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WHOLE BODY & BARE HAND COOLING AT HIGH WIND SPEEDS

RICHARD A. WILSON
KENNETH EASTER
HAROLD E. KERBER, PhD.

GOODYEAR AEROSPACE CORPORATION
AKRON, OHIO

PAUL WEBB, M.D.
JAMES F. ANNIS
WEBB ASSOCIATES

YELLOW SPRINGS, OHIO

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AEROSPACE MEDICAL RESEARCH LABORATORY
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Richard A. Wilson
Kenneth Easter
Harold E. Kerber, Ph.D.
Paul Webb, M.D.*
James F. Annis

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13. ABSTRACT

Men were exposed in a wind tunnel with their backs to the wind, speeds 0 to 110 mph, at ambient temperatures of 21.1C (70F) to -31.7C (-25F) while hanging in a parachute harness clothed in Air Force flight suits at a simulated altitude of 600 feet. In summer flight suits exposures at 100 mph, -1.1C (30F) for 20 minutes following a standard precool of 10 minutes at 10 mph, were tolerated without frostbite. In winter flight suits, after precool at chosen ambient, men withstood 100 mph at -9.4C (15F) for 20 minutes and -17.8C (0 F) for 6.3 minutes. The latter test was terminated when skin on the calf reached the predetermined safety limit of 0 C (32F). At -17.8C (0 F) full 20-minute exposure was tolerated at 50 mph. Considerable discomfort but no tissue cold damage attended the coldest runs when mean weighted skin temperatures fell as low as 16C (60.8F). Rectal temperatures rose slightly then started down near the end of each 30 minute test run. Skin temperatures measured with embedded thermocouples during direct bare hand exposures correlate well with Siple's low speed windchill data; and both provide excessively conservative exposure criteria for well clothed man. Clothed full body exposure data establish a conservative basis for estimating thermally safe temperature-wind speed regimes for towing men during air-to-air rescue maneuvers. They also provide empirical evidence of the types and locations of cold injury to be anticipated when defining medical support for rescue missions or follow-on biothermal testing at higher wind speeds.

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Rescue Operations						

SUMMARY

Currently there is an operational need for determining the tolerable limits of body cooling associated with mid-air rescue of aircrewmen, who may be exposed to effective wind speeds of 100 to 230 mph for a few minutes to an hour. Often it may be necessary to effect rescue when the ambient temperature is 20 C (68 F) or less. Available data and existing indices, such as Siple's Wind-Chill index, are generally not applicable at speeds in excess of 50 mph. Because of these limitations, a preliminary study was conducted to determine guidelines for tolerable limits by exposing humans in a thermally controlled wind tunnel.

Two types of experiments were performed in our study. In full body tests, five Air Force volunteers were exposed to a range of temperatures and wind speeds in a temperature controlled wind tunnel while wearing standard summer or winter flight suits. The subjects were suspended in a parachute harness near the throat of the tunnel with their backs to the wind. In the second type of experiment, bare hands were exposed directly to the same range of environmental conditions. In these tests only the forearm and hand were in the wind stream. Tests in both configurations were performed at temperatures ranging from 21.1 C (70 F) to -31.7 C (-25 F) in combination with wind speeds of 10 mph to 110 mph, the tunnel limit. A total of 175 tests of both types was run. The effective altitude was 600 feet above sea level.

Protocol for the full body exposures called for a 10 minute precooling period at 10 mph wind speed to simulate parachute fall cooling, followed immediately by a 20 minute exposure at the selected test speed. Subjects performed no more than two full body exposure tests during an 8-hour period.

Measurements obtained during full body tests included 17 individual skin temperatures (T_s), rectal temperature (T_{re}), heart rate, and environmental parameters. On-line weighted mean skin temperatures ($\overline{T}_s$) were obtained during part of the experiments. For most bare skin temperature measurements, intraepidermal miniature thermocouples (.002 to .005 inch diameter, copper-constantan wire) were positioned in selected locations on the fingers, hand, and face. Because of the potential danger of cold injury, the colder whole body exposures were approached by increments in exposure severity. Safety protocol dictated test termination when any individual T_s reached 0 C (32 F). For added safety in coldest runs extra thermocouples were glued on skin points known to be coldest, i.e., cheek, jaw, back of neck, rump and calf. No Air Force volunteers suffered cold injuries.

The function of the bare hand exposures was to provide cooling curves for bare skin; bare hand tests in a specific environment often

preceded full body tests as a safety precaution. The colder areas measured, i.e., leading edge of index finger and the tip of the middle finger, reached the O C (32 F) cut-off point in a few seconds at the higher wind velocities when the temperature was near -17.8 C (0 F). Contractor personnel repeatedly accepted hand T_s to -2.2 C (28 F) without frostbite.

Full body exposures in the 1 clo (summer) suit were tolerated for the entire 20 minutes at 100 mph and -1.1 C (30 F) by two subjects. That is, 0 C (32 F) cut-off in an individual T_s was not reached; however, the $\overline{T}_s$ fell more than 12.7 C (23 F). The coldest test condition in the summer flight suit was -6.7 C (20 F). This experiment was terminated after 5 minutes at 100 mph when subjective reports indicated a possibility of skin damage. Complete 20 minute exposures in the 3 clo (winter) suit were made at 100 mph, -9.4 C (15 F) and at 50 mph, -17.8 C (0 F). At 100 mph, -17.8 C (0 F) one subject tolerated the high wind for 6.3 minutes at which time a clothed leg T_s reached 0 C (32 F). Rectal temperature generally rose slightly even during the more severe exposures at the same time as the subjects were shivering. T_{re} generally peaked near the end of each 30 minute full body run. Longer tow may induce significant core temperature loss. After 1 hour in the recovery room, T_{re} did fall by 0.2 to 0.5 C (0.4 to 0.9 F). Calculations of body heat loss using conventional skin-core weighting coefficients ($0.3\ \overline{T}_s + 0.7\ T_{re}$) produced estimates of more than 300 kcal in some exposures.

The T_s cooling curves showed a strong effect of ambient temperature, in runs for which the wind speeds were the same. $\overline{T}_s$ as low as 16 C (60.8 F) was recorded. $\overline{T}_s$ is depressed much more rapidly by 100 mph wind than by 50 mph wind. This suggests that as expected aerodynamic heating is not significant at wind speeds up to 100 mph.

Subjective discomfort under cold conditions can be expected to increase with altitude. In extreme cold the rather well circumscribed rescue system parameters should permit assembly of a first aid subsystem which will substantially augment rescue system effectiveness.

