5259459	0.2005125	38.1241624

Table 16 (Continued).
Summary statistics for right standard rate turn RMS error.

Rate of turn - AFCS out

Group	N	Mean	STD	CV
2	37	0.7583784	0.3219171	42.4480875
3	47	0.7087234	0.2427525	34.2520770
4	46	0.6563043	0.1889193	28.7853114
6	42	0.6940476	0.2166154	31.2104555
7	20	0.8720000	0.3485851	39.9753567
8	36	0.7225000	0.2509795	34.7376484

Altitude - AFCS out

Group	N	Mean	STD	CV
2	37	36.5781081	20.3337956	55.5900692
3	47	31.1587234	16.8430088	54.0555163
4	46	30.1463043	14.5265806	48.1869367
6	42	40.9307143	19.5812574	47.8400090
7	20	45.4280000	27.8194431	61.2385382
8	36	33.7038889	17.4142707	51.6684314

Airspeed - AFCS out

Group	N	Mean	STD	CV
2	37	2.6870270	1.2940760	48.1601392
3	47	2.3127660	1.1984550	51.8191209
4	46	1.9513043	0.9301962	47.6704814
6	42	2.7816667	1.1115577	39.9601338
7	20	3.6265000	2.6842784	74.0184296
8	36	2.6569444	1.5816480	59.5288322

Roll - AFCS out

Group	N	Mean	STD	CV
2	37	5.1881081	2.0994481	40.4665455
3	47	4.8457447	1.5280020	31.5328629
4	46	4.5758696	1.2732733	27.8258206
6	42	4.7573810	1.3613624	28.6157956
7	20	5.8240000	1.9016956	32.6527411
8	36	4.8844444	1.6008720	32.7749041

Slip - AFCS out

Group	N	Mean	STD	CV
2	37	0.6997297	0.2086396	29.8171688
3	47	0.7165957	0.1975423	27.5667633
4	46	0.7556522	0.2843601	37.6310857
6	42	0.7345238	0.2277162	31.0018748
7	20	0.7960000	0.2523031	31.6963663
8	36	0.7925000	0.2062228	26.0218087

Left standard rate turn

Left standard rate turn was scored for the five relevant parameters of rate of turn, altitude, airspeed, slip, and roll. Figure 37 shows the RMS error plotted against maneuver number (three runs of two maneuvers) for the 95°F conditions, Figure 38 for the 105°F conditions.

Collapsing across condition and AFCS, there were no significant differences between the three run numbers for three parameters. For airspeed, the error was significantly higher for the first run than the second or third, and for altitude, the error on the first run was significantly higher than the second. When the 95 nil and 105 vent data were examined in isolation, there were no significant differences between runs.

Figure 39 demonstrates the mean of the RMS error for all left standard rate turn maneuvers in each condition and each subject with the AFCS in. For rate of turn, AFCS in, error rate was significantly lower for 95 liquid than for 105 vent and 105 liquid. For altitude, 95 air had a significantly lower error than 105 air and 105 liquid. For airspeed and slip, there were no differences between conditions. For roll, the error for 95 liquid was significantly lower than 105 liquid.

Figure 40 shows the same data for AFCS out. For rate of turn, AFCS out, the error for 95 liquid was significantly lower than all 105°F conditions. For airspeed, 105 vent was significantly worse than all other conditions. For roll, the error for 105 liquid was significantly worse than 95 air and 95 liquid. For altitude and slip, there were no differences between conditions. The summary statistics are shown in Table 17.

There were no significant differences between the two cooling systems for the data shown in Figures 39 and 40. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems.

Collapsing across condition and AFCS, the error for pilots was significantly greater than for copilots for altitude and roll. For subjects 12 onward, the error was significantly less than the first 8 subjects for rate of turn and roll, and significantly greater for altitude. The error rate was significantly higher for non-UH-60 pilots for altitude and airspeed.

Collapsing across condition, the error without the AFCS was significantly greater for all conditions. There were significant differences between the errors for individual subjects.

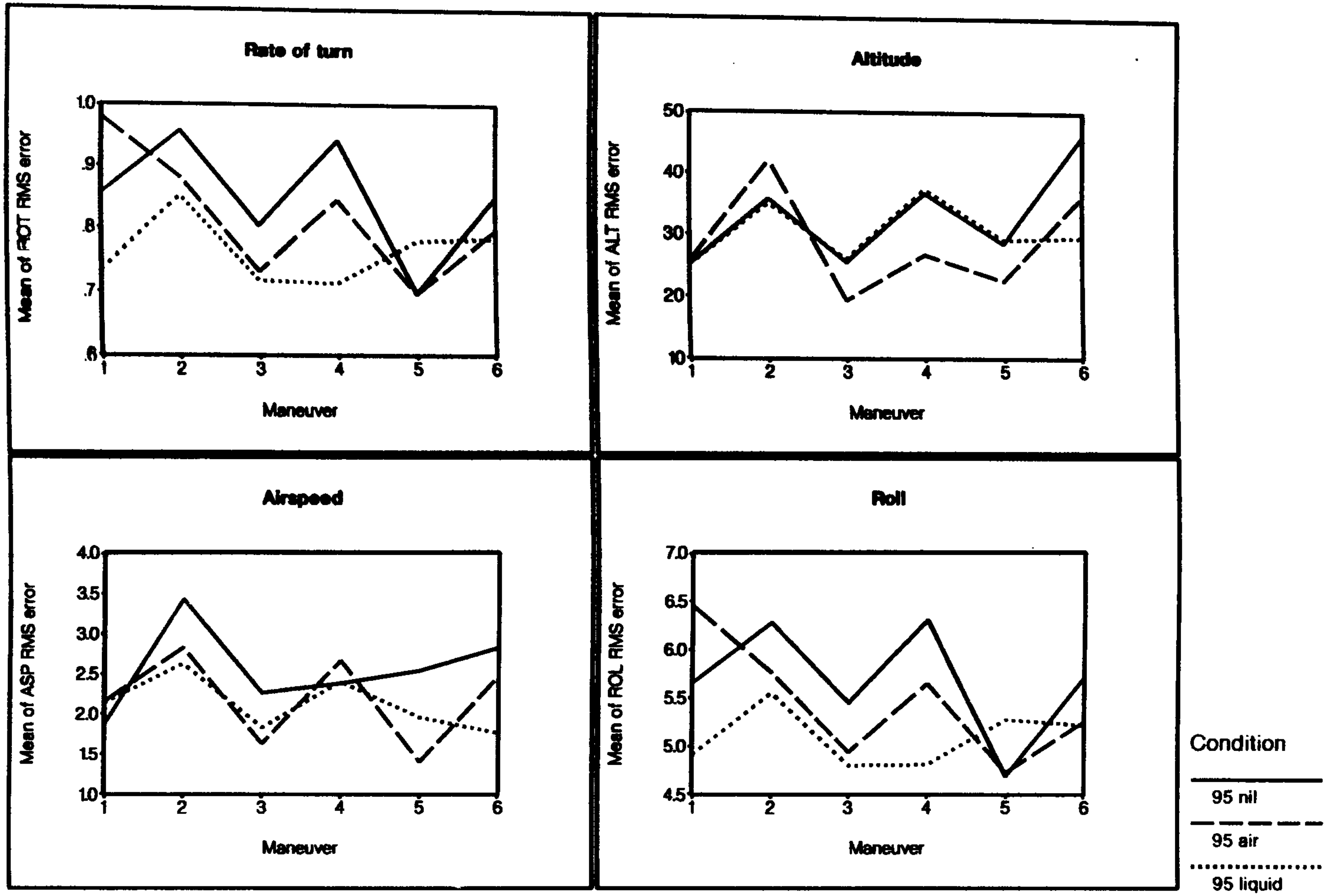

Figure 37. RMS error for left standard rate turn against maneuver number, 95°F.

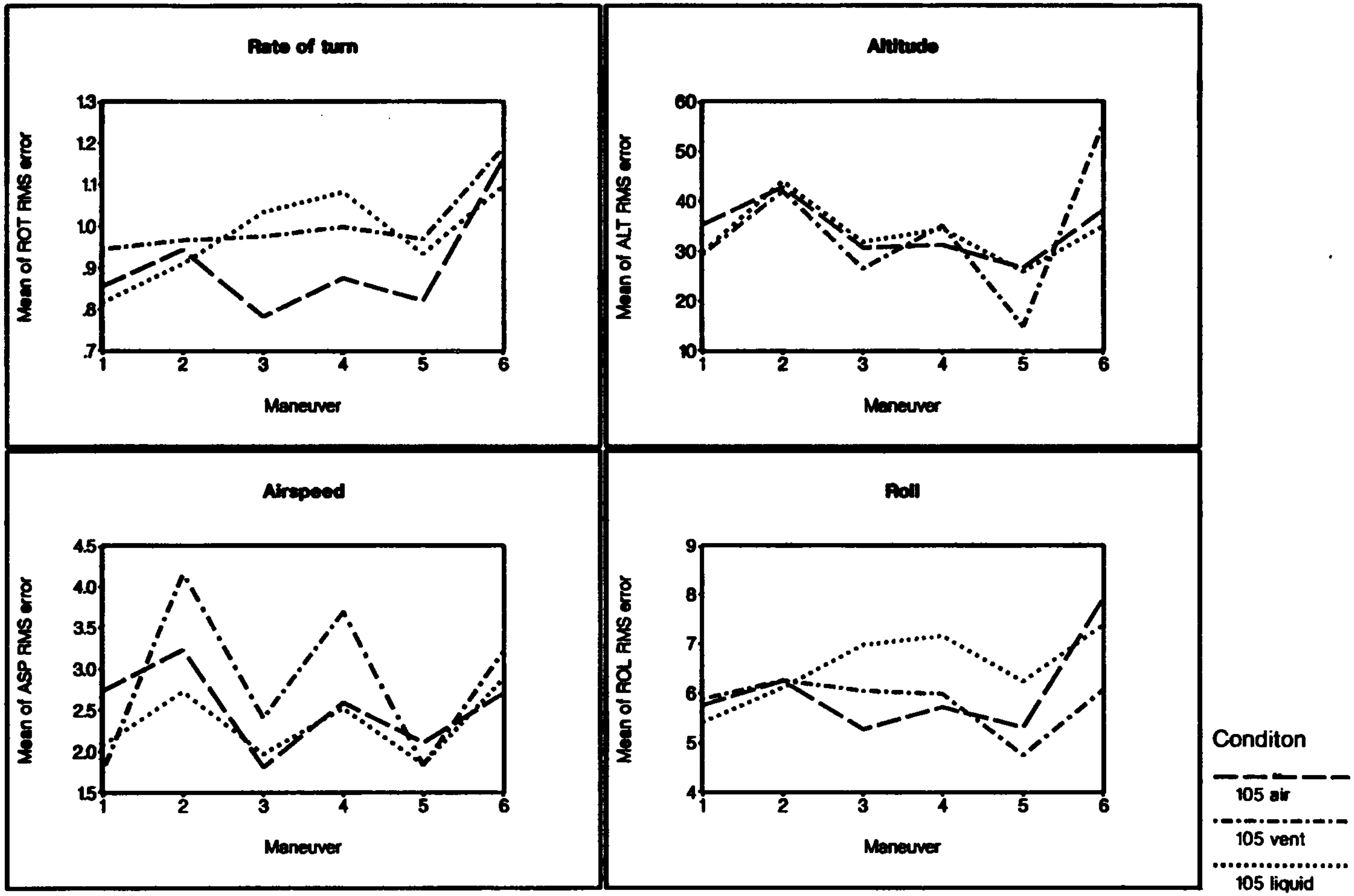

Figure 38. RMS error for left standard rate turn against maneuver number, 105°F.

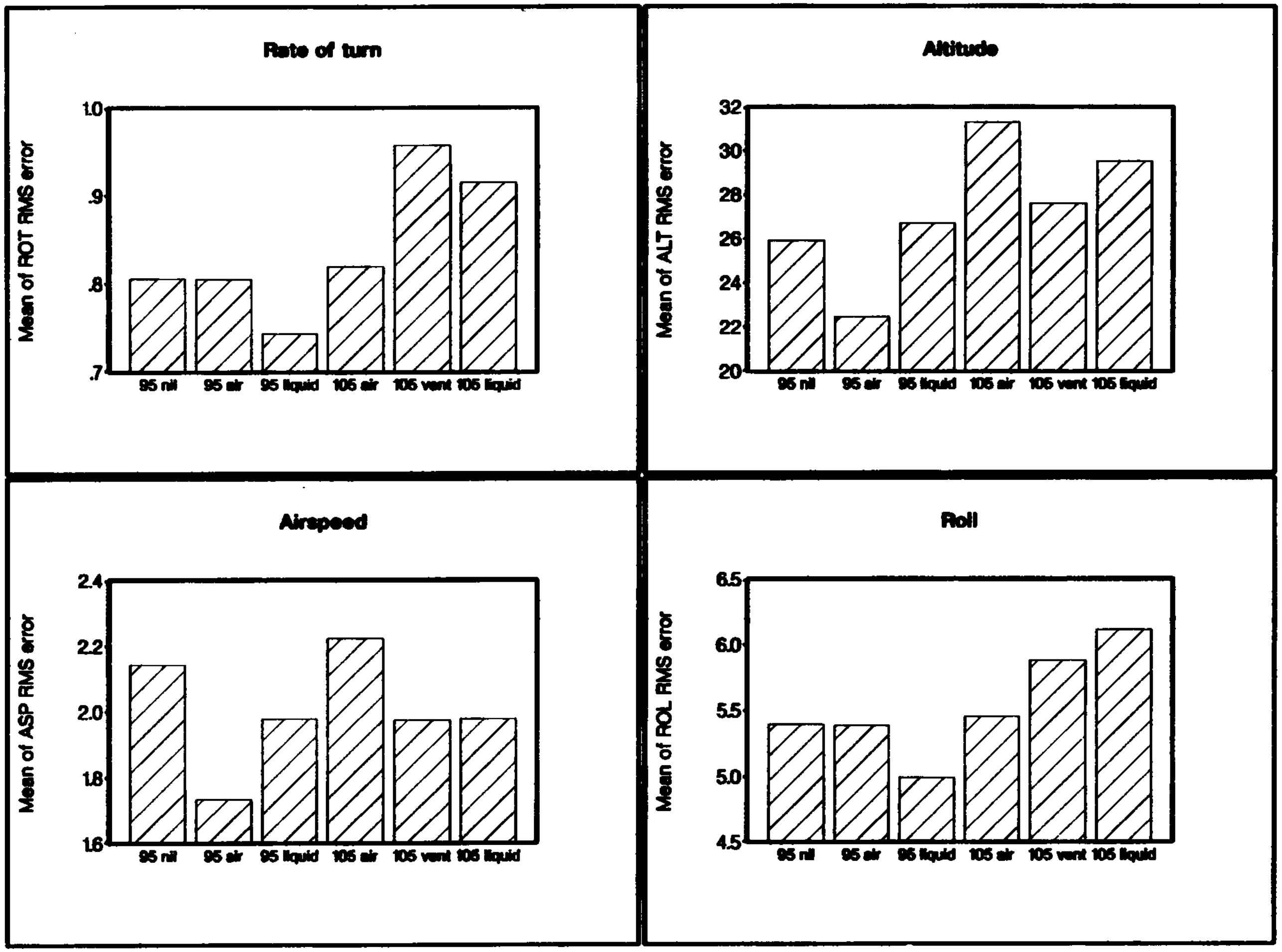

Figure 39. Mean RMS error for left standard rate turn, AFCS in.

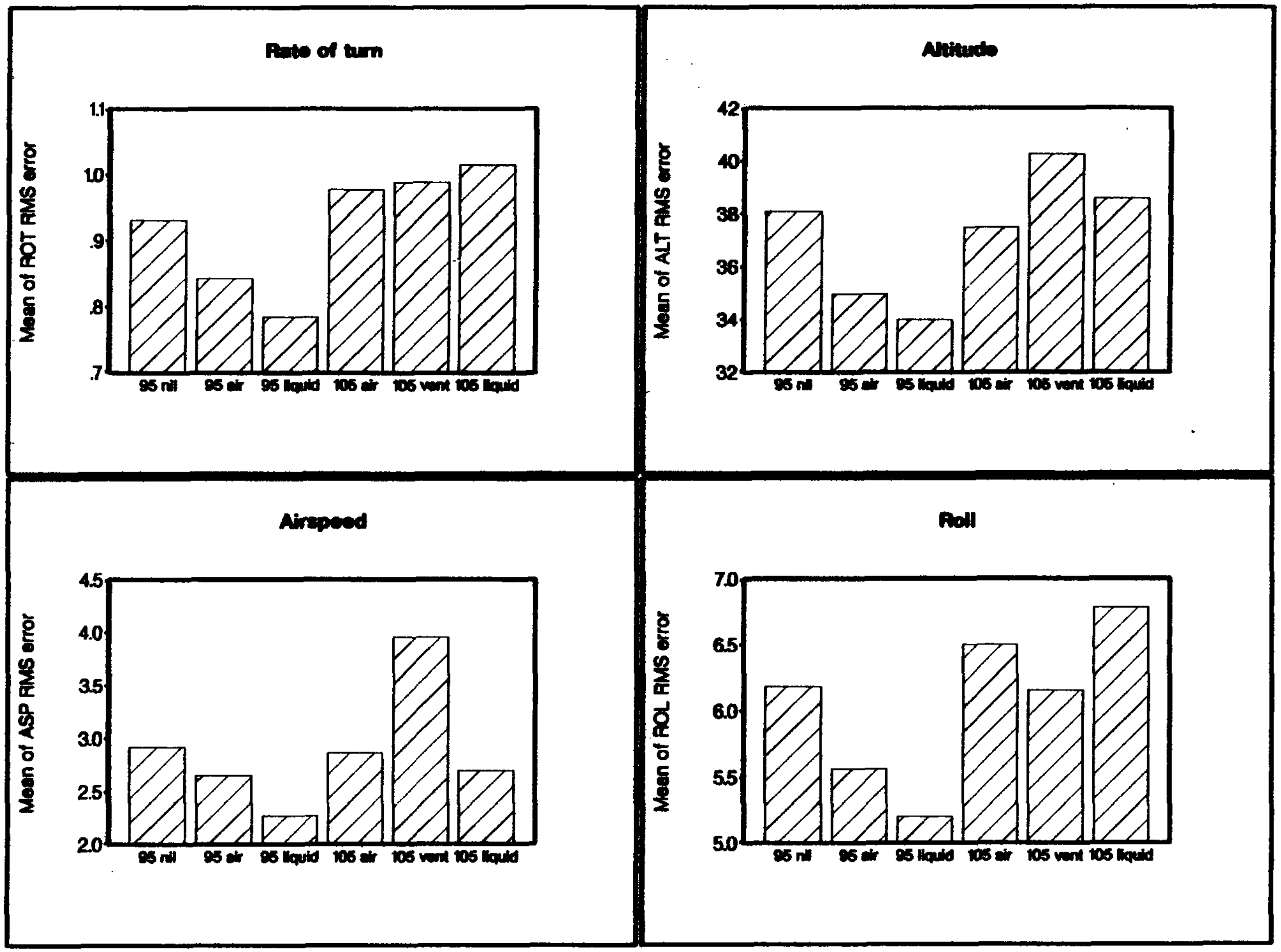

Figure 40. Mean RMS error for left standard rate turn, AFCS out.

Table 17.
Summary statistics for left standard rate turn RMS error.

Rate of turn - AFCS in

Group	N	Mean	STD	CV
2	38	0.8055263	0.2404916	29.8552113
3	47	0.8048936	0.3614516	44.9067565
4	46	0.7432609	0.2613559	35.1634149
6	44	0.8190909	0.2862493	34.9472012
7	20	0.9570000	0.4328863	45.2336755
8	37	0.9148649	0.4047264	44.2389263

Altitude - AFCS in

Group	N	Mean	STD	CV
2	38	25.9086842	14.3677317	55.4552736
3	47	22.4710638	10.9357629	48.6659775
4	46	26.7026087	14.1747839	53.0838919
6	44	31.2936364	20.1978219	64.5429047
7	20	27.6020000	19.1167828	69.2586871
8	37	29.5310811	17.1495047	58.0727289

Airspeed - AFCS in

Group	N	Mean	STD	CV
2	38	2.1431579	0.9413392	43.9229980
3	47	1.7342553	0.9868147	56.9013502
4	46	1.9784783	0.9222749	46.6153662
6	44	2.2222727	1.3167823	59.2538571
7	20	1.9745000	1.2240032	61.9905417
8	37	1.9781081	1.1118274	56.2066054

Roll - AFCS in

Group	N	Mean	STD	CV
2	38	5.3947368	1.4856953	27.5397174
3	47	5.3853191	2.3875227	44.3339126
4	46	4.9934783	1.6478177	32.9993968
6	44	5.4559091	1.8927565	34.6918623
7	20	5.8835000	1.9316894	32.8323175
8	37	6.1167568	2.5982014	42.4767808

Slip - AFCS in

Group	N	Mean	STD	CV
2	38	0.2563158	0.0800142	31.2170482
3	47	0.2610638	0.1110666	42.5438666
4	46	0.2665217	0.0809174	30.3605420
6	44	0.2745455	0.0973953	35.4750918
7	20	0.2465000	0.0705076	28.6034720
8	37	0.2575676	0.0788249	30.6035776

Table 17 (Continued).
Summary statistics for left standard rate turn RMS error.

Rate of turn - AFCS out

Group	N	Mean	STD	CV
2	37	0.9308108	0.5227033	56.1557001
3	47	0.8421277	0.2684815	31.8813336
4	46	0.7841304	0.2681009	34.1908606
6	42	0.9773810	0.3501154	35.8217927
7	20	0.9890000	0.4138255	41.8428252
8	36	1.0144444	0.3634080	35.8233546

Altitude - AFCS out

Group	N	Mean	STD	CV
2	37	38.0778378	21.9216539	57.5706374
3	47	34.9582979	22.1784721	63.4426543
4	46	33.9804348	18.2957772	53.8420926
6	42	37.4907143	13.1576402	35.0957308
7	20	40.2555000	21.2255319	52.7270358
8	36	38.5894444	20.7133282	53.6761503

Airspeed - AFCS out

Group	N	Mean	STD	CV
2	37	2.9154054	2.7421166	94.0560983
3	47	2.6553191	1.2324540	46.4145332
4	46	2.2686957	1.3540156	59.6825583
6	42	2.8628571	1.4043231	49.0532018
7	20	3.9495000	3.1027755	78.5612218
8	36	2.6966667	1.6728521	62.0340720

Roll - AFCS out

Group	N	Mean	STD	CV
2	37	6.1805405	2.8237484	45.6877262
3	47	5.5617021	1.8147120	32.6287162
4	46	5.2004348	1.6832547	32.3675769
6	42	6.5004762	2.3215301	35.7132320
7	20	6.1535000	2.6204545	42.5847812
8	36	6.7816667	2.5373524	37.4148792

Slip - AFCS out

Group	N	Mean	STD	CV
2	37	0.7859459	0.3741617	47.6065469
3	47	0.7529787	0.4135736	54.9250025
4	46	0.7647826	0.3838040	50.1847181
6	42	0.6866667	0.4375858	63.7260821
7	20	0.7825000	0.4511841	57.6593118
8	36	0.6869444	0.4050031	58.9571891

Left descending turn

Left descending is scored for the five relevant parameters of rate of turn, rate of descent, airspeed, slip, and roll. Figure 41 shows the RMS error plotted against maneuver number (three runs of one maneuver) for the 95°F conditions, Figure 42 for the 105°F conditions.

Collapsing across condition, there were no significant differences between the three run numbers for four parameters. For roll, the error was significantly greater on the first run than the third. When the 95 nil and 105 vent data were examined in isolation, there were no significant differences between runs.

Figure 43 demonstrates the mean of the RMS error for all left descending turn maneuvers in each condition and each subject. For rate of turn, error rate was significantly lower for 95 air and 95 liquid than for 105 vent and 105 liquid. For airspeed, rate of climb and slip there were no differences between conditions. For roll, the error for 95 air and 95 liquid was significantly lower than 105 vent and 105 liquid. The summary statistics are shown in Table 18.

There were no significant differences between the two cooling systems for the data shown in Figure 43. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems.

Collapsing across condition, the error for pilots was significantly less than for copilots for airspeed. For subjects 12 onward, the error was significantly less than the first 8 subjects for rate of turn and roll. The error rate was significantly higher for non-UH-60 pilots for airspeed. There were significant differences between the errors for individual subjects.

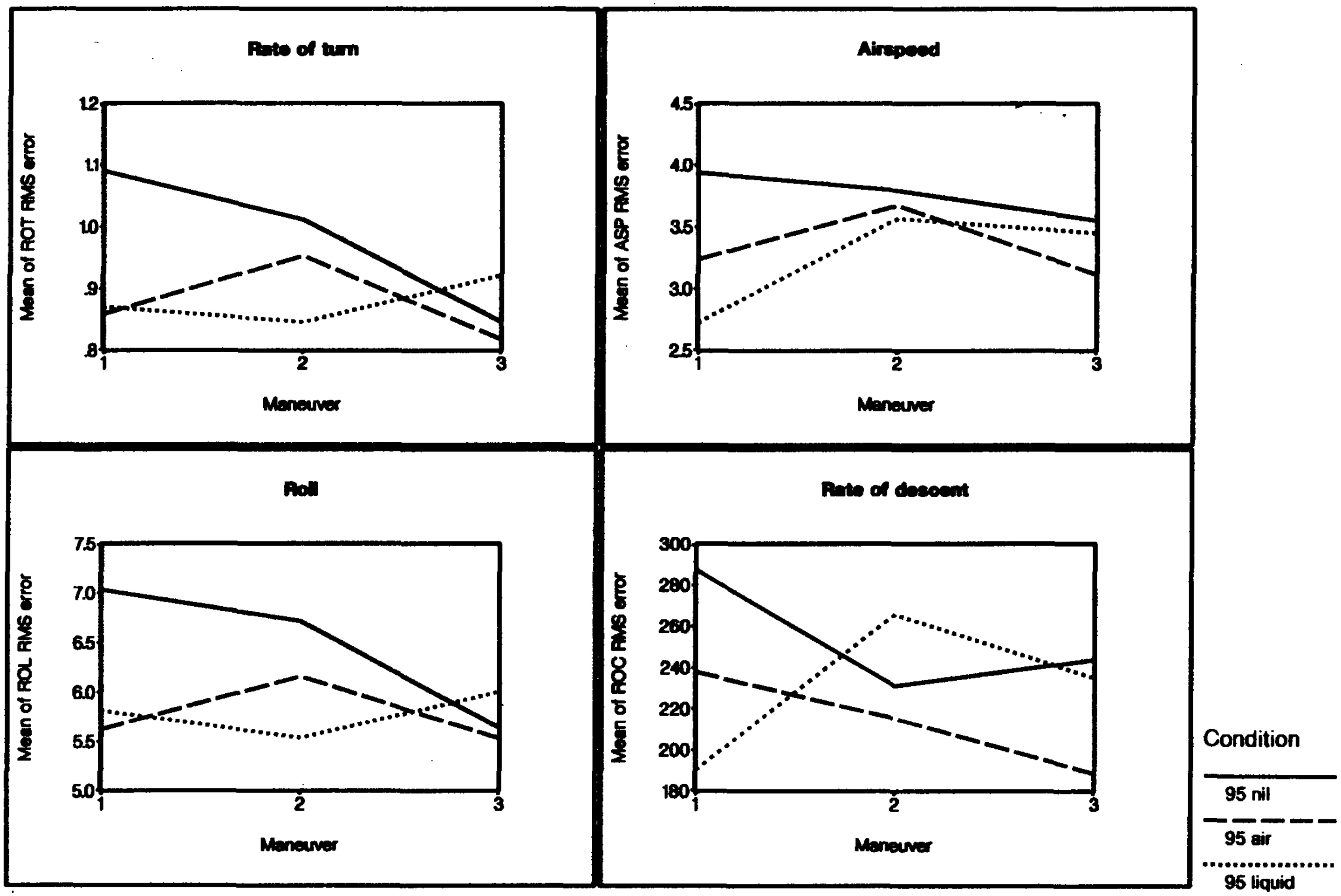

Figure 41. RMS error for left descending turn against maneuver number, 95°F.

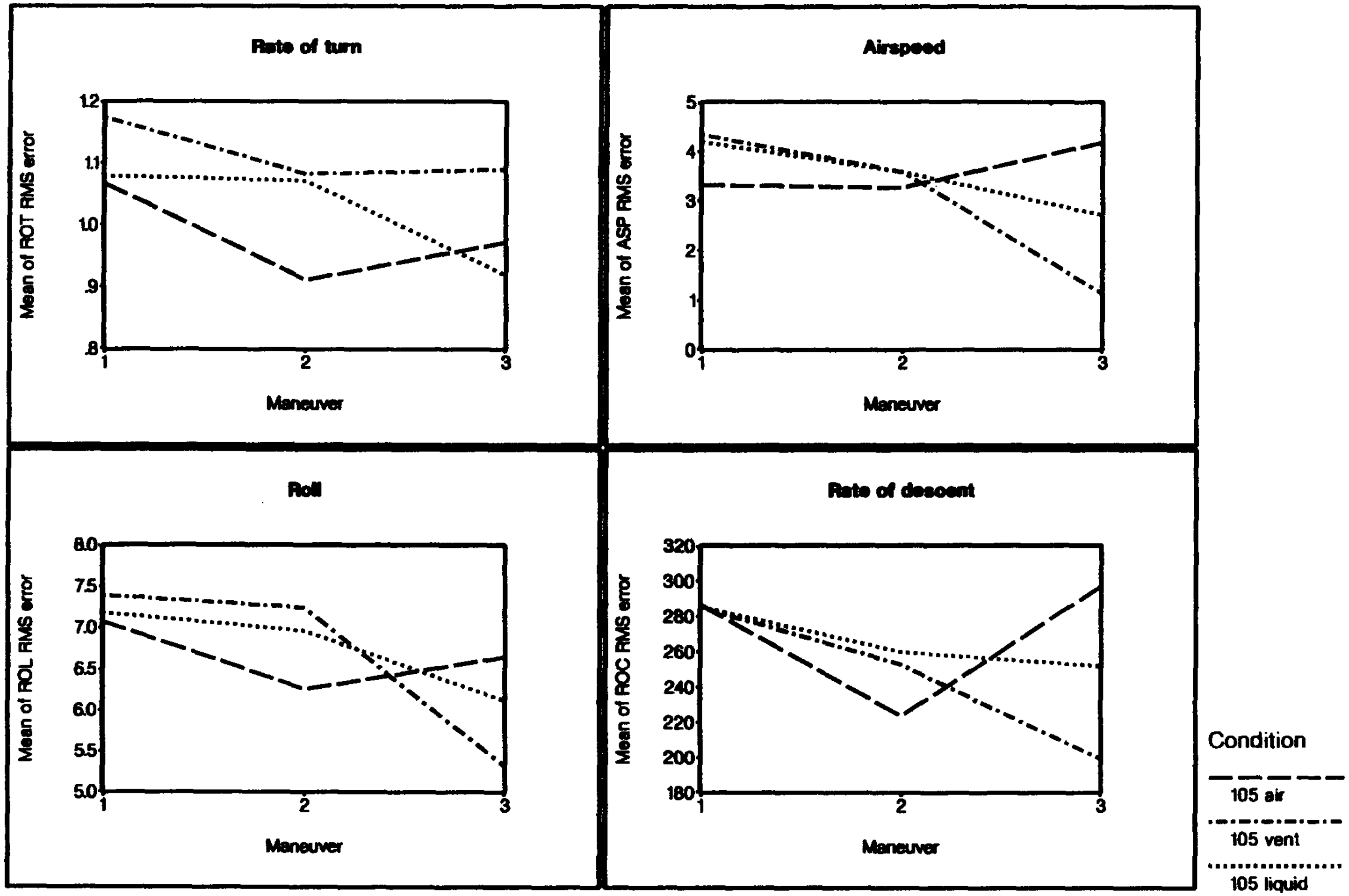

Figure 42. RMS error for left descending turn against maneuver number, 105°F.

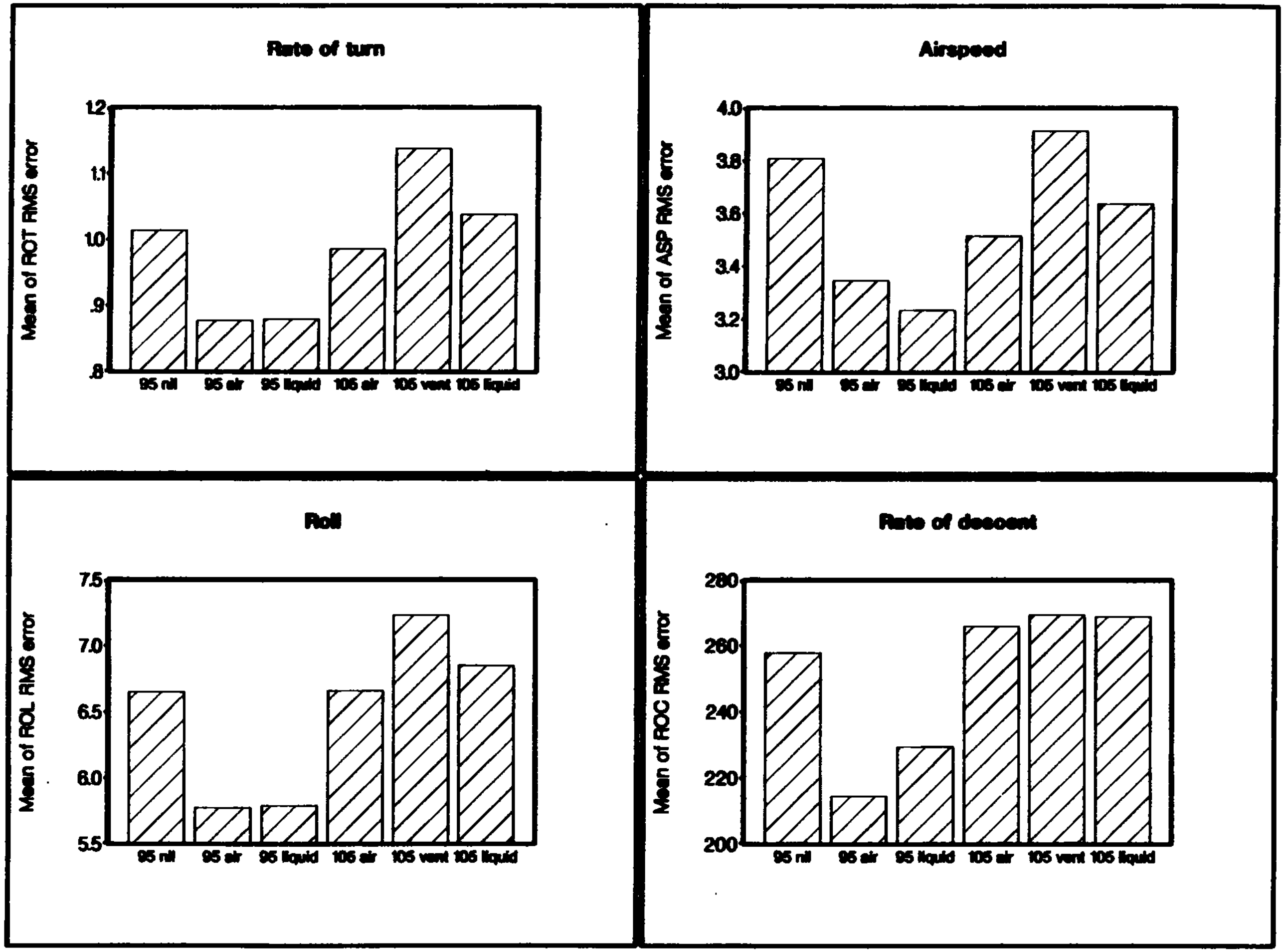

Figure 43. Mean RMS error for left descending turn.

Table 18.
Summary statistics for left descending turn RMS error.

Rate of turn

Group	N	Mean	STD	CV
2	37	1.0140541	0.3748367	36.9641736
3	47	0.8774468	0.2436093	27.7634318
4	46	0.8791304	0.2036208	23.1616196
6	43	0.9848837	0.3630976	36.8670527
7	20	1.1380000	0.4742595	41.6748272
8	37	1.0375676	0.3426725	33.0265284

Rate of descent

Group	N	Mean	STD	CV
2	37	257.8335135	124.9296718	48.4536204
3	47	214.4582979	61.9373464	28.8808347
4	46	229.3943478	122.9289833	53.5884971
6	43	265.8367442	134.5249936	50.6043640
7	20	269.4420000	87.1029767	32.3271712
8	37	268.9467568	114.3036525	42.5004762

Airspeed

Group	N	Mean	STD	CV
2	37	3.8089189	2.2183713	58.2414932
3	47	3.3455319	1.8108607	54.1277372
4	46	3.2341304	2.0104279	62.1628577
6	43	3.5148837	1.7913554	50.9648551
7	20	3.9120000	2.7887926	71.2881546
8	37	3.6364865	2.8690031	78.8949208

Roll

Group	N	Mean	STD	CV
2	37	6.6481081	2.3128360	34.7893856
3	47	5.7746809	1.6231422	28.1079121
4	46	5.7847826	1.4998781	25.9279947
6	43	6.6579070	2.1704033	32.5988822
7	20	7.2330000	2.7246132	37.6691989
8	37	6.8483784	2.2460391	32.7966564

Slip

Group	N	Mean	STD	CV
2	37	0.7964865	0.3413309	42.8545703
3	47	0.7729787	0.3884692	50.2561321
4	46	0.7395652	0.3477416	47.0197403
6	43	0.7604651	0.3672546	48.2934233
7	20	0.7595000	0.4757318	62.6375044
8	37	0.6516216	0.3914681	60.0759885

Descent

Descent was scored for the five relevant parameters of heading, rate of descent, airspeed, slip, and roll. Figure 44 shows the RMS error plotted against maneuver number (three runs of three maneuvers) for the 95°F conditions, Figure 45 for the 105°F conditions.

Collapsing across condition, there were no significant differences between the three run numbers for four parameters. For roll, the error was significantly greater on the first and second runs than the third. When the 95 nil data were examined in isolation, there were no significant differences between runs for four parameters, but for slip the error was significantly greater on the third run than the first two. There were no differences for the 105 vent data.

Figure 46 demonstrates the mean of the RMS error for all descent maneuvers in each condition and each subject. For heading, error rate was significantly lower for 95 air and 95 nil and 105 liquid than for 105 air and 105 vent. The results for airspeed and rate of climb were identical: the error for 105 vent was significantly greater than all other conditions, and 95 air and 95 liquid produced significantly better performance than all other conditions. For roll, the error for 95 air and 95 liquid was significantly lower than all other conditions except 105 liquid. For slip the error for 105 air and 105 vent was significantly greater than the three 95°F conditions and 105 liquid was significantly higher than 95 nil. Table 19 contains the summary statistics.

There were significant differences between the two cooling systems for the data shown in Figure 46, with the liquid cooler providing significantly better performance at 105°F for heading and roll. When the data were examined for pilots only, there were no differences between the systems. When they were analyzed for subjects 12 onward only, the error for airspeed at 105°F was significantly lower with the air system than the liquid.

Collapsing across condition, the error for pilots was significantly less than for copilots for heading, airspeed, and roll. For subjects 12 onward, the error was significantly greater than the first 8 subjects for all parameters. The error rate was significantly higher for non-UH-60 pilots for all parameters except roll. There were significant differences between the errors for individual subjects.

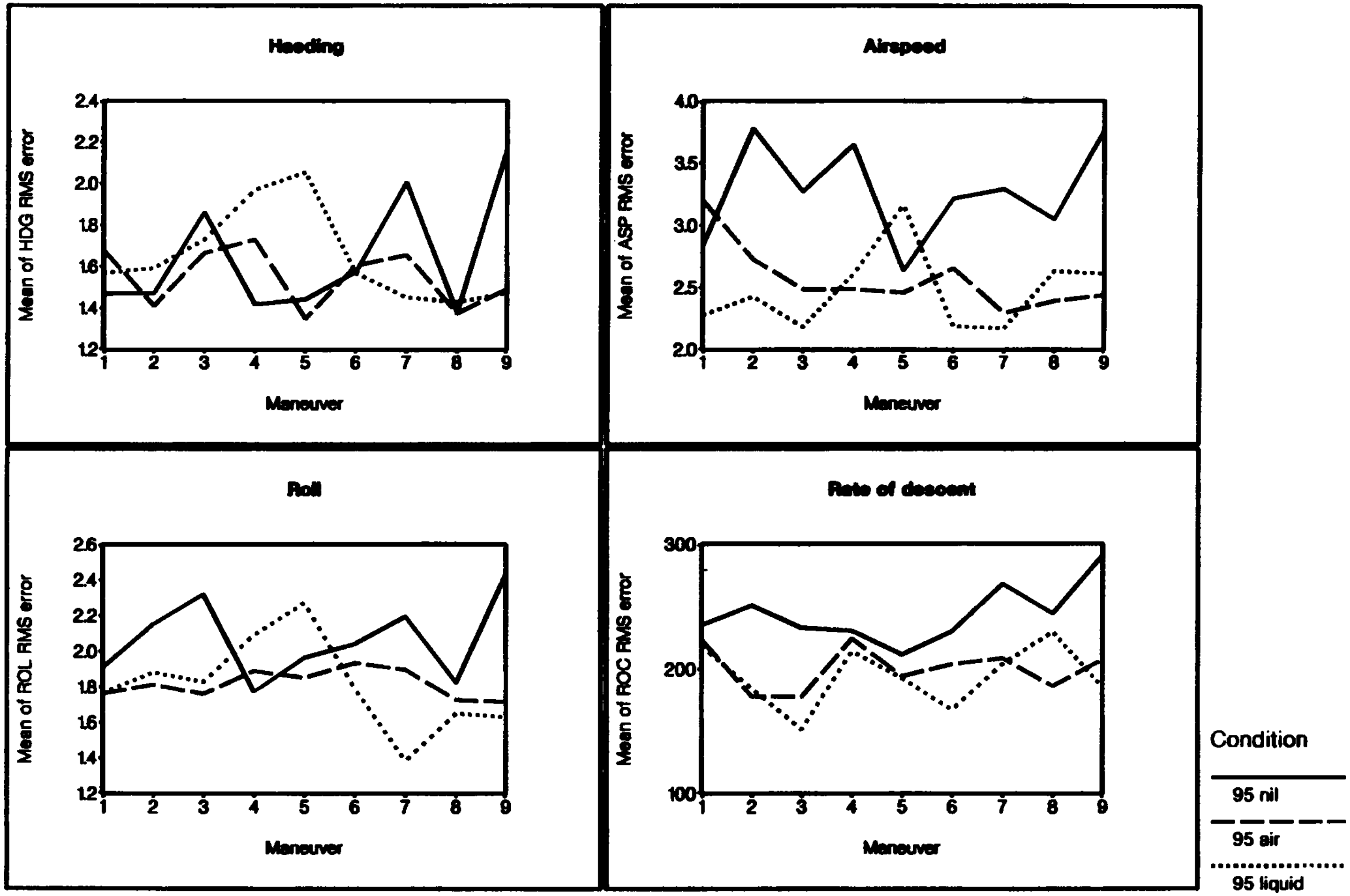

Figure 44. RMS error for descent against maneuver number, 95°F.