Men can be towed for extended periods at 0 C (32 F) or at least a few minutes at -17.8 C (0 F) and 100 mph in standard Air Force winter flight suits with absolutely no cold injury. Predictions have been made on the basis of these experiments that much lower temperatures and/or higher wind speeds can be tolerated with an acceptable occurrence of recoverable hospitalizations. These predictions should be tested by human wind tunnel experiments.

FOREWORD

This report was prepared by Goodyear Aerospace Corporation under Contract F33615-69-C-1063.

The authors wish to acknowledge the contributions of the initial technical monitor, Capt. Grant D. Callin and the first medical monitor, Maj. G. Kress Lochridge. Through Major Lochridge's personal and professional interest much of the necessary medical support was provided and his participation in planning the use of the cold tunnel facilities is evident in the Experimental Protocol, Appendix I. We acknowledge with great appreciation the support, guidance and patience of the Technical Monitor, Dr. A. T. Kissen, and his Branch Chief, John F. Hall, who also provided experience in cold stress physiology.

Any cooperative venture such as this involves many essential ingredients. Certainly foremost in this particular project was the cold wind tunnel facility. We wish to record our thanks to F. C. Ryan, Chief Engineer, Harrison Radiator Division, General Motors Corporation and his staff who made their facilities available and whose thoughtful consideration made our working environment most pleasant and effective.

Air Force personnel included volunteer test subjects, whose cooperation during frequently uncomfortable working conditions was praiseworthy, and the medical monitors who provided project support which was moderated only by their evident concern for the well-being of the test subjects.

The Medical Monitors were as follows:

Maj. G. Kress Lochridge
Capt. L. A. Lohrbauer, USAF, MC
Capt. P. Raskin, USAF, MC
Maj. R. R. Stenlund, USAF, MC

An essential contribution to temperature sensing was made by Robert Welch, a Goodyear Aerospace Corporation (GAC) Welding Engineer, who spent many hours patiently developing a reliable technique for making copper-constantan junctions between very fine wires and who subsequently made many of these thermocouples and welded them to very small stainless steel needles.

Last, but far from least, we acknowledge the work of GAC technicians, Gil Burch and Robert Young, without whose help nothing would have worked during the test runs. Under trying circumstances they modified, matched and calibrated GAC and Air Force equipment. In spite of these difficulties they maintained high quality communication and measurement signals. To all, a heartfelt well done.

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This technical report has been reviewed and is approved.

C. H. KRATOCHVIL, Colonel, USAF, MC
Commander
Aerospace Medical Research Laboratory

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INTRODUCTION

OPERATIONAL REQUIREMENTS

Purpose

Air-to-air rescue systems, currently under development by the U.S. Air Force, involve potential exposure of airmen to cold winds of 100 to 230 mph aloft. Exposure duration of a few minutes to an hour or more are projected where little or no additional thermal protection will be provided over the present standard flight equipment. Certain rescue operations may require that the victim be towed by the rescue aircraft.

One such system, as shown in figure 1, is under development in response to Southeast Asia Operational Requirements (SEAOR) 123 which states an urgent need for a recovery system that would provide an ejected pilot with a discretionary descent capability. This would permit a normal parachute descent or an optional capability to remain at altitudes of 3,000 to 6,000 feet for up to thirty minutes. Although

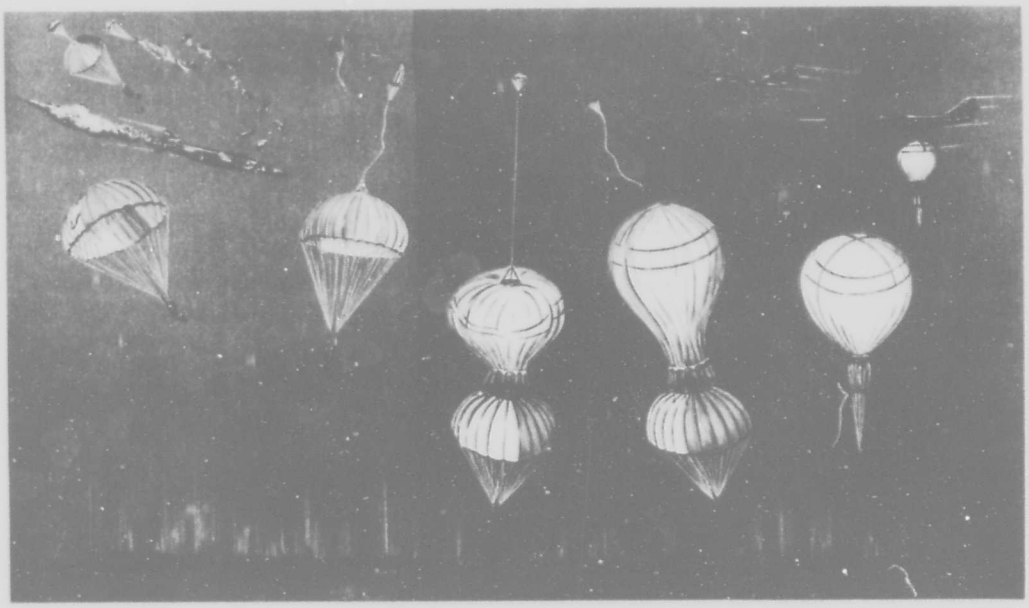


Figure 1. System Incorporating Goodyear Aerospace Pilot Airborne Recovery Device (PARD) - Sequence of Deployment and Pickup Events.

not part of the SEAOR requirement, an aerial retrieval capability was considered by AF operational personnel to be highly desirable.

The present Windchill Index (ref 1) does not apply at high airflow rates and no other reliable guides to thermally safe operational regions are available as a basis for developing such systems.

The study investigated biothermal responses under simulated operational conditions and defined human thermal tolerance limits relative to exposed extremities and total body tolerance limits during air-to-air maneuvers up to 100 mph near sea level. The operational environment was simulated by suspending the subjects in a standard AF parachute harness in a refrigerated wind tunnel facility. Air Force volunteers wore only currently operational Air Force clothing during the study.

Rescue Mission Cooling

In an air-to-air rescue mission (figure 1), the following events affect a crewman being rescued:

(1) Initial physiological state in the aircraft

(2) Ejection from the aircraft

(3) Free fall after ejection

(4) Gradual fall after deployment of parachute

(5) Hanging prior to air snatch

(6) Being towed by pickup aircraft

(7) Termination of towing by reel-in or release.

Free fall, gradual fall, and towing involve relatively high-speed wind flow around the crewman. If coincidentally the ambient air temperature is lower than about 10 C (50 F), the crewman will probably be exposed to serious local cooling and general net heat loss during these three events.

The thermal problems experienced by a crewman being rescued can be summarized as follows:

(1) Overheating of some nature - to be considered only in estimating initial conditions for cooling events

(2) Local cooling on bare skin

(3) Local cooling under clothing effectively modified by wind

(4) Net body heat loss

The degree of local cooling must be determined at various points on the body and the general heat loss measured on human subjects insofar as tests can be made safely. The measured data must be extrapolated to define danger zones by use of physical and/or mathematical models of the crewman and his environment.

The crewman may have patches of bare skin exposed and these will be vulnerable to frostbite and deep freezing. Additionally, even if he is fully covered, the wind is expected to affect seriously the insulating effectiveness of his clothing by:

(1) Compression of clothing and his subjacent vascular bed

(2) Fluttering of clothing in probably other areas (with local stimulation of the subjacent skin)

(3) Exchange of air beneath the clothing via porosities

The cooling effect of these changes will be increased by the presence of sweat and in Item 3 of the list will be modified by humidity of the air.

The types of cooling injury or impairment can be broken down into several categories:

(1) Local cooling
  (a) Stiffness of extremities
  (b) Frostbite, locally serious but recoverable
  (c) Deep tissue freezing

(2) General cooling
  (a) Lethargy
  (b) Unconsciousness
  (c) Death

Cooling versus time curves were developed in this study and interpreted in light of various types of cooling injuries reported in existing literature. Emphasis was placed on those aspects of impairment or injury of most interest to AMRL, i.e. tissue damage or death due to general cooling. Stiffness, lethargy, and unconsciousness may not cause permanent damage, but they will interfere with a person's ability to perform activities contributing to his own recovery.

The crewman's condition in the aircraft prior to ejection and the duration of hanging from a balloon may not appear to contribute to his subsequent cooling during falling and towing. But they help establish his body's thermal physiological initial condition at the beginning of

falling and towing, respectively. In particular, and probably of most importance, the crewman may have dry garments or he may have under-garments wetted with sweat just prior to ejection. A person with damp clothing is far more likely to be injured by cooling than one with dry clothing (ref 2, pp. 124 and 127)

PRIOR WORK INADEQUATE FOR PREDICTION OF HIGH SPEED WIND CHILL

A sizable number of indices and predictive equations exist in the physiology literature for the estimation of thermal stress (or lack of it); however, very few are intended for use in the evaluation of cold stress of clothed humans in highly convective cold environments. Perhaps the best known and most widely used index related to cold tolerance is the Wind-Chill Index developed by Siple and Passel (ref 14)

The results of this work have been used in chart and nomograph forms (ref 2) for practical judgments of the danger to bare surfaces under given cooling situations. Molnar (ref 12) has made an analysis of Siple's experiments and empirical cooling formula. The data used for fitting the formula for heat loss rate extended only up to 27 mph. Heat loss charts, etc. for higher speeds have been extrapolated from this formula. The heat loss rate as predicted from this formula begins to decrease above 56 mph as pointed out by both Siple and Molnar. This leads to an amateur discussion of aerodynamic heating following Molnar's paper. In fact as discussed in Section VI of this study, true aerodynamic heating is essentially negligible at 100 mph and is equivalent to an effective rise of ambient temperature of approximately 4.4 C (8F) at 230 mph. Furthermore, the test results clearly show a much greater cooling rate at 100 mph than 50 mph (figure 2).

Various temperature adjustments as correction scales, such as, Effective Temperature (ET), Houghten and Yagloglou (ref 10); Equivalent Temperature, Dufton (ref 5); and Operative Temperature, Gagge (ref 7), have limited applicability to cold stress situations and say little, if anything, about the convective cooling power of the environment. Indeed, the central theme is one of comfort offset rather than thermal stress per se. The Wind-Chill Index (and others) do not take into account the effect of clothing upon heat flow rates. Burton (ref 4), cognizant of this fact, developed the Thermal Wind Decrement which includes clothing (I_{cl}) and air (I_a) insulation factors as well as the rate of heat production (MR). This scale, too, is a temperature correction device. In environments where the wind velocity exceeds 50 mph, these indices are not applicable.

Many studies have been performed in which physical models; e.g., Siple's cylinder, have been placed in cold high velocity winds. The resulting heat transfer equations must be applied to human subjects with caution. The search for comparable studies performed on humans