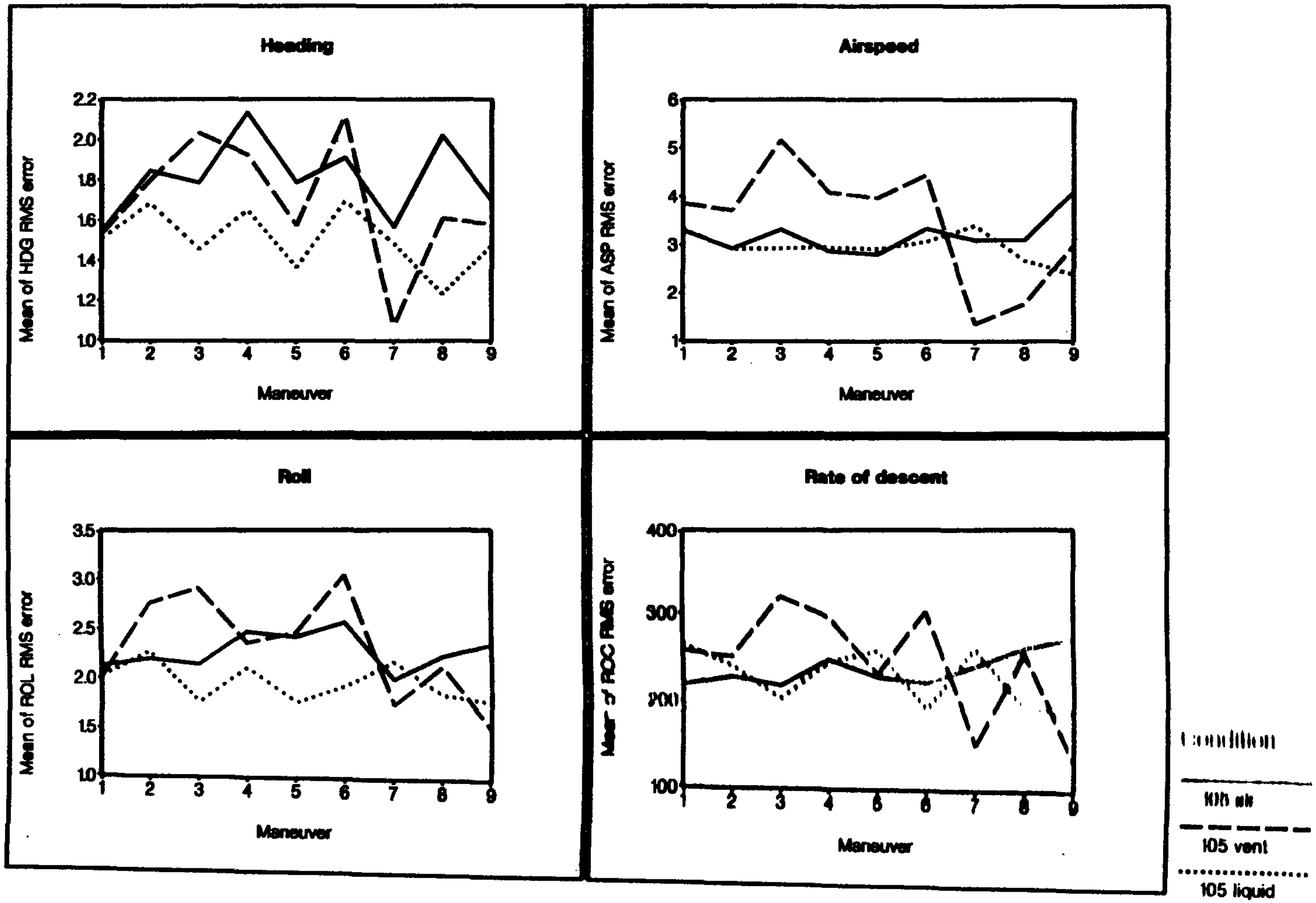

Figure 45. RMS error for descent against maneuver number, 105°F.

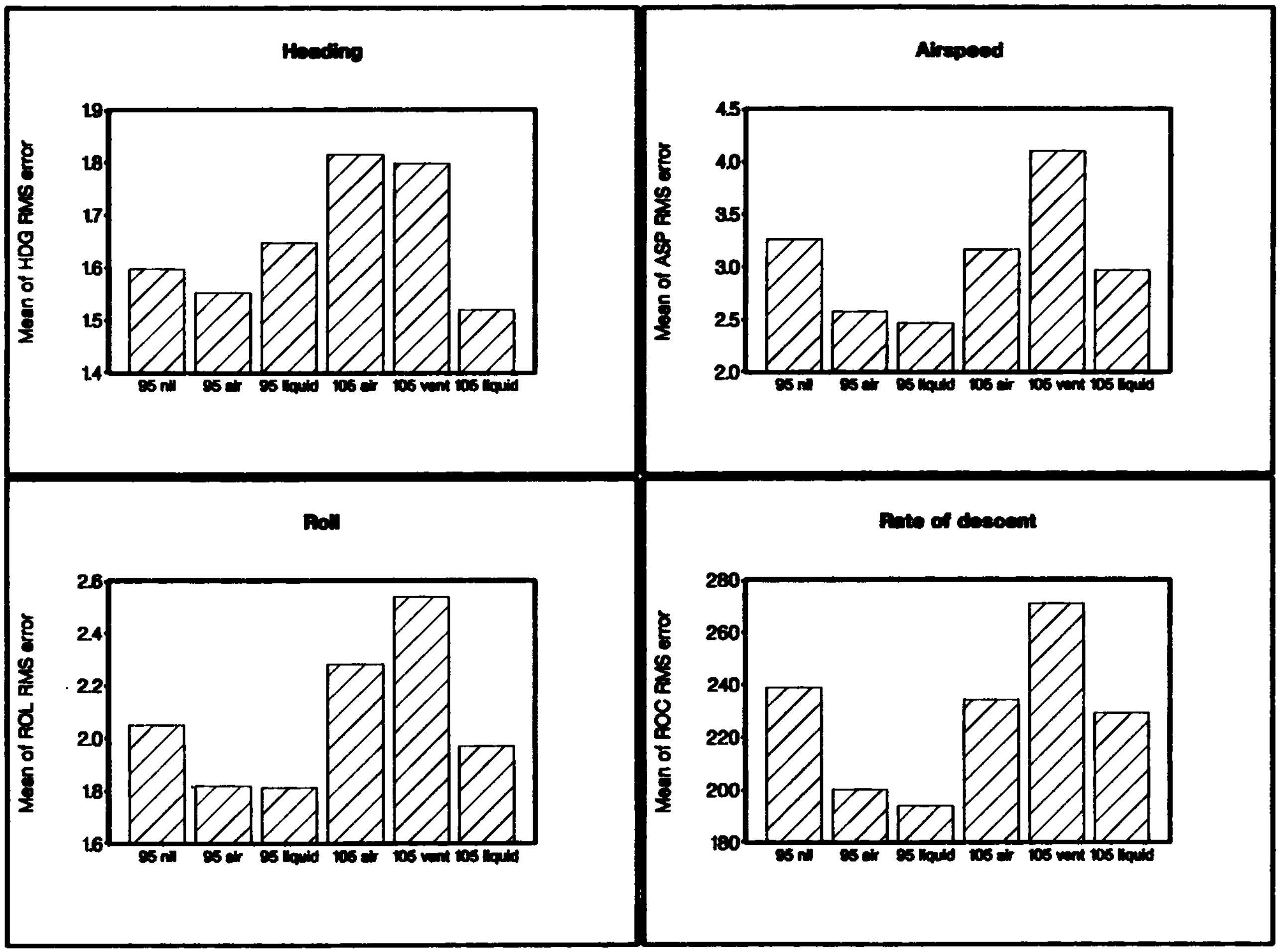

Figure 46. Mean RMS error for descent.

Table 19.
Summary statistics for descent RMS error.

Heading

Group	N	Mean	STD	CV
2	111	1.5969369	0.7725740	48.3784893
3	141	1.5519858	0.7152295	46.0847932
4	138	1.6478261	0.8744214	53.0651500
6	127	1.8155906	0.8438439	46.4776523
7	60	1.7983333	0.7151251	39.7659944
8	110	1.5197273	0.6117166	40.2517340

Rate of descent

Group	N	Mean	STD	CV
2	111	238.9446847	104.0661671	43.5524093
3	141	200.4003546	76.9722310	38.4092289
4	138	193.9307246	67.0099107	34.5535298
6	127	234.1945669	93.4170938	39.8886682
7	60	270.8873333	99.4197762	36.7015227
8	110	229.0429091	93.6408837	40.8835550

Airspeed

Group	N	Mean	STD	CV
2	111	3.2628829	2.2398500	68.6463496
3	141	2.5734752	1.2577588	48.8739422
4	138	2.4680435	1.3217290	53.5537182
6	127	3.1656693	1.5807476	49.9340712
7	60	4.1018333	2.7556995	67.1821417
8	110	2.9690000	1.7895133	60.2732657

Roll

Group	N	Mean	STD	CV
2	111	2.0505405	0.8946150	43.6282542
3	141	1.8185816	0.6987454	38.4225488
4	138	1.8110145	0.7977654	44.0507459
6	127	2.2816535	1.0062596	44.1022078
7	60	2.5383333	1.2029275	47.3904447
8	110	1.9696364	0.9083041	46.1153206

Slip

Group	N	Mean	STD	CV
2	111	0.4281081	0.2627530	61.3753746
3	141	0.4437589	0.2476303	55.8028985
4	138	0.4676087	0.3084658	65.9666603
6	127	0.5681890	0.2950368	51.9258169
7	60	0.5771667	0.3519394	60.9770801
8	110	0.5170000	0.2896203	56.0193971

Climb

Climb was scored for the five relevant parameters of heading, rate of climb, airspeed, slip, and roll. Figure 47 shows the RMS error plotted against maneuver number (three runs of two maneuvers) for the 95°F conditions, Figure 48 for the 105°F conditions.

Collapsing across condition, there were no significant differences between the three run numbers for four parameters. For airspeed, the error was significantly greater on the first run than the second and third. When the 95 nil data were examined in isolation, the error for roll was significantly greater on the third run than on the second. For the 105 vent data, the error for rate of climb was significantly greater on the third run than the first.

Figure 49 demonstrates the mean of the RMS error for all climb maneuvers in each condition and each subject. There were no differences between conditions for heading and slip. For airspeed, the error for 95 air was significantly less than for all other conditions except 95 liquid, and the error for 95 liquid was significantly less than for 105 liquid. For rate of climb, the error was significantly higher for 105 vent and 105 liquid than the three 95°F conditions. Table 20 contains the summary statistics.

There were no significant differences between the two cooling systems for the data shown in Figure 49. When the data were examined for pilots only, there were still no differences between the systems. When they were analyzed for subjects 12 onward only, the error for heading, airspeed, and rate of climb at 105°F was significantly lower with the air system than the liquid.

Collapsing across condition, the error for pilots was significantly less than for copilots for roll and slip. For subjects 12 onward, the error was significantly greater than the first 8 subjects for heading and airspeed. The error rate was significantly higher for non-UH-60 pilots for heading and airspeed. There were significant differences between the errors for individual subjects.

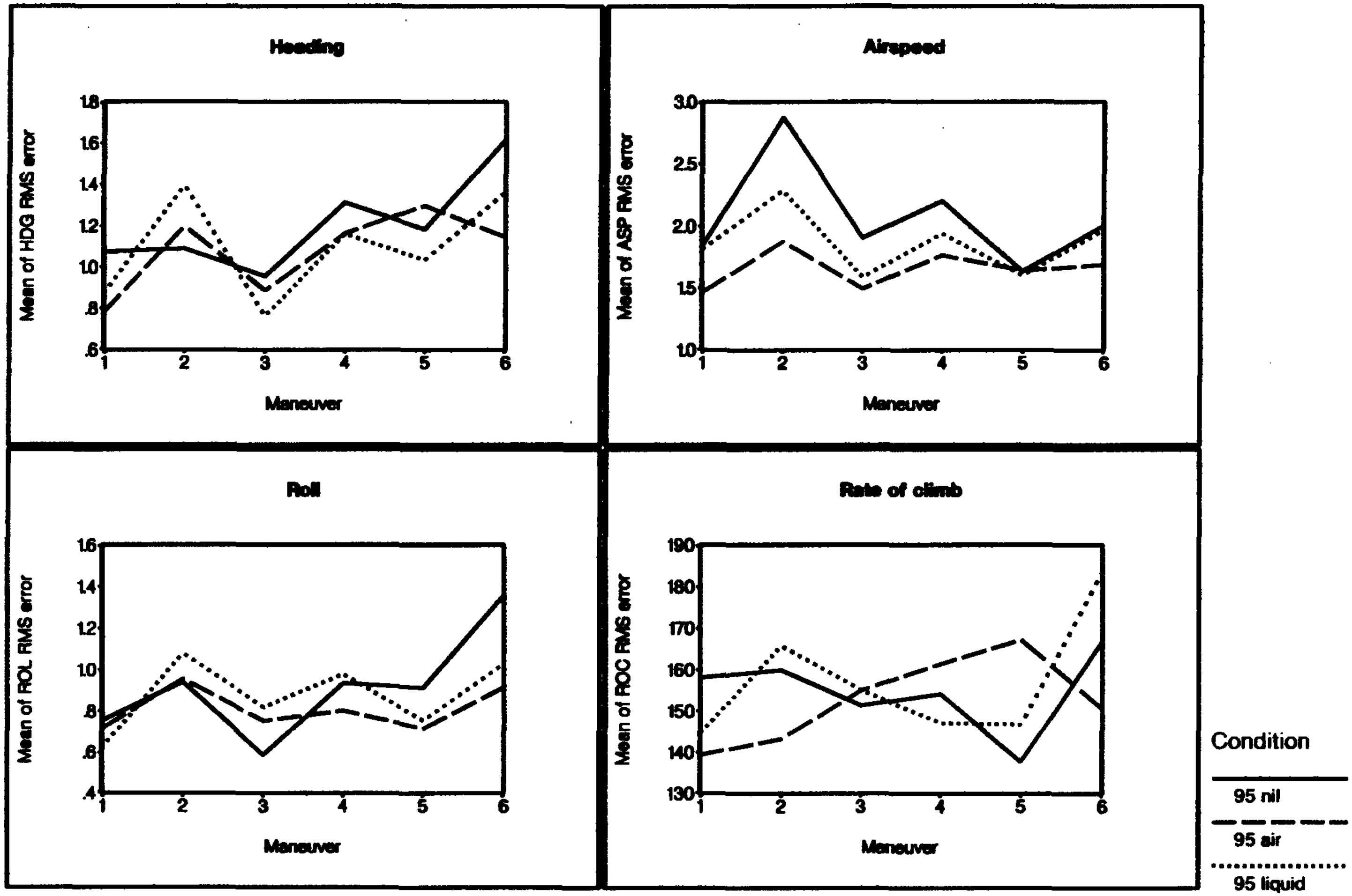

Figure 47. RMS error for climb against maneuver number, 95°F.

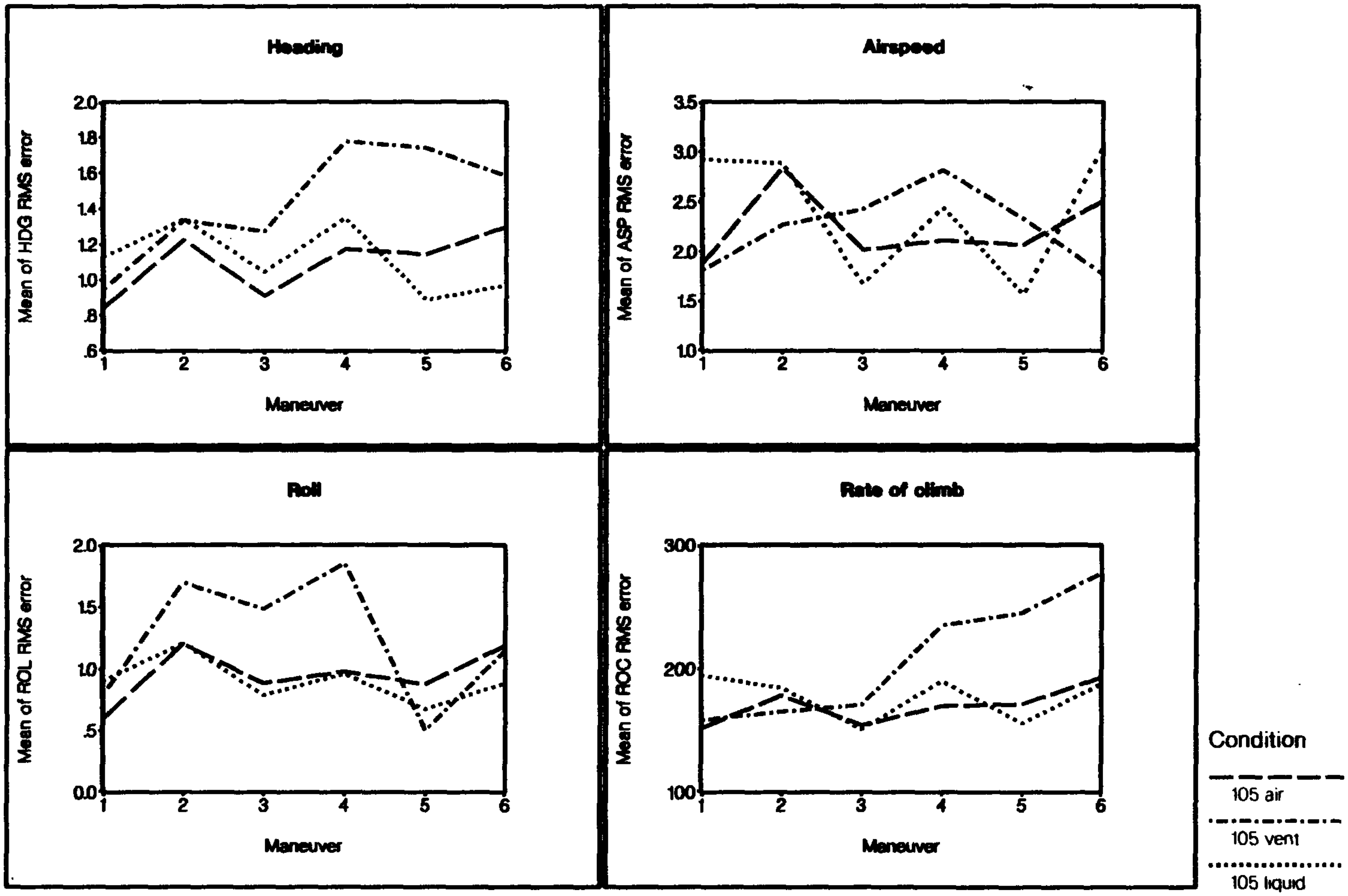

Figure 48. RMS error for climb against maneuver number, 105°F.

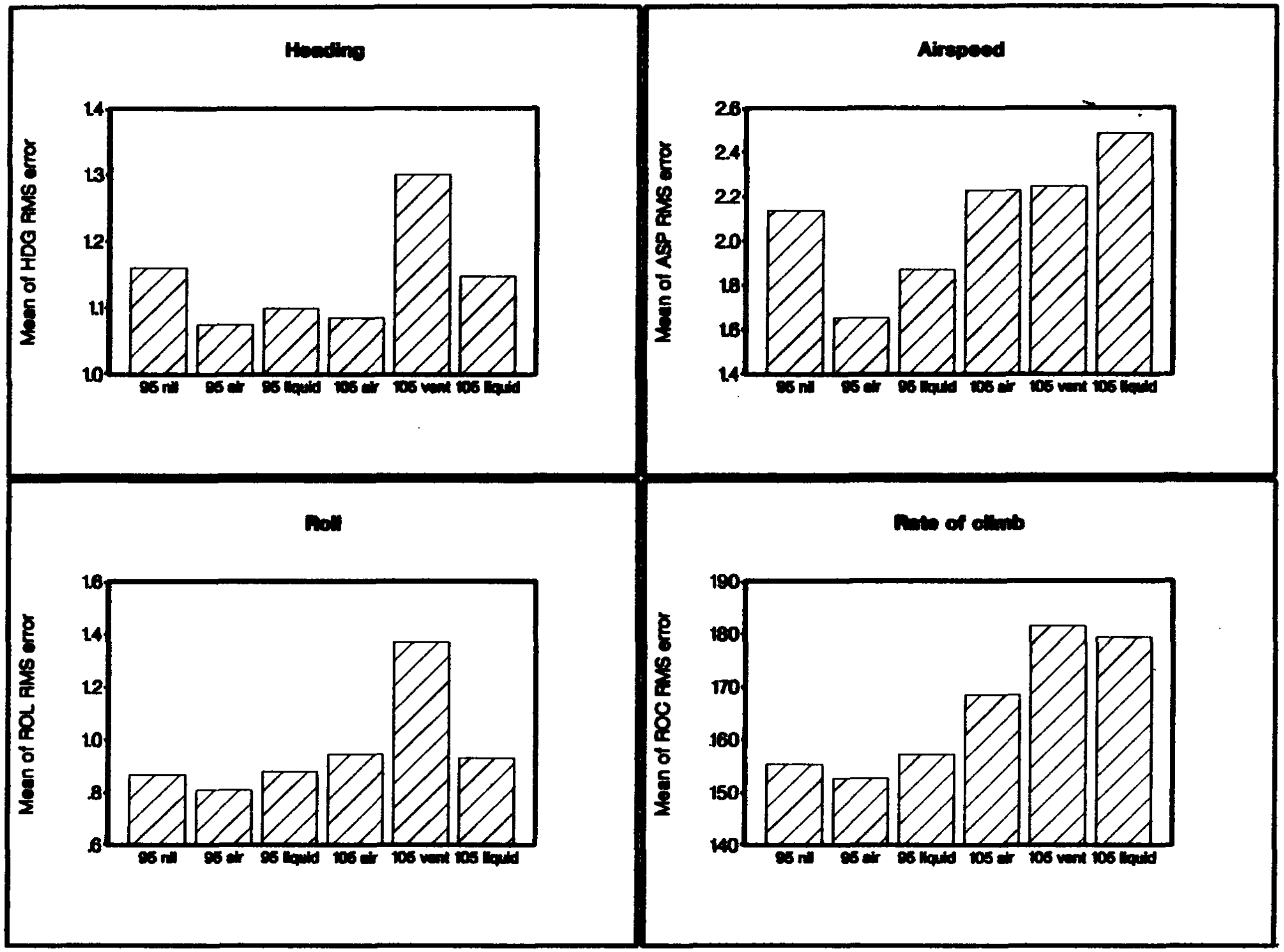

Figure 49. Mean RMS error for climb.

Table 20.
Summary statistics for climb RMS error.

Heading

Group	N	Mean	STD	CV
2	76	1.1600000	0.5966149	51.4323186
3	94	1.0748936	0.7087423	65.9360369
4	92	1.0982609	0.5877048	53.5123143
6	87	1.0844828	0.5171405	47.6854538
7	40	1.3005000	0.7913926	60.8529518
8	74	1.1470270	0.7536391	65.7036898

Rate of climb

Group	N	Mean	STD	CV
2	76	155.3386842	46.6546978	30.0341785
3	94	152.6945745	51.8850723	33.9796436
4	92	157.1645652	54.4485595	34.6442975
6	87	168.4488506	57.6528541	34.2257331
7	40	181.3947500	71.0951012	39.1935826
8	74	179.3013514	79.6322466	44.4125189

Airspeed

Group	N	Mean	STD	CV
2	76	2.1365789	1.1022021	51.5872397
3	94	1.6524468	0.9100191	55.0710087
4	92	1.8693478	0.8521412	45.5849462
6	87	2.2290805	1.1745871	52.6937975
7	40	2.2442500	0.9108150	40.5843841
8	74	2.4831081	1.6439769	66.2064169

Roll

Group	N	Mean	STD	CV
2	76	0.8660526	0.5334519	61.5957774
3	94	0.8085106	0.3762005	46.5300576
4	92	0.8794565	0.5448165	61.9492206
6	87	0.9451724	0.5409033	57.2280075
7	40	1.3695000	1.4090640	102.8889356
8	74	0.9294595	0.5815565	62.5693203

Slip

Group	N	Mean	STD	CV
2	76	0.3813158	0.1923354	50.4399297
3	94	0.3441489	0.1967172	57.1604834
4	92	0.3646739	0.1973865	54.1268499
6	87	0.3805747	0.2121450	55.7433121
7	40	0.4117500	0.2095892	50.9020496
8	74	0.3531081	0.2362604	66.9087993

Straight and level

Straight and level was scored for the five relevant parameters of heading, altitude, airspeed, slip, and roll. Figure 50 shows the RMS error plotted against maneuver number (three runs of two maneuvers) for the 95°F conditions, Figure 51 for the 105°F conditions.

Collapsing across condition and AFCS, there were no significant differences between the three run numbers for all parameters. When the 95 nil data were examined in isolation, the error for airspeed on the third run was significantly higher than on the second. There were no significant differences between runs for the 105 vent data.

Figure 52 demonstrates the mean of the RMS error for all straight and level maneuvers in each condition and each subject with the AFCS in. For heading, AFCS in, there were no significant differences between error rates for the different conditions. For altitude, the error rate was significantly lower for 95 air and 95 liquid than for 105 air and 105 liquid. For airspeed, 95 air and 95 liquid had a significantly lower error than 105 air and 105 liquid. For roll, the error for 105 vent was significantly higher than all conditions except 105 air. For slip, the error for 95 liquid and 105 liquid was significantly lower than 105 vent.

Figure 53 shows the same data for AFCS out. For heading, AFCS out, the error for 95 air was significantly lower than 95 nil and 105 vent. For altitude, the error for 95 air was significantly lower than all conditions except 95 liquid, and 95 liquid was significantly lower than 105 vent. For airspeed, 105 vent was significantly worse than all other conditions. For roll, the error for 105 vent was significantly higher than all other conditions. The error for 95 nil and 105 air was significantly worse than 95 air, 95 liquid and 105 liquid. The summary statistics are in Table 21.

There were significant differences between the two cooling systems for the data shown in Figures 52 and 53, with liquid cooling producing better performance for roll at 105°F. When the data were examined for pilots only, there were no differences between the systems. For subjects 12 onward only, the air system produced significantly lower errors than the liquid system for altitude and airspeed at 105°F.

Collapsing across condition and AFCS, the error for pilots was significantly greater than for copilots for altitude, and greater for pilots for heading and roll. For subjects 12 onward, the error was significantly greater than the first 8 subjects for all parameters. The error rate was significantly higher for non-UH-60 pilots for all parameters except roll.

Collapsing across condition, the error without the AFCS was significantly greater for all parameters except slip. There were significant differences between the errors for individual subjects for all parameters except heading.

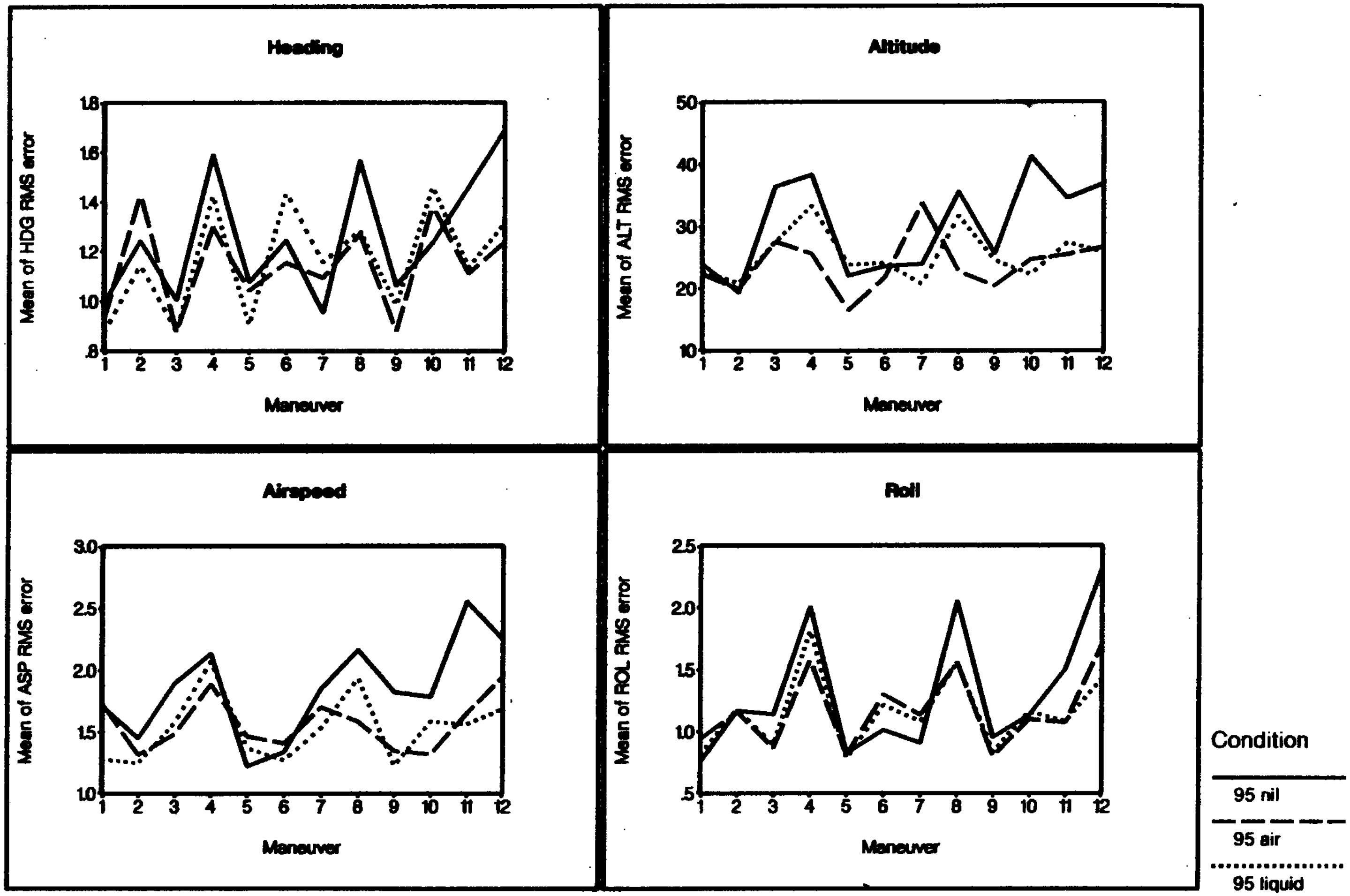

Figure 50. RMS error for straight and level against maneuver number, 95°F.

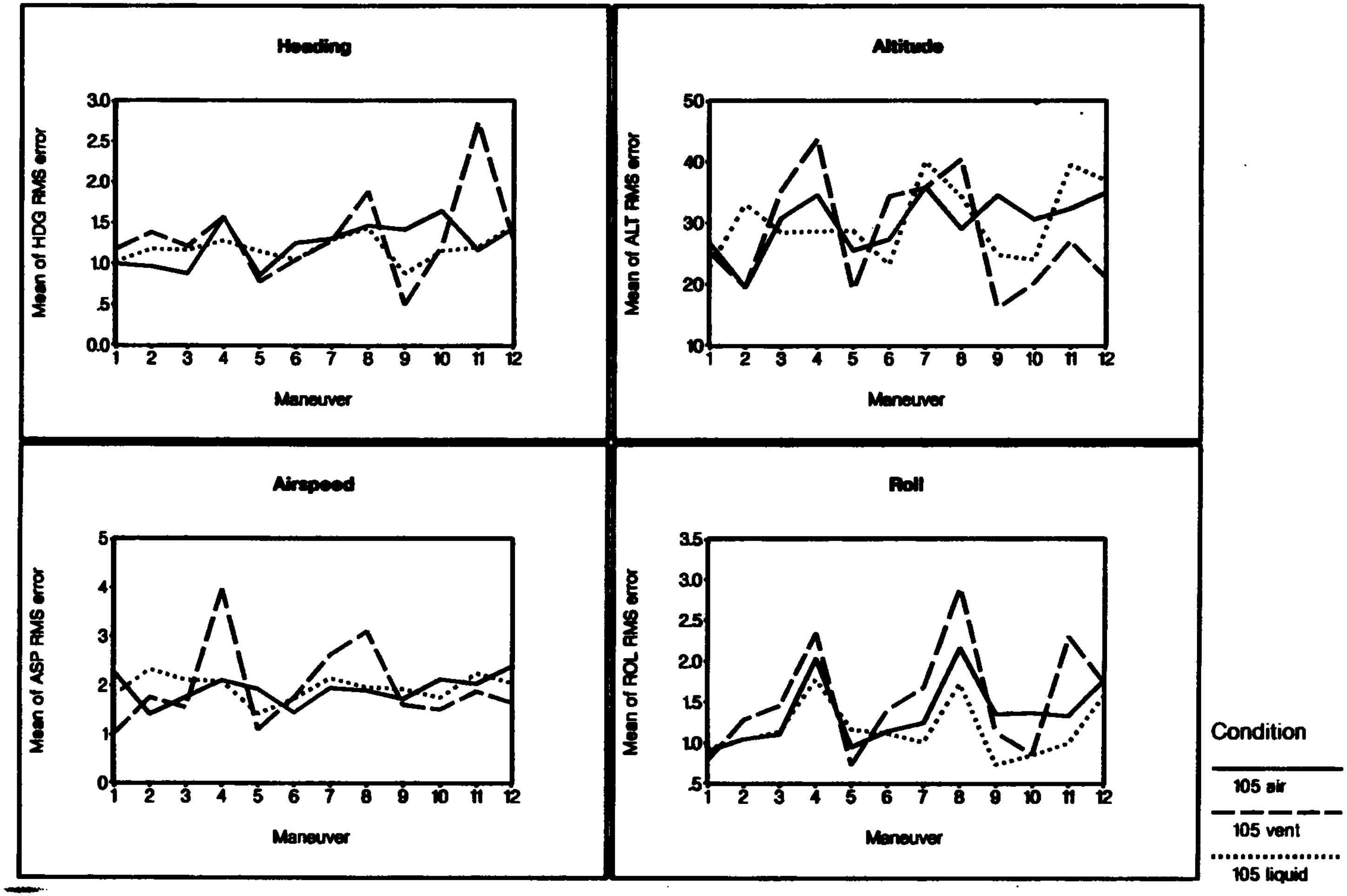

Figure 51. RMS error for straight and level against maneuver number, 105°F.

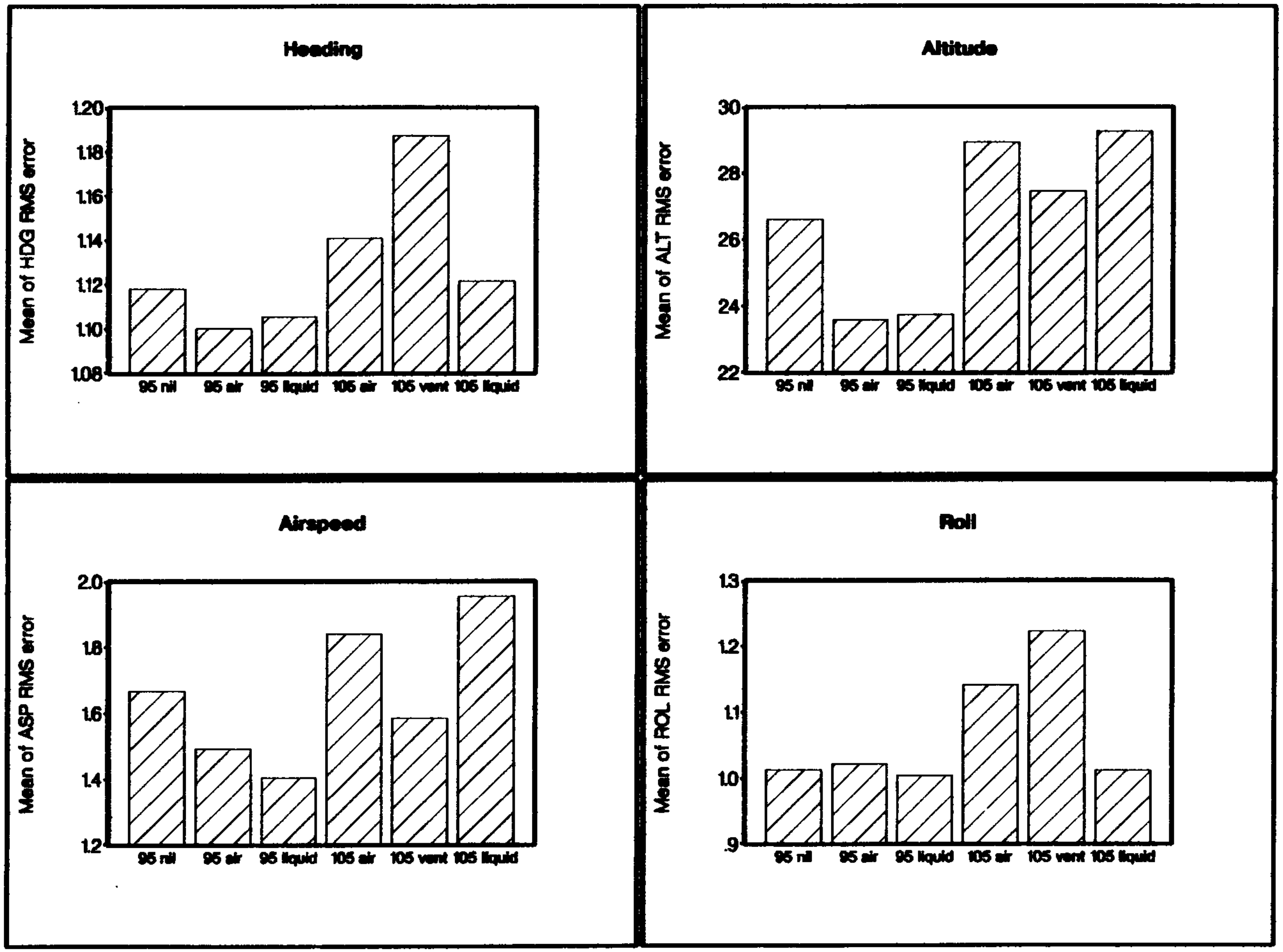

Figure 52. Mean RMS error for straight and level, AFCS in.

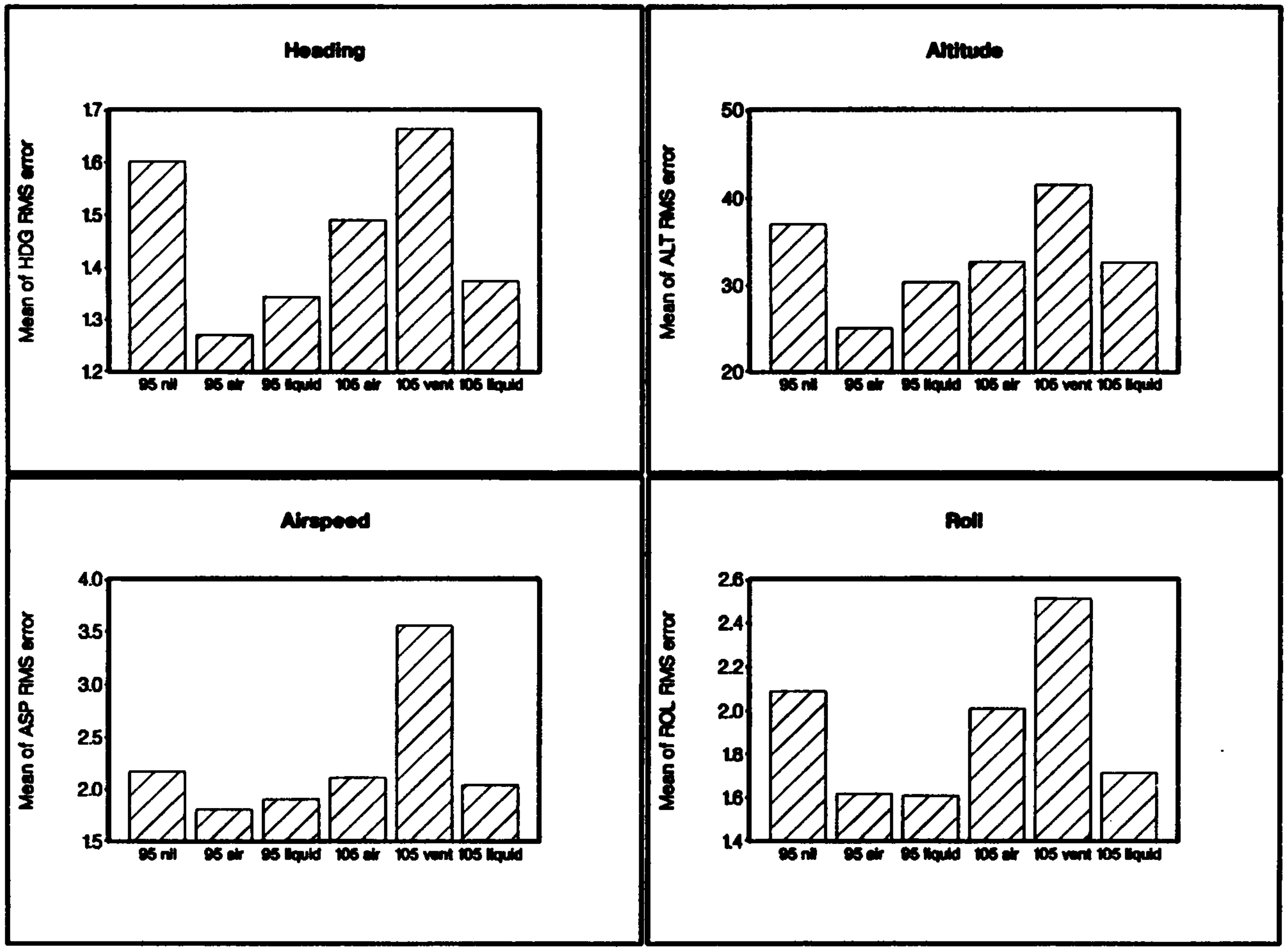

Figure 53. Mean RMS error for straight and level, AFCS out.

Table 21.
Summary statistics for straight and level RMS error.

===

Heading - AFCS in

Group	N	Mean	STD	CV
2	113	1.1182301	0.5773388	51.6296936
3	141	1.1002128	0.6229704	56.6227190
4	139	1.1055396	0.6247111	56.5073531
6	131	1.1408397	0.6017322	52.7446728
7	60	1.1873333	0.6450696	54.3292766
8	111	1.1216216	0.6457266	57.5708025

Altitude - AFCS in

Group	N	Mean	STD	CV
2	114	26.7699123	19.3331864	72.2198347
3	141	23.5887234	14.8979762	63.1571956
4	140	34.2166429	124.7670877	364.6386006
6	131	28.9390076	17.7539213	61.3494473
7	60	27.4573333	18.0991166	65.9172412
8	111	29.2600901	19.1180358	65.3382669

Airspeed - AFCS in

Group	N	Mean	STD	CV
2	113	1.6672566	0.8767444	52.5860514
3	141	1.4921986	0.9384532	62.8906378
4	139	1.4921986	0.9384532	49.0634733
6	131	1.8408397	1.1723632	63.6863270
7	60	1.5843333	0.9963363	62.8867841
8	111	1.9537838	1.4538445	74.4117378

Roll - AFCS in

Group	N	Mean	STD	CV
2	113	1.0130088	0.5946456	58.7009265
3	141	1.0214894	0.6884340	67.3951194
4	139	1.0046763	0.4712615	46.9068009
6	131	1.1411450	0.6127738	53.6981541
7	60	1.2230000	0.8954656	73.2187737
8	111	1.0123423	0.6333503	62.5628611

Slip - AFCS in

Group	N	Mean	STD	CV
2	113	0.3464602	0.2016358	58.1988423
3	141	0.3531915	0.1652544	46.7889055
4	139	0.3359712	0.1499842	44.6419636
6	131	0.3641221	0.1756783	48.2470898
7	60	0.3961667	0.2234331	56.3987600
8	111	0.3364865	0.1719812	51.1108872

Table 21 (Continued).
Summary statistics for straight and level RMS error.