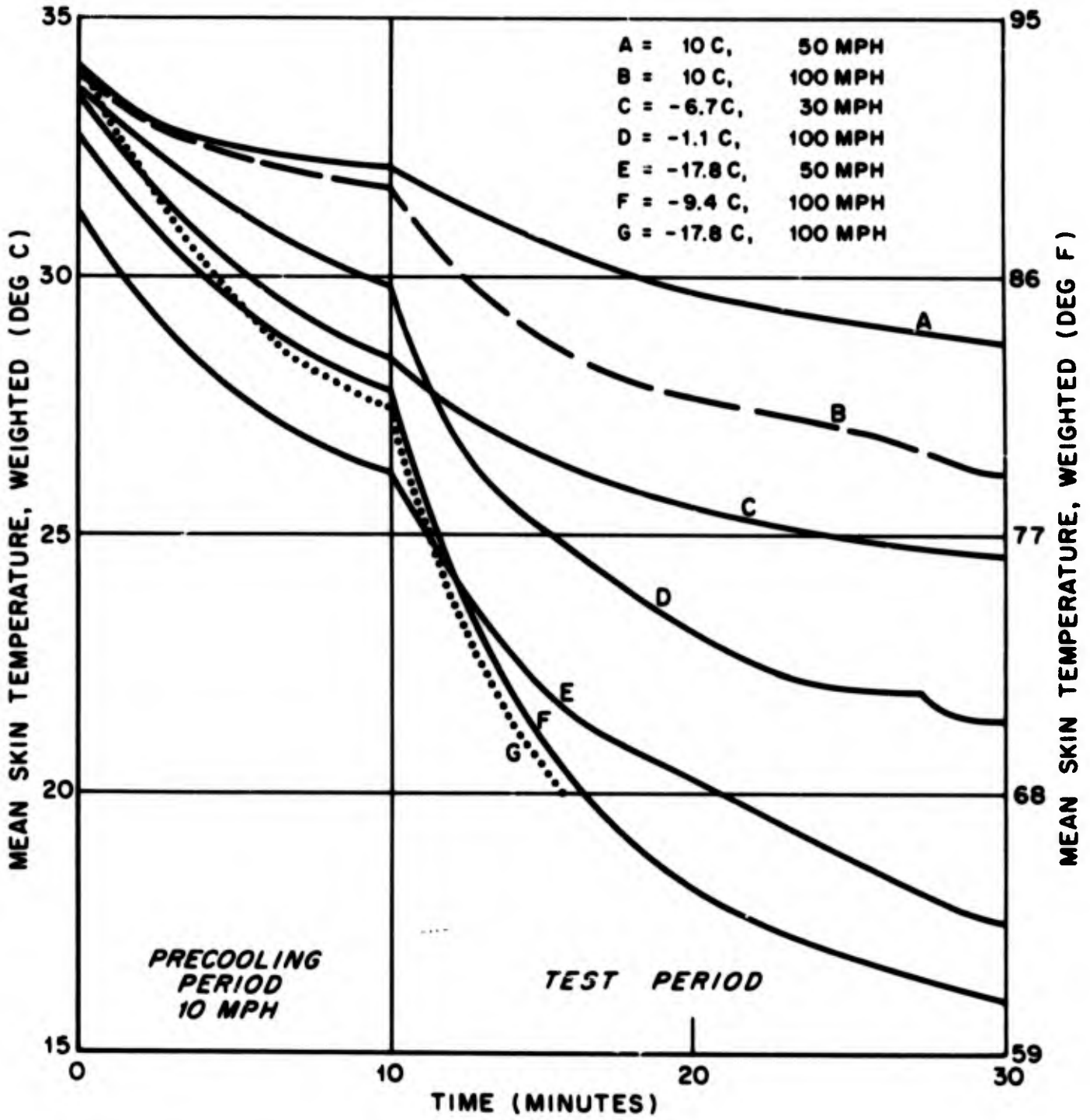


Figure 2. Cooling Curves of Weighted Mean Skin of Subject 2 in Winter Flight Suit

has been rather unrewarding. Specifically, exposure of people in wind tunnels for the purpose of determining the thermal effects of high wind velocities is apparently very rare. It is known that the Nazis did expose humans to similar stress conditions; however, the data is of doubtful character and its availability is limited. Wind-blast effect on tissues has been studied in wind tunnels, but skin temperatures are not recorded. Hetherington, et. al, (ref 9), did expose people to high wind velocities at extremely low temperatures for periods of three minutes. Skin temperatures were measured, but not very successfully. The primary purpose of this study was to obtain information about vascular effects of tumbling; hence the questionability of the temperature data was not critical.

A search of the literature since World War II plus MEDLARS for the last ten years has revealed no recent pertinent studies. In the final analysis it may be this study which will pave the way for future work. Now that the groundwork is laid, men may be cold stressed in wind tunnels with some security.

TEST FACILITY AND SUBJECTS

An overview of available Government and private test facilities quickly narrowed to a choice between an icing wind tunnel at the NASA Lewis Research Center, Cleveland, Ohio, and a cold tunnel at the Harrison Radiator Division, General Motors Corporation, Lockport, N. Y. Although the Lewis facility was capable of higher velocities, it was not man-rated.

Working closely with the AF Medical Monitor, GAC investigated the feasibility of developing equipment and procedures which would insure the safety of test subjects and satisfy both AF and NASA safety review boards. It soon became evident that project aims were best served by accepting the velocity limitations of the Lockport facility and getting on with the exploratory tests. In so doing the preliminary nature of the project was recognized as well as its limited time and budget resources. The Lockport facility included a closed loop subsonic open-throat tunnel capable of 110 mph operation from 51.7 C (125 F) down to -31.7 C (-25 F). This tunnel and its related control equipment are described in Appendix I.

Human test subjects and medical support were provided by the Aerospace Medical Research Laboratory. AF subjects were from the hazardous duty panel and each was equipped with his own lightweight cotton underwear (fitted with sensors to pick up body temperature at standard locations), summer and winter flight suits, helmet and oxygen mask. Individual subject characteristics are described in Section III.

An AF Medical Monitor was present during all test runs to insure personnel safety and comfort within the experimental demands of the project.

SAFETY

A sequential approach to testing was selected to provide running baseline data on which to build knowledge and predict reactions from one test run to the next. To push beyond previous laboratory work with safety, it was continually necessary to project test conditions into the more severe regions while at all times observing approved test protocol and exercising conservative judgment before setting new conditions to expose a test subject in the wind tunnel.

During the entire study, the subjects were closely evaluated before, during, and after each test run. Subjects reported any sources of discomfort, numbness, etc. The test conductors maintained a rather continuous series of questions and conversation during runs. Pertinent remarks were written on record charts. If either the test conductors or medical monitor saw symptoms incompatible with continued homeostasis of the subject, the run was immediately discontinued and medical care administered as necessary. Other reasons for discontinuation of a test run were loss of communication with a subject, loss of objective readouts of critical skin or rectal temperatures, desire of a subject to withdraw, or the opinion of any of the investigators a subject should be withdrawn. All prescribed safety precautions were observed at all times throughout the test program.

Details of the test safety criteria and their implementation are described in Section II Appendixes III and IV contain additional data and remarks that will be useful in judging safety criteria for follow-on biothermal testing.

SECTION II

METHODS

INTRODUCTION

All full-body exposure runs were made with a subject suspended in a back pack parachute harness with his back to and immediately in front of a 5 foot high by 7 foot wide opening through which a source of wind was emitted (figure 3, subject 3 in 100 mph wind). At this speed the subject's body swings out to a steady attitude as much as 45 degrees from the horizontal, the angle being a function of the positions of his arms and legs.

The precooling events of the operational sequence, free fall and parachute drop, were simulated by exposing the subject for 10 minutes in a 10 mph wind. Then, without moving the subject or changing the temperature the wind was increased in a few seconds to a preselected value (30 to 110 mph) to simulate a towing event.