Heading - AFCS out

Group	N	Mean	STD	CV
2	37	1.6016216	0.8313527	51.9069348
3	47	1.2702128	0.3667868	28.8760134
4	46	1.3443478	0.5242504	38.9966319
6	42	1.4916667	0.4435440	29.7347949
7	20	1.6640000	0.5816347	34.9540096
8	36	1.3747222	0.5819597	42.3328921

Altitude - AFCS out

Group	N	Mean	STD	CV
2	37	37.0091892	19.2003519	51.8799583
3	47	24.9768085	11.4918930	46.0102539
4	46	30.3658696	15.7348492	51.8175484
6	42	32.6814286	14.5133633	44.4085952
7	20	41.4500000	20.4828580	49.4158216
8	36	32.6202778	18.2785405	56.0342883

Airspeed - AFCS out

Group	N	Mean	STD	CV
2	37	2.1675676	0.8894424	41.0341263
3	47	1.8023404	0.6831615	37.9041318
4	46	1.9026087	0.7480595	39.3175707
6	42	2.1050000	0.7857675	37.3286200
7	20	3.5530000	2.4468779	68.8679405
8	36	2.0375000	1.1709761	57.4712191

Roll - AFCS out

Group	N	Mean	STD	CV
2	37	2.0870270	0.8530822	40.8754747
3	47	1.6146809	0.5478569	33.9297327
4	46	1.6080435	0.7540398	46.8917573
6	42	2.0104762	0.7337606	36.4968569
7	20	2.5115000	1.0539364	41.9644179
8	36	1.7144444	0.7520883	43.8677562

Slip - AFCS out

Group	N	Mean	STD	CV
2	37	0.3040541	0.1874012	61.6341807
3	47	0.2893617	0.1442131	49.8383407
4	46	0.3008696	0.1794786	59.6532850
6	42	0.3878571	0.1854926	47.8249705
7	20	0.4010000	0.2061144	51.4001070
8	36	0.3319444	0.1763085	53.1138538

Simulator instructor/operator comments

There was no formal subjective assessment of flight performance in this study. However, the simulator instructor/operator did make a number of observations, noting in particular the occasions on which the simulator 'crashed' into the terrain or hit trees. There was one crash in each of the 95°F conditions by three different subjects. There was one crash at 105 nil, two at 105 air, four at 105 liquid and four at 105 vent. Of the 14 crashes, only 2 were due to non-UH-60 pilots.

Survival time

The simplest measure of the ability to operate in NBC protective clothing is 'survival time,' that is the length of time that the conditions can be endured before the subject removes himself from the experiment, or the physiological criteria are met.

The overall survival times are shown in Table 22. Subjects who reached the physiological limits for withdrawal are indicated. The subjects who quit voluntarily did so usually complaining of headache, nausea, or both. One subject quit during both liquid sessions because of painful 'hotspots' on his head caused by the tubes in the cooler cap. On the 105°F run for the final two subjects, the air cooler failed. Their values therefore are not included in the summary statistics or graphs. Subjects 14 and 15 were a day late starting the study, and the vent condition was dropped to allow their participation. The means are graphed in Figure 54, together with the minimum survival time for each condition.

A significant condition effect was present, ($F(6,78) = 53.32$, $p < 0.0001$). The mean survival time at 95°F without cooling was 285 minutes, the minimum 118. Only one individual in either case failed to complete 6 hours exposure with cooling at 95°F, so that comparison of the minimum values is not very relevant. The posthoc analysis indicated that the increase in survival time for both cooled conditions over the uncooled was statistically significant, (air $p < 0.05$, liquid $p < 0.01$), but the two cooled conditions cannot be separated statistically.

At 105°F without cooling, the mean survival time was only 79 minutes, with a minimum of 40 minutes. The additional evaporative cooling provided by the vent air increased mean survival time significantly to 150 minutes ($p < 0.01$), with a minimum of 66 minutes. With cooling, the air system produced a better survival time with 333 minutes ($p < 0.01$) compared with 294 ($p < 0.01$) minutes for the liquid system, and a larger difference in minimum times, 225 and 113 minutes respectively.

The increased survival time with cooling compared with vent and uncooled conditions is statistically significant. The two cooled conditions cannot be separated statistically.

Because of the differences between cooling capacity for the two sides of both coolers, the mean and minimum survival times in Figure 55 have been computed for the better (right) side. The differences between the two conditions at both temperatures are now minimized, and cannot be separated statistically. Analyzing data for the last six subjects only, to take account of the poorer air cooler performance in the first half of the study, there is a significant effect for condition, ($F(6,30) = 49.78, p < 0.001$). Posthoc analysis reveals a significant difference between the mean survival times for the two cooled conditions at 105°F (360 minutes for air, 256 for liquid), ($p < 0.01$) but none at 95°F.

Table 22.
Survival time (minutes).

Sub nil	95 air	95 liquid	95 nil	105 vent	105 nil	105 air	105 liquid
3	360	360	360	40*	113*	360	360
4	225*	360	360	55*	66*	360	360
5	118	249	360	74*	89	225	312
6	330	360	360	74*	201*	242*	360
7	220	360	360	82*	180	360	360
9	149	360	360	50	150*	315	271
10	295*	360	360	130*	202	322*	197*
11	260	360	360	142	360	322*	360
12	360	360	330	60*	115	360	290
13	360	360	360	105*	115	360	360
14	360	360	360	82*		360	113
15	330	360	360	69*		360	258
16	257	360	360	58	85	360	155
17	360	360	360	90*	125*	360	360
18†	360	360	360	65*	259	300**	205
19†	310	360	360	65*	288	300**	360
Mean	285	353	358	79	150	333	294

† Data not included in mean
* Reached physiological criteria
** Run halted due to cooler failure.

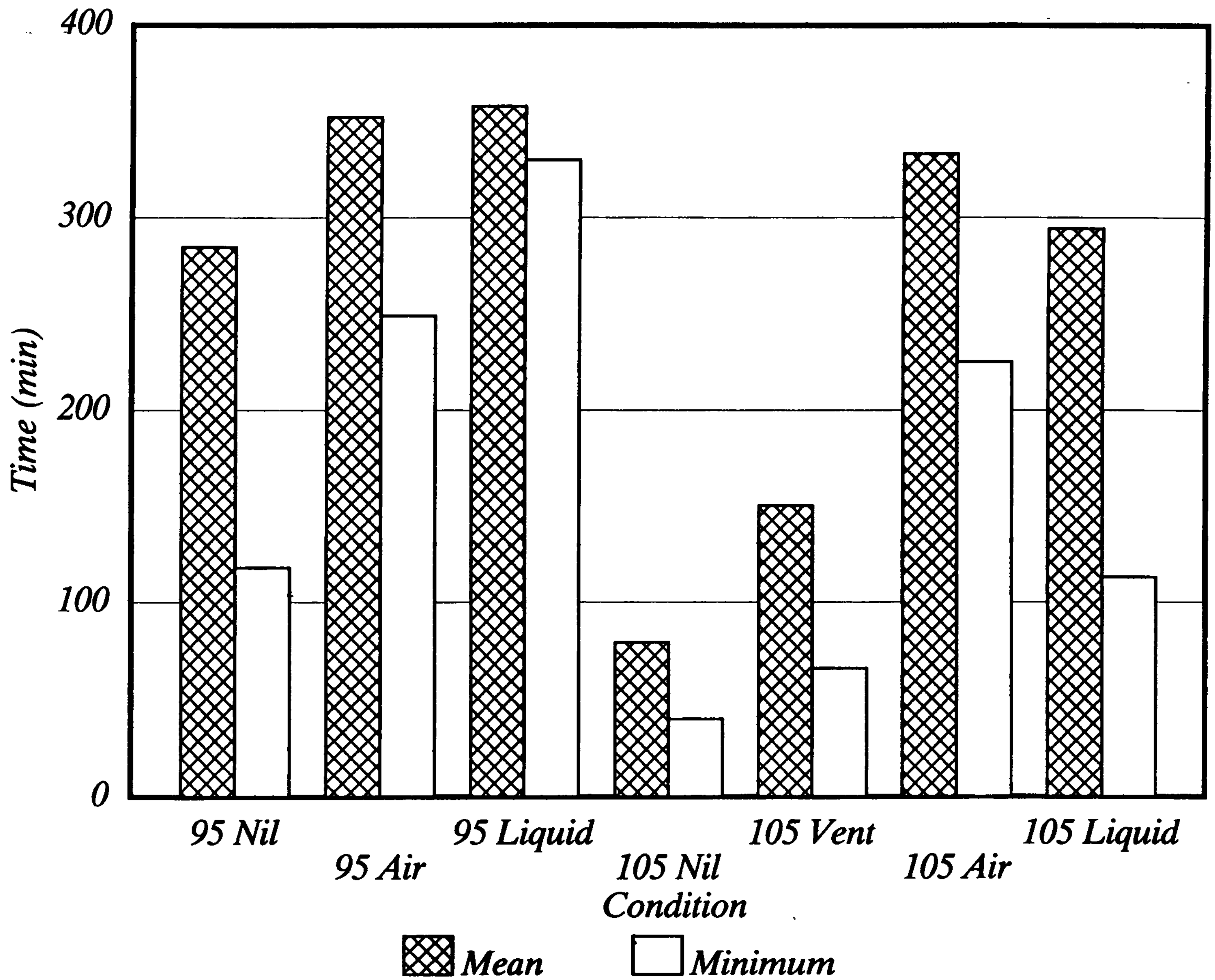

Figure 54. Survival time.

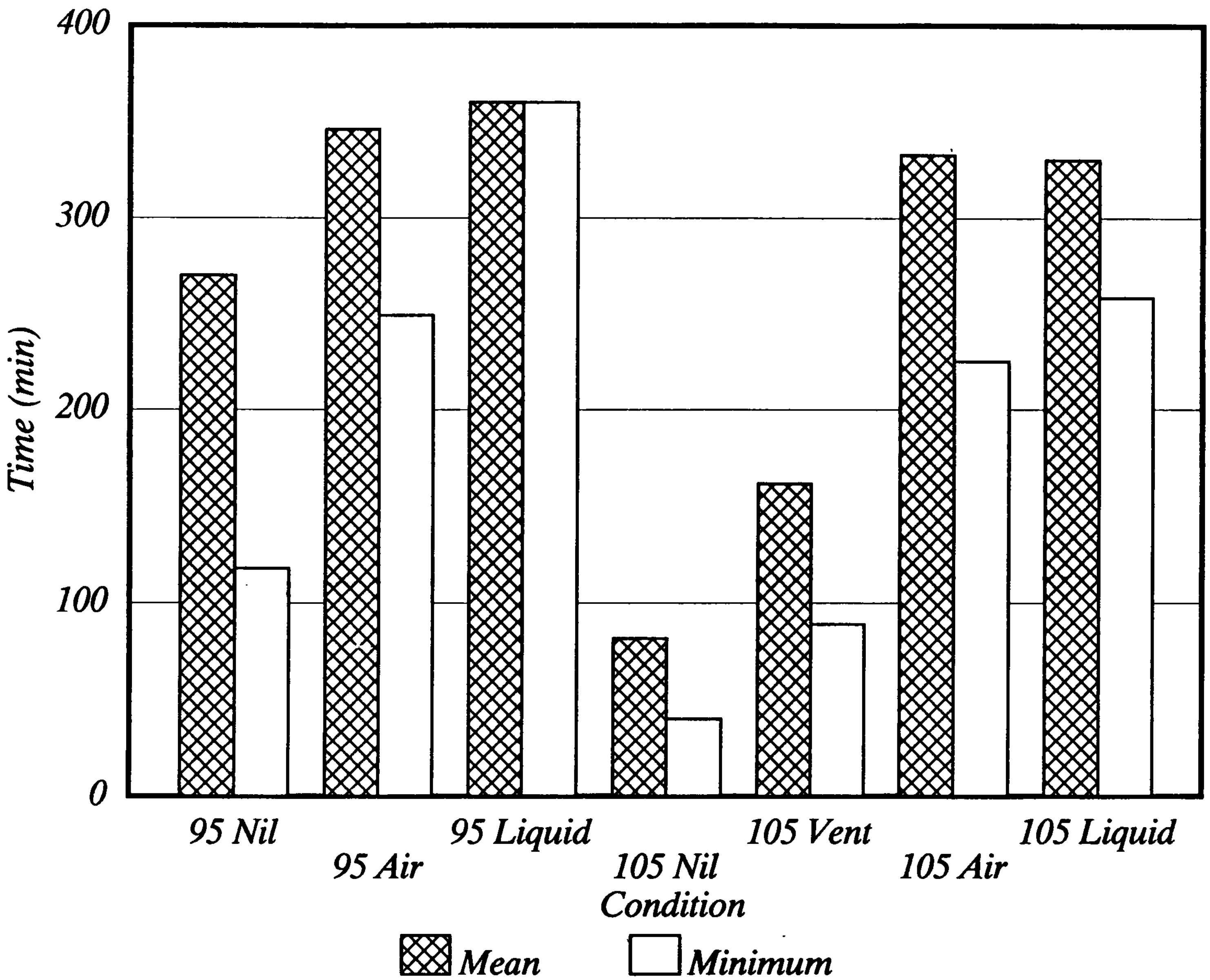

Figure 55. Survival time, pilots only.

Physiology

Rectal temperature

Figure 56 plots the mean rectal temperature recorded at 1-minute intervals on the treadmill and walking to the simulator. Because there is no practical difference on the treadmill between the different conditions within the same cooling vest, since the treadmill room air temperature could not be raised above about 95°F, the data are meaned across the vest worn. Air thus includes 95 air, 105 air, and 105 vent. There is a close correlation between all three conditions, with a steady increase throughout the period on the treadmill, and a tendency for an acceleration of the rate of rise as the latent period for rectal temperature increases compared to deep body temperature is passed towards the end of the recording period.

Figure 57 shows the same information for the 6 hours during which subjects were in the simulator at 95°F, plotted at 5-minute intervals. There is a variable gap between the end of the data in Figure 56 and the start of those in Figure 57, as the subjects underwent the process of strapping into the simulator and connecting to the data-recording apparatus, during which time rectal temperature continued to rise before recording resumed. There is an obvious difference between the mean rectal temperature without cooling and with either conditioning system, and a smaller difference between the two cooling systems with the liquid system producing the cooler temperatures. The trend is for the mean rectal temperature with the liquid system to continue falling throughout the test period, whereas the air-cooled curve levels after 2 hours to maintain a temperature which is elevated by half a degree Celsius.

The significance of differences between the various simulator curves was determined by plotting the 99 percent confidence intervals for selected curves. Figure 58 demonstrates this for the simulator rectal temperature at 95°F. The differences on the treadmill were analyzed by selecting the first available simulator value for each variable in each condition and performing analysis of variance. This indicated that there were no significant differences between conditions for the rectal temperatures.

To take into account the reduced air cooling capacity during the first half of the study, Figure 59 repeats the same simulator rectal temperature data selected for the last eight subjects. The curves are very similar to those in Figure 57.

The drop in the no cooling curve is due to the loss of subjects from the data pool as they dropped out, those who left

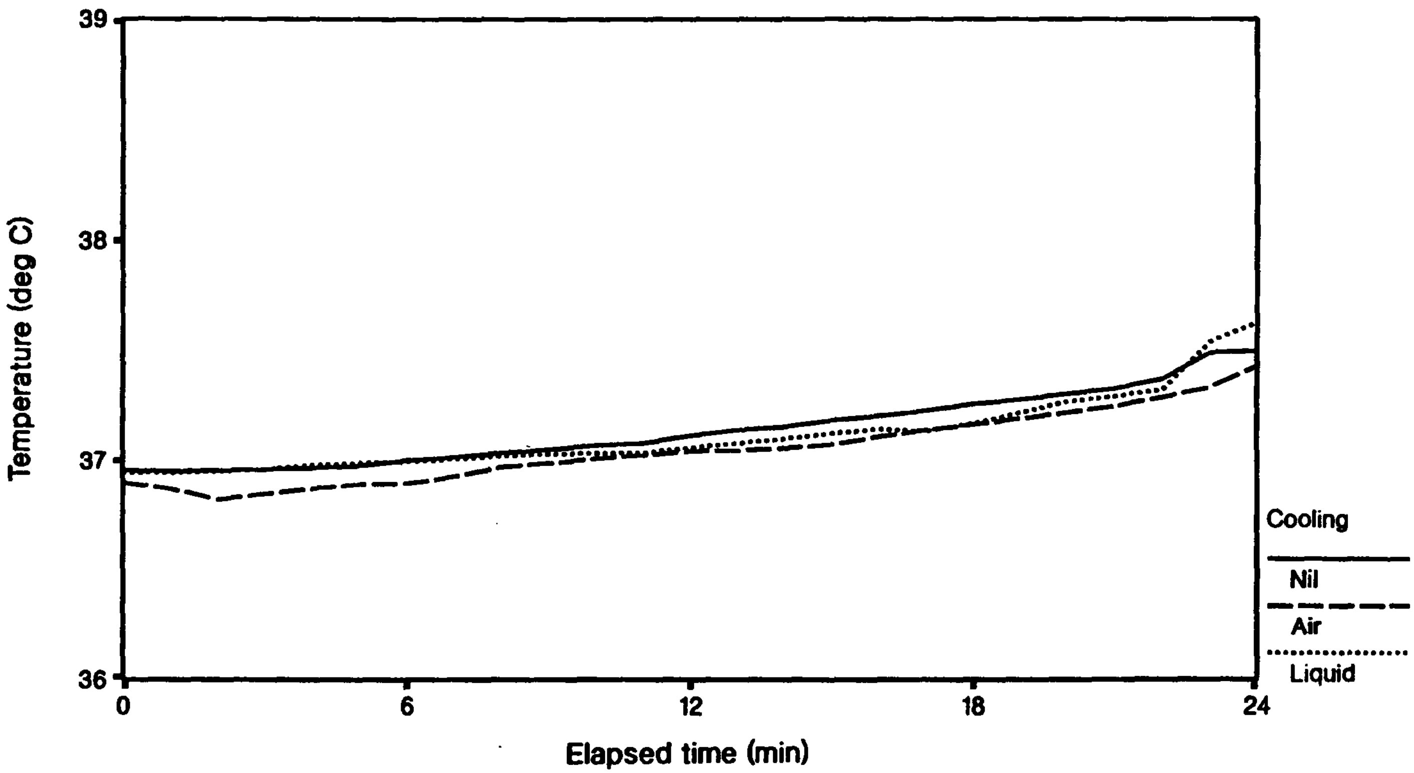

Figure 56. Treadmill rectal temperature.

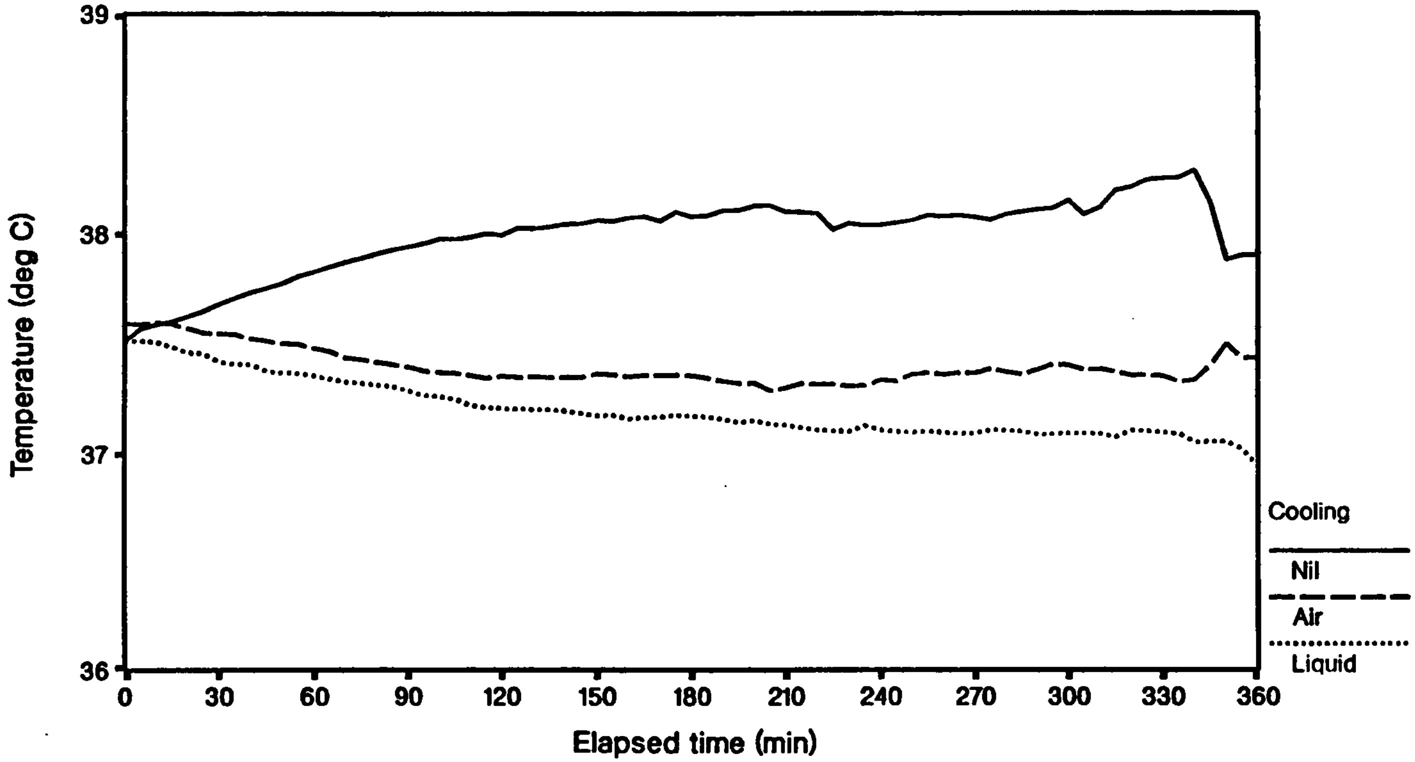

Figure 57. Simulator rectal temperature, 95°F.

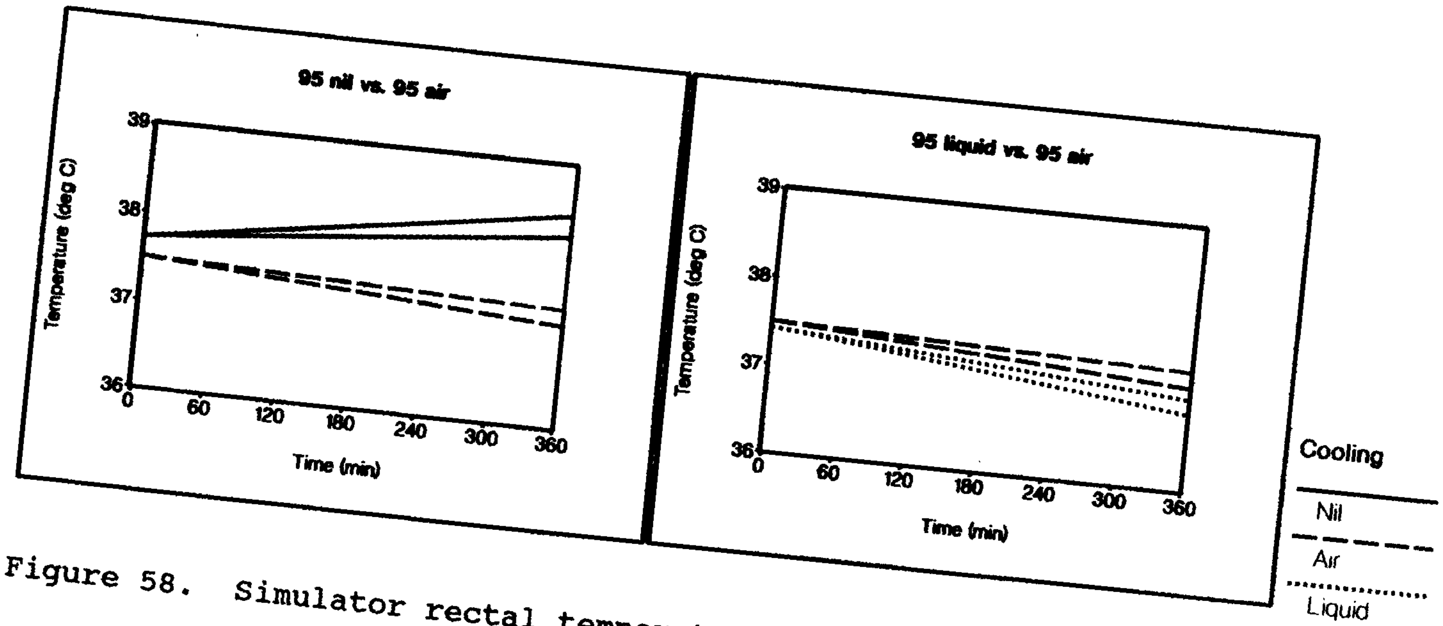

Figure 58. Simulator rectal temperature confidence intervals, 95°F.

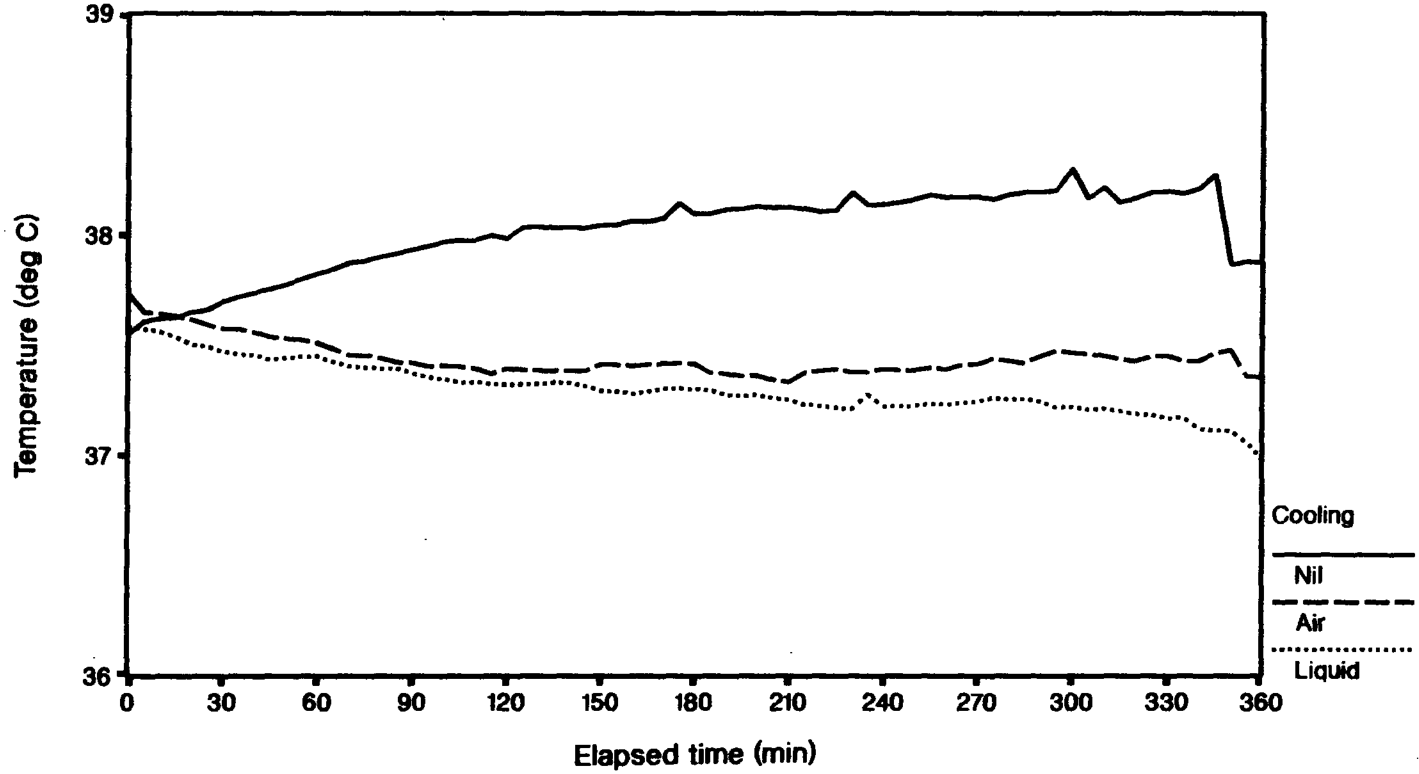

Figure 59. Simulator rectal temperature, 95°F, last 8 subjects only.

having a higher rectal temperature, leaving the mean value for the remainder lower.

Figure 60 shows the mean rectal temperatures in the simulator at 105°F, and Figure 61 the confidence intervals. The stepped appearance in the uncooled curve is again due to loss of subjects. The advantage of vent air over no cooling is shown by the lower values, though N is only 3 beyond 200 minutes, and 1 after 280 minutes. There is no significant difference between the air and liquid curves, but that is due in part to the higher (but statistically insignificant) initial value for the liquid curve due to the larger skin area insulated by the liquid vest and hood. There is an initial rise for both systems, though after 2 hours the temperature starts to fall for the liquid system, but keeps on rising for the air system.

Figure 62 contains the same data for the second half of the study only. Again there is very little difference from the curves in Figure 60.

<u>Mean skin temperature</u>

The treadmill mean skin temperatures are shown in Figure 63. There is clearly little to separate the different vest conditions, and statistical analysis of the first skin temperature values in the simulator confirmed this.

Figure 64 contains the mean skin temperature data for the simulator at 95°F, with the confidence intervals in Figure 65. Unlike the rectal temperature, there is no rise in skin temperature with time without cooling, though both cooling systems show an initial fall, followed by a steady rise after 90 minutes for the air system and 180 minutes for the liquid, with the liquid system consistently providing the lower values.

Figure 66 shows the same data for 105°F, with the confidence intervals in Figure 67. Here the uncooled skin does show an increase in temperature with time. The liquid system appears to provide a sustained decrease in mean temperature, while the temperature with the air system starts to rise after 150 minutes.

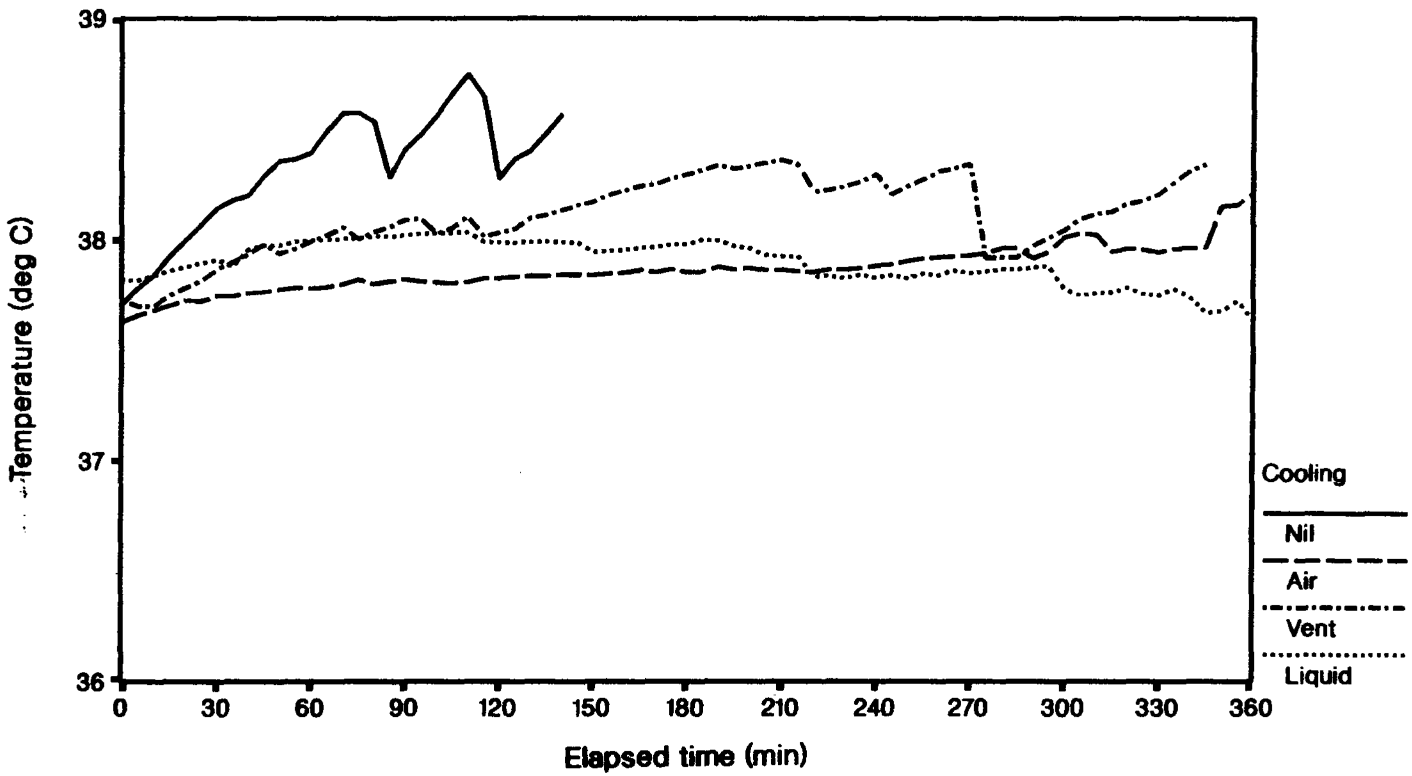

Figure 60. Simulator rectal temperature, 105°F.

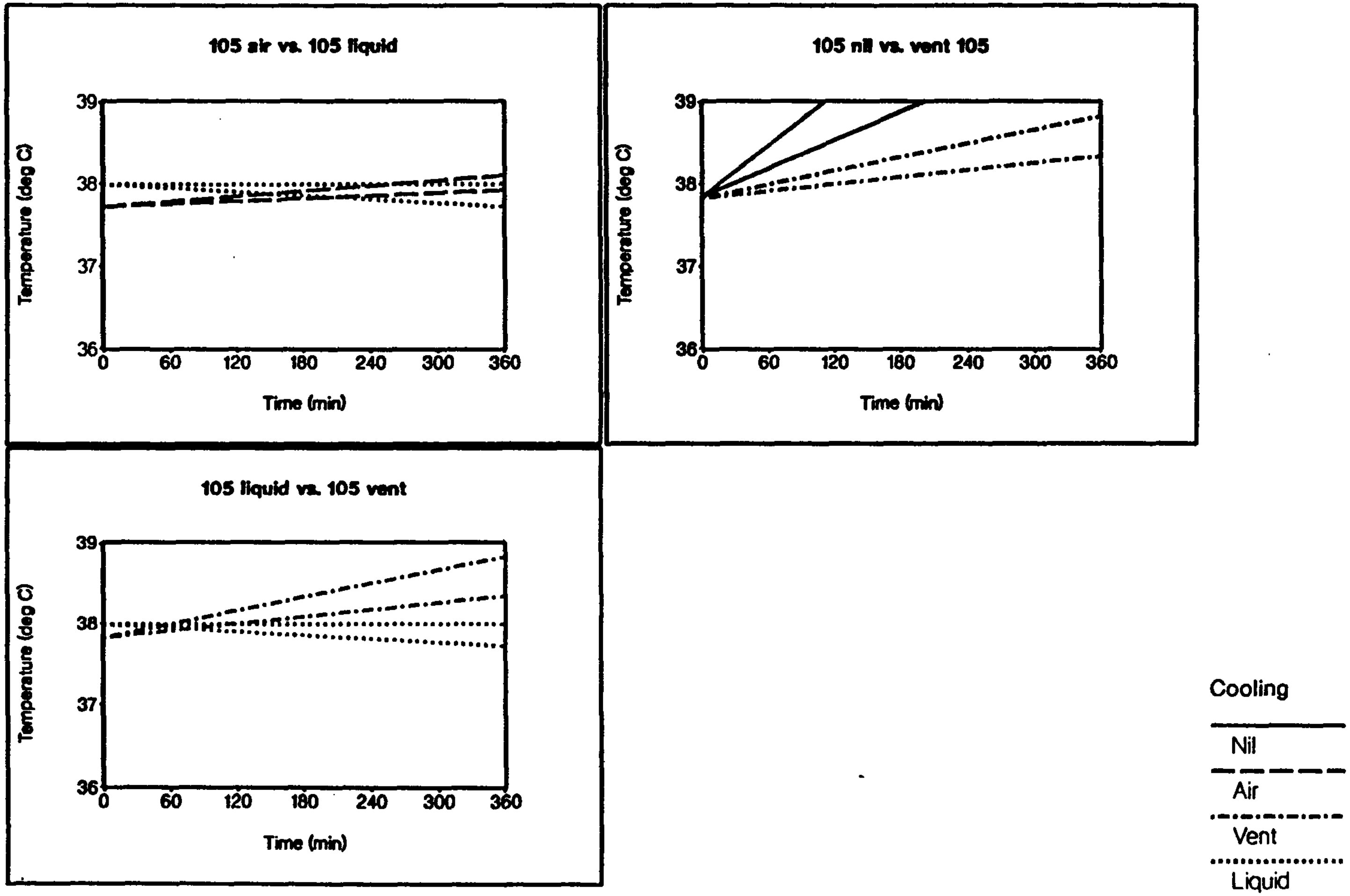

Figure 61. Simulator rectal temperature confidence intervals, 105°F.

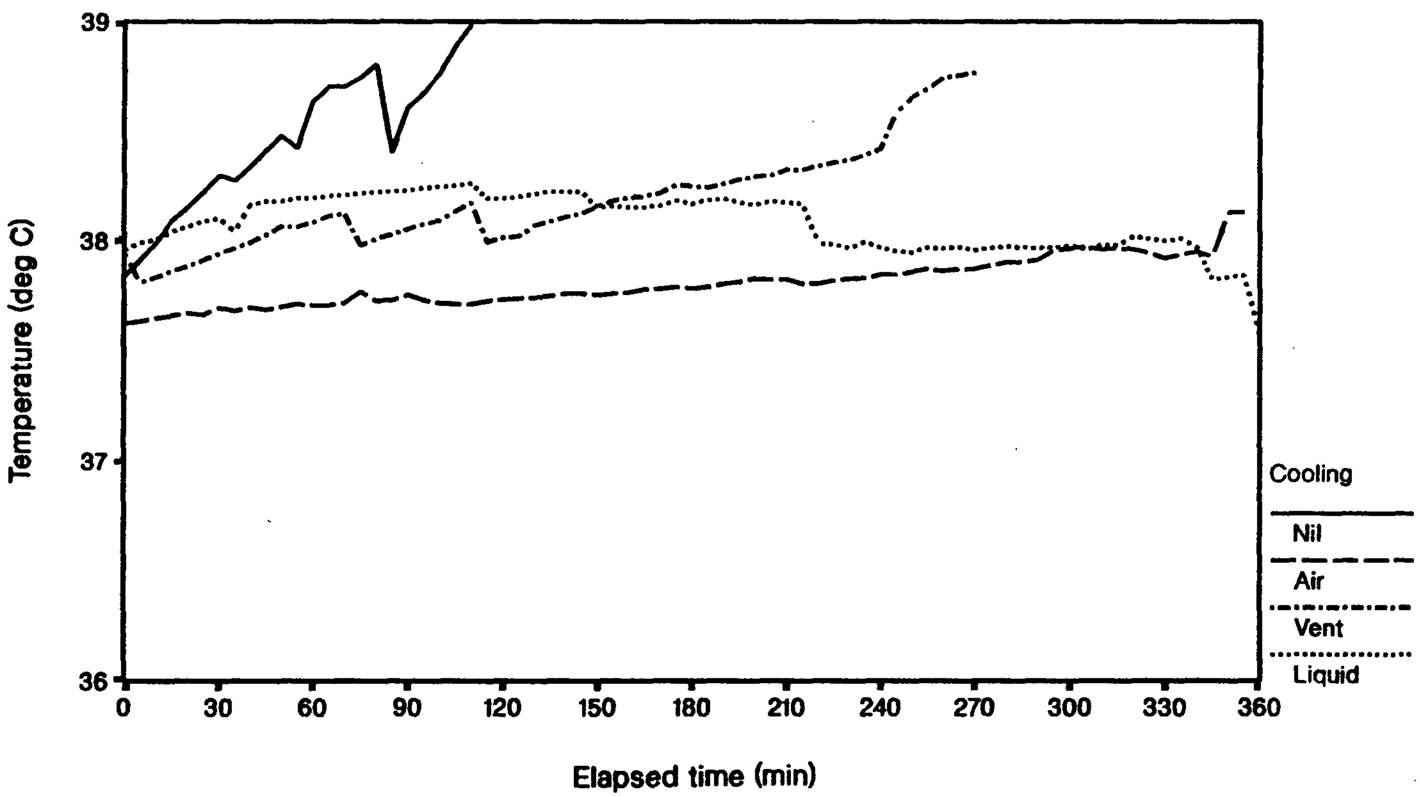

Figure 62. Simulator rectal temperature, 105°F, last 8 subjects only.

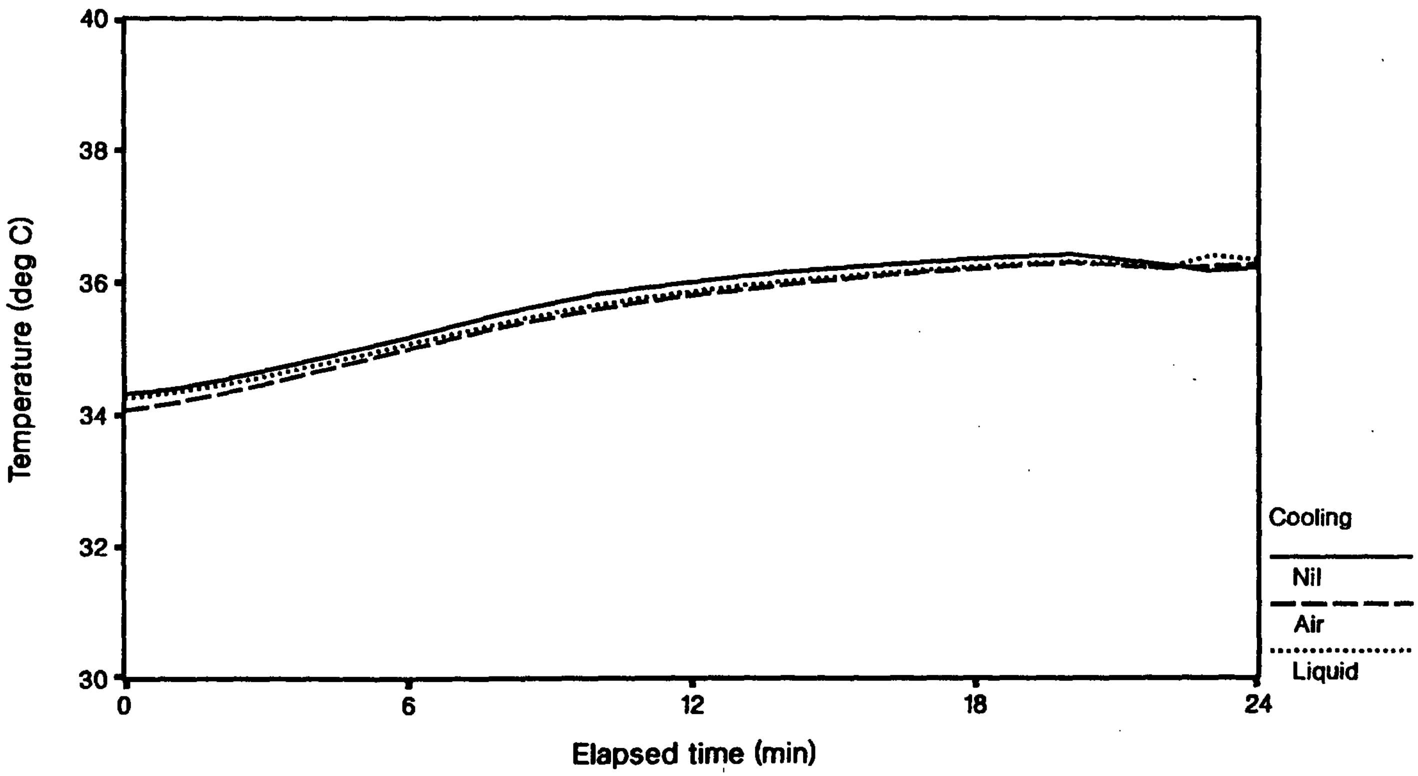

Figure 63. Treadmill mean skin temperature.

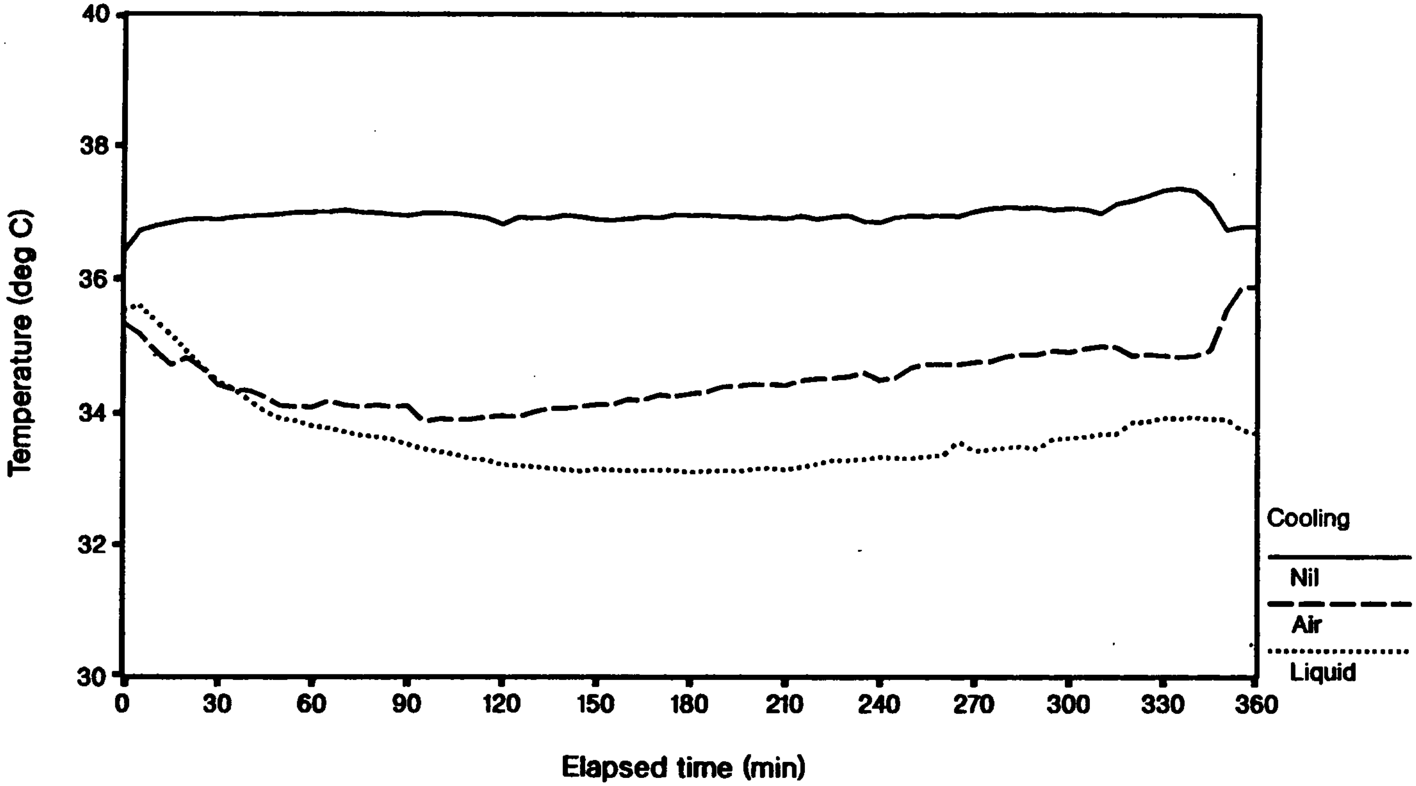

Figure 64. Simulator mean skin temperature, 95°F.

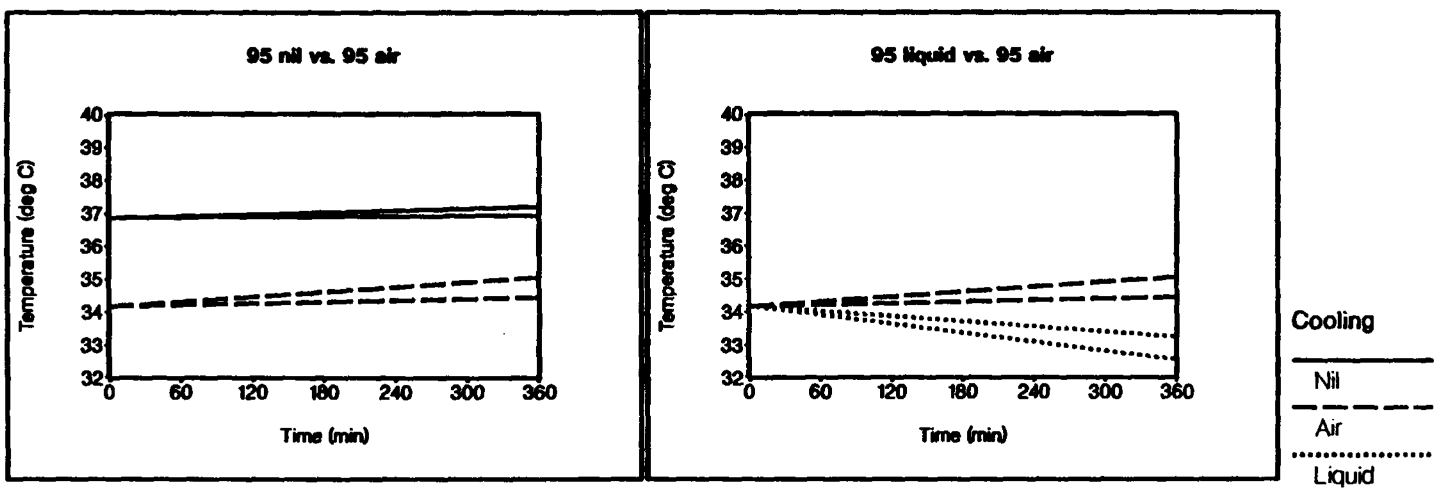

Figure 65. Simulator mean skin temperature confidence intervals, 95°F.

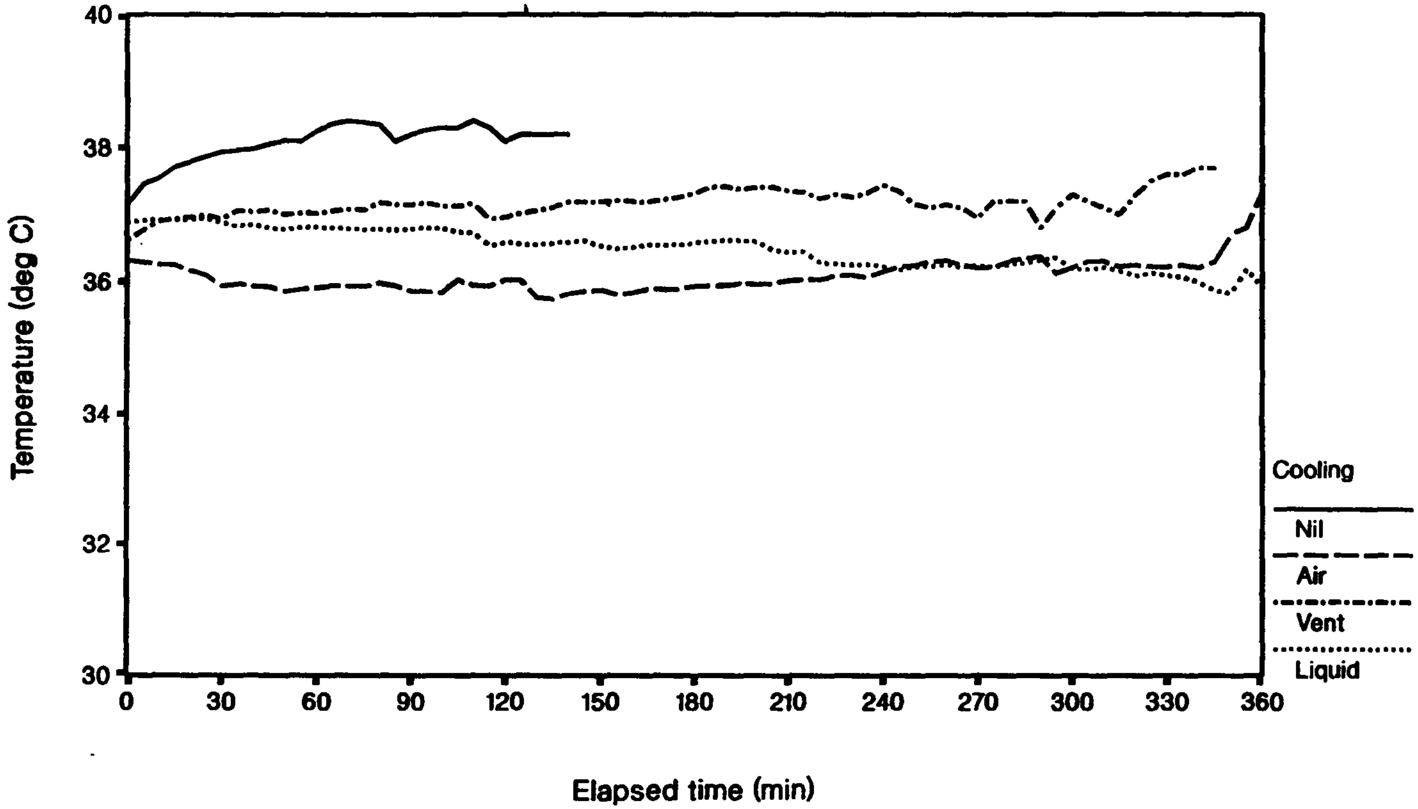

Figure 66. Simulator mean skin temperature, 105°F.

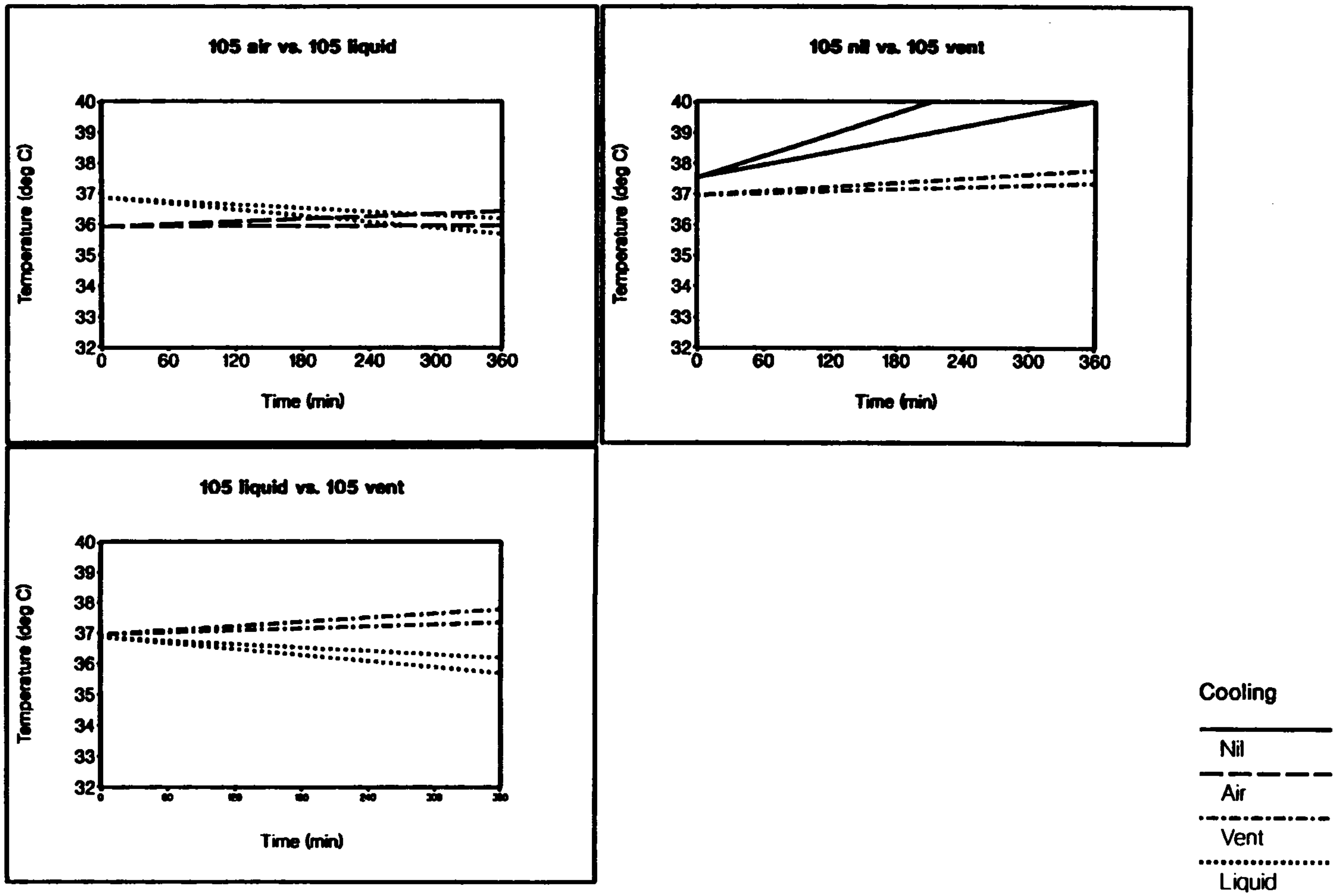

Figure 67. Simulator mean skin temperature confidence intervals, 105°F.

Heart rate

The treadmill heart rates are shown in Figure 68. Without any cooling vest, the heart rate is lower than with either vest, and with little difference between the vests themselves.

The simulator heart rates at 95°F are in Figure 69, the confidence intervals in Figure 70. The results are similar to the rectal temperatures with the uncooled condition producing a steady increase with time, which was not diminished as the hotter subjects dropped out. Both cooling conditions reduce the initial exercise-induced elevation, with the liquid system producing a lower overall level.

Figure 71 contains the data for the last eight subjects only and again shows little difference from those in Figure 69.

Figures 72 and 73 show the same curves for the 105°F with their confidence intervals. There is little, if any, benefit from the vent condition compared with no cooling. There is no significant difference between the cooling systems, though the tendency is for the liquid values to be slightly higher.

Figure 74 is derived from the same data for the last eight subjects only, and shows a clear difference between the two cooling systems with the air system producing consistently lower heart rates, albeit with a tendency to rise towards the liquid values as the day progressed.

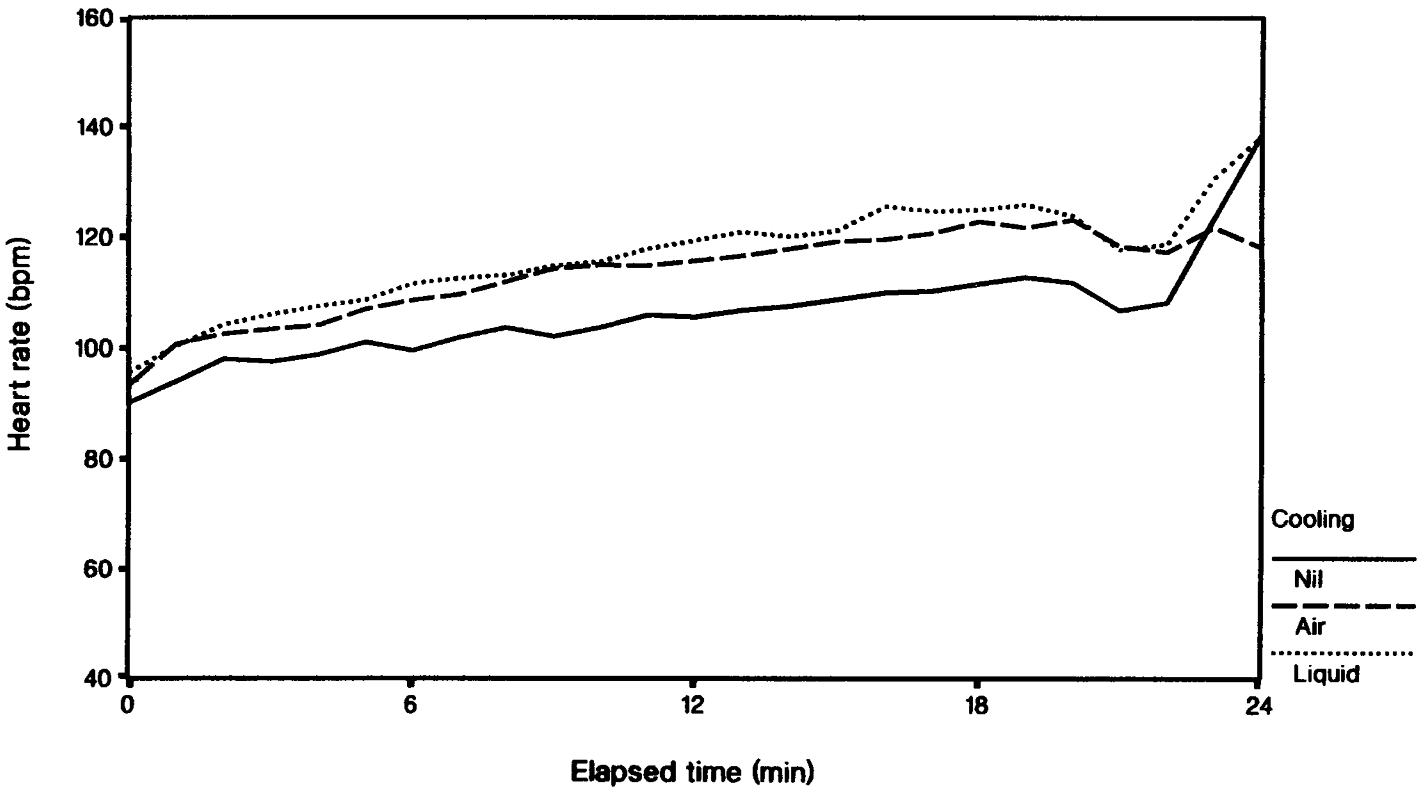

Figure 68. Treadmill heart rate.

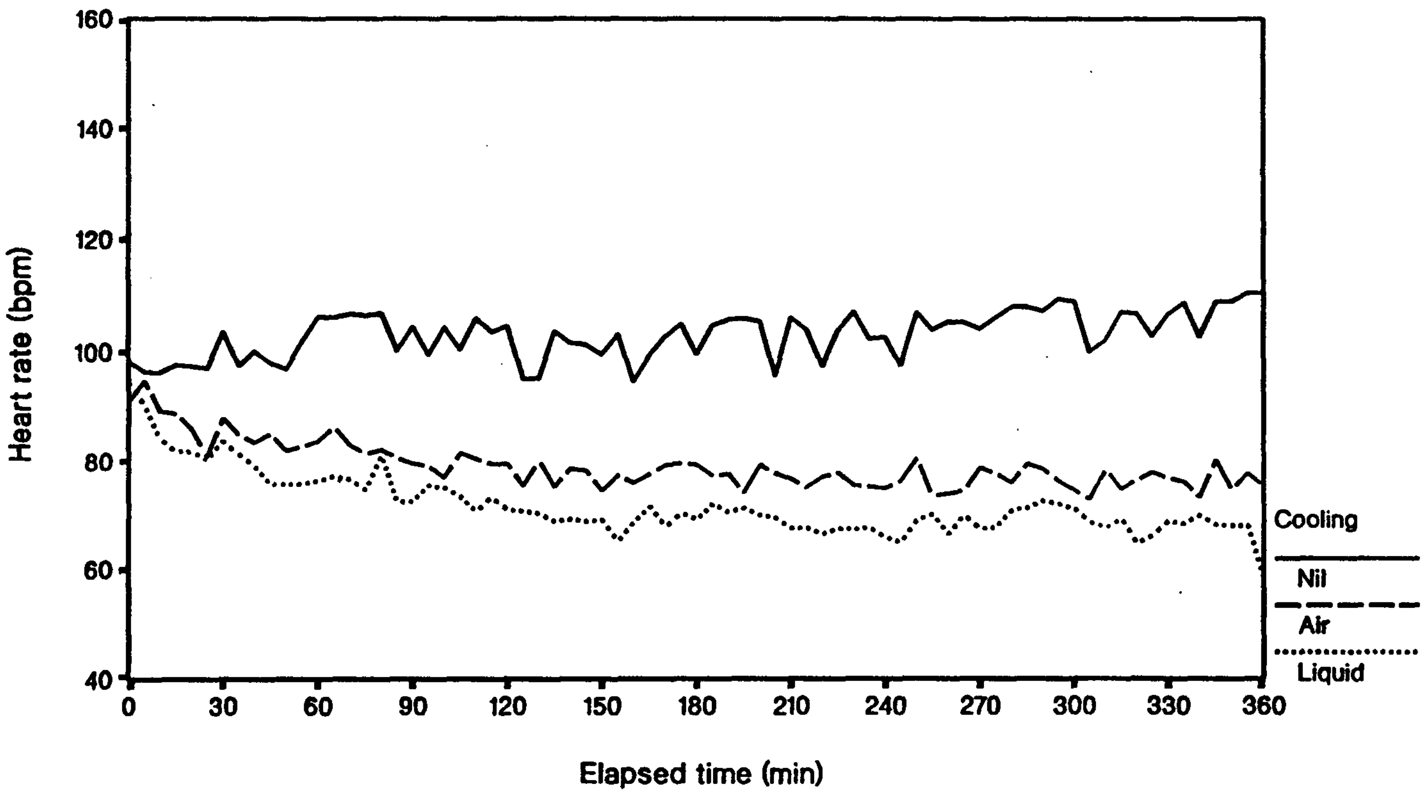

Figure 69. Simulator heart rate, 95°F.

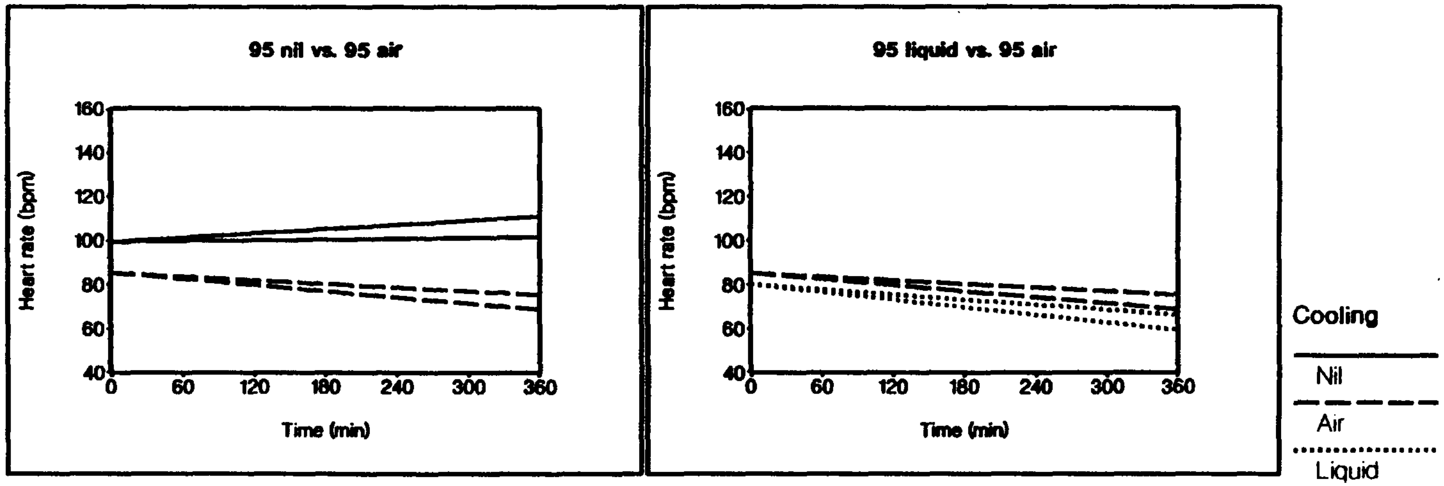

Figure 70. Simulator heart rate confidence intervals, 95°F.

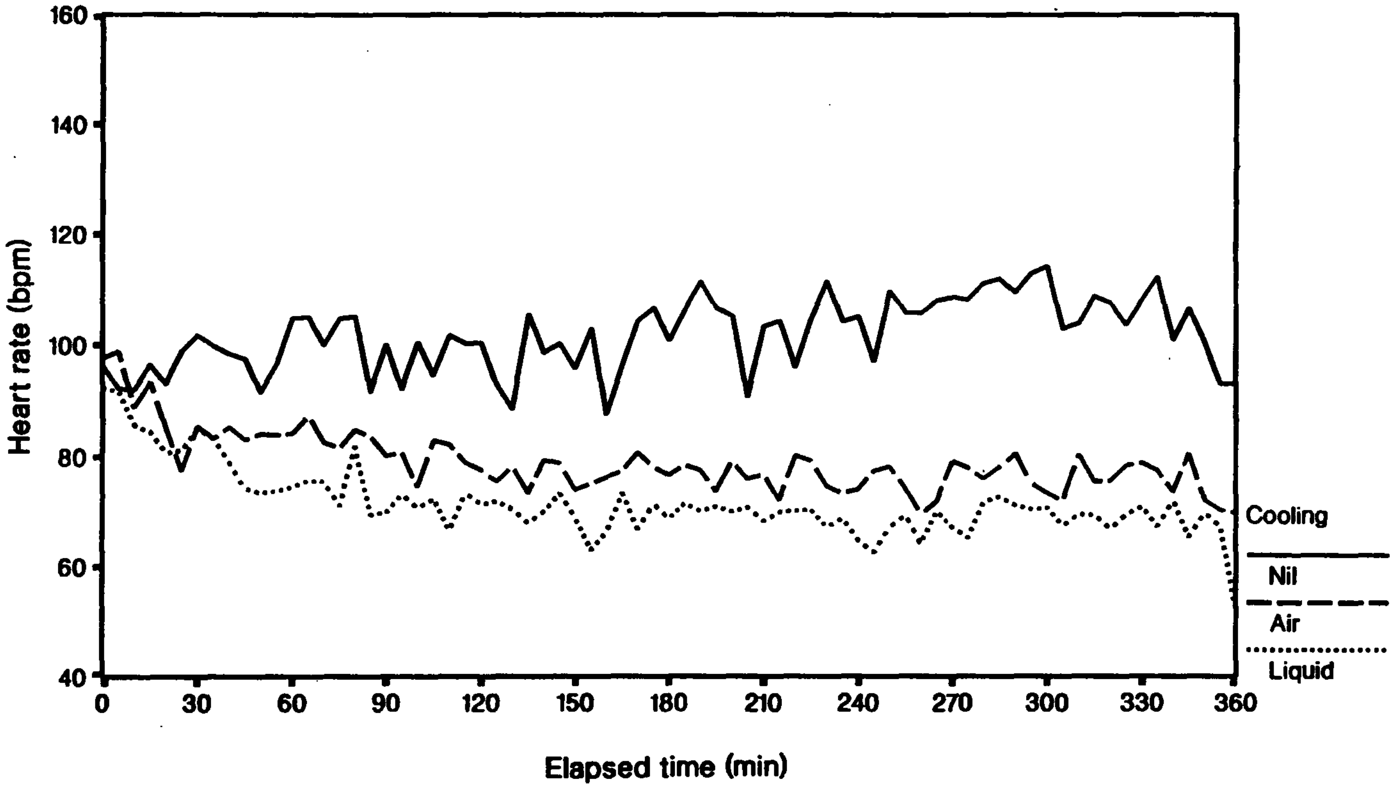

Figure 71. Simulator heart rate, 95°F, last eight subjects only.

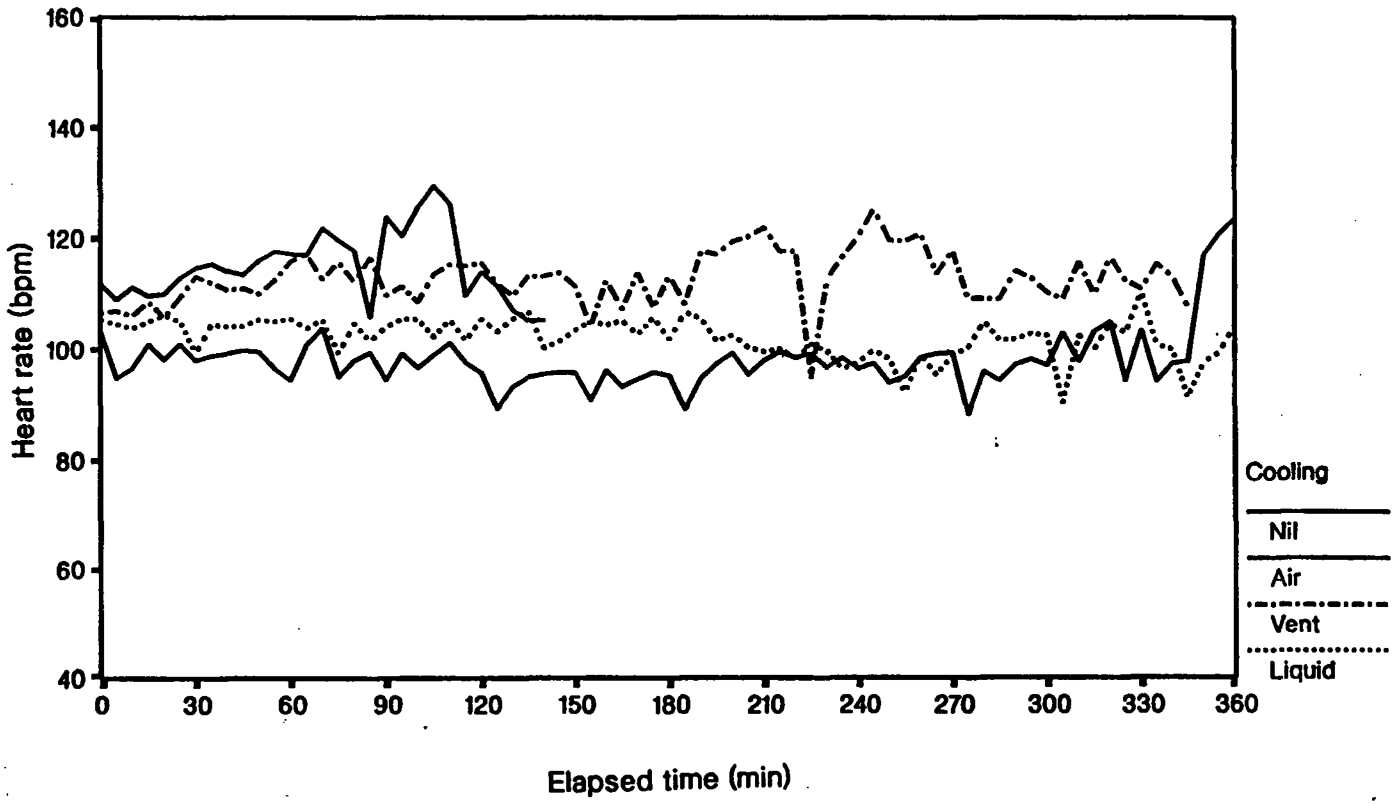

Figure 72. Simulator heart rate, 105°F.

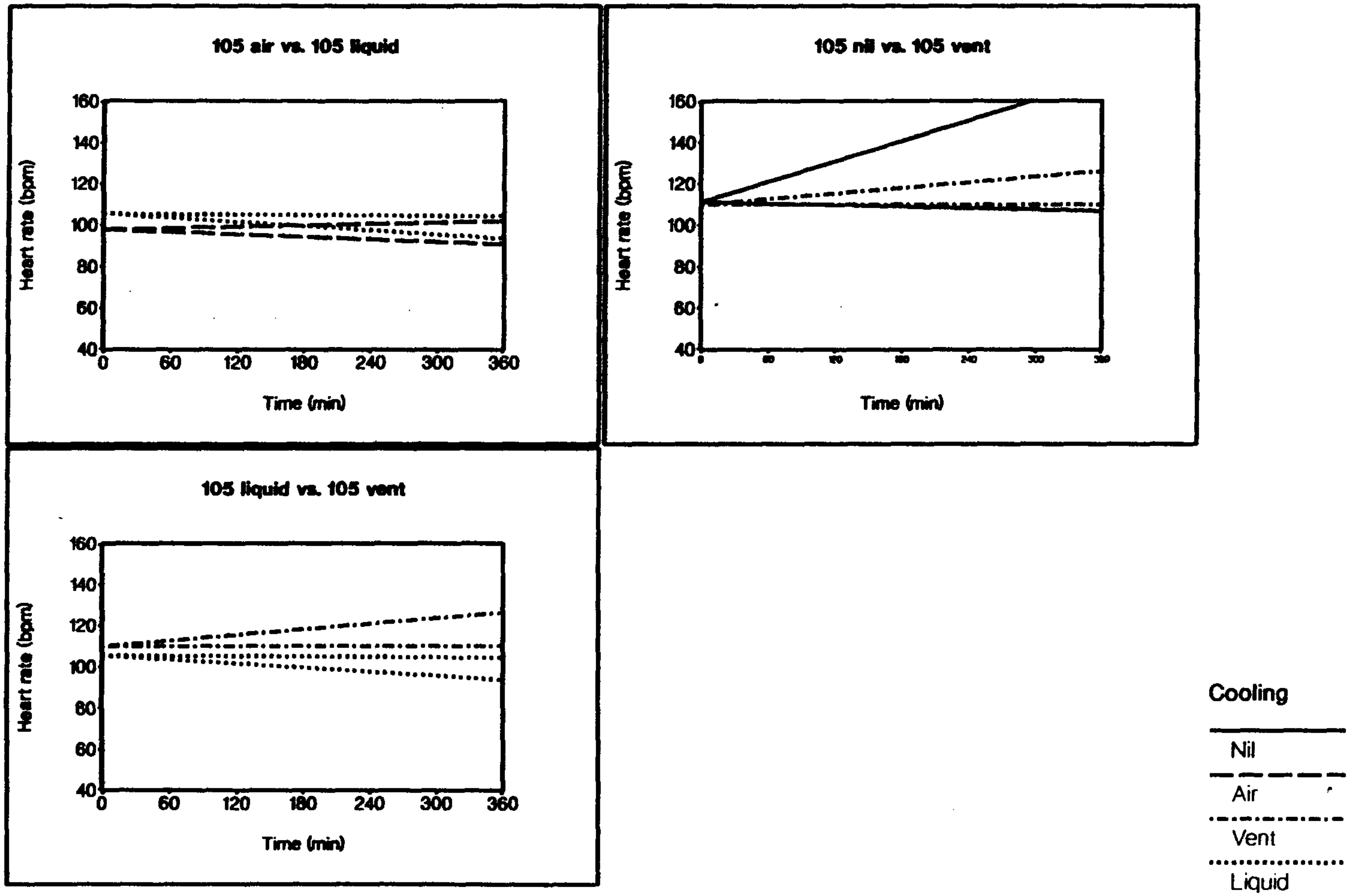

Figure 73. Simulator heart rate confidence intervals 105°F.

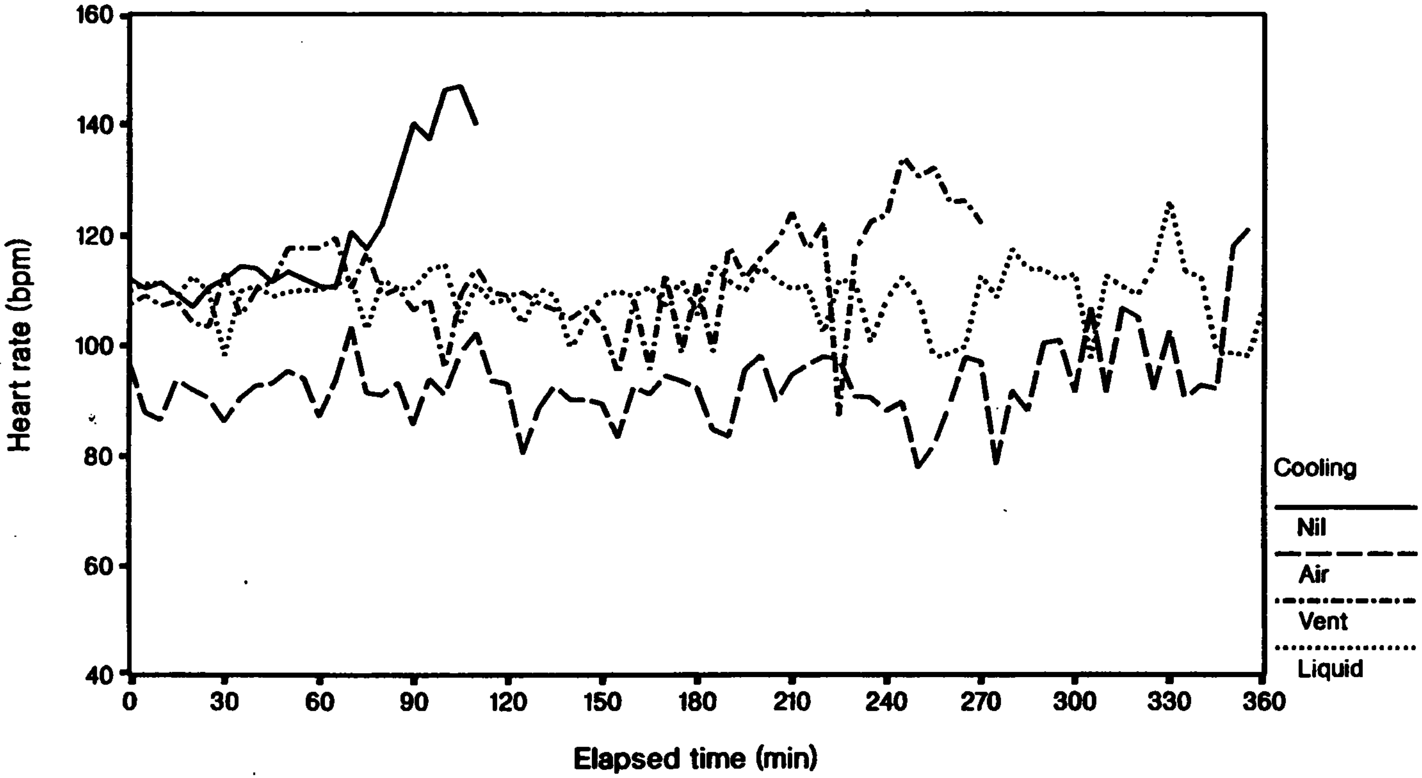

Figure 74. Simulator heart rate, 105°F, last eight subjects only.

Water balance

Figure 75 graphs the water balance data in terms of weight (kg) for dehydration, sweat loss, water drunk, and urine voided at 95°F, and Figure 76 shows the same information at 105°F. ANOVA demonstrates a main effect for condition for dehydration ($F(6,90) = 4.86$, $p = 0.0002$), for sweat production ($F(6,90) = 17.58$, $p < 0.0001$), and water consumption ($F(6,90) = 6.84$, $p < 0.0001$). For dehydration, the only significant difference within temperature groups, is between 95 nil and 95 air ($p < 0.05$). The weight of sweat loss was significantly greater for 95 nil than both 95 air and 95 liquid ($p < 0.01$) and greater for 95 air than 95 liquid ($p < 0.05$). The weight of water drunk was significantly greater at 95°F without cooling than with the liquid ($p < 0.01$) or air cooling system ($p < 0.05$).

The absence of significant differences at 105°F is because of the smaller exposure time for the no cooling condition which does not allow as much total dehydration to occur. The total dehydration for all the conditions at 105°F was twice that found at 95 nil. Much of this was caused by a reluctance among subjects to drink water from canteens which quickly warmed as it sat in the simulator cockpit. Some subjects complained of nausea if they drank.

Figures 77 and 78 show the data for dehydration and sweat loss as a rate (g/minute), to allow for the different exposure times. There was a main effect for condition for dehydration ($F(6,90) = 15.70$, $p < 0.0001$), for sweat production ($F(6,90) = 40.80$, $p < 0.0001$), and water consumption ($F(6,90) = 17.91$, $p < 0.0001$). None of the dehydration differences at 95°F is statistically significant. The 105 nil condition produced a significantly greater rate of dehydration than 105 vent ($p < 0.05$) and both 105°F cooled conditions ($p < 0.01$), and the 105 vent rate was significantly higher than 105 air ($p < 0.01$). For sweat rate, 95 nil was significantly higher than both cooled conditions at 95°F ($p < 0.01$). The sweat rate at 105 nil was significantly higher than all other conditions ($p < 0.01$), and at 105 vent, significantly higher than the two cooled conditions ($p < 0.01$). The significant differences in the rate of water consumption within temperature are between 105 nil and all other 105°F conditions ($p < 0.01$), and between 95 nil and 95 liquid ($p < 0.05$).

In the same way that other data have been analyzed separately to allow for the effects of poor air cooler performance in the study, so have the water balance data. Figures 79 and 80 show the weight data. There were no significant differences within temperature for the dehydration

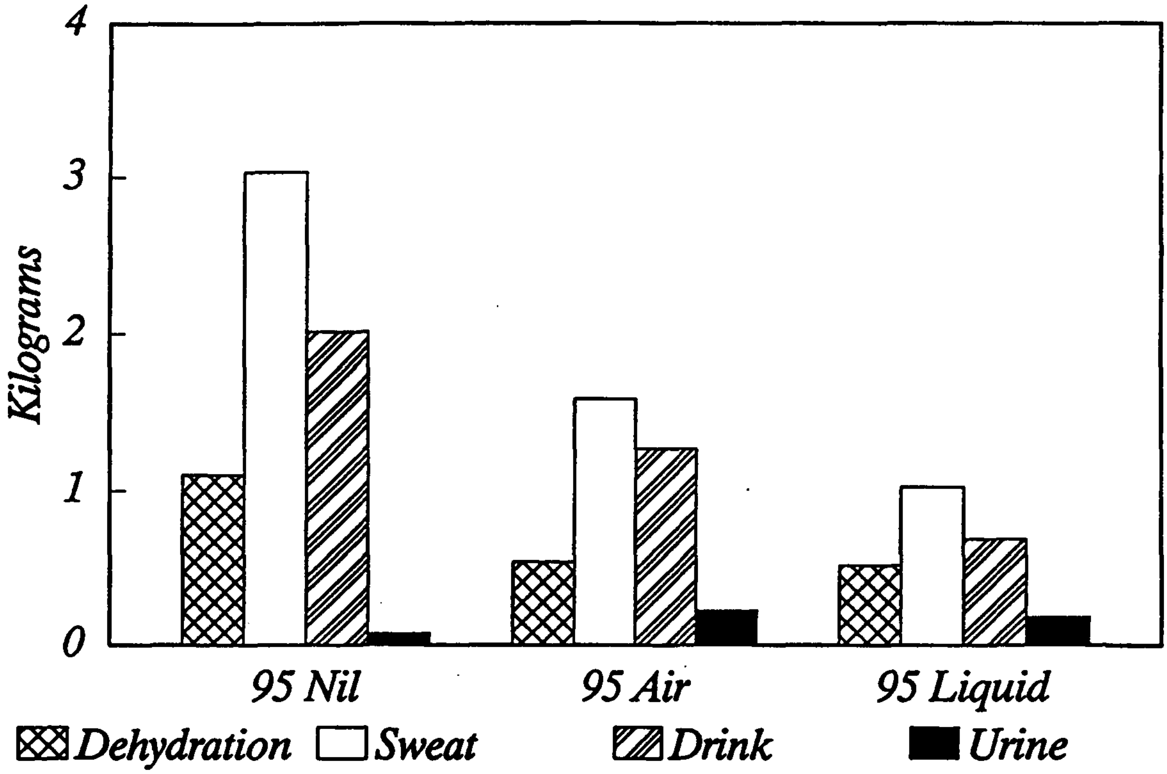

Figure 75. Water balance by weight, 95°F.