This simulation may be conservative in three respects. First, if the airman ejects near his intended PARD floating altitude, his precooling would not be that used in this program. Second, the free fall and parachute drop phases would ordinarily exert their most emphatic cooling effects on some parts of the body other than those most cooled during the towing period. Third, even if the subject were strongly precooled on certain parts of his body, a period of hanging beneath the PARD ballute nearly at rest, relative to the surrounding air, could serve to somewhat rewarm him prior to tow. This is demonstrated specifically for bare

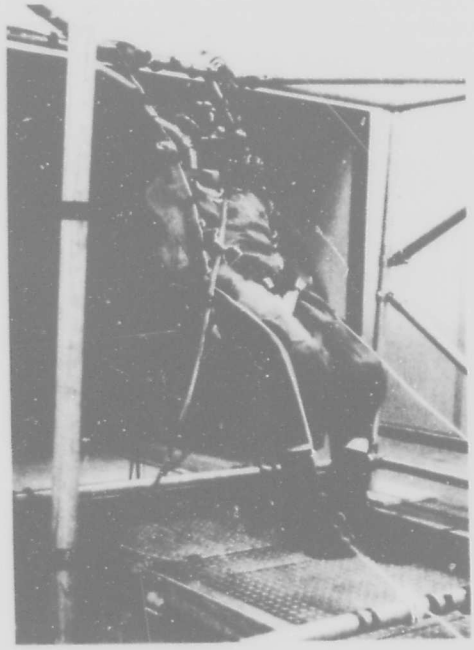


Figure 3. Full Body Test Position of Subject 3 at Wind Velocity of 100 mph

hands in figure 4. In all of these cases the net cooling of some specific body locations would probably be less than was simulated through a given duration of tow.

Runs with only bare hands exposed to the wind were made to test the worst case effect,(loose or missing clothing)and to examine maximum temperature decay rates. This permitted some anticipation of dangerous situations which might arise in whole body runs.

The wind tunnel which was the source of cold wind has been described in more detail in Appendix I.

TEMPERATURE MEASUREMENTS

During Phase II testing, a Skin and Body Temperature Computer (Type 441 Cutler-Hammer, Airborne Instruments Laboratory) was used to record body temperatures. This computer precisely measures and records skin and body temperatures that are sensed by thermistor probes, part of the underwear worn by the test subjects and supplied by the Aerospace Medical Research Laboratory (AMRL),applied to 18 different locations on the body. The computer automatically computes and records weighted-mean skin temperature and weighted-mean body temperature in addition to the individual readouts.

Table I illustrates the location of the thermistors on the body, records the weighting coefficients of each sensor as originally supplied by AMRL and also records the actual coefficients used in the computer recorder as supplied by the Government for use at Lockport, N. Y. A 24-channel Brown recorder was used during the Phase I testing for the whole body runs. This recorder was capable of recording all of the underwear thermistor readings, but could not compute weighted-mean temperatures. With the addition of the computer recorder during Phase II testing, the 24-channel was used as a pretest checkout system and during posttest rewarming to record the rewarming trends of each subject after the test runs. Occasionally complete, noninterrupted records were made of pretest, precool, cool and rewarming cycles on the temperature computer. A sample of these curves has been plotted in figures 5 and 6.

As shown in figure 7 the thermistor sensors in the underwear were located in seventeen strategic locations on the body in addition to a rectal temperature probe. As the testing program progressed and the ambient temperature decreased, additional temperature probes (thermocouples) were placed on the body in cold areas not covered by the thermistors. The critical areas with respect to temperature, recorded by the thermocouples, were the rump and the back of the legs, also much irritation and discomfort was experienced on the face. The thermocouples were cemented to the bare skin (as on the rump, legs,

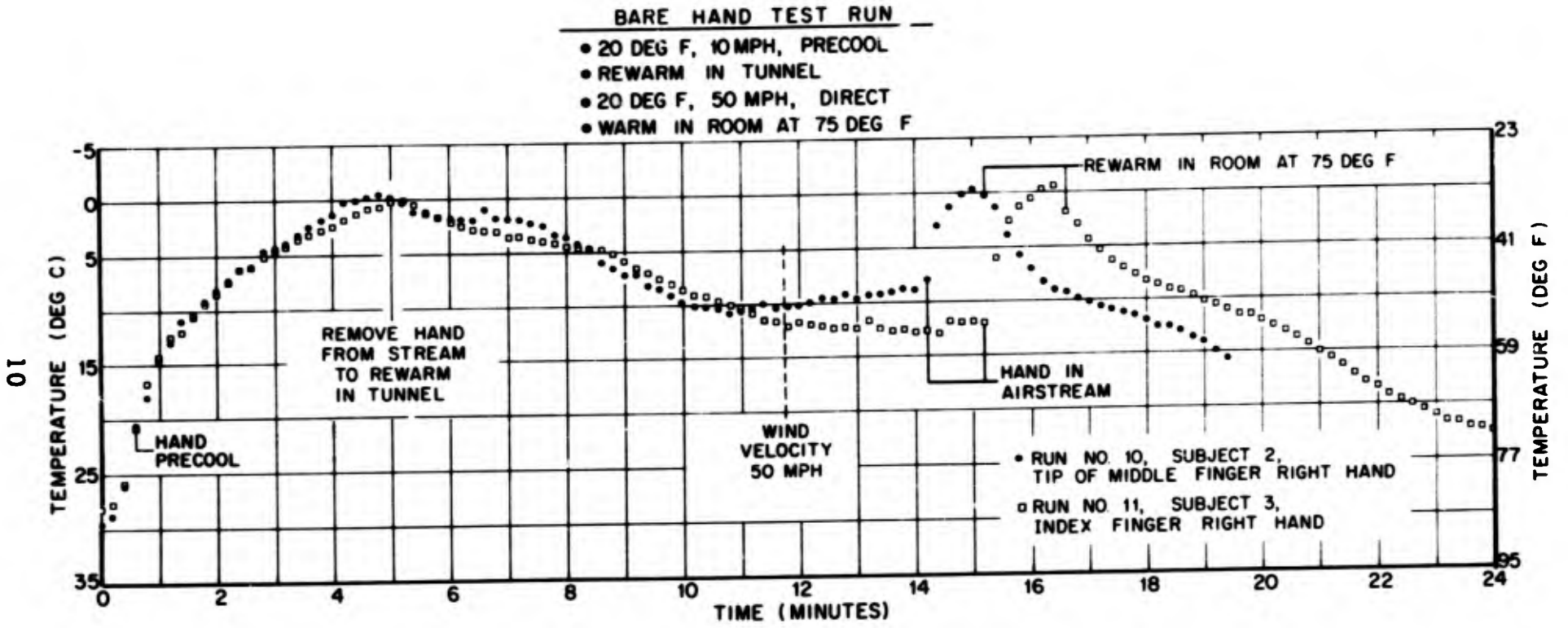


Figure 4. Hand Cooling Interrupted by Rewarm in Tunnel

Table I. Skin Temperature Weighting Coefficients

Number and Letter	Location	Weights Originally Supplied by AMRL	*Weights Computer Dials
1-A	Forehead	0.037	0.0338
2-B	Neck	0.037	0.0339
3-C	Scapula	0.063	0.0625
4-D	Kidney	0.063	0.0640
5-E	Nipple	0.063	0.0676
6-F	Abdomen	0.063	0.0640
7-V	Rump	0.063	0.0628
8-H	Upper Arm, Rt.	0.075	0.0743
9-J	Lower Arm, Lt.	0.075	0.0625
10-K	Hand, Rt.	0.0295	0.0252
11-L	Hand, Lt.	0.0295	0.0180
12-M	Upper Ant. Leg, Rt.	0.0875	0.0852
13-N	Upper Post Leg, Lt.	0.0875	0.0865
14-P	Lower Post Leg, Rt.	0.0875	0.0865
15-R	Lower Ant Leg, Lt.	0.0875	0.0864
16-S	Foot, Rt.	0.026	0.0359
17-T	Foot, Lt.	0.026	0.0358