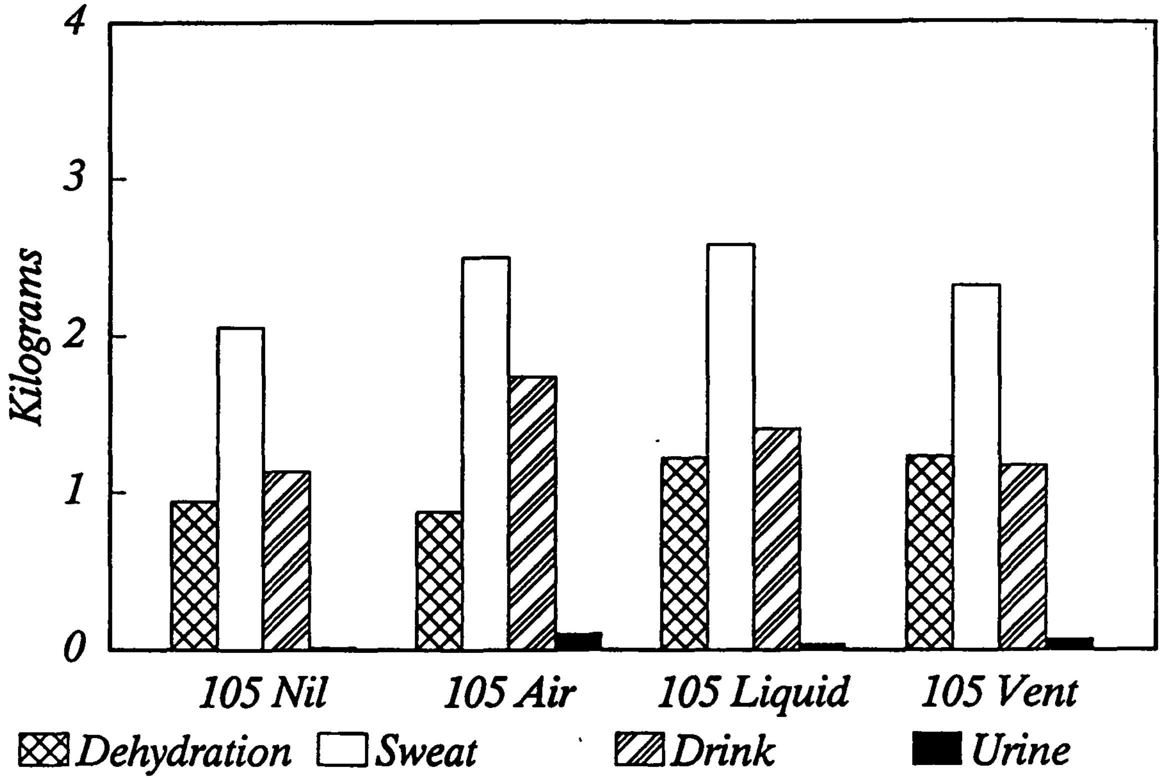

Figure 76. Water balance by weight, 105°F.

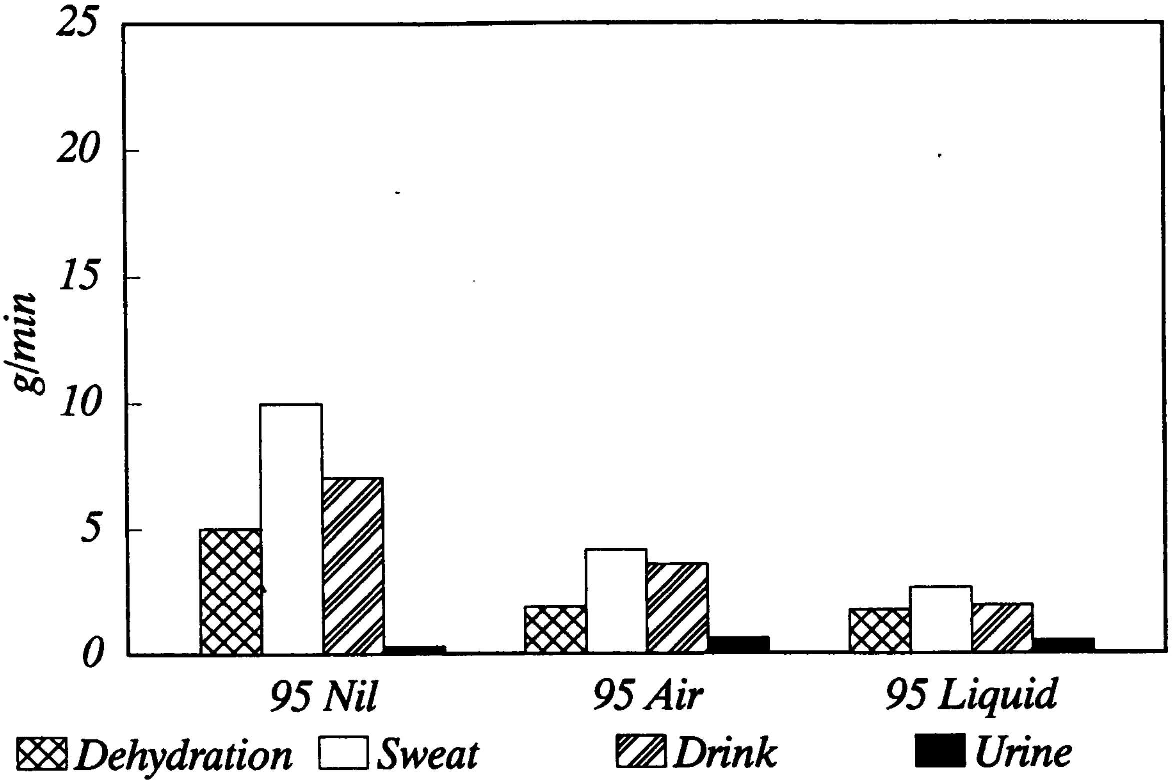

Figure 77. Water balance by rate, 95°F.

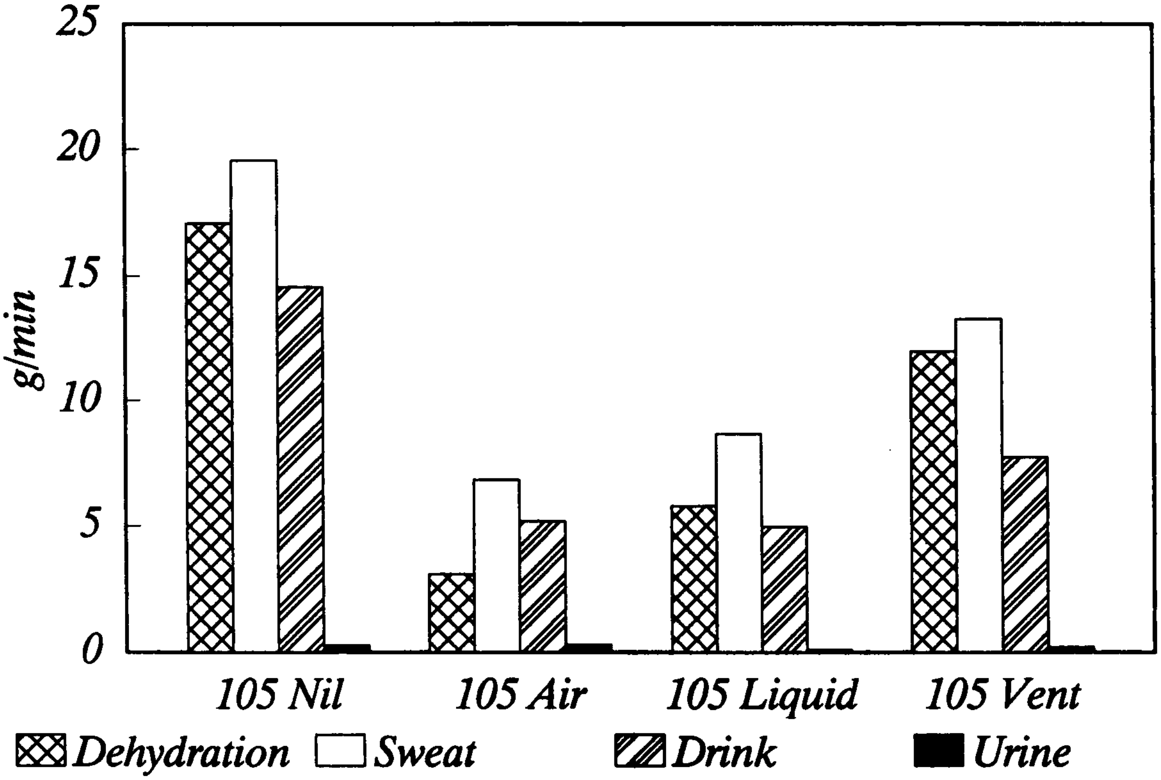

Figure 78. Water balance by rate, 105°F.

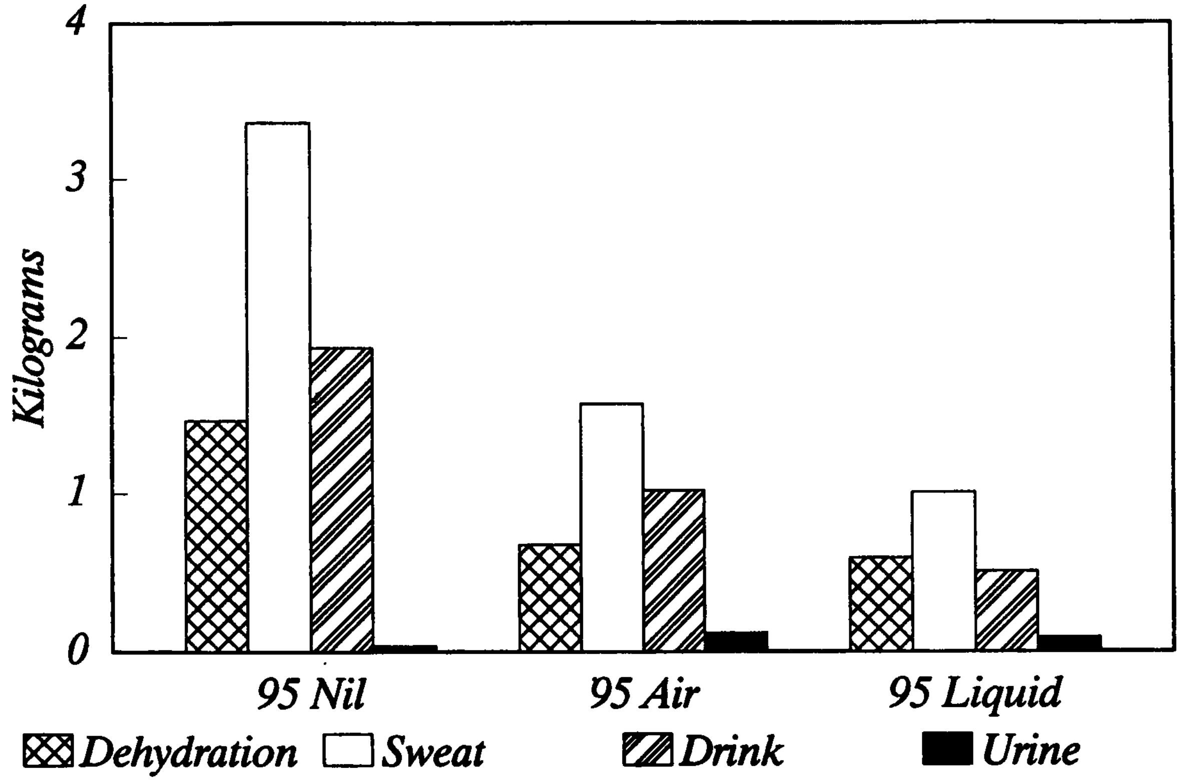

Figure 79. Water balance by weight, 95°F, last eight subjects.

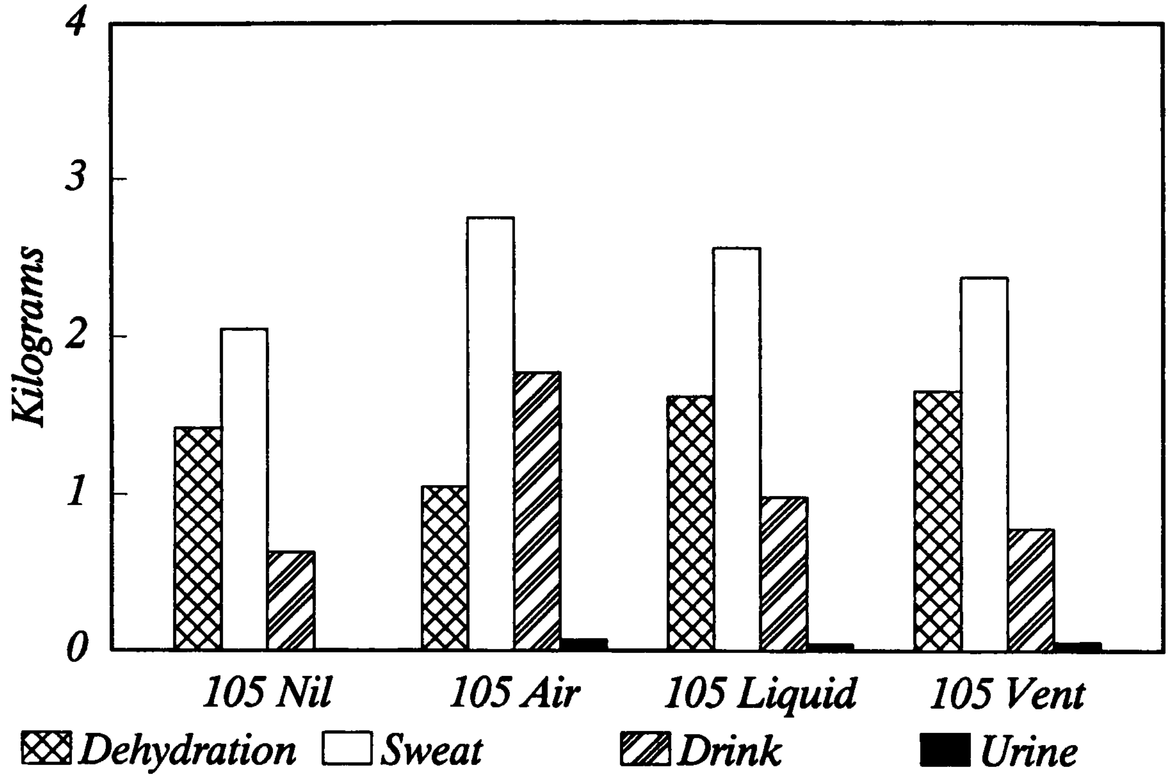

Figure 80. Water balance by weight, 105°F, last eight subjects.

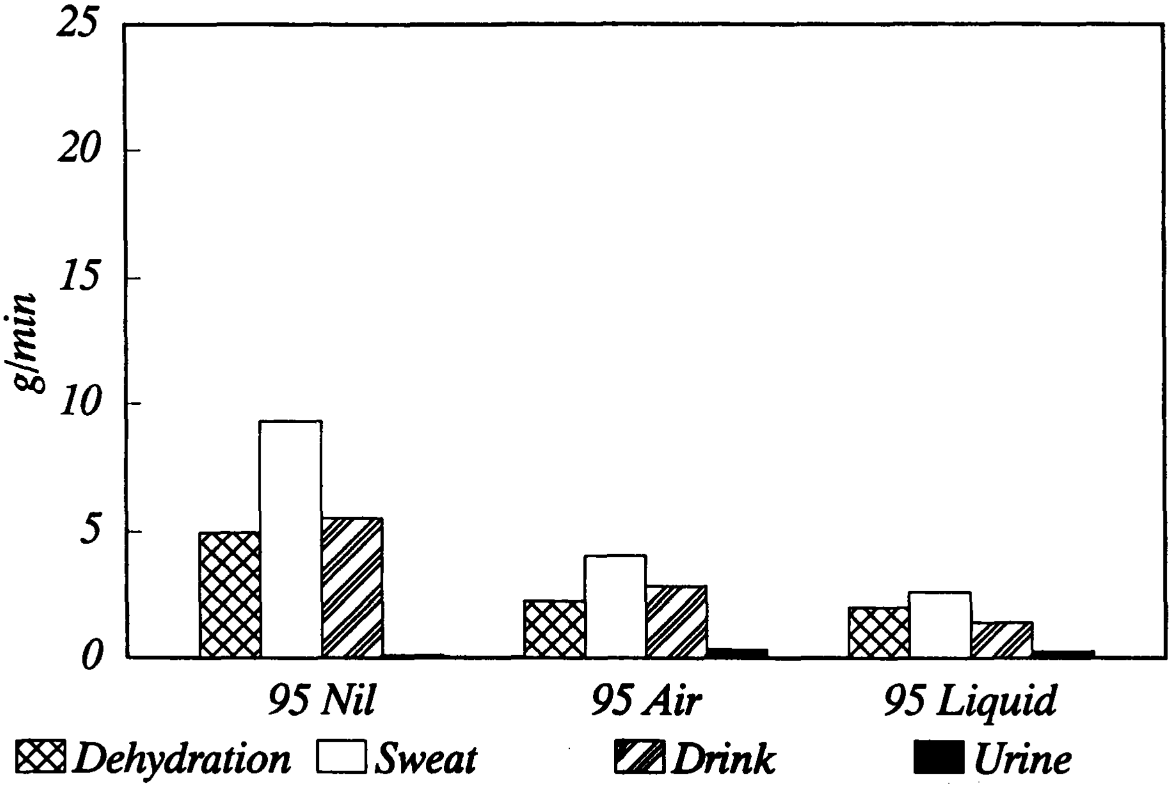

Figure 81. Water balance by rate, 95°F, last eight subjects.

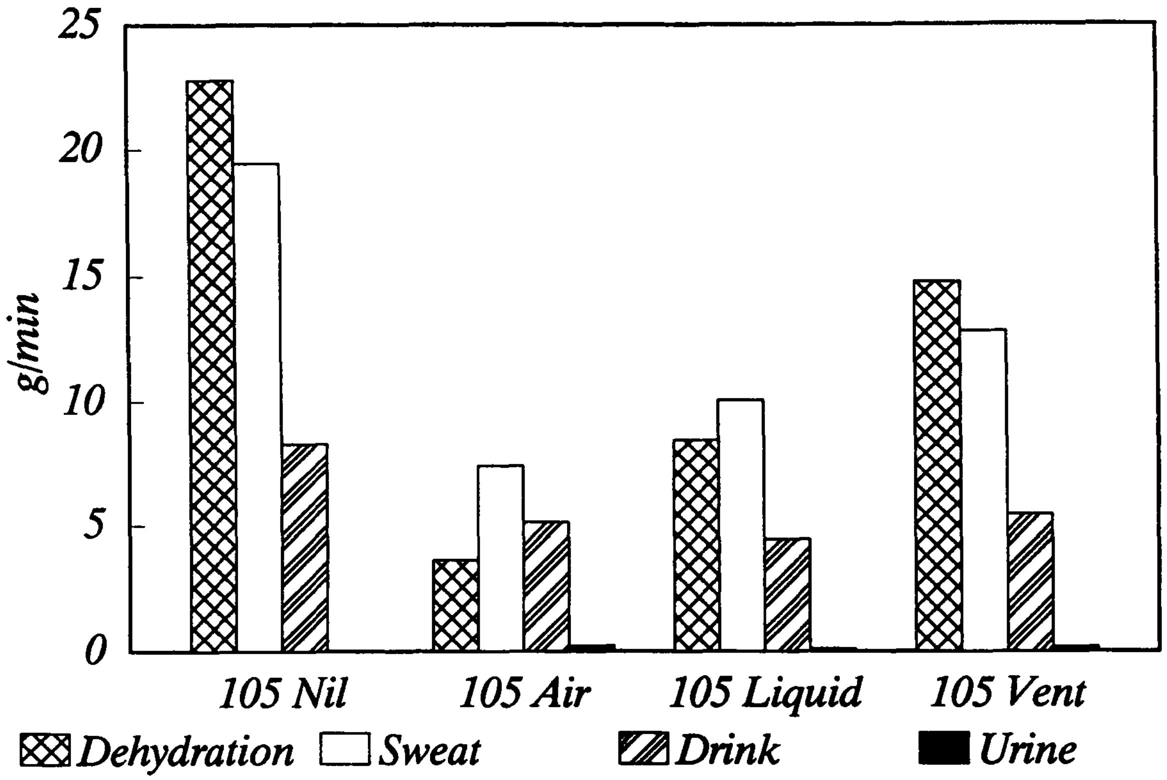

Figure 82. Water balance by rate, 105°F, last eight subjects.

data. There was a condition main effect for sweat production ($F(6,42) = 15.17$, $p < 0.0001$), and water consumption ($F(6,42) = 11.18$, $p < 0.0001$). The weight of sweat loss at 95 nil was significantly greater than 95 air and 95 liquid ($p < 0.01$). The weight of water drunk at 95 nil was significantly more than at 95 liquid ($p < 0.01$), and 105 air was significantly more than 105 nil ($p < 0.05$).

The rate data for the last eight subjects are in Figures 81 and 82. There was a main effect for condition for dehydration ($F(6,42) = 37.30$, $p < 0.0001$), for sweat production ($F(6,42) = 15.10$, $p < 0.0001$), and water consumption ($F(6,42) = 9.06$, $p < 0.0001$). There is a significant difference in the rate of dehydration between 105 nil and all other 105°F conditions ($p < 0.01$), and between 105 vent and 105°F liquid ($p < 0.05$) and 105 air ($p < 0.05$). The rate of sweat loss at 95 nil was significantly greater than for 95 liquid ($p < 0.05$) and 95 air ($p < 0.01$). The rate of sweat loss at 105 nil was significantly greater than all other 105°F conditions ($p < 0.01$) and the rate for 105 vent was significantly greater than 105 air ($p < 0.05$). The rate of sweat loss at 105 liquid was significantly greater than 105 air ($p < 0.05$). The rate at which water was drunk was significantly greater at 95 nil than 95 liquid ($p < 0.05$), and at 105 nil compared with 105 liquid ($p < 0.05$).

There are no significant differences in urine output for any of the graphed data.

The summary statistics for water balance are in Table 23.

Fatigue checklist

The mean scores for the fatigue checklist are plotted in Figure 83 for 95°F and Figure 84 for 105°F. Session one is the baseline, completed after dressing in the uniform of the day. Once the simulator flight was over, even if the subject retired early, no further checklists were completed. The results are therefore a mean of survivors only. At 105°, as so few subjects survived long enough without cooling to complete session two, that condition is not included in the graphs or the analyses. Both the graphs show a main effect for session ($F(2,30) = 22.96$, $p < 0.0001$).

Figure 83 shows a marked improvement in fatigue score for both systems compared with no cooling ($p < 0.01$), and liquid is consistently better than air, though the difference is not significant. Figure 84 shows that the fatigue score with cooling is significantly better than with vent air ($p < 0.01$), but there is no difference between cooling types. The data missing for the

Table 23.
Summary statistics for water balance.

	Initial	Dehydration			Sweat loss			Drink	Urine
	Wt (kg)	Wt (kg)	%	Rate (g/min)	Wt (kg)	%	Rate (g/min)	Wt (kg)	Wt (kg)
95 nil									
Mean	82.75	1.10	1.33	4.99	3.03	3.67	9.94	2.01	0.08
Std	8.17	0.96	1.21	5.35	0.89	1.10	3.38	0.78	0.16
95 air									
Mean	82.57	0.54	0.65	1.86	1.58	1.95	4.14	1.27	0.22
Std	8.22	0.35	0.42	1.20	0.50	0.69	1.27	0.79	0.40
95 liquid									
Mean	82.54	0.52	0.62	1.74	1.02	1.24	2.62	0.69	0.18
Std	8.18	0.28	0.33	0.93	0.26	0.30	0.65	0.30	0.42
105 nil									
Mean	82.46	0.94	1.14	17.06	2.05	2.51	19.55	1.13	0.02
Std	8.08	0.84	0.98	13.98	0.58	0.72	6.53	0.81	0.05
105 air									
Mean	82.60	0.87	1.06	3.10	2.50	3.04	6.81	1.73	0.11
Std	8.24	0.69	0.84	2.35	1.09	1.34	2.60	1.02	0.27
105 liquid									
Mean	82.58	1.22	1.46	5.77	2.58	3.15	8.63	1.40	0.04
Std	8.19	0.63	0.73	3.73	0.85	1.08	3.89	0.71	0.09
105 vent									
Mean	81.99	1.23	1.49	11.94	2.32	2.85	13.23	1.17	0.07
Std	6.84	0.68	0.84	7.29	0.56	0.73	6.31	0.95	0.18

two subjects who did not complete the vent condition were estimated from the mean of the others for the analyses.

Figures 85 and 86 repeat the same information using only subjects 12 onwards. There is again a main effect for session ($F(2,14) = 10.01$, $p = 0.0022$). Figure 85 shows the 95°F data, when both systems still provide better cooling than none at all, though the difference is only significant for the liquid ($p < 0.05$), but there is now no difference between systems. At 105°F (Figure 86), the fatigue score is better for air than liquid, though the difference is not significant.

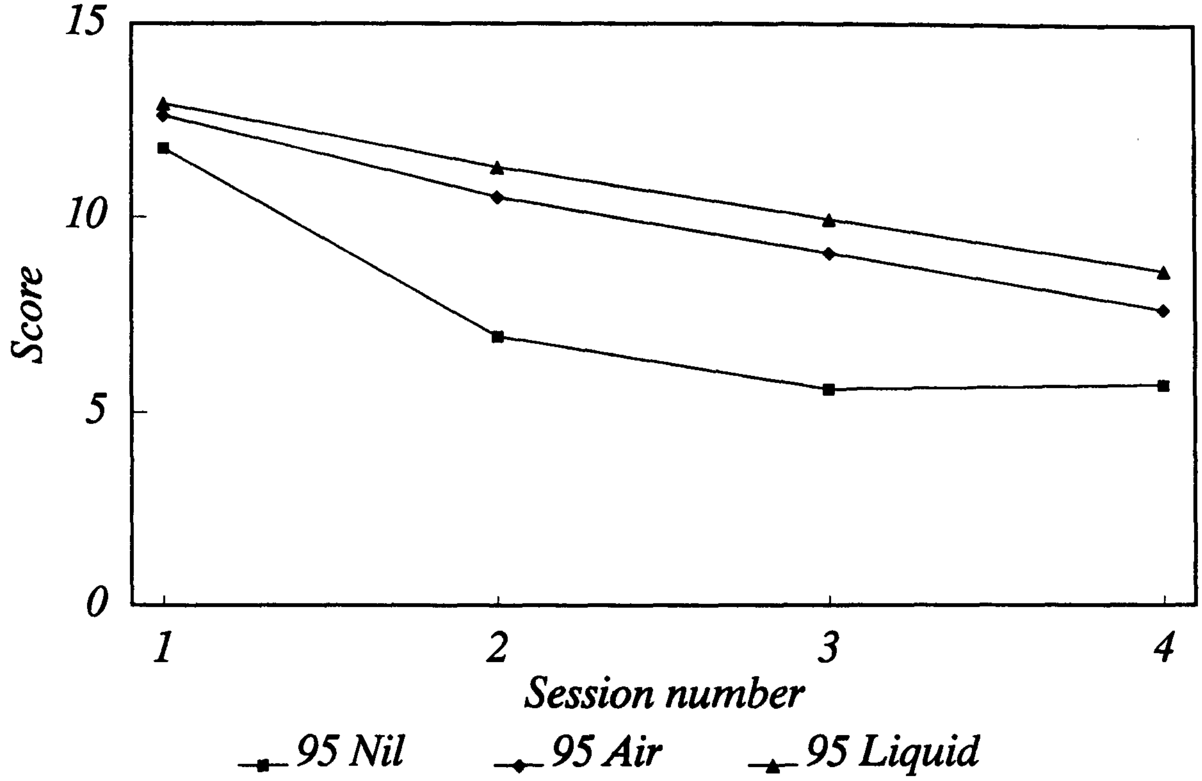

Figure 83. Fatigue checklist scores, 95°F.

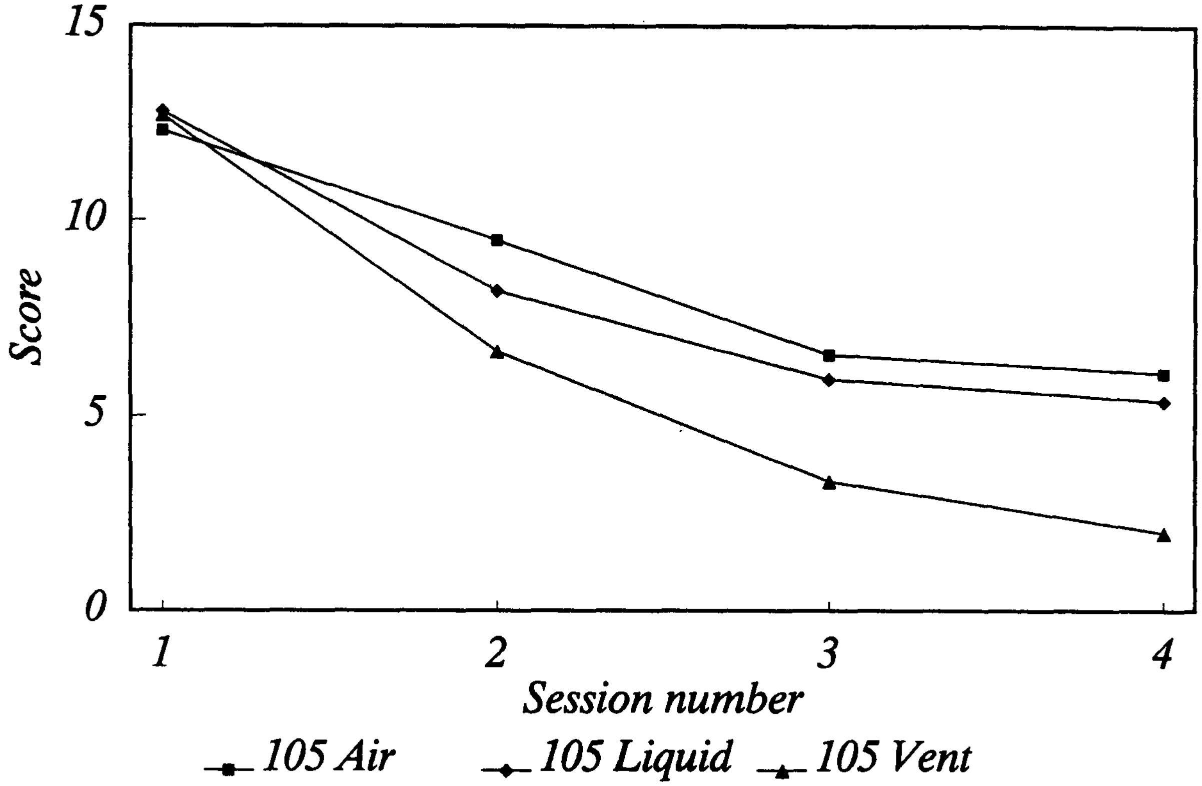

Figure 84. Fatigue checklist scores, 105°F.

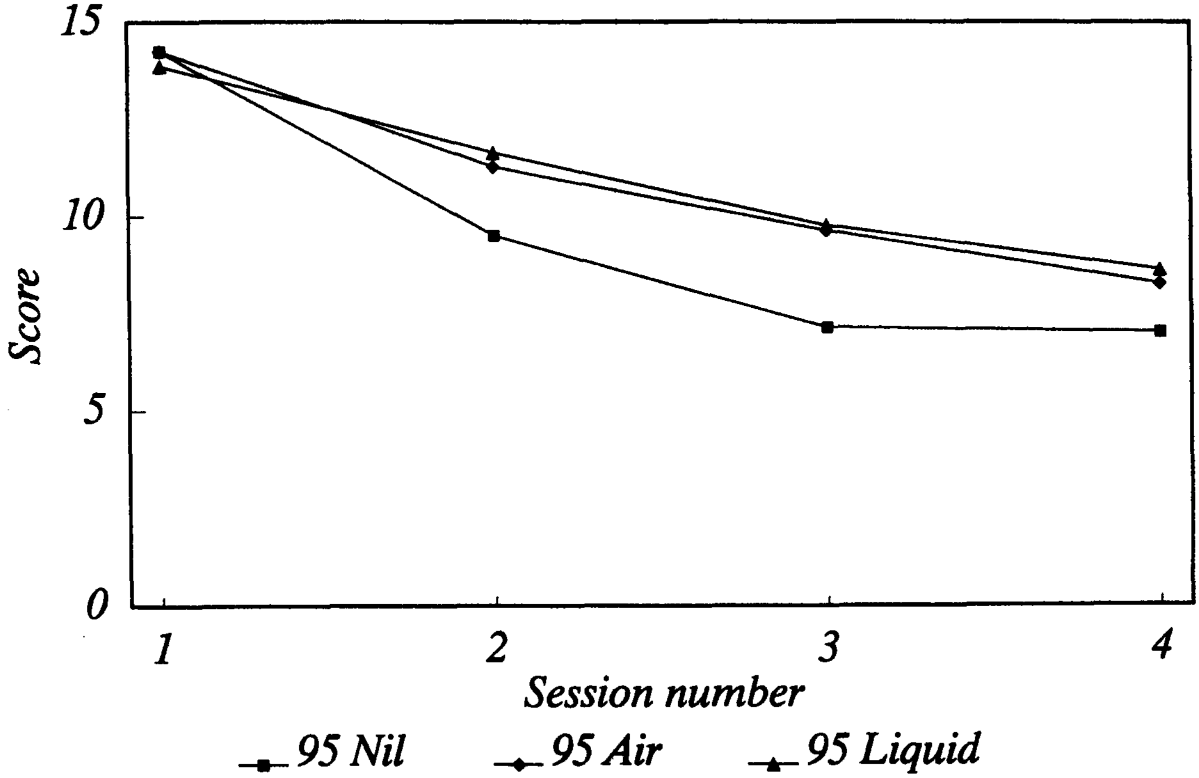

Figure 85. Fatigue checklist scores, 95°F, last eight subjects.

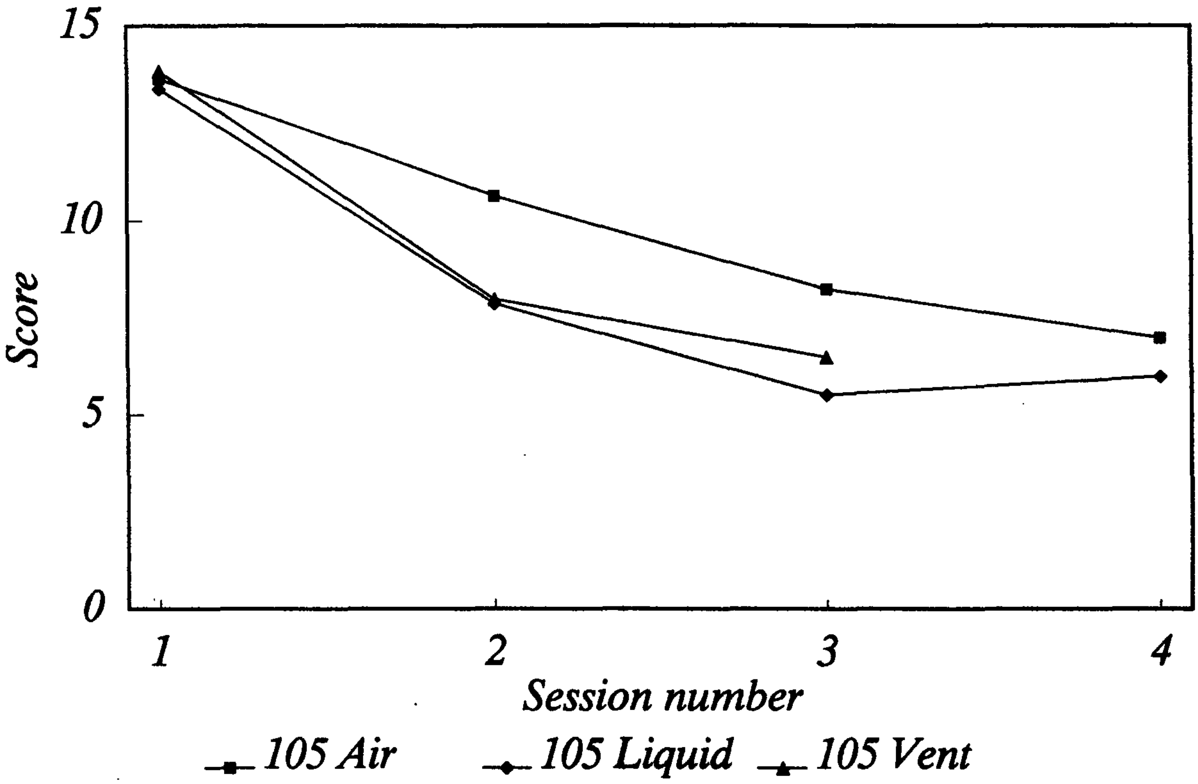

Figure 86. Fatigue checklist scores, 105°F, last eight subjects.

Performance assessment battery

Three measures from each PAB test were analyzed: percent correct, reaction time, and throughput (a derived score indicating the number of correct responses per minute). Whenever the sphericity assumption was violated, the Greenhouse-Geisser degrees of freedom correction was used. Percent correct scores were transformed into 2*asin(sqrt(x)) as suggested by Weiner (1971). Posthoc analyses were conducted using Newman-Keuls analysis. The results of each test are discussed separately.

Encode/decode (Griddle)

A significant main effect for session was found for reaction time ($F(2,22) = 6.05$, $p = 0.0081$). Posthoc analyses revealed that the preflight session was significantly faster than both the second ($p < 0.01$) and the third sessions ($p < 0.05$) (Figure 87). In addition, a significant difference was found in the throughput measure, with the preflight session having more correct responses per minute than the third session ($p < 0.05$) (Figure 88).

Six-letter search (MAST-6)

A significant main effect for condition was found in percent correct ($F(2,22) = 3.62$, $p = 0.0438$). The 95 liquid condition showed significantly better performance than the 95 nil condition ($p < 0.05$) (Figure 89.)

Logical reasoning

A significant main effect for condition was found in the reaction time measure ($F(2,22) = 3.55$, $p = 0.0462$), with the 95 nil condition having a significantly faster reaction time than 95 air condition ($p < 0.05$) (Figure 90.) A significant main effect for session was found in percent correct ($F(2,22) = 4.26$, $p = 0.0272$). The posthoc analysis revealed that the preflight session was more accurate than the second and third sessions ($p < 0.05$ and $p < 0.01$, respectively). The second session also was significantly better than the third session ($p < 0.01$). (Figure 91.)

Digit recall

Reaction time showed a significant main effect for condition ($F(2,22) = 5.35$, $p = 0.0128$), with the 95 nil condition having a faster response than the 95 liquid condition ($p < 0.05$) (Figure 92). There was a tendency for a condition effect for percent correct ($F(2,22) = 3.10$, $p = 0.0653$), with the 95 liquid showing more accurate performance than the no cooling condition (Figure 93.) In addition, there was a significant main effect for session for both percent correct ($F(2,22) = 8.58$, $p = 0.0396$) and

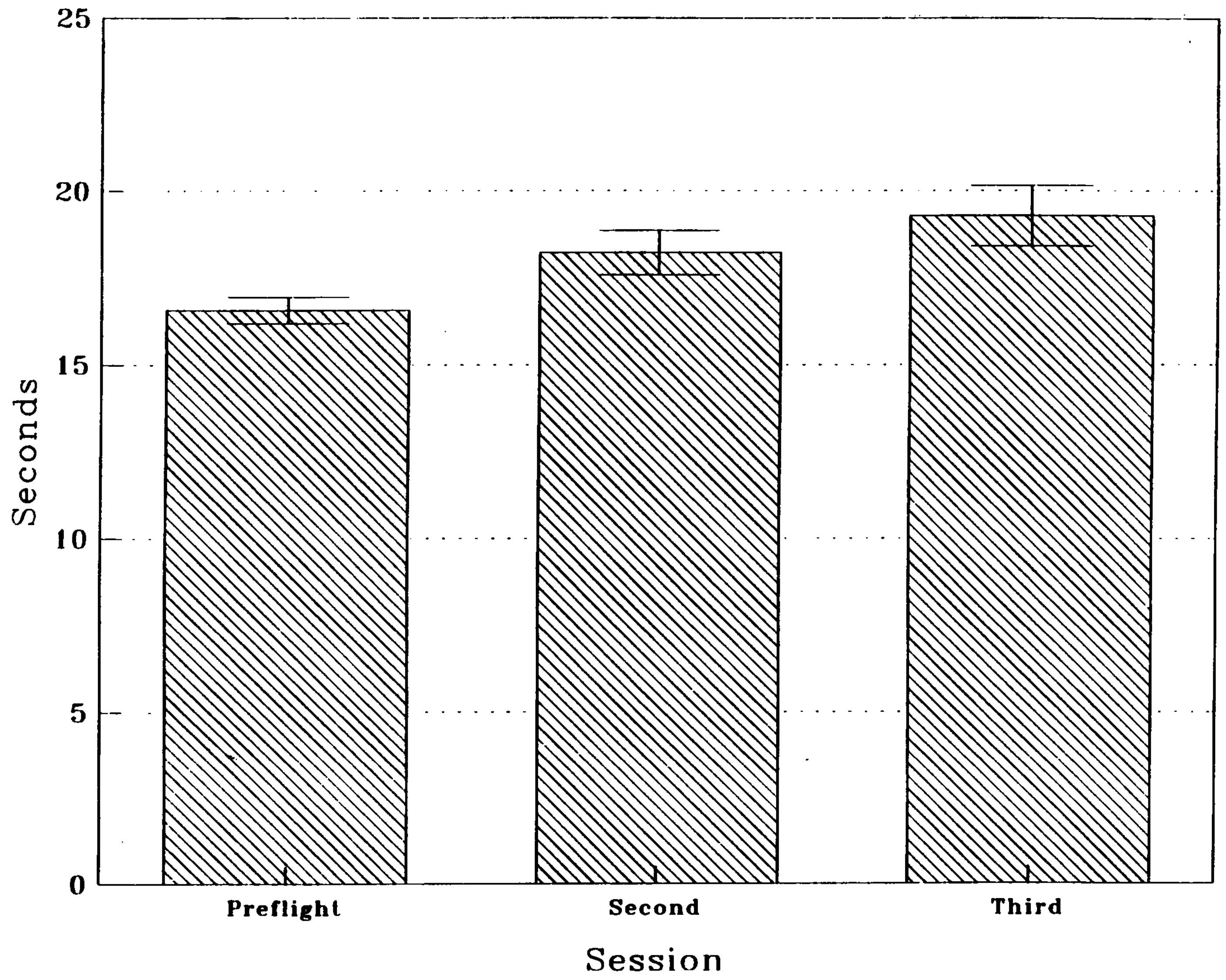

Figure 87. Encode/decode session effect for reaction time.

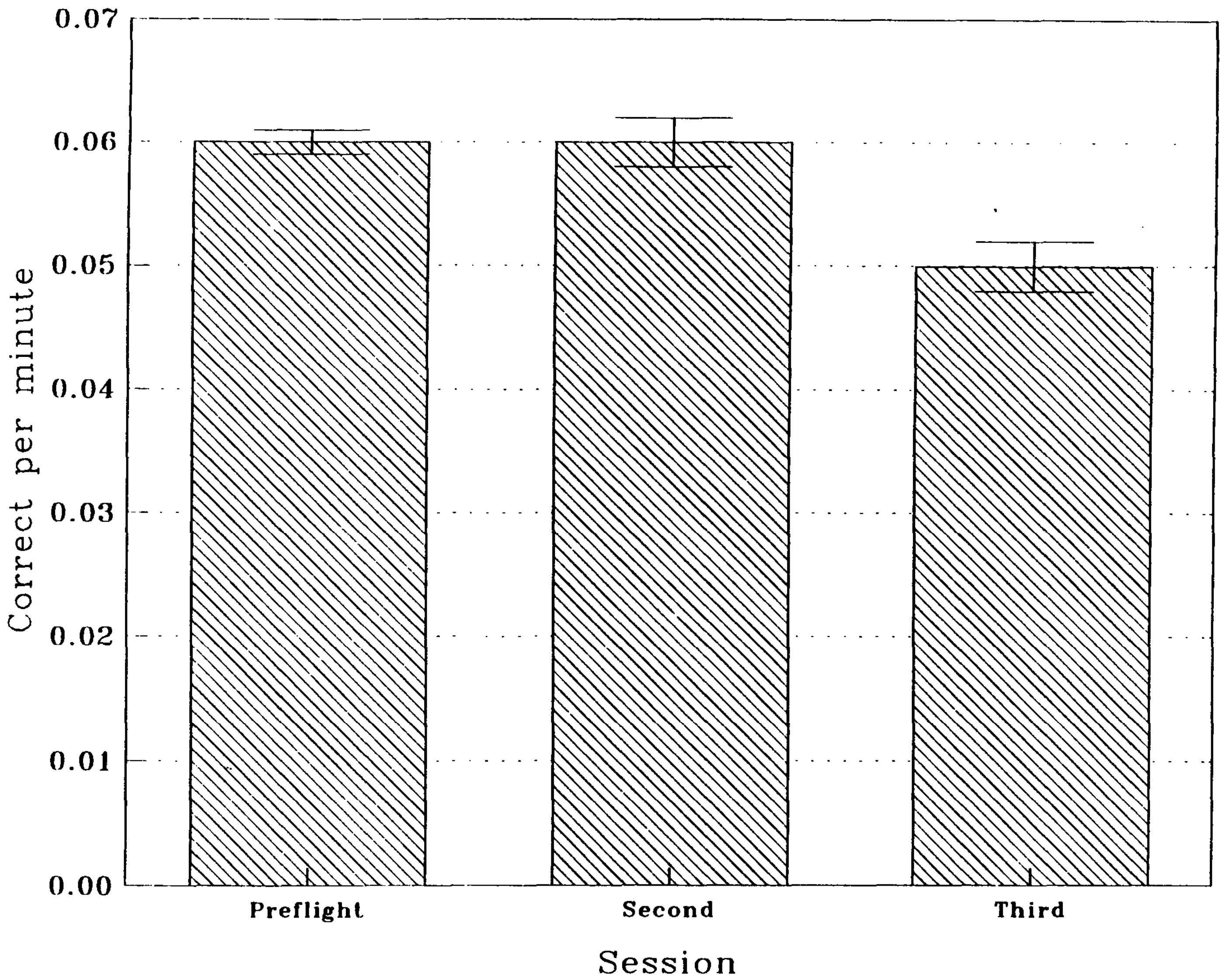

Figure 88. Encode/decode session effect for throughput.

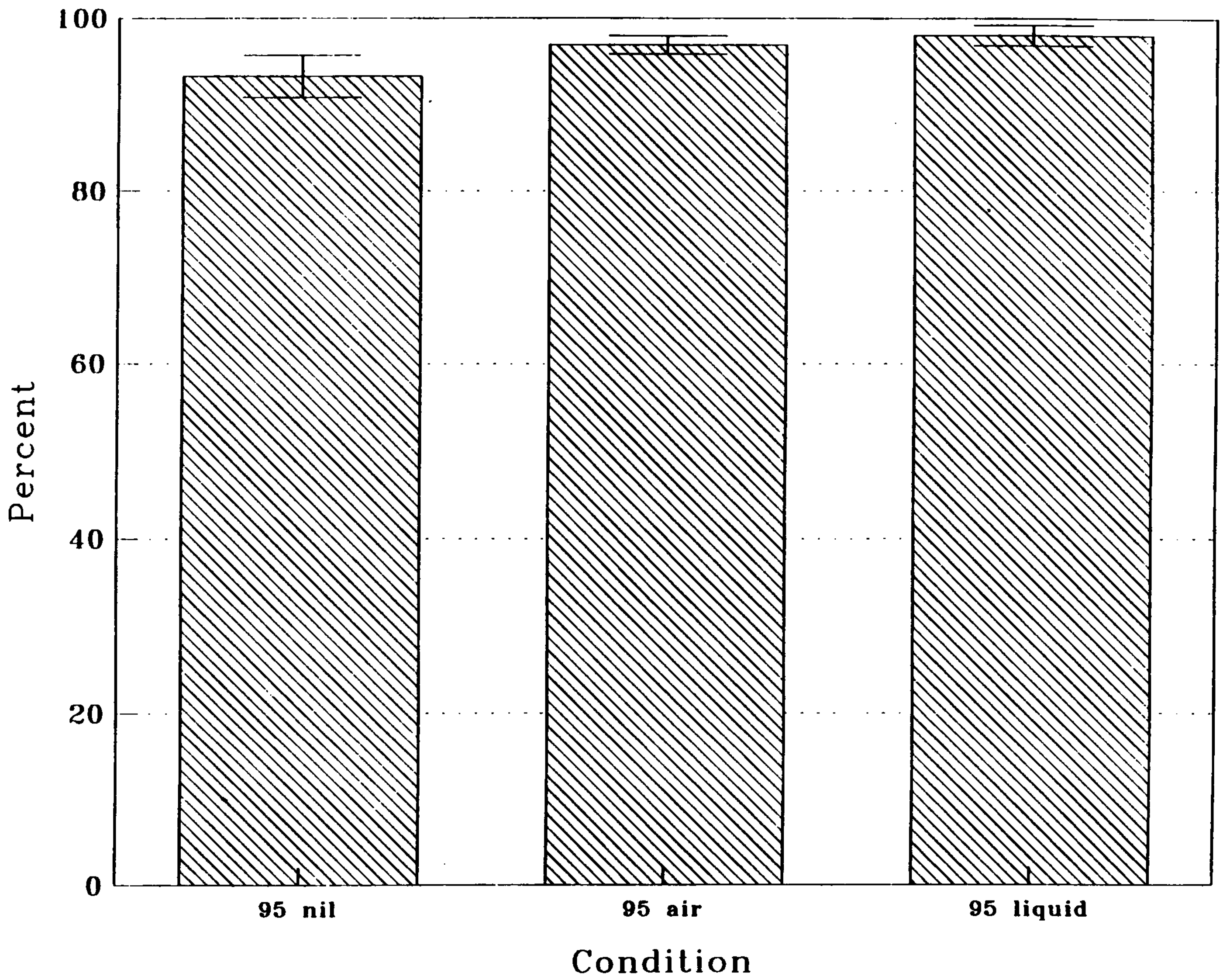

Figure 89. Six-letter search condition effect for percent correct.

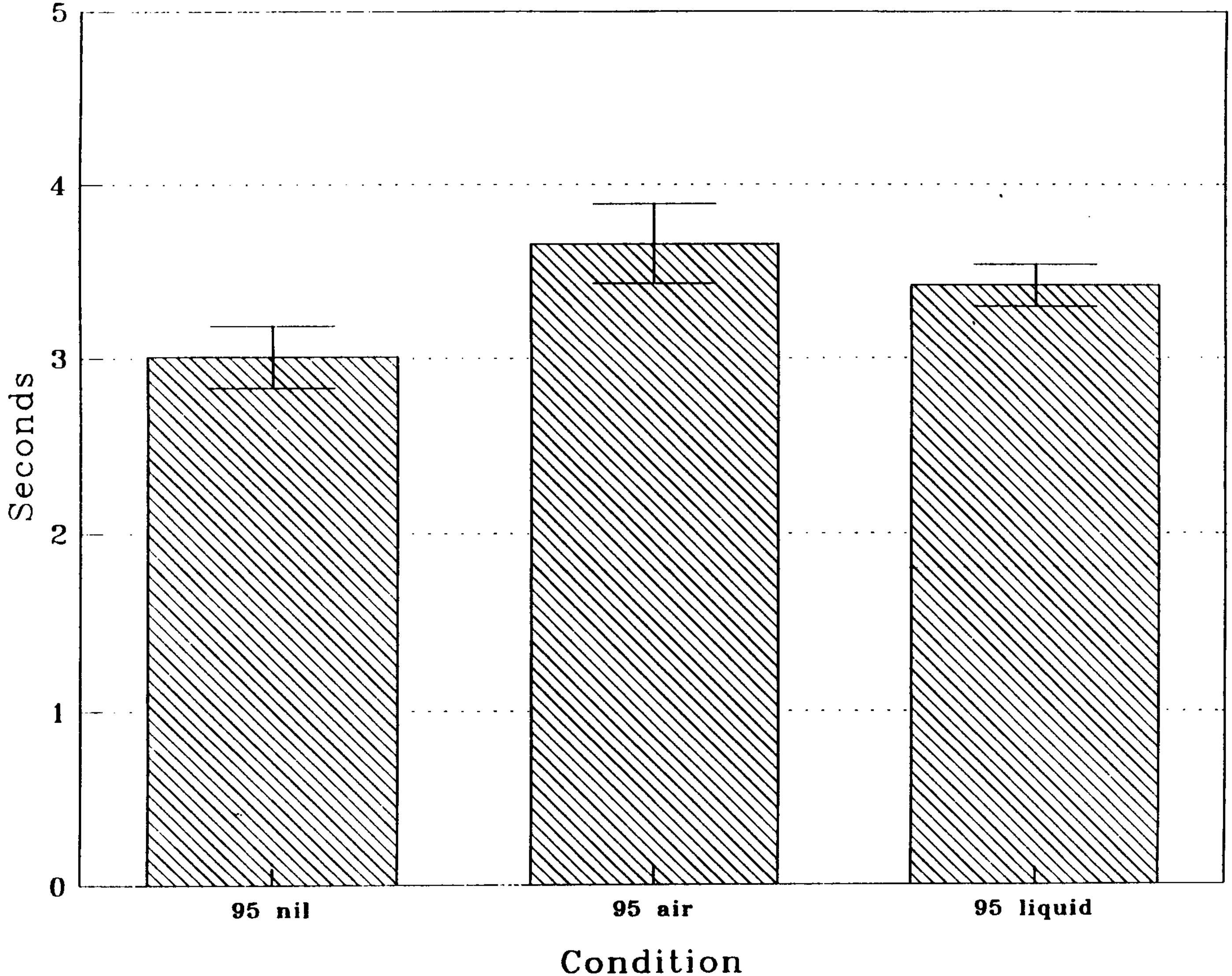

Figure 90. Logical reasoning condition effect for reaction time.

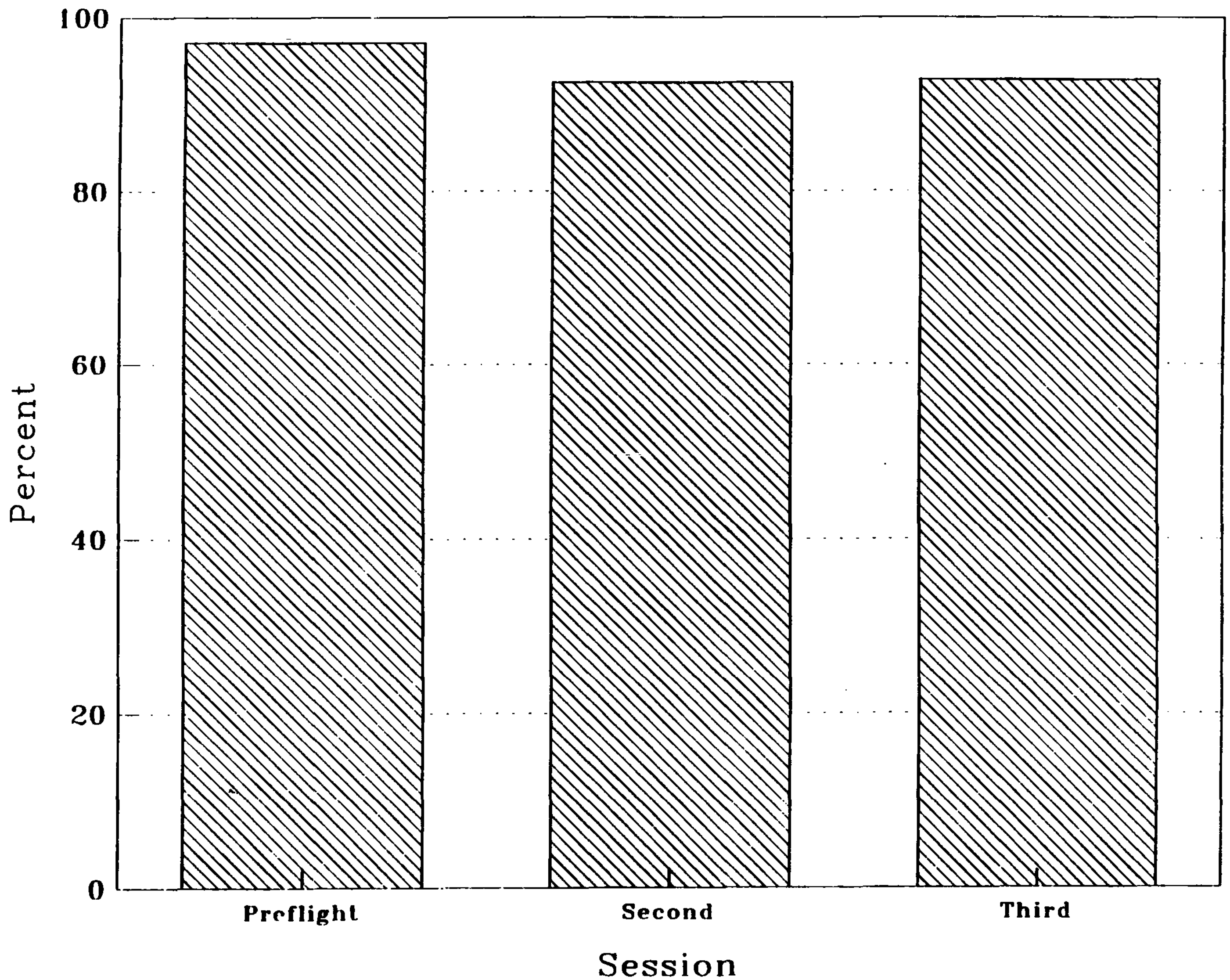

Figure 91. Logical reasoning session effect for percent correct.

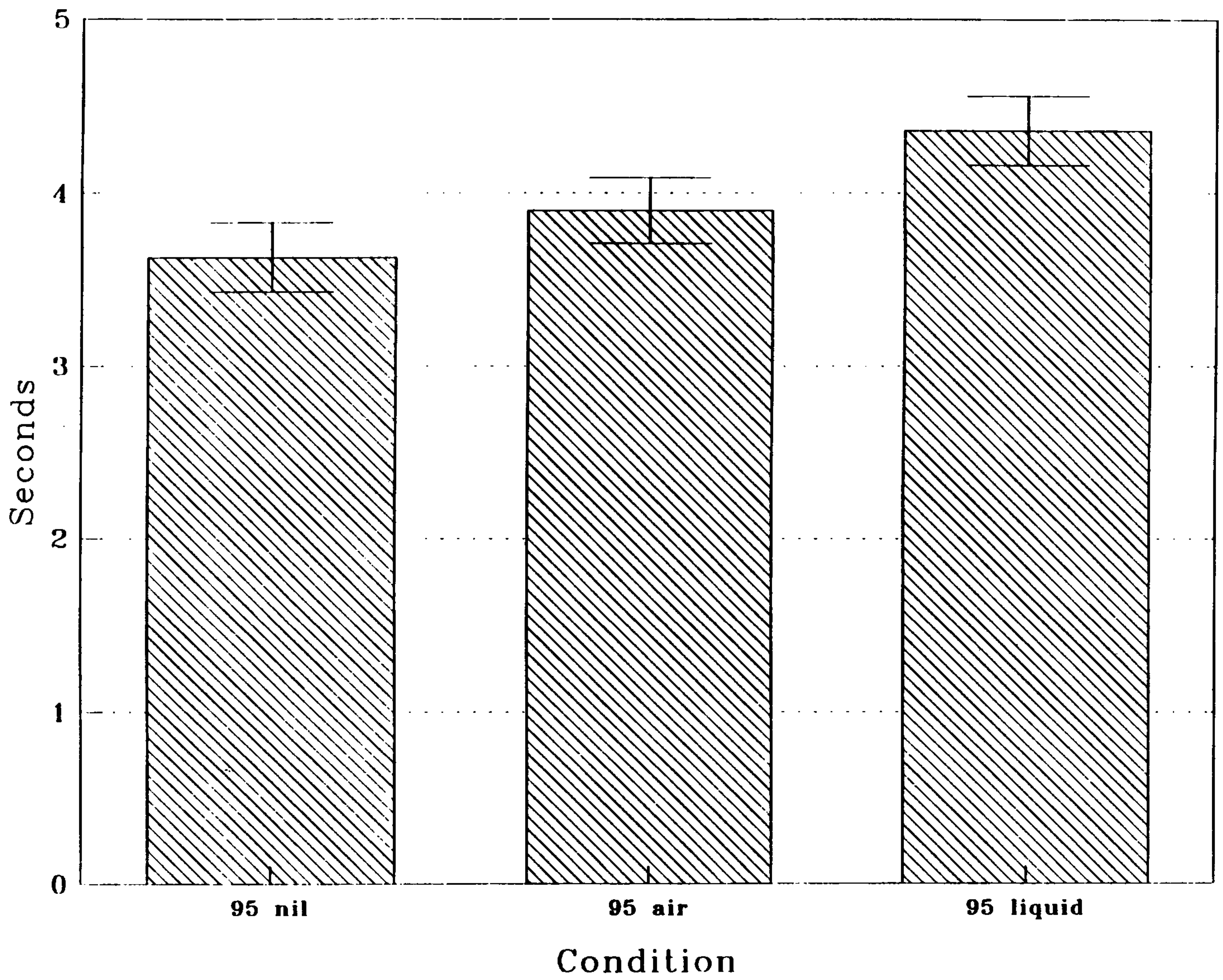

Figure 92. Digit recall condition effect for reaction time.

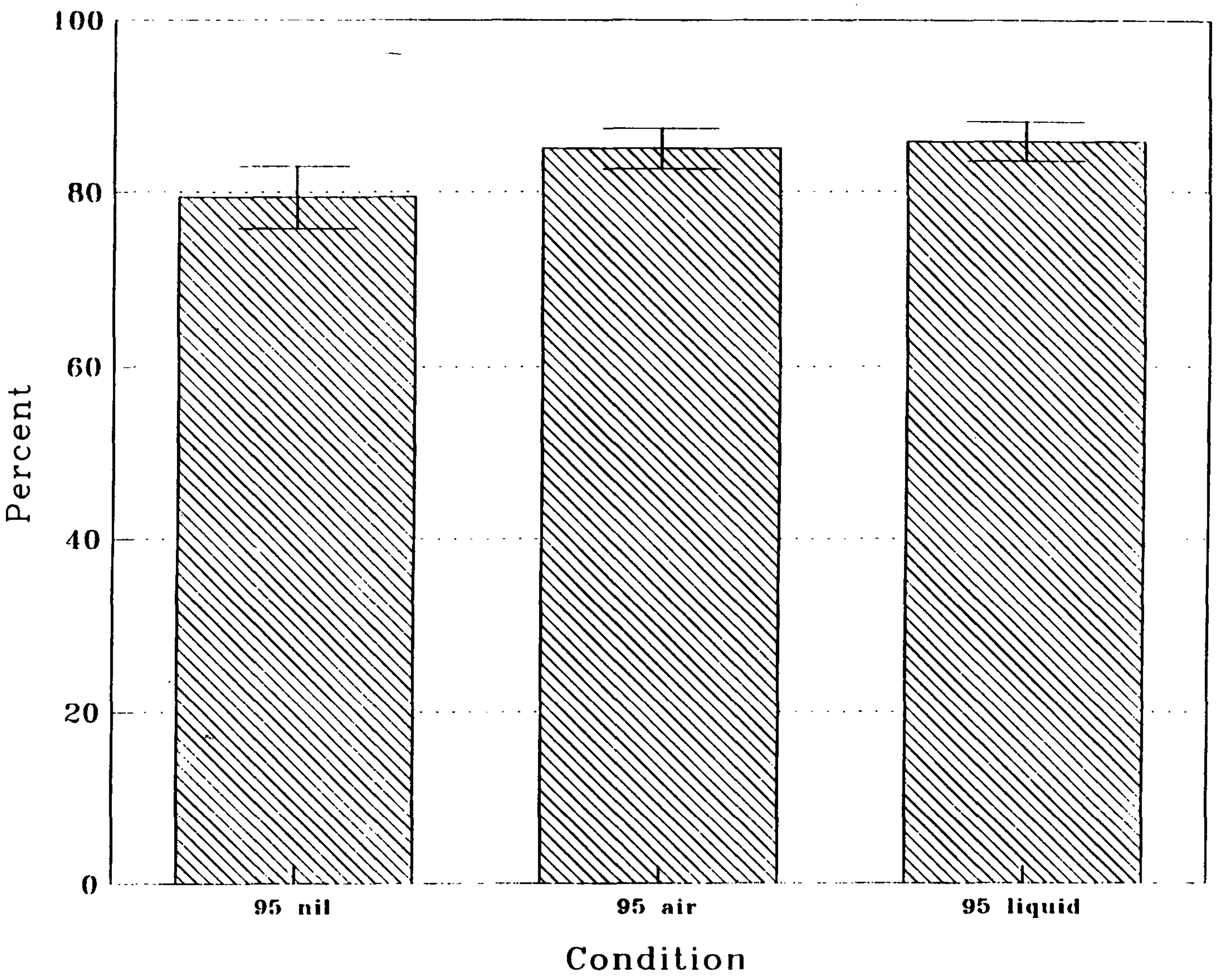

Figure 93. Digit recall condition effect for percent correct.

throughput ($F(2,22) = 3.75$, $p = 0.0396$). Posthoc analyses revealed that the preflight session was significantly better than both the second and third sessions ($p < 0.01$), and the preflight session having more correct responses per minute than the third session ($p < 0.05$) (Figures 94 and 95).

Serial addition/subtraction

A significant main effect for session was found for reaction time ($F(2,22) = 7.74$, $p = 0.0029$), with the preflight session having significantly faster times than both the second ($p < 0.01$) and the third session ($p < 0.05$) (Figure 96).

Matrix I

Significant main effects for condition were found for both reaction time ($F(2,22) = 5.61$, $p = 0.0107$) and throughput ($F(2,22) = 4.62$, $p = 0.0212$). Posthoc analysis revealed that reaction time was faster for the 95 nil condition than for the 95 liquid ($p < 0.01$). In addition, the 95 nil condition had more correct responses per minute than the 95 liquid condition ($p < 0.05$) (Figures 97 and 98).

Wilkinson four-choice reaction time

A significant condition by session interaction was found for reaction time ($F(4,44) = 2.61$, $p = 0.0479$); however, simple effect analyses did not reveal any significant differences. No other significant effects were found for this test.

Sleep

Sleep recordings

Each subject's polysomnogram for each night was scored visually for stage using standardized criteria (Rechtschaffen and Kales, 1968). Stages 1, 2, 3, 4, REM, and movement time were scored for each 30-second epoch from lights out until lights on the following morning. The first night served as acclimation; the second night, which followed a training day in the simulator served as baseline. Since the 105 vent condition was not common to all 8 subjects in the sample, this condition was dropped from the analysis. The conditions analyzed were baseline, 95 nil, 95 air, 95 liquid, 105 nil, 105 air, and 105 liquid. The variables analyzed from the sleep data are listed in Table 24.

Sleep onset was defined as time elapsed from lights out until the subject remained in stage 2 sleep for 5 consecutive minutes. REM latency was defined as time elapsed from sleep onset until the first REM period of at least 2 consecutive minutes. Each slow wave sleep period was calculated as the

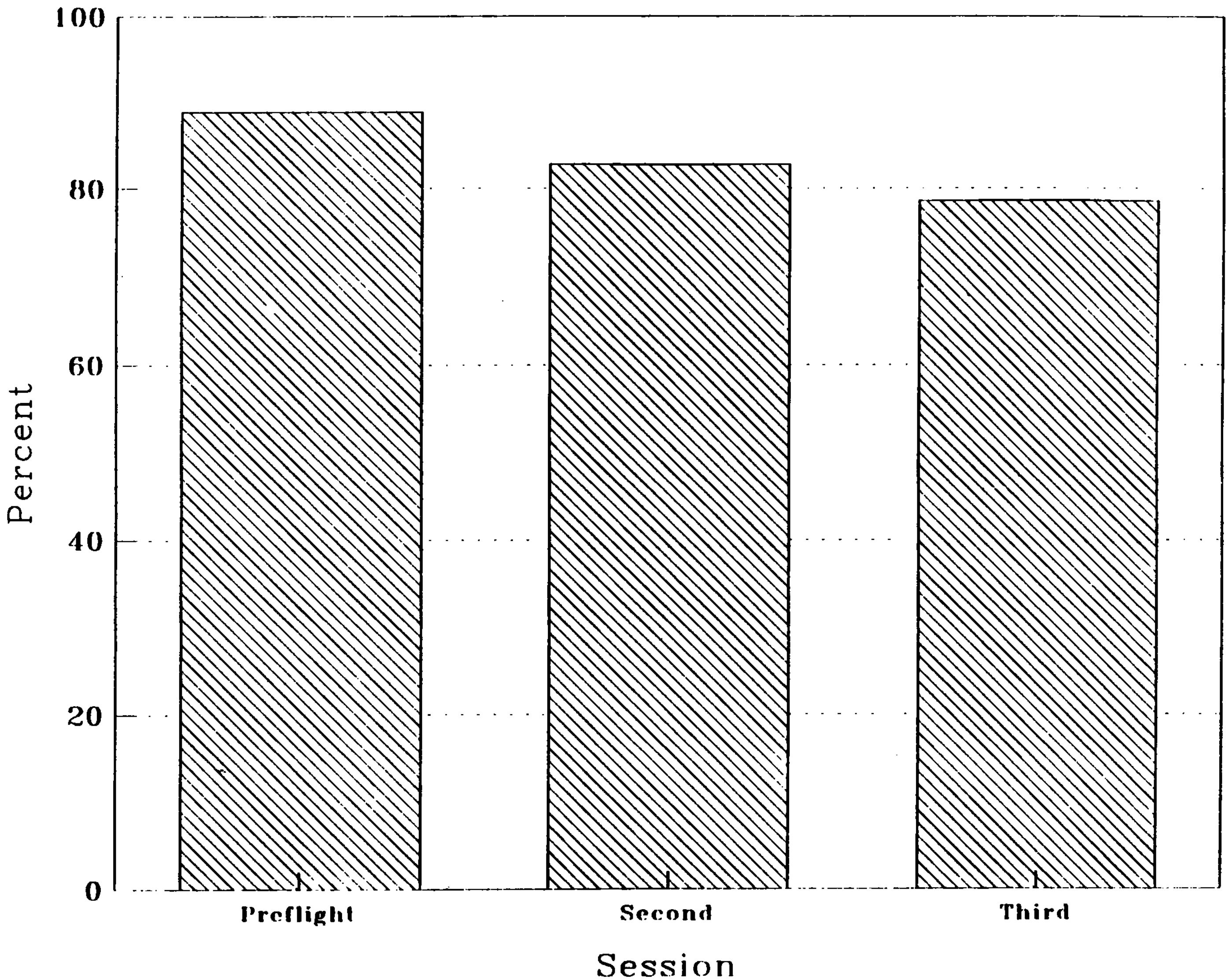

Figure 94. Digit recall session effect for percent correct.

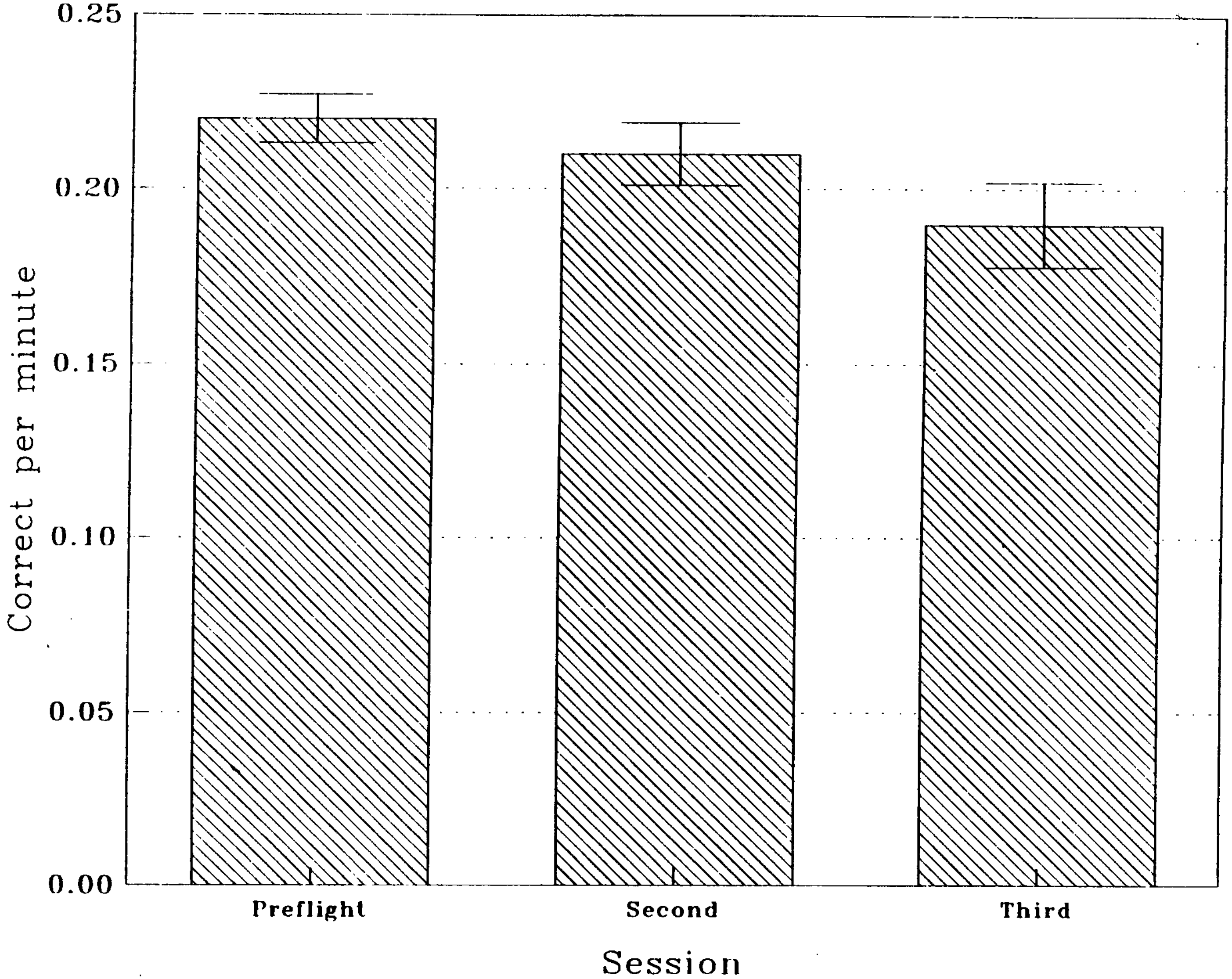

Figure 95. Digit recall session effect for throughput.

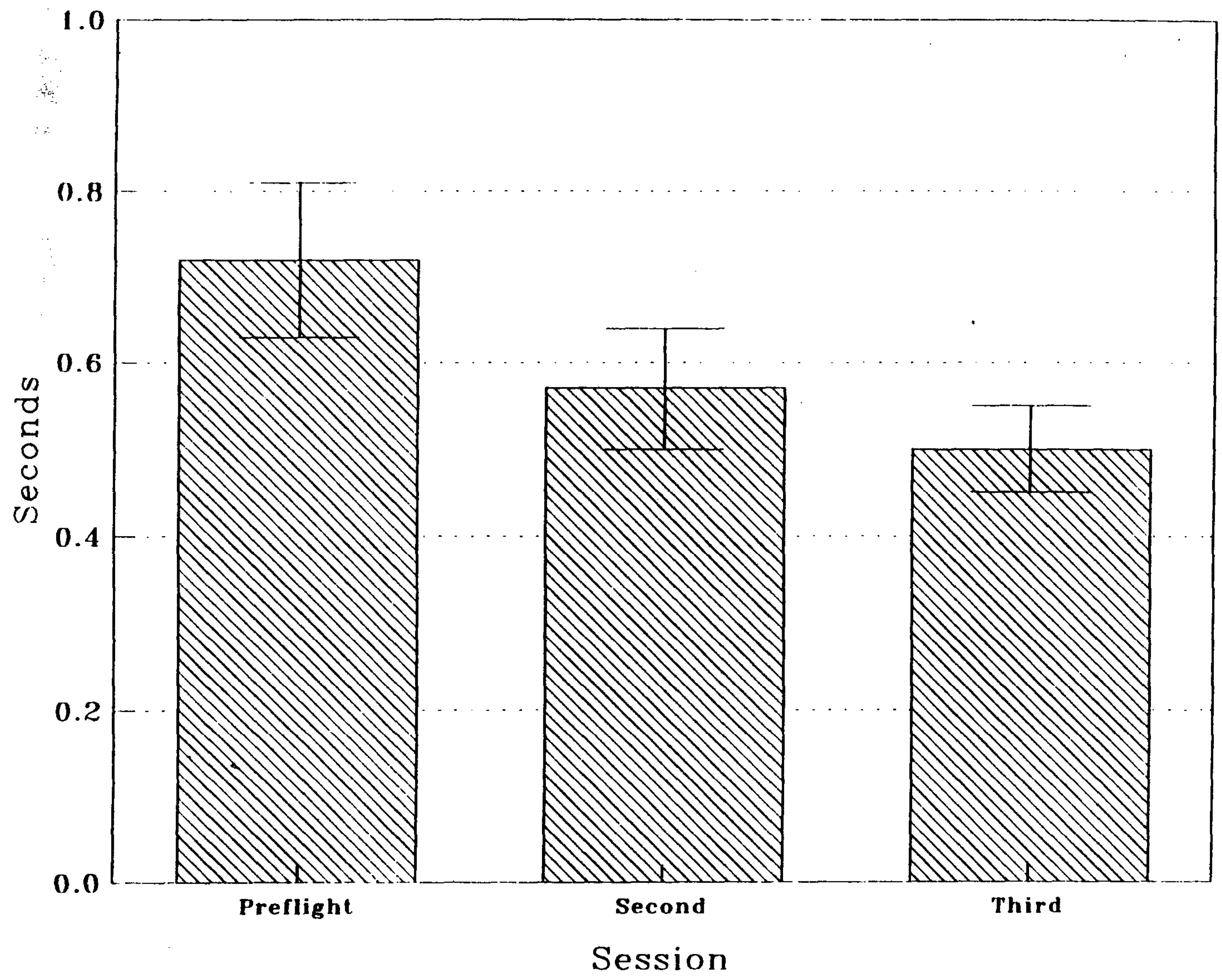

Figure 96. Serial addition/subtraction session effect for reaction time.

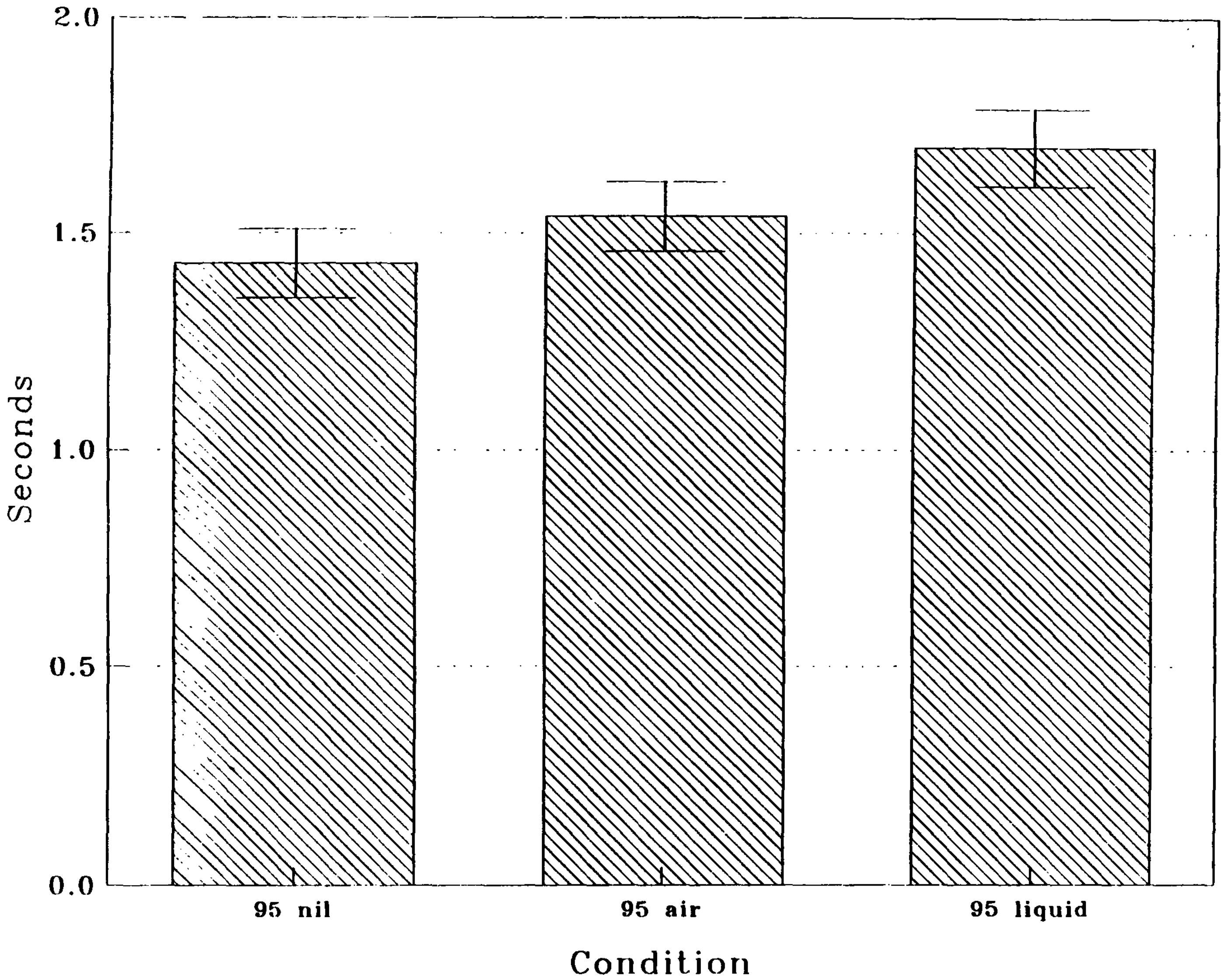

Figure 97. Matrix I condition effect for reaction time.

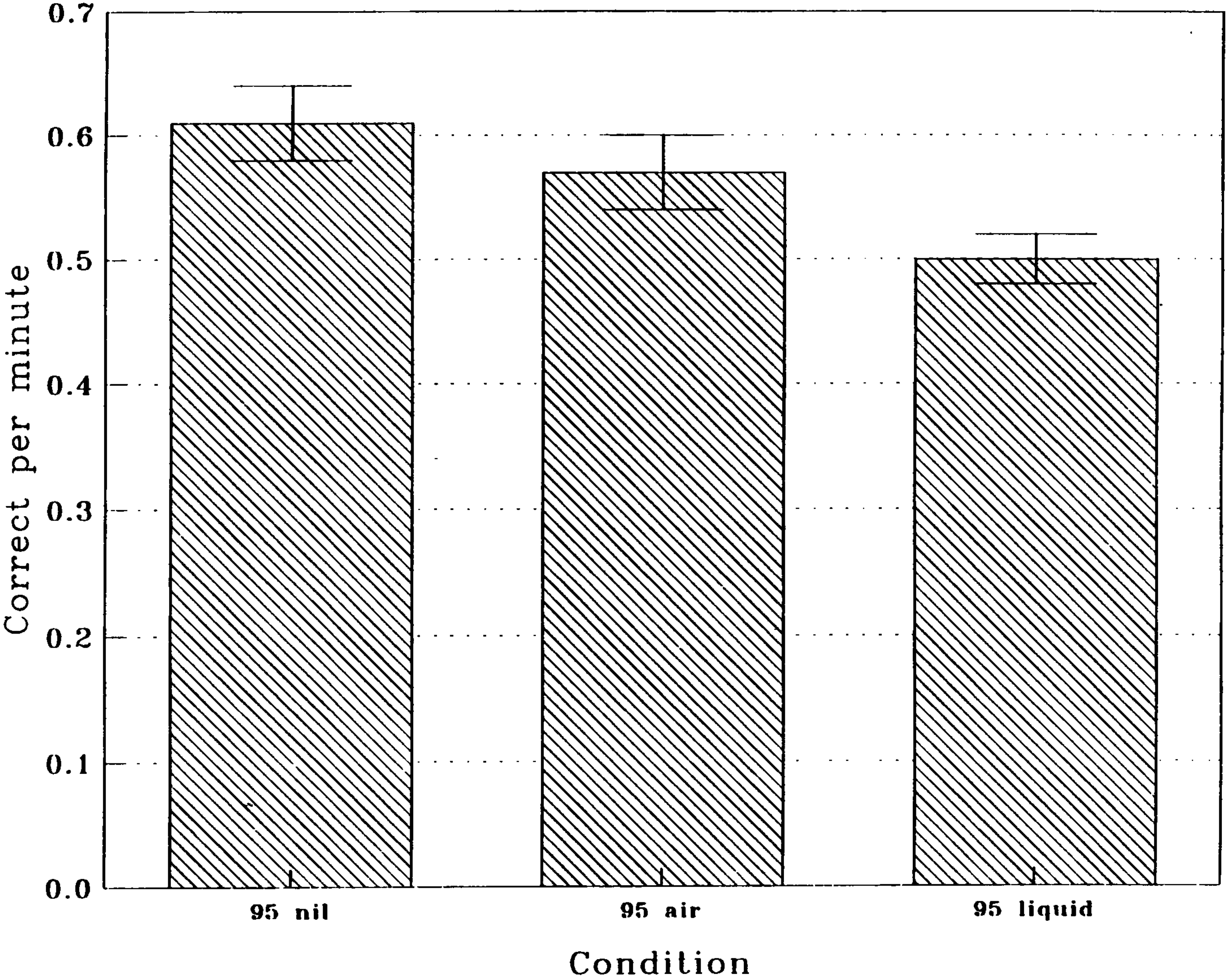

Figure 98. Matrix I condition effect for throughput.