*14 and 15 inverted incorrectly in list on face of computer

and any covered areas) with Touch-N-Glue, U. S. Plywood Corp., sewn through the epidermis (as on the face or back of neck periodically), and also taped to the skin (most taping was done in Phase I), figure 7. A 12-channel Bristol printing recorder and a two-channel Brown pen recorder were used exclusively for the thermocouple readouts. Thermocouples were applied with minimum glue. Glue was wiped from the surface to avoid improper insulation.

For the bare hand test runs, thermocouples were implanted intra-epidermally on the right or left hand as shown in figures 8 and 9. All of the subjects with the exception of subject 4 had the thermocouple probes implanted in the right hand while subject 4 used the left hand.

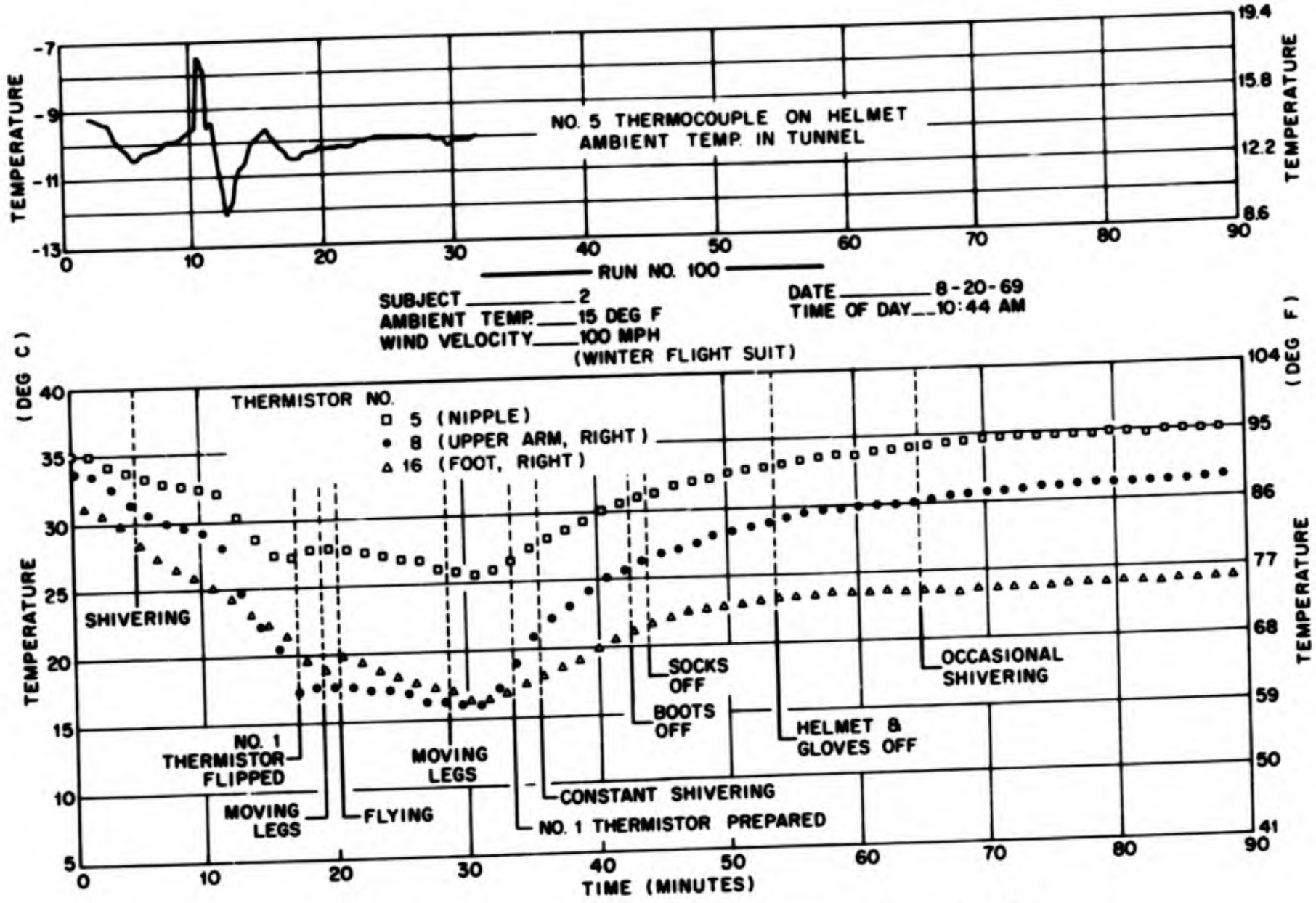


Figure 5. Selected Whole Body Temperatures: Sheet I

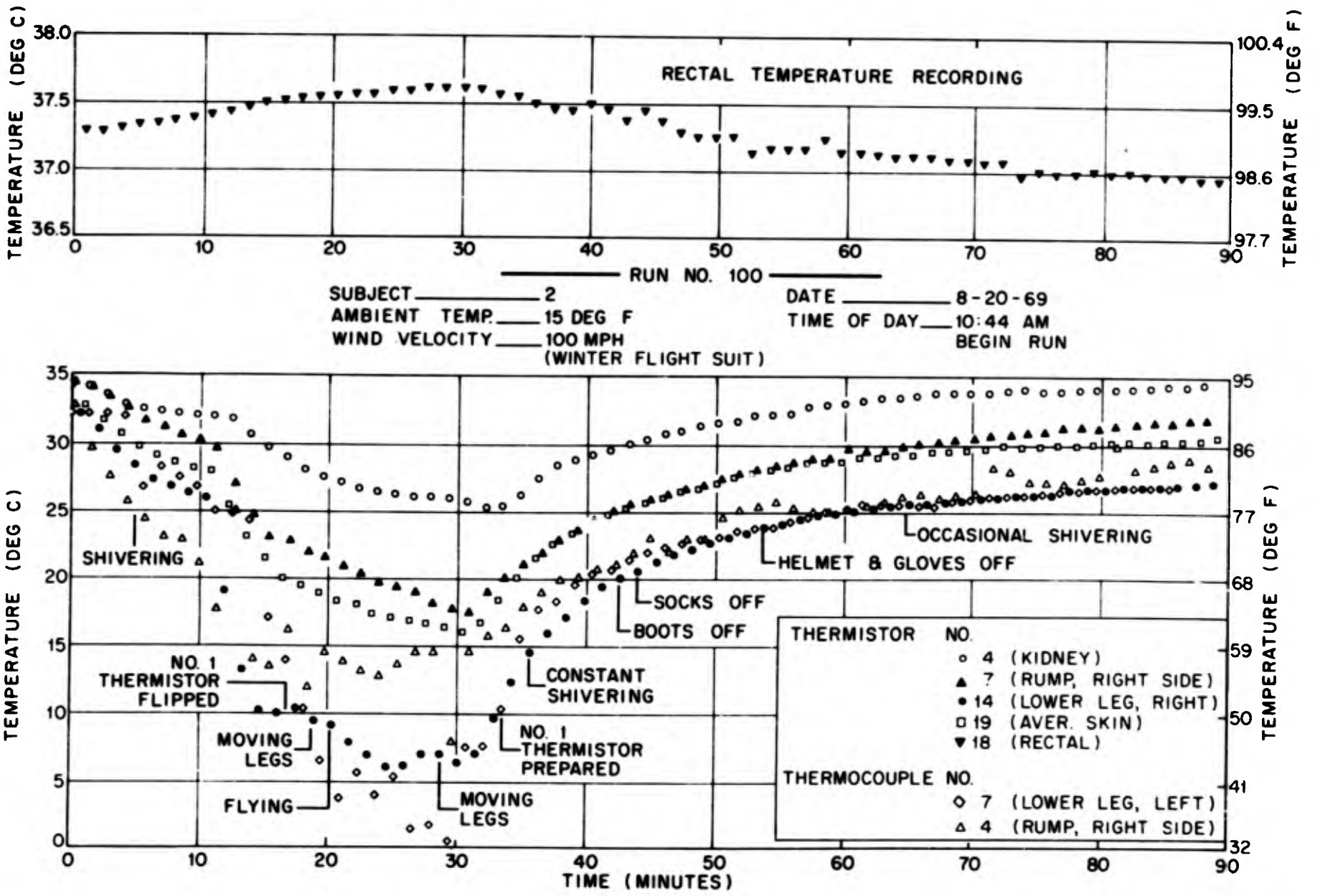


Figure 6. Selected Whole Body Temperatures: Sheet II

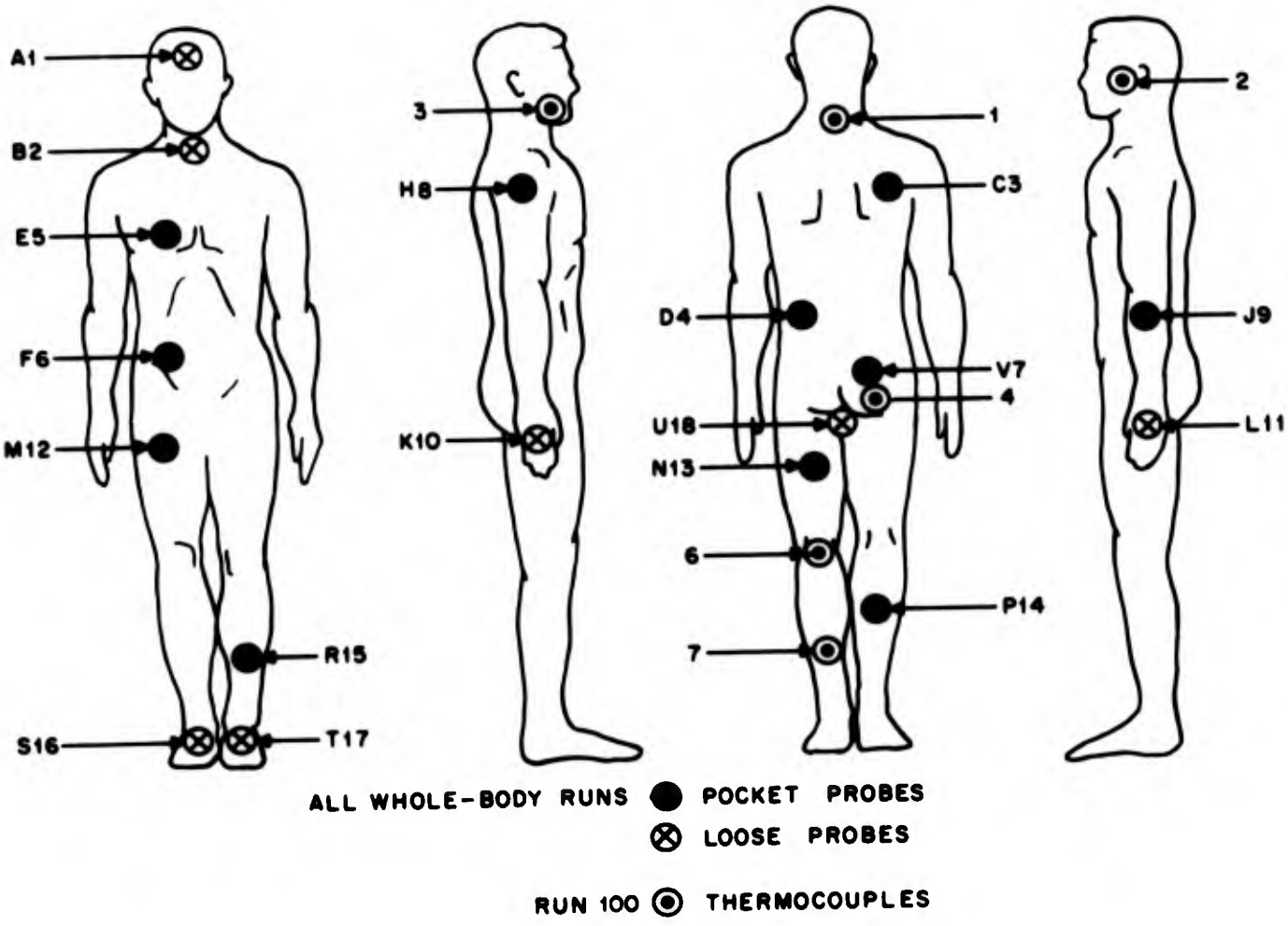


Figure 7. Probe Location Chart for YSI Thermistor Underwear

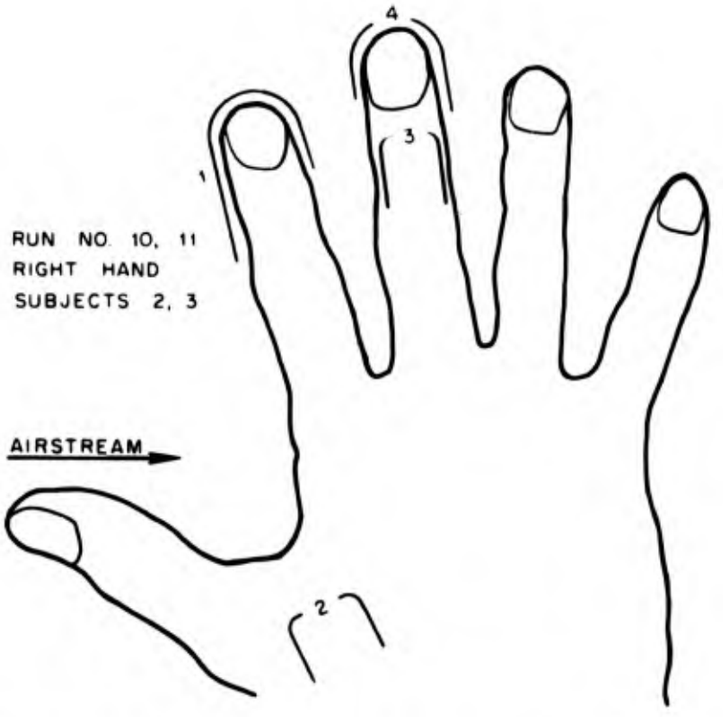


Figure 8. Bare Hand Thermocouple Locations - Right Hand

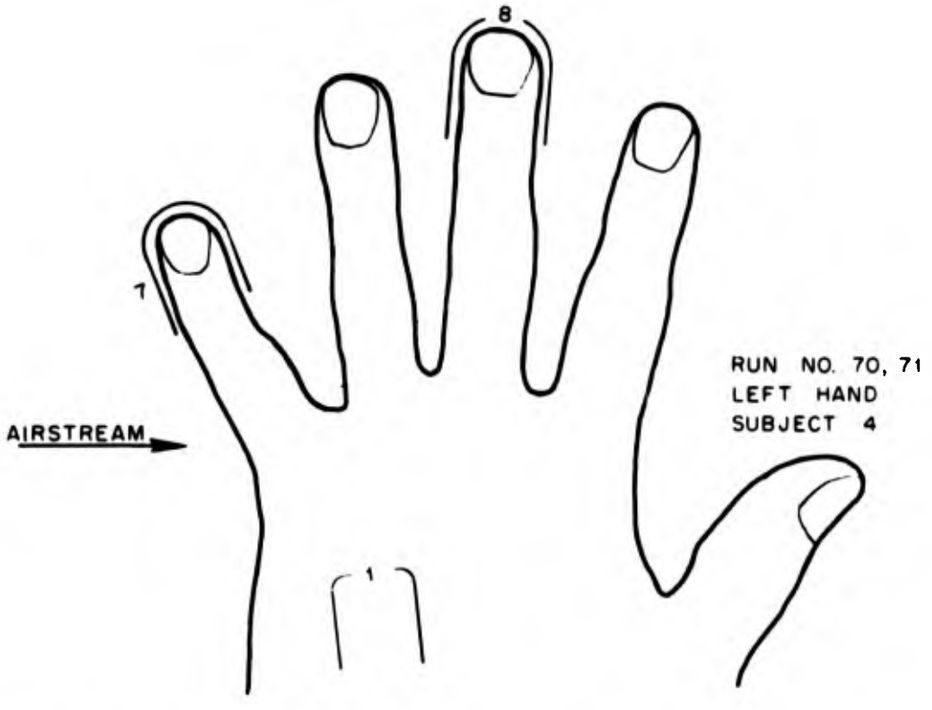


Figure 9. Bare Hand Thermocouple Locations - Left Hand