Table 24.
Sleep Measures.

Minutes in bed
Minutes asleep
Minutes until sleep onset
Minutes in stages 1, 2, 3, 4, and REM
Minutes scored as movement time
Minutes awake after sleep onset
Latency to the first REM period
Percent of time spent in each stage
Percent of time spent in slow wave sleep
Minutes in slow wave sleep during each period
Minutes in each REM period

number of minutes in either stage 3 or stage 4 sleep during each third of the night. Each REM period was defined as the first epoch of stage REM through the last epoch of stage REM, with each period separated by at least 10 minutes.

No significant differences among the conditions were found for minutes in bed, minutes asleep, sleep onset time, minutes awake after sleep onset, or REM latency. There was a tendency for differences in the conditions for percent of stages 1 and 2 ($F(6,42) = 2.21$, $p = 0.0603$; $F(6,42) = 2.15$, $p = 0.0679$). In addition, there was a tendency for percentage of slow wave sleep to be different between the conditions ($F(6,42) = 2.15$, $p = 0.0565$). The percentage of time scored as REM sleep was significantly different between the conditions ($F(6,42) = 3.03$, $p = 0.015$), with posthoc analysis indicating the 105 liquid condition was significantly lower than the baseline, 105 nil, and the 95 air conditions ($p < 0.05$). Minutes scored as movement time also was significantly different between the conditions ($F(6,42) = 2.38$, $p = 0.0457$), with posthoc analysis indicating the 95 air condition had more movement time than the 105 liquid condition ($p < 0.05$).

The sleep record was divided into periods of slow wave sleep and REM sleep over the night, with slow wave sleep and REM sleep analyzed for each period. A significant effect was found for the second slow wave sleep period ($F(6,42) = 2.43$, $p = 0.0419$). However, posthoc tests did not show a significant difference between any of the means. No other period of either slow wave sleep or REM sleep showed a significant difference between the conditions. Figures 99 and 100 show the percentage of time spent in each stage and how these relate to changes in the conditions.

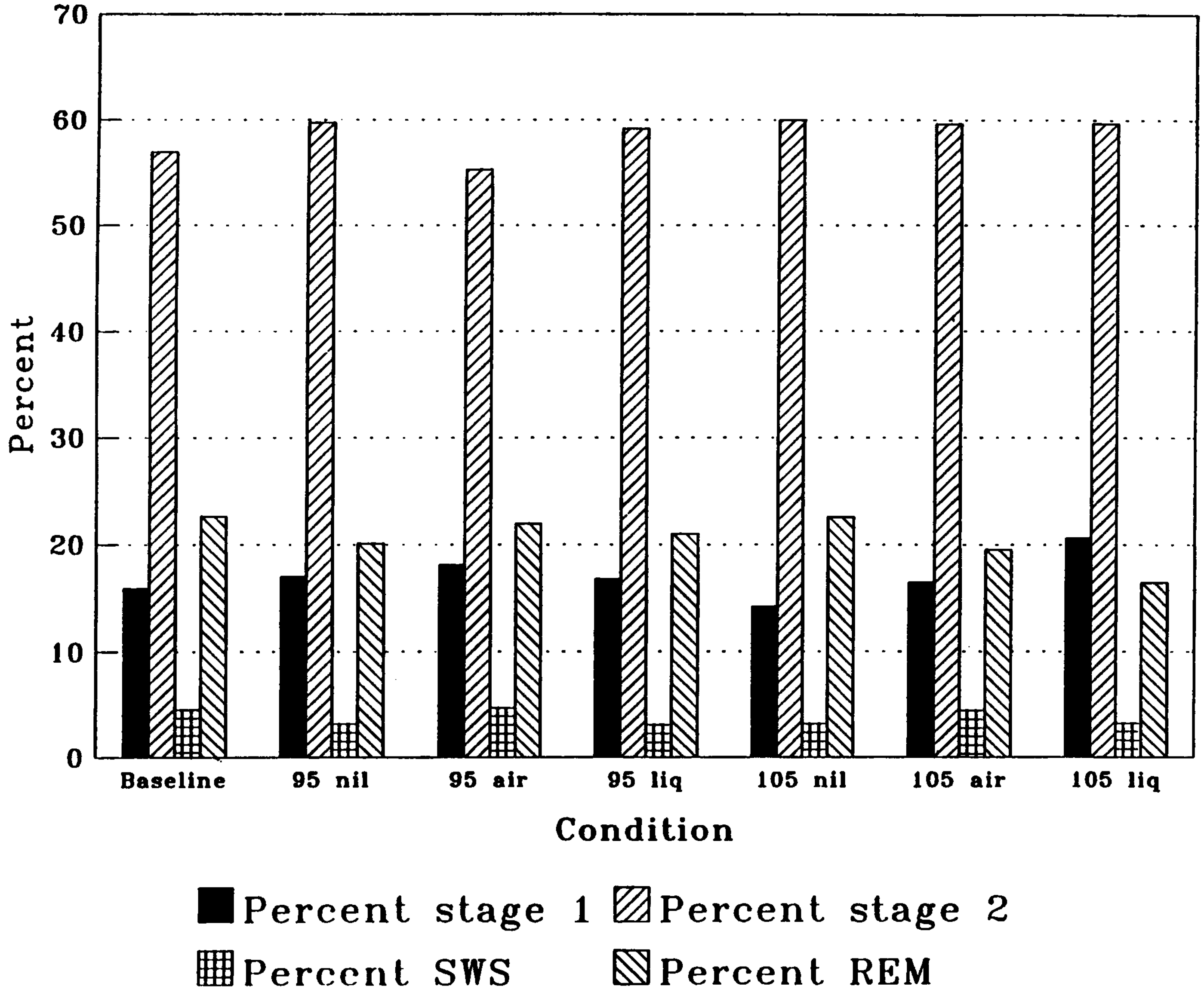

Figure 99. Percentage time in each sleep condition.

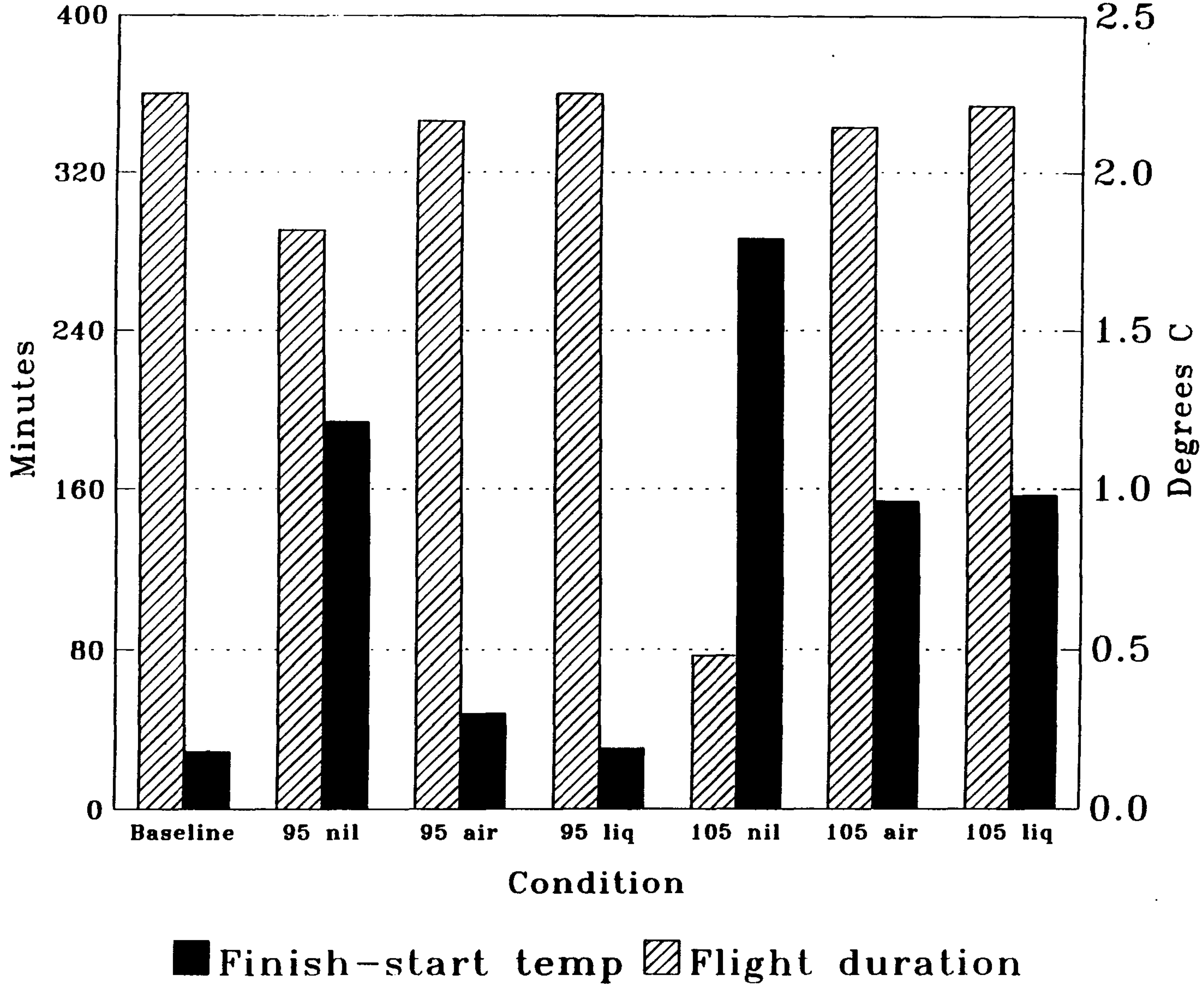

Figure 100. Flight duration and temperature rise by condition.

Environmental temperature

The temperatures recorded in the simulator cockpit, treadmill room, and bedrooms are shown in Table 25. The temperatures in the treadmill room were as hot as could be achieved with the use of space heaters, and showed considerable variation, related to the outside air temperature and the efficiency of the Laboratory's air conditioning system. The RH, calculated from a psychrometric chart using the mean values in the table, was 23 percent.

The recorded temperatures are slightly higher than those selected on the simulator ECS, due probably to the differing positions of the Wibgets and the ECS sensors. RH at 95°F was 53 percent and at 105°F, 55 percent. The bedroom temperatures were uncontrolled and dependent on the air conditioning system. The mean bedroom RH was 50 percent.

Table 25.
Environmental temperatures (°C).

	Dry bulb	Wet bulb	WBGT
Treadmill	34.92	20.03	24.29
Simulator			
95°F	34.63	27.04	29.85
105°F	39.62	31.82	34.67
Bedroom	22.20	15.71	17.67

Postflight questionnaire

A postflight questionnaire was used to obtain subject opinions of human factors aspects of wearing the two clothing assemblies. A detailed analysis appears in Appendix I.

They were first asked to rate how easy or difficult it was to perform the various activities that make up flying the aircraft, on a seven-point scale where one was very difficult and seven very easy. The lowest scores were received for tasks relating to the view inside the cockpit and reaching inside the cockpit. There were no clear differences between conditions.

The effect of the components of the uniform on four specific aspects of performance was assessed on a five-point scale where zero was not at all impaired, four extremely impaired. Any ratings of one or higher required subjects to explain in more detail. For seeing inside the cockpit, the mean score for the mask and hood indicated slight to moderate impairment, and the survival vest/armor combination produced scores indicating slight impairment. When subjects were asked to explain how the items of equipment impaired seeing inside the cockpit, the most consistent complaints were about the reduced visual fields produced by the mask and perspiration causing fogging and smearing of eyepieces, and greatly reduced head movement because of the mask hose interacting with the SARVIP. The SARVIP was criticized separately for the same reason.

In the section on problems manipulating the controls, the mask hose was criticized consistently for interfering with cyclic inputs, as was the SARVIP, and it was reported to be difficult to feel the pedal microswitches through boots and overboots. The flight glove/NBC glove combination was reported to reduce significantly manual dexterity.

When asked about any impairment of the ability to move within the cockpit to reach controls, the mask and its hose were both criticized for causing restriction to head and body movements, as was the survival vest/armor combination.

Section three addressed other compatibility issues relating to specific items of equipment. The only new problems related to the hood of the liquid-cooled suits in that it tended to cause hot spots and/or headache in some individuals.

Heat stress was assessed for each of the three sorties of the day using a five-point scale in which zero was not at all hot, four extremely hot. The liquid system produced consistently better results at the lower temperature, the air system slightly better at 105°F.

A similar scale was used to rate the importance of the effect of being hot on the ability to fly, and was repeated for each individual item of equipment. The effect on flying was predictably rated worse for the uncooled conditions, and the air cooling was rated worse than the liquid at 95°F. The mask and hood received the most blame for the cause of the heat stress.

Fit or comfort of the various components of the ensemble were assessed by asking for yes or no responses, with space for explanation. There were no consistently reported complaints.

In the last section, the subjects were asked to rate the overall acceptability using a seven-point scale. The uncooled (95°F and 105°F), vent and 105°F cooled conditions were all rated in the unacceptable half. Both cooling systems came out as between somewhat and moderately acceptable at 95°F, with little difference between them at either temperature.

The worst problems overall were said to be sweat in the face, irritation to the skin of the face by the mask, restriction of head movement by the mask hose, and hot spots on the head. When asked for suggested improvements, the only consistent one was for redesign of the mask to move the hose, and respiratory air cooling.

In addition to the formal questionnaire analysis of subjective opinions, the subjects were all debriefed individually by the principal investigator and asked specifically which cooling system they preferred at each of the two temperatures. At 95°F, nine preferred the liquid system, seven preferred air. At 105°F, 11 preferred the liquid system, and 5 preferred air. The reason given for liquid preference at 105°F was that they could feel the cold liquid and felt better for it, whereas the benefits of the air system were more subtle.

Discussion

Conditioning systems

The reliability and performance problems with the air conditioning unit were a cause for concern and produced major difficulties in interpreting the data. It was decided at the start of the study to accept any minor variations in performance due to differences in flow rate between individual subjects, as this would reflect the case in the aircraft. Similarly, major differences produced by the subjects selecting a lower cooling rate, or even no cooling at all, were deemed preferable to enforcing a single controlled level of cooling. As the main investment was in measuring flight performance, it was felt important to allow the subjects to choose their own comfort level, the potential for impaired performance being just as great if the subjects were overcooled as if they were undercooled.

These assumptions were made on the basis that both cooling units would perform as advertised, and clearly this was not the case. On the other hand, for the second half of the study, MRI had the air cooler running to the best performance they could get from it (as confirmed by tests of the unit on return to their facility after the conclusion of the study), albeit still not up to its theoretical maximum. It was compared to the liquid conditioner in identical usage conditions, and it is concluded that the data for the last eight subjects at least are valid.

One of the conclusions from this experience is that it is virtually impossible to tell subjectively that the systems functioned optimally, and a production system should contain some sort of warning to indicate when cooling falls below a preset value.

There were large differences between the cooling supplied to the pilot and copilot for both systems, caused in part by differential recirculation of hot air, but also by the interdependence of each half of the system on the other. A production version should have the two halves controlled as independently as possible, including independent flow controls.

One of the important differences between the systems as used in this study was the provision of head cooling with the liquid system. There are no clear distinctions between any of the factors measured which relate to head cooling alone. Subjective response was mixed: some subjects preferred the liquid system because it had head cooling, in others it caused hot spots on the head and was deemed more trouble than it was worth. One of the design features of the Exotemp suit is that the hood can be used or not, depending on the desires of the individual. Frim (1989) concluded that head cooling is desirable but not essential for preventing heat strain in pilots.

There are many other factors besides those measured in this study which must be taken into account in deciding which system to procure, and Appendix K is an attempt to summarize these.

Survival time

The simplest demonstration of the advantages of microclimate cooling to the aviator is obtained from considering the effect on survival time. Without cooling, the mean survival time at 95°F was 285 minutes. This correlates well with the 298 minutes reported from a previous study under similar conditions (Thornton et al. 1992). With cooling, the mean time was in excess of 350 minutes for both systems. The reduction in the mean from 360 minutes was due in each case to one individual who failed to complete the full study period.

At 105°F without cooling, the mean survival time was only 79 minutes. Air cooling increased it to 333 minutes, liquid cooling to 294 minutes. Some of the difference between systems derive from the problems two of the subjects reported with discomfort from the liquid cooling cap rather than differences in cooling effect.

Flight performance

Effects of cooling

The effects on flight performance of cooling compared with no cooling at 95°F showed significant improvement for only 8 of the 55 maneuver parameters scored for the liquid system and 7 for the air system. At 105°F, the subjects did not survive long enough without cooling to obtain any meaningful data for comparison. Using the 105 vent condition as a basis for comparison, bearing in mind that it in itself provides considerable relief compared with no cooling, the liquid system provided significantly better results in 18 cases, the air system in 13.

Using only the data for the last 8 subjects to optimize the effects of the air conditioning unit, there were no significant differences in flight performance between the 2 systems at 95°F, but at 105°F the air system produced significantly better performance in 11 out of 55 cases.

Exposure time

There was little evidence of increasing performance error with time, confirming the findings of a previous study which used the same flight profile, but without the hotter temperature condition, and without cooling (Thornton et al. 1992). One of the factors contributing to that effect is that the subjects suffering most from the conditions, and whose performance could be expected to deteriorate the most, tended to quit or be removed. Another problem is that performance is not scored for the entire duration of the flight, but for discrete segments. Scoring began for individual maneuvers only when the pilot had brought the simulator within certain constraints, i.e., they were already settled into the maneuver before scoring began. The time which they took to get established might be expected to vary with condition, though that was not recorded. Similarly, flight performance may have shown greater variation with condition during portions when the aviators knew they were not being scored.

Intersubject variation

One of the problems of analyzing the flight performance data, which was again present in the previous study (Thornton et al., 1992) was the large degree of intersubject variation. There were none of the 55 maneuver parameters in which there was no significant difference in flight performance between subjects, and typically the Duncan posthoc analysis grouped the subjects into four or five significantly different sets.

A further cause for variation in this study was due to the differential cooling for both conditioning units which meant that the pilot always received more cooling than the copilot. There were 11 examples of the pilot having significantly better performance than the copilot for the same 55 maneuver parameters and 6 of the copilot having the better performance. This is further complicated by the mix of 11 UH-60 and 5 non-UH-60 aviators. There were 15 maneuver parameters (of 37) in which the UH-60 pilots performed better, and 2 in which the non-UH-60 aviators had a significantly lower error score.

Training

The effects of training on performance were not analyzed separately. The previous study (Thornton et al., 1992) demonstrated that flight performance asymptote was reached within the first two flights and was not affected by wearing NBC IPE. Subjects in this study were given a minimum of four training flights, two in the standard flight suit and two in NBC IPE. The non-UH-60 aviators were given extra training if the simulator I/O judged they needed it.

Flight profile

The flight profile was not particularly taxing for the skills of the pilots. It consisted of routine flight maneuvers only, with no real emergencies (other than failing the AFCS), no unexpected events, and no enemy threat. It was the result of a compromise between the demands of real world combat flight and the restrictions which had to be imposed in order to allow accurate objective comparisons of different conditions. The results should, therefore, be considered conservative, in that the real world would be expected to produce more significant decrements in performance.

Conversely, low level flight in the real aircraft produces better situational awareness than simulated flight. The visual system in the simulator does not give sufficiently accurate height clues near to the ground, and the consequences of crashing bear no comparison. Therefore, it is unlikely that the 14 crashes which occurred in the simulator would have happened in the aircraft.

Physiology

There was a significant rise in rectal temperature in the 95°F uncooled condition, with two subjects reaching the physiological withdrawal limit of 39°C. Both cooling systems provided adequate control of the temperature, with the liquid producing lower temperatures and a more sustained cooling than the air. The mean rectal temperature with the air system started to rise later in the test period.

At 105°F without cooling, there was a dramatic rise in rectal temperature, with all but three of the subjects reaching

39°C. There can be no doubt that all subjects would have become serious heat stress casualties had they been forced to remain in the IPE at that temperature. Both cooling systems produced big improvements, but the air system again resulted in an increase in rectal temperature with time. Three subjects using the air system and one using the liquid (all in the first half of the study) reached the physiological withdrawal criteria. The vent mode produced a moderate improvement in rectal temperature.

The treadmill exercise period produced a small but statistically insignificant greater rise in mean rectal temperature with the liquid vest compared with the air vest. With a longer ground wear period before flight, this might have produced more of a problem.

The mean heart rate also was much reduced by cooling at both temperatures. At 95°F, the liquid system produced the lower mean, but at 105°F, the air system had the lower value, though it rose slightly with time and tended to converge with the liquid results.

A significant degree of dehydration occurred at 95°F without cooling. The rate of dehydration at 95°F was reduced to less than half the uncooled rate by both cooling systems. The rate of sweating also was considerably reduced by cooling, to a slightly lesser extent by the air system, which drives the rate of evaporation to achieve its effects.

The amount of dehydration at 105°F for all conditions was twice that at 95°F without cooling. Much of this was due to the reluctance of the subjects to drink warm water. The rate of sweating and dehydration was reduced greatly by cooling.

Performance assessment battery

The main finding for the cognitive tests was that the subjects tended to have a faster reaction time in the 95 nil condition than in either of the cooling conditions at 95°F. However, accuracy tended to be worse during no cooling than in the cooling conditions, with significantly better performance in the six-letter search task during the liquid cooling condition at 95°F. The digit recall task tended to have better accuracy during the liquid cooling condition than the no cooling condition at 95°F.

Matrix I showed both faster reaction time and higher number of correct responses per minute in the 95 nil condition than in the 95 liquid condition. On this test, it appears that the performance accuracy did not get worse while their reaction time increased during the no cooling condition. This task assesses spacial skills which is a skill required of pilots every time they fly. The literature indicates that heat generally does not affect tasks which are well learned (Hancock, 1982).

Four of the seven tests showed a decline in speed and/or accuracy over time. Accuracy during the preflight session was significantly better than the second and third sessions for logical reasoning and digit recall. Reaction time during the preflight session was faster than during the second and third sessions for encode/decode and serial addition/subtraction. These results indicate that fatigue during the flight negatively affects performance on some tasks regardless of the cooling system in use.

Sleep measures

The effect of the conditions on sleep during the night was small. The effect of heat on the REM sleep of the pilots was the only sleep parameter to differ statistically between the conditions. This effect appeared to be the result of an interaction between an increase in core temperature of at least 0.9°C and remaining in the simulator for at least 5 hours. Both of these conditions occurred in the 105 liquid condition and 105 air condition. A statistically significant decrease in the amount of REM sleep occurred in the 105 liquid condition when compared to the baseline, 95 air, and the 105 nil conditions. There was a tendency for a decrease in REM sleep after the 105 air condition. However, this effect did not reach statistical significance.

An increase in REM latency did not show a statistically significant effect. However, it is interesting to note that all the subjects missed their first REM period at some time during the study. Two subjects missed the first period after the 105 nil condition, two in the 105 air condition, and one each in the 95 nil and 95 liquid conditions. One subject missed his first REM period on three different nights. Other investigators have found similar effects with body heating (Bunnell et al., 1988, Horne and Reid, 1984). However, this study did not find a corresponding increase in slow wave sleep as was found in the previous studies.

It appears that an increase in core temperature alone did not affect REM sleep. The 105 nil condition produced an average rise in core temperature of over 1.5°C above baseline, but the subjects did not remain in the hot environment long enough to produce an effect on REM sleep. There was a tendency for the amount of slow wave sleep after this condition to increase, but this effect did not reach statistical significance. Literature which examined the effects of passive body heating on sleep indicates that heating which occurred within 4.5 hours of bedtime produced more of an effect on sleep architecture than heating which occurred more than 8 hours from bedtime (Bunnell et al., 1988). The aviators in this study were in the hot environment 10 to 12 hours before bedtime, which would account for the lack of effect on sleep in the 105 nil condition.

Subjective fatigue

Both temperatures produced a steady increase in subjective fatigue with time. There was a big improvement caused by the use of cooling, and there were no significant differences between the systems.

Postflight questionnaire

The results of the postflight questionnaire confirm the problems already reported by Thornton et al. (1992) relating to restriction of head movement caused by the weight of the mask hose and its interaction with the SARVIP, especially on flexing the neck to look down. It was aggravated in this study by the increased clothing bulk caused by wearing the air vest.

Conclusions

When reading the conclusions of this study, it should be borne in mind that the conditions were not worst case. The flight profile was undemanding and well-rehearsed, with no true emergencies or unplanned deviations, and the environmental conditions are not the most extreme that can be encountered. Furthermore, the AUIB is not in service, and the current NBC IPE can be expected to produce a greater heat load. There were considerable technical problems encountered with the air cooling unit, and the analysis of the data had to take this into account.

1. The use of microclimate cooling produced a large increase in the time subjects were able to survive in NBC IPE in both hot conditions.

2. A significant improvement in flight performance was obtained by the use of microclimate cooling.

3. There was no evidence of flight performance decrement with increasing time in the environment, up to the 6 hours tested.

4. There was a considerable degree of variation in the size of the measured performance error parameters between individual subjects.

5. UH-60 pilots performed significantly better than non-UH-60 pilots.

6. Subjects experienced a considerable degree of heat strain without cooling, as shown by their rectal temperature and heart rate, which was prevented completely at 95°F and partially at 105°F.

7. Microclimate cooling produced big reductions in the rate of sweat loss and dehydration.

8. There is a significant problem with interaction between the hose of the M43 mask and the SARVIP/body armor combination.

9. The liquid system was a little better than the air system in its prevention of heat strain.

10. Reduction in flight performance error was better with the air system than with the liquid system.

11. The performance assessment battery indicated that, generally, reaction time was faster during the no cooling condition, but that accuracy was generally better in the cooled conditions.

12. The performance assessment battery scores declined over time, regardless of the cooling conditions.

13. Prolonged exposure to elevated rectal temperature produced a reduction in the amount of REM sleep and a tendency to delay its onset.

Recommendations

1. Flight in NBC IPE in hot conditions poses a significant threat to flight performance and safety. This can be offset largely by the use of microclimate cooling, the procurement of which should proceed as soon as practical.

2. As tested under the conditions and limitations of this study, there is little to choose between air and liquid systems in terms of their effect on physiology or performance.

3. Whichever system is selected, it should be configured so that the coolant supplies to the pilot and copilot are not dependent on each other.

4. Some form of feedback is required to confirm to users that the system is functioning correctly, particularly for an air system.

5. The compatibility between the M43 mask and the SARVIP should be improved.

<u>References</u>

Bayes, S.A. 1983. <u>Microclimate cooling systems study helicopters</u>. Natick, MA: U.S. Army Natick Research and Development Center. NATICK/TR/84/013L.

Belyavin, J.J., Gibson, T.M., Anton, D.J., and Truswell, P. 1979. Prediction of body temperature during exercise in flying clothing. <u>Aviation, space, and environmental medicine</u>. 50: 911-916

Bomalaski, S., Chen, T., and Constable, S.H. 1989. Combinations of microclimate air cooling during work in the chemical defense ensemble decrease thermal strain and increase work performance. <u>Proceedings of the 1989 medical defense bioscience review</u>.

Bunnell, D.E., Agnew, J.A., Horvath, S.M., Jopson, L., and Wills, M. 1988. Passive body heating and sleep: Influence of proximity to sleep. <u>Sleep</u>. 11: 210-219.

Caderette, B.S., Pimental, N.A., Levell, C.A., Bogart, J.E., and Sawka, M.N. 1986. <u>Thermal responses of tank crewmen operating with microclimate cooling under simulated NBC conditions in the desert and tropics</u>. Natick, MA: U.S. Army Research Institute of Environmental Medicine. USARIEM-T7-86.

Caderette, B.S., DeCristofano, B.S., Speckman, K.N., and Sawka, M.N. 1988. <u>Evaluation of three commercial microclimate cooling systems</u>. Natick, MA: U.S. Army Research Institute of Environmental Medicine. USARIEM-M19-89.

Di Nisi, J., Ehrhart, J., Galeou, M., and Libert, J.P. 1989. Influence of repeated passive body heating on subsequent night sleep in humans. <u>European journal of applied physiology</u>. 59: 138-145.

Duncan, D.B. 1955. Multiple range and multiple F tests. <u>Biometrics</u>, 11: 1-42.

Fine, B.J., and Kobrick, J.L. 1987. Effect of heat and chemical protective clothing on cognitive performance. <u>Aviation, space, and environmental medicine</u>. 58: 149-154.

Frim, J. 1989. Head cooling is desirable but not essential for preventing heat strain in pilots. <u>Aviation, space, and environmental medicine</u>. 60: 1056-1062.

Hamilton, B.E., Folds, D., and Simmons, R.R. 1982. Performance impact of current United States and United Kingdom aircrew chemical defense ensembles. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 82-9.

Hamilton, B.E., Simmons, R.R., and Kimball, K.A. 1982. Psychological effects of chemical defense imposed heat stress on Army aviators. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 83-6.

Hamilton, B.E., and Zapata, L. 1983. Psychological measurements during the wear of the U.S. aircrew chemical defense assembly. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 83-7.

Hancock, P.A. 1982. Task categorization and the limits of human performance in extreme heat. Aviation, Space, and Environmental Medicine, 53: 778-784.

Horne, J.A., and Reid, A.J. 1984. Night-time sleep EEG changes following body heating in a warm bath. Electroencephalograph and clinical neurophysiology. 60: 154-157.

Kaufman, J.W., Dejneka, K.Y., Morrissey, S., and Bittner, A., Jr. 1988. Evaluation of thermal stress induced by helicopter aircrew chemical, biological radiological (CBR) protective ensemble. Warminster, PA: Naval air Development Center. NADC-89009-60.

Knox III, F.S., Nagel G.A., Hamilton B.E., Olazabal R.P., and Kimball, K.A. 1982. Physiological impact of wearing aircrew chemical defense protective ensembles while flying the UH-1H in hot weather. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 83-4.

Kobrick, J.L., and Fine, B.J. 1983. Environmental factors and work. In Oborne, D.J., and Gruneberg, M.M., eds. Psychology and productivity at work: the physical environment. London: Wiley.

Masadi, R., Finney, R.F., and Blackwell, C. 1991. Evaluation of five commercial microclimate cooling systems for military use. Natick, MA: U.S. Army Natick Research, Development and Engineering Center. (Un-numbered).

Mitchell, G., Knox, F., Edwards, R. Schrimsher, R., Siering, G., Stone, L., and Taylor, P. 1986. Microclimate cooling and the aircrew chemical defense ensemble. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 86-12.

Pearson, R.G., and Byers, G.E., Jr. 1956. The development and validation of a checklist for measuring subjective fatigue. Randolph Air Force Base, TX: United States Air Force School of Aerospace Medicine. USAFSAM Report No 56-115.

Pimental, N.A., Sawka, M.N., and Tassinari, T.H. 1985. Effectiveness of an air-cooled vest in reducing heat stress of soldiers in chemical protective clothing. Natick, MA: U.S. Army Institute of Environmental Medicine. USARIEM-T5-86.

Ramanathan, N.L. 1964. A new weighting system for mean surface temperature. Journal of applied physiology. 19: 531-533.

Rechtschaffen, A., and Kales, A. 1968. A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Washington, DC: Public Health Service, U.S. Government Printing Office.

Sweitzer, J.R. 1989. Operational assessment of the aircrew microclimate conditioning system (AMCS). Fort Rucker, AL: Test Evaluation Division, Directorate of Combat Development, U.S. Army Aviation Center.

Thorne, D.R., Genser, S.G., Sing, H.C., and Hegge, F.W. 1985. The Walter Reed performance assessment battery. Neurobehavioural toxicology and teratology. 7: 415-418.

Thornton, R. 1991. Microclimate cooling comparison study in the UH-60 helicopter flight simulator. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR 91-10-3-1.

Thornton, R., and Brown, G.A. 1982. The energy expenditure of helicopter crewmen. Farnborough, Hants., U.K.: Royal Air Force Institute of Aviation Medicine. Aircrew Equipment Group Report No. 469.

Thornton, R., Brown, G.A., and Higenbottam, C. 1984. The energy expenditure of helicopter pilots. Aviation, space, and environmental medicine. 55: 746-750.

Thornton, R., Brown, G.A., and Redman, P.J. 1985. The effect of the U.K. aircrew chemical defense assembly on thermal strain. Aviation, space, and environmental medicine. 56: 208-211.

Thornton, R., and Guardiani, F. 1992. Cockpit temperatures in the UH-60 helicopter. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. (In press).

Thornton, R., Caldwell, J.L., Clark, W., Guardiani, F., and Rosario, J. 1992. Effects on physiology and performance of wearing the aviator NBC ensemble while flying the UH-60 helicopter flight simulator in a controlled heat environment. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. (In press).

U.S. Army Human Engineering Laboratory. 1990. Human factors engineering assessment for the aircrew microclimate conditioning system in-process review. Fort Rucker, AL: U.S. Army Aviation Center. (Un-numbered).

Vallerand, A.L., Michas, R.D., Frim, J., and Ackles, K.N. 1991. Heat balance of subjects wearing protective clothing with a liquid- or air-cooled vest. Aviation, space, and environmental medicine. 62:393-391.

Weiner, B.J. 1971. Statistical principles in experimental design. New York: McGraw Hill.

Appendix A.

Subject Briefing Letter.

SUBJECT BRIEF

Effects of Microclimate Cooling on Physiology and Performance while flying the UH-60 Helicopter Simulator in NBC Conditions in a Controlled Heat Environment

Name _______________ Rank ___

Unit ______________________ Trial Dates ______________

Thank you for volunteering to take part in the USAARL study on the effects of microclimate cooling on physiology and performance while flying the UH-60 helicopter simulator in NBC conditions in a controlled heat environment. The aim of the trial is to determine how well two different personal cooling systems prevent heat stress and maintain performance, when used with the new aviator CD uniform (the AUIB and M43 mask) in the UH-60 aeromedical simulator, in hot conditions. It will take two working weeks to complete and you will be flying for up to 6 hours per day, alternating duties between pilot and copilot. You will fly a maximum of 52 hours total, and will cover all the usual emergencies with an IP.

The USAARL UH-60 simulator is an aeromedical version of the standard training simulator, with the addition of a system which can be used to control cockpit temperature and humidity. You will be flying in hot conditions, in MOPP IV, both with and without individual microclimate cooling. You will need your boots, gloves, and kneeboard. We will supply undergarments for use with the AUIB in order to protect your own. You should also bring your medical records. It is essential that you are medically fit, and that you are not required to wear visual correction for flying duty.

The simulator is instrumented to enable accurate measurement of flight parameters, and will be used in conjunction with several computer-based tests to measure your performance. Other factors affecting performance can obviously interfere with the experiment, and so we request you get a good night's sleep each day and refrain from alcohol for the duration of the experiment.

We also plan to assess the effects of heat stress on sleep by recording a sleep encephalogram (EEG). This will be done on the night after every test day, when you will be required to sleep in USAARL's Sleep Laboratory wearing scalp electrodes. You will be free on those days to leave USAARL on completion of the daytime portion of the study (normally around 1600), returning at 2100. For the remaining nights, you will be accommodated in the BOQ, including the Sunday before the first test day. We will make the reservations for you and will pay all TDY expenses. To allow for the problem of time zone changes affecting sleep patterns and performance, if you are transitting more than 2 time zones, you will be expected to travel to Fort Rucker on the preceding Friday to give you the weekend to adapt. You should plan on being released on the Saturday morning following the end of the study. You will be free for the middle weekend, from 0700 on the Saturday to 0730 Monday.

At the beginning of each day you will be instrumented to record your temperature and heart rate, both to gain experimental data and to make sure that you do not exceed rigidly designed parameters which are written into the protocol to ensure your safety. Your core body temperature will be measured using a rectal probe. A trained medical monitor will be with you in the simulator at all times to observe your core temperature and ensure your well-being. A flight surgeon will be on immediate standby should any problem arise. You may of course terminate the trial yourself at any stage should you develop any subjective symptoms which make you feel you cannot continue, such as excessive headache, nausea, or light-headedness.

You will be allowed free access to water during the flights, through the M43 drinking tube, but you will not be able to eat - have a good breakfast. We will provide all your meals in the laboratory, or you can eat out if you so choose. If you have any particular dietary needs or preferences, please let us know so that we can plan accordingly.

Records of the trial will not identify you by name, nor will you be identifiable in any subsequent report. The aim is to present group data showing how large numbers of aviators perform.

Your participation in this trial is very important to the Army and to our aviation community in particular, thus we hope you will always perform your best throughout the trials. You will undoubtably learn more about yourself and your ability to perform in such conditions as we are studying, and you will be contributing to our knowledge of how best to design equipment and procedures for flying in chemical threat environments. The outcome of this study will have an important influence on the choice of microclimate cooling system selected for Army use.

On the first day of the study, you should check out of the BOQ then report to the CQ desk at USAARL at 0730. Breakfast will be available for you at USAARL. If you develop any medical problems, or you have any questions in the meantime, please contact LTC Robert Thornton at AUTOVON 558-6846, (205) 255-6846, or CPT Wayne Clark at AUTOVON 558-6871.

Appendix B.

Manufacturers' list.

Boisig Instruments Inc
P.O. Box 860
Champlain, NY 12919

Digital Equipment Corporation
P.O. Box CS2008
Nashua, NH 03061

Dresser Measurement
P.O. Box 42176
Houston, TX 77242

Exotemp Limited
1231 Pembroke Street East
Pembroke, Ontario
Canada K8A TR8

Grass Instrument Company
101 Old Colony Avenue
P.O. Box 514
Quincy, MA 02169

Hans Rudolf, Inc
7200 Wyandotte
Kansas City, MO 64114

Lotus Development Corporation
55 Cambridge Parkway
Cambridge, MA 02142

Midwest Research Institute
425 Volker Boulevard
Kansas City, MS 64110

Nihon Koden (America), Inc
17112 Armstrong Avenue
Irvine, CA 92714

Paravant Computer Systems
7800 Technology Drive
Melbourne, FA 32904

Reuter Stokes Canada Limited
465 Dobbie Drive
Cambridge, Ontario
Canada N1R 5X9

SAS Institute Inc
P.O. Box 8000
Cary, NC 27512-8000

Science/Electronics
P.O. Box 986
Dayton, OH 45401

Signet Scientific Co
3401-T Aerojet Ave
El Monte, CA 91734

SPSS Inc
444 N. Michigan Avenue
Chicago, IL 60611

Vermont Medical Inc
Bellows Falls, VT 05101

Yellow Springs Instrument Co
P.O. Box 279
Yellow Springs, OH 45387

Appendix C.

AVSCOM tasking letter.

DEPARTMENT OF THE ARMY

PRODUCT MANAGER, AVIATION LIFE SUPPORT EQUIPMENT
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120-1798

REPLY TO
ATTENTION OF

SFAE-AV-LSE (70)

1 6 JUL 1991

MEMORANDUM FOR Cdr, USAARL, ATTN: SGRD-UAD (LTC Shannahan), P.O. Box 577,
Fort Rucker, AL 36362-5292

SUBJECT: Air Versus Liquid Cooling Evaluation of Army Aviators

1. Reference meeting between LTC Reynolds, Mr. R. Bee, and Mr. L. Plog, this office, and LTC Shannahan and LTC Thornton, USAARL, 14 Apr 91, subject as above.

2. Request you consider and evaluate air versus liquid cooling effects upon Army aviator test subjects during your ongoing heat stress tests in the UH-60 Black Hawk simulator. As discussed during referenced meeting, the results are needed as soon as possible to assist both developer and user in selection of the best overall cooling option for Army rotary wing aviators. Both types of coolers which were developed by Midwest Research Institute have been furnished your facility for use as conditioned air and cooled liquid sources. Air and liquid vests have been furnished by Natick labs.

3. Point of contact for this action is Mr. Tom Vincent or Mr. Lem Plog, SFAE-AV-LSE, DSN 693-3574 or commercial (314) 263-3574.

JAMES C. REYNOLDS
LTC, AV
Product Manager
Aviation Life Support Equipment

Appendix D.

Fatigue checklist.

Instructions

The statements which follow are to help you decide how you feel at this time - not yesterday, not an hour ago - but right now. For each statement you must determine whether you feel (1) "Better that", (2) "Same as", or (3) "Worse than" the feeling described by that statement.

No	Better than	Same as	Worse than	Statement
1	( )	( )	( )	very lively
2	( )	( )	( )	extremely tired
3	( )	( )	( )	quite fresh
4	( )	( )	( )	slightly tired
5	( )	( )	( )	extremely lively
6	( )	( )	( )	somewhat fresh
7	( )	( )	( )	very tired
8	( )	( )	( )	very refreshed
9	( )	( )	( )	quite tired
10	( )	( )	( )	ready to drop

Appendix E.

Postflight questionnaire.

SUBJECT # ________

DATE ___________

COOLING SYSTEM (air, liquid, None) _____________

DAY # ____

INVESTIGATOR'S REMARKS:

AUIB UH-60 SIMULATOR STUDY

CLOTHING AND INDIVIDUAL EQUIPMENT SURVEY

END OF DAY QUESTIONNairE

The Behavioral Sciences Division at the U.S. Army Natick Research, Development and Engineering Center (NATICK) has devised this questionnaire to obtain your opinions concerning how the items in your flight ensemble affected your performance in this simulator study. NATICK is responsible for developing soldier clothing and equipment or the entire U.S. Army. Most of the items which you will be wearing in this study were developed by NATICK.

By completing this questionnaire, you will be giving us invaluable assistance in providing equipment that will enhance your ability to accomplish your flight duties. We will take your answers seriously, so please take this questionnaire seriously and answer each question carefully.

Please take into consideration only what you experienced today in responding to this questionnaire. If you do not understand a question, please ask for assistance before going on.

Thank you.

Questionnaire Section I. EASE OF PERFORMING FLIGHT ACTIVITIES

1. Please rate how easy or difficult it was to perform each of the listed activities today. Circle one answer for each activity.

VERY DIFFICULT	MODERATELY DIFFICULT	SLIGHTLY DIFFICULT	NEITHER DIFFICULT NOR EASY	SLIGHTLY EASY	MODERATELY EASY	VERY EASY
1	2	3	4	5	6	7

a. View areas inside the cockpit	1	2	3	4	5	6	7
b. Read gauges, displays, controls	1	2	3	4	5	6	7
c. See your copilot	1	2	3	4	5	6	7
d. View outside cockpit windows	1	2	3	4	5	6	7
e. Control the cyclic	1	2	3	4	5	6	7
f. Control the collective	1	2	3	4	5	6	7
g. Manipulate food pedals	1	2	3	4	5	6	7
h. Manipulate radio controls	1	2	3	4	5	6	7
i. Press Doppler keys	1	2	3	4	5	6	7
j. Manipulate other controls	1	2	3	4	5	6	7
k. Access ensemble components (e.g., closures, pockets)	1	2	3	4	5	6	7
l. Be heard by your copilot	1	2	3	4	5	6	7
m. Be heard by outside agencies	1	2	3	4	5	6	7
n. Hear copilot	1	2	3	4	5	6	7
o. Hear outside agencies	1	2	3	4	5	6	7
p. Hear important aircraft sounds	1	2	3	4	5	6	7
q. Bend forward to reach controls	1	2	3	4	5	6	7
r. Reach to the left	1	2	3	4	5	6	7
s. Reach to the right	1	2	3	4	5	6	7
t. Reach up above the head	1	2	3	4	5	6	7
u. Reach down	1	2	3	4	5	6	7
v. Sit properly	1	2	3	4	5	6	7

Questionnaire section II. PERFORMANCE IMPAIRMENT ASSOCIATED WITH EACH ITEM IN THE FLIGHT ENSEMBLE.

II. A. SEEING INSIDE THE COCKPIT

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO SEE INSIDE THE COCKPIT (E.G., VIEW COCKPIT AREAS; READ GAUGES, DISPLAYS, CONTROLS; SEE Copilot). Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

a. SUIT	0	1	2	3	4
b. HELMET	0	1	2	3	4
c. MASK AND HOOD	0	1	2	3	4
d. GLOVES	0	1	2	3	4
e. BOOTS	0	1	2	3	4
f. SURVIVAL VEST/ARMOR	0	1	2	3	4
g. COOLING SYSTEM	0	1	2	3	4

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED SEEING INSIDE THE COCKPIT.

a. SUIT

b. HELMET

c. MASK AND HOOD

d. GLOVES

e. BOOTS

f. SURVIVAL VEST/ARMOR

g. COOLING SYSTEM COMPONENTS

II. B. MANIPULATING CYCLIC, COLLECTIVE, AND FOOT PEDALS

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO MANIPULATE THE CYCLIC, COLLECTIVE, AND FOOT PEDALS. Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

a. SUIT	0	1	2	3	4
b. HELMET	0	1	2	3	4
c. MASK AND HOOD	0	1	2	3	4
d. GLOVES	0	1	2	3	4
e. BOOTS	0	1	2	3	4
f. SURVIVAL VEST/ARMOR	0	1	2	3	4
g. COOLING SYSTEM	0	1	2	3	4

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED MANIPULATION OF THE CYCLIC, COLLECTIVE, AND FOOT PEDALS.

a. SUIT

b. HELMET

c. MASK AND HOOD

d. GLOVES

e. BOOTS

f. SURVIVAL VEST/ARMOR

g. COOLING SYSTEM COMPONENTS

II. C. MANIPULATING OTHER CONTROLS/SWITCHES, ETC.

1. Please rate the extent to which the items in our ensemble seemed to <u>IMPAIR YOUR ABILITY TO MANIPULATE OTHER CONTROLS/SWITCHES (E.G., RADIO, DOPPLER, THROTTLE, INTERCOM, CLOCK)</u>. Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

a. SUIT	0	1	2	3	4
b. HELMET	0	1	2	3	4
c. MASK AND HOOD	0	1	2	3	4
d. GLOVES	0	1	2	3	4
e. BOOTS	0	1	2	3	4
f. SURVIVAL VEST/ARMOR	0	1	2	3	4
g. COOLING SYSTEM	0	1	2	3	4

2. For each instance above where you gave a rating of '1' or higher, please <u>EXPLAIN HOW THE ITEM(S) IMPAIRED MANIPULATING OTHER CONTROLS</u>.

a. SUIT

b. HELMET

c. MASK AND HOOD

d. GLOVES

e. BOOTS

f. SURVIVAL VEST/ARMOR

g. COOLING SYSTEM
COMPONENTS

II. D. MOVING THE BODY AND ARMS TO REACH CONTROLS AND OTHER OBJECTS

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO IMPAIR YOUR ABILITY TO MOVE YOUR BODY AND ARMS TO REACH CONTROLS AND OTHER OBJECTS (E.G., BENDING FORWARD; REACHING ABOVE THE HEAD, DOWN TO THE LEFT, AND TO THE RIGHT). Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

a. SUIT	0	1	2	3	4
b. HELMET	0	1	2	3	4
c. MASK AND HOOD	0	1	2	3	4
d. GLOVES	0	1	2	3	4
e. BOOTS	0	1	2	3	4
f. SURVIVAL VEST/ARMOR	0	1	2	3	4
g. COOLING SYSTEM	0	1	2	3	4

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED MOVING THE BODY AND ARMS.

a. SUIT

b. HELMET

c. MASK AND HOOD

d. GLOVES

e. BOOTS

f. SURVIVAL VEST/ARMOR

g. COOLING SYSTEM COMPONENTS

Questionnaire section III. OTHER COMPATIBILITY ISSUES.

1. Did the cooling system or its components impair the operation of any of the equipment you wore or carried? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

2. Did you have any problems with the seat restraint harness which were related to what you were wearing in today's sessions? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

3. Did you encounter any difficulties reading materials and handling items positioned on your lap (e.g., using kneeboard)? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

4. Did you experience problems in today's sessions that had to do with components of the cooling system interfering with each other? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

Questionnaire Section IV, COMFORT, FIT, AND HEAT STRESS.

1. Please rate how <u>HOT</u> you felt in today's sessions. Circle one answer for each flight.

	NOT AT ALL HOT	SLIGHTLY HOT	MODERATELY HOT	CONSIDERABLY HOT	EXTREMELY HOT
a. FIRST SORTIE	0	1	2	3	4
b. SECOND SORTIE	0	1	2	3	4
c. THIRD SORTIE	0	1	2	3	4

IF YOU ANSWERED <u>NOT AT ALL</u> TO <u>ALL PARTS</u> OF THE ABOVE QUESTION, SKIP THE REMAINING QUESTIONS ON THIS PAGE AND GO ON TO QUESTION 4 ON THE NEXT PAGE.

---

2. Please rate how important <u>BEING HOT</u> was in affecting your ability to accomplish your duties today. Circle one answer for each flight.

NOT AT ALL IMPORTANT	SLIGHTLY IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT	EXTREMELY IMPORTANT
0	1	2	3	4

a. FIRST SORTIE	0	1	2	3	4
b. SECOND SORTIE	0	1	2	3	4
c. THIRD SORTIE	0	1	2	3	4

3. Please rate how important each of the items in your flight ensemble and cooling system was in MAKING YOU FEEL HOT in today's sessions. Circle one answer for each item.

NOT AT ALL IMPORTANT	SLIGHTLY IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT	EXTREMELY IMPORTANT
0	1	2	3	4

SUIT	0	1	2	3	4
HELMET	0	1	2	3	4
MASK	0	1	2	3	4
MASK HOOD	0	1	2	3	4
FLIGHT GLOVES	0	1	2	3	4
RUBBER GLOVES	0	1	2	3	4
SURVIVAL VEST	0	1	2	3	4
ARMOR PLATE/CARRIER	0	1	2	3	4
FLIGHT BOOTS	0	1	2	3	4
OVERBOOTS	0	1	2	3	4
COOLING SYSTEM	0	1	2	3	4

4. Did you experience any major problems with FIT or COMFORT of the items (OTHER THAN HEAT STRESS)? Answer by placing an 'X' next to 'YES' or 'NO' for each item listed. Where you answer 'yes', please explain what the problem was in the space provided. If the fit or comfort problem affected your performance, give details in your answer.

a. SUIT YES_____ NO_____

b. HELMET YES_____ NO_____

c. MASK YES_____ NO_____

d. MASK HOOD YES_____ NO_____

e. FLIGHT GLOVES AND RUBBER GLOVES YES_____ NO_____

f. SURVIVAL VEST/ ARMOR PLATE/CARRIER YES_____ NO_____

g. FLIGHT BOOTS AND OVERBOOTS YES_____ NO_____

h. COOLING SYSTEM COMPONENTS YES_____ NO_____

QUESTIONNAIRE SECTION V. OVERALL ACCEPTABILITY.

1. Please rate the overall acceptability of the flight ensemble for wear during missions conducted under environmental conditions like you experienced today. Circle one number.

VERY UNACCEPTABLE	MODERATELY UNACCEPTABLE	SOMEWHAT UNACCEPTABLE	NEITHER UNACCEPTABLE NOR ACCEPTABLE	SOMEWHAT ACCEPTABLE	MODERATELY ACCEPTABLE	VERY ACCEPTABLE
1	2	3	4	5	6	7

2. Please rate the overall acceptability of the cooling system for use during missions conducted under environmental conditions like you experienced today. Circle one number.

VERY UNACCEPTABLE	MODERATELY UNACCEPTABLE	SOMEWHAT UNACCEPTABLE	NEITHER UNACCEPTABLE NOR ACCEPTABLE	SOMEWHAT ACCEPTABLE	MODERATELY ACCEPTABLE	VERY ACCEPTABLE
1	2	3	4	5	6	7

3. What was the <u>WORST</u> problem which you experienced <u>IN TODAY'S SESSIONS</u> related to wearing your ensemble? Please give details below <u>and</u> indicate what you think can be done to the ensemble to improve the situation:

WORST PROBLEM(S):

WHAT CAN BE DONE:

Appendix F.

Timetable.

TIMETABLE

Day	Time	Activity	Responsible
1	0730	Arrive USAARL	SSG Rosario
	0745	Breakfast	SSG Rosario
	0815	Subject brief	LTC Thornton
	0845	PAB training	SSG Fallaria
	0915	Simulator brief	Mr Woodrum
	1030	Flight 1	Mr Woodrum
	1230	Flight 2	Mr Woodrum
	1430	Debrief	Mr Woodrum
	1500	Questionnaire	SSG Rosario
	1515	PAB training	SSG Fallaria
	1545	Debrief	LTC Thornton
	1600	Handover	Dr Caldwell
2	0730	Collect subjects	SSG Rosario
	0740	IPE fitting/instrumentation	SGT Guardiani
	0845	PAB training	SSG Fallaria
	0930	Flight 1	Mr Woodrum
	1130	Flight 2	Mr Woodrum
	1330	Debrief	Mr Woodrum
	1400	Questionnaire	SSG Rosario
	1430	PAB Training	SSG Fallaria
	1500	MMPI	SGT Rosario
	1600	Handover	Dr Caldwell
3-10	0730	Collect subjects	SSG Rosario
	0740	IPE fitting/instrumentation	SGT Guardiani
	0810	PAB	SSG Fallaria
	0840	Treadmill	SGT Guardiani
	0900	Simulator	Mr Woodrum
	1530	Questionnaire	SSG Rosario
	1600	Handover	Dr Caldwell

Appendix G.

Initial subject questionnaire.

INITIAL SUBJECT QUESTIONNaire

A. PERSONAL DATA

1. Subject ID No ____

2. Name ________________________________

3. Rank _________

4. Unit _________________________________

5. Date of birth ________MO ________DAY ________YR

6. Present marital status _______________

7. Years of Active Duty Military Service ______

B. MEDICAL HISTORY

8. How often do participate in vigorous physical exercise?

___Never ___Occasionally ____Regularly ____Times per wk

Usual type of exercise ____________ _______________________

9. Average no of hours sleep per night _____

10. Have you ever smoked or chewed tobacco (regular basis?) ____

When did you stop? _______

Do you smoke or chew tobacco presently? ___________

What do you smoke? _____ How much per day? _____

11. What is your present average weekly alcohol consumption? ___

12. How many cups of coffee do you normally drink per day? _____

Caffeinated _____ Decaffeinated _____

13. How do you describe your health at present?

_____fair _____good _____excellent

14. What if any medical problems have you had since your last flight physical? _______________________________________

15. Are you presently taking any medication, prescribed or otherwise ? _____Yes _____No

If yes, what? ____

16. Do you require corrective lenses for flying? ____Yes ____No

17. Handedness: Left ____ Right _____ Ambidextrous ____

18. Have you ever suffered a heat induced illness? _____

If yes, details ____

19. Do you suffer from any allergies? _____

If yes, details ____

C. FLIGHT EXPERIENCE HISTORY

	IP	PC	PI	TOTAL
20. Flight hours	____	____	____	_____
21. UH-60 flight hours	____	____	____	_____
22. UH-60 simulator hours	____	____	____	_____

23. How often do you suffer airsickness?

_____occasionally _____frequently _____never

24. How often do you suffer simulator sickness?

_____occasionally _____frequently _____never

25. When did you last fly in NBC protective clothing at MOPP IV?

____

26. Total flying hours in NBC protective clothing at MOPP IV

____

D. MEASUREMENTS

27. Height (cm) ____________ 28. Weight (kg) ____________

29. AUIB size ______/______ 30. M43 size ______________

31. Helmet size ____________ 32. Undershirt size ______

33. Underpants size ______ 34. Boot size _____________

34. Sock size _____________ 35. Overboot size ________

36. Flight glove size ___ 37. NBC glove size _______

38. SARVIP size ___________ 39. Armor size ____________

Appendix H.

Volunteer consent forms.

VOLUNTEER AGREEMENT AFFIDAVIT

For use of this form, see AR 70-25; the proponent agency is OTSG

PRIVACY ACT OF 1974

Authority: 10 USC 3013, 44 USC 3101, and 10 USC 1071-1087.

Principle Purpose: To document voluntary participation in the Clinical Investigation and Research Program. SSN and home address will be used for identification and locating purposes.

Routine Uses: The SSN and home address will be used for identification and locating purposes. Information derived from the study will be used to document the study; implementation of medical programs; adjudication of claims; and for the mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State and local agencies.

Disclosure: The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this investigational study.

PART A(1) - VOLUNTEER AFFIDAVIT

Volunteer Subjects in Approved Department of the Army Research Studies

Volunteers under the provisions of AR 40-38 and AR 70-25 are authorized all necessary medical care for injury or disease which is the proximate result of their participation in such studies.

I, ______________________________, SSN ______________,

having full capacity to consent and having attained my __________ birthday, do hereby volunteer/~~give consent as legal representative for~~ XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX to participate in Effects of microclimate cooling on physiology and performance while flying the UH-60 simulator in a controlled heat environment.

(Research study)

____

under the direction of LTC Robert Thornton, M.D.

conducted at the U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL

(Name of Institution)

The implications of my voluntary participation/consent as legal representative; duration and purpose of the research study; the methods and means by which it is to be conducted; and the inconveniences and hazards that may reasonably be expected have been explained to me by

______________________________.

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights/the rights of the person I represent on study-related injury, I may contact

Command Judge Advocate General

at HQ, USAMRDC, Ft Detrick, Frederick, MD; Tel: DSN 343-2065, Comm (301) 663-2065

(Name, Address and Phone Number of Hospital (Include Area Code))

I understand that I may at any time during the course of this study revoke my consent and withdraw/have the person I represent withdrawn from the study without further penalty or loss of benefits; however, I/the person I represent may be required (military volunteer) or requested *(civilian volunteer)* to undergo certain examination if, in the opinion of the attending physician, such examinations are necessary for my/the person I represent's health and well-being. My/the person I represent's refusal to participate will involve no penalty or loss of benefits to which I am/the person I represent is otherwise entitled.

____

PART A (2) - ASSENT VOLUNTEER AFFIDAVIT *(MINOR CHILD)*

I, ______________________________, SSN ______________ having full capacity to consent and having attained my __________ birthday, do hereby volunteer for ______________

______________________________ to participate in ______________________________

(Research Study)

____

under the direction of ______________________________

conducted at ______________________________.

(Name of Institution)

(Continue on Reverse)

DA FORM 5303-R, MAY 88 PREVIOUS EDITIONS ARE OBSOLETE

PART A(2) - ASSENT VOLUNTEER AFFIDAVIT (*MINOR CHILD*) (*Cont'd.*)

The implications of my voluntary participation; the nature, duration and purpose of the research study; the methods and means by which it is to be conducted; and the inconveniences and hazards that may reasonably be expected have been explained to me by

____

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights I may contact

____

at ____
(Name, Address, and Phone Number of Hospital (Include Area Code))

I understand that I may at any time during the course of this study revoke my assent and withdraw from the study without further penalty or loss of benefits; however, I may be requested to undergo certain examination if, in the opinion of the attending physician, such examinations are necessary for my health and well-being. My refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled.

____

PART B - TO BE COMPLETED BY INVESTIGATOR

INSTRUCTIONS FOR ELEMENTS OF INFORMED CONSENT: *(Provide a detailed explanation in accordance with Appendix E, AR 40-38 or AR 70-25.)*

The aim of this trial is to assess the prototype aviator microclimate conditioning system in the UH-60 aeromedical simulator in hot NBC conditions. It will take one working week to complete and you wull be flying the simulator for up to 6 hours per day alternating duties between polot and copilot.

The USAARL UH-60 simulator is an aeromedical version of the standard training simulator with an additional system that controls cockpit temperature and humidity. You will be flying in a variety of hot conditions in NBC equipment, and can expect to accumulate up to 40 simulator hours.

At the beginning of each day, you will be instrumented to record your temperature and heart rate, both to gain experimental data, and to make sure you do not exceed rigidly designed parameters which are written into the protocol to ensure your safety. Your core body temperature will be measured using a rectal probe. A trained medical monitor will be with you in the simulator at all times to observe your temperature and heart rate and ensure your well-being. A flight surgeon will be on immediate standby should any problem arise. You may, of course, terminate the trial yourself at any stage should you develop systems which make you feel you cannot continue, such as excessive headache or nausea.

I do ☐ do not ☐ (*check one & initial*) consent to the inclusion of this form in my outpatient medical treatment record.

SIGNATURE OF VOLUNTEER	DATE	SIGNATURE OF LEGAL GUARDIAN (*If volunteer is a minor*)

PERMANENT ADDRESS OF VOLUNTEER	TYPED NAME OF WITNESS	
	SIGNATURE OF WITNESS	DATE

DA FORM 5303-R, MAY 88
PART B (Continued)

The objective criteria which will be used to terminate the experiment are core temperature reaching 39.5°C (103°F), or a heart rate of 150 for more than 15 minutes.

The simulator is instrumented to enable accurate measurement of flight parameters, and will be used in conjunction with several computer-based tests to measure the effect of the AUIB and heat on your performance. Other factors affecting performance can obviously interfere with the experiment, and so we will be inviting you to ensure that you get a good night's sleep each day, and refrain from alcoholic beverages for the duration of the experiment. Your urine will be tested for alcohol each morning.

The only other risks to you are of skin irritation due to the prolonged wearing of NBC equipment and the monitoring electrodes. If you have a history of such problems, you should make this clear to the flight surgeon at the initial briefing.

Each day will begin with a 20 minute period of light exercise on a treadmill (at a moderate walk) to represent the added workload of preflighting the aircraft. You will be allowed free access to water during the flights, through the M43 drinking tube on the NBC days, but you will not be able to eat.

You will be required to sleep in the laboratory on four nights, to allow sleep electroencephalography (EEG) recordings to be made. This will entail sleeping with electrodes glued to your scalp. You will have a private room to yourself, and we will provide all your meals. You will be allowed to leave the laboratory at the end of the day's flying, if you choose, returning at 2100 hrs.

Records of the trial will not identify you by name, nor will you be identifiable in any subsequent report. The aim is to present group data showing how large numbers of aviators perform.

Your participation in this trial is very important to the Army and to our aviation community in particular, thus we hope you will always perform your best throughout the trials. You will undoubtably learn more about yourself and your ability to perform in such conditions as we are studying, and you will be contributing to our knowledge of how best to design equipment and procedures for flying in chemical threat environments.

I have received a copy of this volunteer consent form

____
(signature)

VOLUNTEER REGISTRY DATA SHEET

THIS FORM IS AFFECTED BY THE PRIVACY ACT OF 1974

1. AUTHORITY: 5 USC 301; 10 USC 1071-1090; 44 USC 3101; EO 9397
2. Principal and Routine Purposes: To document participation in research conducted or sponsored by the U.S. Army Medical Research and Development Command. Personal information will be used for identification and location of participants.
3. Mandatory or Voluntary Disclosure: The furnishing of the SSN is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your participation in the research study.

PART A-INVESTIGATOR INFORMATION

(To Be Completed By Investigator)

PLEASE PRINT, USING INK OR BALLPOINT PEN

1. Study NR: __________ 2. Protocol Title: Effects of microclimate cooling on physiology and performance while flying UH-60 helicopter simulator in NBC conditons in a controlled heat environment

3. Contractor (Laboratory/Institute Conducting Study):

4. Study Period: From: 01/___/___ (DA/MO/YR) To: 15/___/___ (DA/MO/YR)

5. Principal/Other Investigator(s) Names(s) 6. Location/Laboratory

(1) THORNTON, Robert (Last) (First) (MI) ______/______

(2) ______________________________ ______/______

(3) ______________________________ ______/______

PART B-VOLUNTEER INFORMATION

(To Be Completed By Volunteer)

PLEASE PRINT, USING INK OR BALLPOINT PEN

7. SSN: ____/____/______ 8. Name: __________ (Last) __________ (First) ____ (MI)

9. Sex: M__F__ 10. Date of Birth: __/__/__ 11. *MOS/Job Series:__ 12. *Rank/Grade:____

13. Permanent Home Address (Home of Record) or Study Location Address:

_______________________ (Street) (P.O. Box/Apartment No.)

_______________________ (City) (Country) (State) (Zip Code)

( ) - (Perm Home Phone No)

14. *Local Address (If Different From Permanent Address):

_______________________ (Street) (P.O. Box/Apartment No.)

_______________________ (City) (Country) (State) (Zip Code)

( ) - (Local Phone No)

15.*Military Unit: ______________________ Zip Code: __________

Organization: __________ Post: __________ Duty Phone No. ( ) -

USAMRDC Form 60-R Revised 1 Apr 88 (Supersedes previous editions)

PART C-ADDITIONAL INFORMATION

(To Be Completed By Investigator)

PLEASE PRINT, USING INK OR BALLPOINT PEN

16. Location of Study: USAARL, Fort Rucker, AL 36362

17. Is Study Completed: Y___ N___

    Did volunteer finish participation: Y___ N___ If YES, Date finished: ___/___/___ (DA/MO/YR)

    If NO, Date withdrawn: ___/___/___ (DA/MO/YR) Reason withdrawn:

18. Did Any Serious or Unexpected Adverse Incident or Reaction Occur: Y___N___ If YES, Explain:

19.*Volunteer Followup: ______________________________

    Purpose: ______________________________

    Date: ___/___/___ (DA/MO/YR) Was contact made: Y___N___ If No action taken, explain:

20.*Hard Copy Records Retired: Place: ______________________ File NR: _____ __ __________

21.*Product Information:

    Product: ______________________________

    Manufacturer: ______________________________

    Lot NR: __________________ Expiration Date: __________

    NDA NR: __________________ IND/IDE NR: __________

*Indicates that item may be left blank if information is unavailable or does not apply.
Entries must be made for all other items.

Unconditional Consent for use of Picture and Sound

The United States Government is granted the right to use, to the extent and for the purpose it desires, any pictures (still, motion, those retransmitted via TV or recorded on video tape or otherwise) and sounds (vocal, instrumental, or otherwise) whether used together or separately, taken or recorded by or on behalf of the U.S. Army Aeromedical Research Laboratory.

____________________ ____________________________________

(DATE) (SIGNATURE)

____

(HOME ADDRESS)

____

(MILITARY ADDRESS)

Above consent obtained by: ______________________________

(SIGNATURE)

Effects of Microclimate Cooling on Physiology and Performance while flying the UH-60 Helicopter Simulator in NBC Conditions in a Controlled Heat Environment

Physicians' Statement

After review of medical records and the subjects' questionnaire answers, the subject is authorized to participate in all aspects of this study.

Subject: ______________________ SSN: ______________

Signed: ________________ (Physician)

Print: ________________

Date: __________

Appendix I.

Postflight questionnaire analysis.

The original postflight questionnaire has been reproduced as in Appendix E, except that the numbers to circle have been replaced by the mean score from all subjects. The written comments also have been summarized, where appropriate. Numbers in parentheses refer to the number of respondents who made that comment. All information that has been added to the original questionnaire appears in bold type.

The abbreviations used in the tables are liq for liquid, ven for vent.

AUIB UH-60 SIMULATOR STUDY

CLOTHING AND INDIVIDUAL EQUIPMENT SURVEY

END OF DAY QUESTIONNAIRE

The Behavioral Sciences Division at the U.S. Army Natick Research, Development and Engineering Center (NATICK) has devised this questionnaire to obtain your opinions concerning how the items in your flight ensemble affected your performance in this simulator study. NATICK is responsible for developing soldier clothing and equipment or the entire U.S. Army. Most of the items which you will be wearing in this study were developed by NATICK.

By completing this questionnaire, you will be giving us invaluable assistance in providing equipment that will enhance your ability to accomplish your flight duties. We will take your answers seriously, so please take this questionnaire seriously and answer each question carefully.

Please take into consideration only what you experienced today in responding to this questionnaire. If you do not understand a question, please ask for assistance before going on.

Thank you.

Questionnaire Section I. EASE OF PERFORMING FLIGHT ACTIVITIES

1. Please rate how easy or difficult it was to perform each of the listed activities today. Circle one answer for each activity.

VERY DIFFICULT	MODERATELY DIFFICULT	SLIGHTLY DIFFICULT	NEITHER DIFFICULT NOR EASY	SLIGHTLY EASY	MODERATELY EASY	VERY EASY
1	2	3	4	5	6	7

		95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a.	View areas inside the cockpit	3.4	3.8	3.7	3.5	3.2	3.6	3.2
b.	Read gauges, displays, controls	3.8	3.6	3.6	3.4	3.2	3.5	3.1
c.	See your copilot	3.5	3.7	3.6	3.4	3.1	3.1	3.6
d.	View outside cockpit windows	3.4	3.8	3.4	3.5	3.3	3.3	3.5
e.	Control the cyclic	4.5	4.1	4.7	4.4	4.3	4.9	4.6
f.	Control the collective	4.6	4.7	4.8	4.4	4.4	4.9	4.5
g.	Manipulate food pedals	4.9	3.8	4.3	3.8	4.0	4.4	4.2
h.	Manipulate radio controls	4.9	4.0	4.0	4.0	3.5	3.9	3.6
i.	Press Doppler keys	4.7	3.8	4.1	3.7	3.4	3.6	3.9
j.	Manipulate other controls	4.8	3.9	4.3	3.9	4.0	3.7	4.3
k.	Access ensemble components (e.g., closures, pockets)	3.8	3.4	3.9	3.1	3.1	3.4	3.6
l.	Be heard by your copilot	5.0	5.0	5.1	5.3	5.1	6.1	5.2
m.	Be heard by outside agencies	5.0	4.9	4.9	4.9	4.8	5.3	5.1
n.	Hear copilot	5.2	5.0	5.1	5.3	5.3	5.5	5.3
o.	Hear outside agencies	5.0	4.9	4.9	4.9	5.3	5.4	5.1
p.	Hear important aircraft sounds	4.6	5.1	4.9	4.7	4.6	5.0	4.6
q.	Bend forward to reach controls	3.8	3.7	4.0	3.9	3.6	3.6	3.8
r.	Reach to the left	3.8	3.2	3.8	3.8	3.6	3.4	3.7
s.	Reach to the right	3.9	3.6	3.9	3.8	3.6	3.5	4.0
t.	Reach up above the head	3.8	3.4	3.8	3.5	3.4	3.6	3.9
u.	Reach down	3.6	3.4	3.4	3.6	3.4	3.4	3.6
v.	Sit properly	3.8	3.6	3.6	3.4	3.3	3.6	3.6

Questionnaire section II. PERFORMANCE IMPAIRMENT ASSOCIATED WITH EACH ITEM IN THE FLIGHT ENSEMBLE.

II. A. SEEING INSIDE THE COCKPIT

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO SEE INSIDE THE COCKPIT (E.G., VIEW COCKPIT AREAS; READ GAUGES, DISPLAYS, CONTROLS; SEE COPILOT). Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. SUIT	0.1	0.1	0.1	0.1	0.1	0.1	0.1
b. HELMET	0.3	0.2	0.4	0.2	0.3	0.2	0.4
c. MASK AND HOOD	1.8	1.4	1.4	1.2	2.0	1.7	1.6
d. GLOVES	0.3	0.1	0.1	0.2	0.1	0.1	0.1
e. BOOTS	0.0	0.1	0.1	0.1	0.0	0.1	0.1
f. SURVIVAL VEST/ARMOR	0.5	0.7	0.6	0.6	1.1	0.9	0.9
g. COOLING SYSTEM	N/A	0.3	0.1	N/A	0.4	0.5	0.1

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED SEEING INSIDE THE COCKPIT.

a. SUIT

Bulky; restricting movement slightly. (5)

b. HELMET

Rides down on forehead restricting upward vision. (4)

c. MASK AND HOOD

Eye openings too small. (3) Field-of-view reduced. (13)
Images distorted through lower lens. (1)
Hose length limits head movement. (3)
Peripheral vision is diminished. (7)
Perspiration caused eye pieces to fog and smear. (13)
Hose on mask greatly reduced free movement of head. (15)
Difficult to see through. (1)

d. GLOVES

Too bulky making it difficult to see small items. (6)

e. BOOTS

f. SURVIVAL VEST/ARMOR

Gets in the path of the mask hose making it difficult to move head. (14)

g. COOLING SYSTEM
COMPONENTS

II. B. MANIPULATING CYCLIC, COLLECTIVE, AND FOOT PEDALS

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO MANIPULATE THE CYCLIC, COLLECTIVE, AND FOOT PEDALS. Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. SUIT	0.1	0.1	0.1	0.1	0.0	0.1	0.1
b. HELMET	0.0	0.1	0.1	0.1	0.0	0.1	0.0
c. MASK AND HOOD	0.3	0.4	0.2	0.3	0.0	0.1	0.2
d. GLOVES	0.4	0.3	0.3	0.3	0.4	0.3	0.3
e. BOOTS	0.8	0.8	0.6	0.6	0.8	0.9	0.8
f. SURVIVAL VEST/ARMOR	0.3	0.3	0.4	0.3	0.6	0.1	0.4
g. COOLING SYSTEM	N/A	0.3	0.1	N/A	0.4	0.2	0.1

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED MANIPULATION OF THE CYCLIC, COLLECTIVE, AND FOOT PEDALS.

a. SUIT

Bulky. (2)

b. HELMET

c. MASK AND HOOD

Hose binds and impairs cyclic inputs. (13)

d. GLOVES

Slight loss of control touch. (6)
Very bulky. (9)
Difficulty using trim release. (3)

e. BOOTS

Difficult to feel pedal microswitches. (15)
Precise pedal inputs are difficult. (5)
Cause over control of pedals. (2)

f. SURVIVAL VEST/ARMOR

Impedes freely controlling the cyclic. (8)

g. COOLING SYSTEM COMPONENTS

Air: Bulkiness restricts movement. (3)
Causes poor seating position. (1)

II. C. MANIPULATING OTHER CONTROLS/SWITCHES, ETC.

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO MANIPULATE OTHER CONTROLS/SWITCHES (E.G., RADIO, DOPPLER, THROTTLE, INTERCOM, CLOCK). Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. SUIT	0.1	0.0	0.1	0.1	0.0	0.1	0.2
b. HELMET	0.1	0.1	0.1	0.1	0.1	0.1	0.3
c. MASK AND HOOD	0.3	0.3	0.4	0.4	0.3	0.3	0.7
d. GLOVES	0.8	0.7	0.6	0.7	0.9	0.8	0.9
e. BOOTS	0.0	0.2	0.1	0.1	0.3	0.1	0.1
f. SURVIVAL VEST/ARMOR	0.1	0.2	0.1	0.3	0.5	0.1	0.4
g. COOLING SYSTEM	N/A	0.2	0.1	N/A	0.1	0.1	0.1

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED MANIPULATING OTHER CONTROLS.

a. SUIT

Bulky. (3)

b. HELMET

c. MASK AND HOOD

Visibility limitations. (13) **Hose limits head movements. (10)**
Fogged and smeared eye pieces. (8)

d. GLOVES

Gloves are bulky making contact with switches difficult. (15)
Excessive sweat caused tingling. (1) **Dexterity reduced. (13)**

e. BOOTS

f. SURVIVAL VEST/ARMOR

Degrades downward head movements. (6)
Too bulky making it difficult to reach. (9)

g. COOLING SYSTEM
COMPONENTS

II. D. MOVING THE BODY AND ARMS TO REACH CONTROLS AND OTHER OBJECTS

1. Please rate the extent to which the items in our ensemble seemed to IMPAIR YOUR ABILITY TO IMPAIR YOUR ABILITY TO MOVE YOUR BODY AND ARMS TO REACH CONTROLS AND OTHER OBJECTS (E.G., BENDING FORWARD; REACHING ABOVE THE HEAD, DOWN TO THE LEFT, AND TO THE RIGHT). Circle one answer for each item.

NOT AT ALL IMPAIR	SLIGHTLY IMPAIR	MODERATELY IMPAIR	CONSIDERABLY IMPAIR	EXTREMELY IMPAIR
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. SUIT	0.3	0.3	0.1	0.1	0.2	0.3	0.3
b. HELMET	0.1	0.1	0.3	0.2	0.4	0.3	0.3
c. MASK AND HOOD	0.4	0.8	0.6	0.8	1.1	1.1	0.8
d. GLOVES	0.0	0.1	0.1	0.1	0.1	0.3	0.1
e. BOOTS	0.1	0.1	0.1	0.1	0.1	0.2	0.1
f. SURVIVAL VEST/ARMOR	0.6	0.5	0.6	0.8	1.1	1.1	0.9
g. COOLING SYSTEM	N/A	0.3	0.1	N/A	0.9	0.7	0.3

2. For each instance above where you gave a rating of '1' or higher, please EXPLAIN HOW THE ITEM(S) IMPAIRED MOVING THE BODY AND ARMS.

a. SUIT

Bulky; limiting ease of limb movement. (9)
Pants too large. (1)
Constraining when reaching overhead. (1)

b. HELMET

Limits mobility. (3)

c. MASK AND HOOD

Impedes head from moving freely. (15)
Difficulty reaching around hose. (5)
Hose hooks right arm. (4)
air hose restricting to body movements. (10)

d. GLOVES

Sense of touch degraded. (4)

e. BOOTS

f. SURVIVAL VEST/ARMOR

Difficult to bend forward. (10)
Difficult to move body. (3)
Difficult to sit properly. (4)
Difficult to reach across chest. (6)
Right arm restricted. (3)
Difficult to look down. (12)
Restricted head movement. (5)

g. COOLING SYSTEM COMPONENTS

Air: Bulky; difficulty moving. (2)
Hose too short. (1)

Liquid: Hose too short. (1)

Questionnaire section III. OTHER COMPATIBILITY ISSUES.

1. Did the cooling system or its components impair the operation of any of the equipment you wore or carried? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

2. Did you have any problems with the seat restraint harness which were related to what you were wearing in today's sessions? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

Difficult to acquire belts. (12)
Gloves made it difficult to fasten. (7)
Mask hose impaired looking down. (8)
Very bulky. (6)

3. Did you encounter any difficulties reading materials and handling items positioned on your lap (e.g., using kneeboard)? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

Mask hose impedes downward viewing. (15)
Sweat caused eye pieces to fog and smear. (10)
Gloves made it difficult to hold PAB. (1)

4. Did you experience problems in today's sessions that had to do with components of the cooling system interfering with each other? Please put an 'X' next to your answer.

YES _____ NO _____

If 'YES', please give details:

AIR: **Input hose came out of suit. (5)**
Inhibited ease of breathing. (2)

LIQUID: **Cooling hood caused hot spots. (9)**
Suit had to be repositioned to keep liquid flowing. (2)
Cooling hood caused headaches. (5)

Questionnaire Section IV, COMFORT, FIT, AND HEAT STRESS.

1. Please rate how HOT you felt in today's sessions. Circle one answer for each flight.

NOT AT ALL HOT	SLIGHTLY HOT	MODERATELY HOT	CONSIDERABLY HOT	EXTREMELY HOT
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. FIRST SORTIE	1.6	0.8	0.3	2.6	1.6	2.1	2.1
b. SECOND SORTIE	2.0	0.6	0.2	2.6	1.7	2.5	1.9
c. THIRD SORTIE	2.0	0.7	0.2	2.5	1.9	3.5	2.0

IF YOU ANSWERED NOT AT ALL TO ALL PARTS OF THE ABOVE QUESTION, SKIP THE REMAINING QUESTIONS ON THIS PAGE AND GO ON TO QUESTION 4 ON THE NEXT PAGE.

---

2. Please rate how important BEING HOT was in affecting your ability to accomplish your duties today. Circle one answer for each flight.

NOT AT ALL IMPORTANT	SLIGHTLY IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT	EXTREMELY IMPORTANT
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. FIRST SORTIE	1.4	1.0	0.4	2.4	1.4	2.3	1.7
b. SECOND SORTIE	1.8	1.0	0.2	2.8	1.8	3.0	1.9
c. THIRD SORTIE	2.5	0.9	0.4	2.5	2.2	3.5	1.7

3. Please rate how important each of the items in your flight ensemble and cooling system was in MAKING YOU FEEL HOT in today's sessions. Circle one answer for each item.

NOT AT ALL IMPORTANT	SLIGHTLY IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT	EXTREMELY IMPORTANT
0	1	2	3	4

	95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
a. SUIT	2.4	1.2	1.0	2.5	2.0	2.6	2.1
b. HELMET	1.4	1.1	0.8	2.5	1.3	1.9	1.9
c. MASK AND HOOD	3.0	1.9	1.3	2.8	2.5	2.8	2.4
d. GLOVES	2.2	1.4	1.1	2.2	2.3	2.1	2.4
e. BOOTS	1.4	0.7	1.1	1.5	1.4	1.5	1.3
f. SURVIVAL VEST/ARMOR	1.9	1.2	0.9	2.9	1.9	1.4	1.7
g. COOLING SYSTEM	N/A	0.6	0.5	N/A	0.8	2.0	1.3

4. Did you experience any major problems with FIT or COMFORT of the items (OTHER THAN HEAT STRESS)? Answer by placing an 'X' next to 'YES' or 'NO' for each item listed. Where you answer 'yes', please explain what the problem was in the space provided. If the fit or comfort problem affected your performance, give details in your answer.

a. SUIT YES_____ NO_____

Pants were too large. (6)
Sleeves and legs were too short. (2)

b. HELMET YES_____ NO_____

Too tight. (2)
Caused headaches. (7)
Caused hot spots. (8)
Earcups were uncomfortable. (5)

c. MASK YES_____ NO_____

Visibility limitations. (12)
Hot spots on forehead. (4)
Tight fit around forehead and eye brows. (7)
Hot air in mask was very uncomfortable. (6)
Burns face and forehead due to sweat. (5)
Irritates face around eyes and nose. (9)
Mask slips up when looking down. (1)

d. MASK HOOD YES_____ NO_____

Very hot. (5)
Restricts movement of head. (3)

e. FLIGHT GLOVES AND RUBBER GLOVES YES_____ NO_____

Excessive sweat. (7) **Large and bulky. (4)**

f. SURVIVAL VEST/ ARMOR PLATE/CARRIER YES_____ NO_____

Contacts mask hose restricting head movements. (10)
Too heavy and cumbersome. (8)
Impairs proper seating causing back pain. (2)

g. FLIGHT BOOTS AND OVERBOOTS YES_____ NO_____

Excessive sweat. (1) **Large and cumbersome. (1)**

h. COOLING SYSTEM COMPONENTS YES_____ NO_____

Air: Difficulty breathing. (4)

Liquid: Cooling cap caused hot spots. (9)

QUESTIONNAIRE SECTION V. OVERALL ACCEPTABILITY.

1. Please rate the overall acceptability of the flight ensemble for wear during missions conducted under environmental conditions like you experienced today. Circle one number.

VERY UNACCEPTABLE	MODERATELY UNACCEPTABLE	SOMEWHAT UNACCEPTABLE	NEITHER UNACCEPTABLE NOR ACCEPTABLE	SOMEWHAT ACCEPTABLE	MODERATELY ACCEPTABLE	VERY ACCEPTABLE
1	2	3	4	5	6	7
95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
3.5	5.2	5.4	2.0	3.7	2.7	3.9

2. Please rate the overall acceptability of the cooling system for use during missions conducted under environmental conditions like you experienced today. Circle one number.

VERY UNACCEPTABLE	MODERATELY UNACCEPTABLE	SOMEWHAT UNACCEPTABLE	NEITHER UNACCEPTABLE NOR ACCEPTABLE	SOMEWHAT ACCEPTABLE	MODERATELY ACCEPTABLE	VERY ACCEPTABLE
1	2	3	4	5	6	7
95 nil	95 air	95 liq	105 nil	105 air	105 ven	105 liq
N/A	5.3	5.3	N/A	4.4	2.4	3.6

3. What was the WORST problem which you experienced IN TODAY'S SESSIONS related to wearing your ensemble? Please give details below and indicate what you think can be done to the ensemble to improve the situation:

WORST PROBLEM(S):

Visibility limitations of mask and field-of-view. (8)
Mask irritated face. (9)
Mask moves up when looking down. (2)
Fatigue and frustration with heat. (13)
Breathing hot air made subject nauseous. (7)
Sweat on face and eyes caused eye pieces to fog and smear. (10)
Difficulty breathing. (6)
Mask hose restricting head movements. (10)
Hot spots on head. (9)
Proper seating position. (5)
Drinking hot water. (7)
Heat buildup on head and face. (8)
Hands became soaked and very hot. (2)

WHAT CAN BE DONE:

Move eye pieces closer. (4)
Move hose to side of mask. (9)
Cool air through mask. (10)
Redesign armor with lighter material. (2)
Cool lower body as well. (4)
Mole skin on inside of mask. (3)
Redesign mask. (5)
Enlarge eye pieces. (3)
Keep drinking water cool. (7)

Appendix J.

Abbreviations.

AGL	above ground Level
ACP	air check points
AFCS	automatic flight control system
AMPM	aircrew member's protective mask
ANOVA	analysis of variance
AO	area of operations
AUIB	Aircrew Uniform Integrated Battlefield
BPM	beats per minute
CRT	cathode ray tube
DA	doppler/altitude
DIG	digital image generator
DS	direct support
ECS	environmental control system
GLM	general linear models
I/O	instructor/operator
IPE	individual protective equipment
liq	liquid
MRI	Midwest Research Institute
NBC	nuclear, biological, chemical
NRDEC	Natick Research Development and Engineering Center
PAB	performance assessment battery
P^2NBC^2	physiological and psychological effects of the environment and sustained operations in combat
PTFE	polytetrafluoroethylene
RH	relative humidity
RMS	root mean square
SARVIP	Survival Armor Recovery Vest (Including Packets)
USAARL	United States Army Aeromedical Research Laboratory
ven	vent
WBGT	wet bulb globe temperature

Appendix K.

Theoretical comparison of air versus liquid systems

air system advantages

Evaporative cooling
- more 'physiological,' some autoregulation
- less sweat to degrade chemical protection
- more comfortable

Easier to adapt to include respiratory cooling

Can utilize existing aircraft environmental control systems

Relatively tolerant of small systems leaks

Provides overpressure inside IPE which aids protection

air system disadvantages

Air must be filtered
- cost
- weight, bulk
- maintenance, reliability

Requires separate blower
- cost
- weight, bulk
- maintenance, reliability

Protection of integrity of NBC protection more difficult during entry and exit drills in a contaminated environment

Open loop system dumping processed air is less efficient

Condensation to remove

liquid system advantages

Closed loop system, more efficient

Portable ground cooling readily available using ice pack systems

Head and leg cooling available if required

Closed system is less vulnerable to NBC contamination

No filters or blower required

Minimal condensation

liquid system disadvantages

Uses more electrical power per watt of cooling

Cannot be used to provide breathing air cooling

Intolerant of even small coolant leaks

Conductive cooling - less comfortable
- clothing wet

Cannot make use of existing aircraft systems