These thermocouples were very sensitive and broke periodically due to hand movements. The thermocouples were made of 2, 3 and 5 mil copper and constantan wires welded together at a central joint which was implanted into the epidermis. They were taped and cemented along the hand to restrict movement of the thermocouples during testing and to prevent the wires from snagging on the subject's clothing or other objects but were never cemented over the implanted area. These thermocouples with stainless steel needles attached for penetrating the skin were fabricated at Goodyear Aerospace. Needles were 6 to 12 mil in diameter.

The 24-channel recorder was run at 48 sec/cycle or 2 sec/printout. The 12-channel Bristol printer and the 2-channel Brown continuous recorder speeds were varied from 1 inch/min up to 2 inch/min and 16 inches/min, respectively. The majority of the test runs were made at 1 inch/min. All recorder calibrations were checked before and after the test runs each day to insure accurate readout. New thermocouples were implanted in the subject's skin each day for the test runs except for one experimental sequence in which subject 4 wore his thermocouples for four days. It was conceivable that all the subjects could have worn the thermocouples for a period of time but this was not desirable as it restricted the subject's activity. The area in which the thermocouples were implanted was cleaned with alcohol daily.

CLOTHING

The subjects from the Aerospace Medical Research Laboratory brought their summer flight suits (1CLO), winter flight suits (3CLO), and special thermistor underwear. Each uniform included the following:

- Winter Flight Suit:
  - Helmet - HGU-2/AP
  - Boot - Combat*
  - Coverall - CWU 1/P
  - Gloves - Shell HAU-6/P with woolen inserts
  - Underwear - ordinary cotton underwear, long
  - Socks - wool
  - Oxygen Mask
- Summer Flight Suit:
  - Helmet - HGU-2/AP

* Subject 1 wore jungle boots for several test runs.

Summer Flight Suit (Cont)

- Boot - combat*
- Coverall - Type K-2B
- Gloves - GS/FRP-1 or B-3A
- Underwear - ordinary cotton underwear, long
- Socks - wool
- Oxygen Mask

In all whole body runs the B-5 parachute harness was used.

The clo value of the flight suits has been assumed on the basis that the suits supplied were standard winter and summer assemblies and the original work statement called out 1 and 3 clo assemblies.

Definition: 1 clo is the insulation across which a temperature drop of 0.18 C occurs during steady heat flow of 1 K cal/m.^{2}hr., under standard conditions of air movement. This amount of thermal insulation in clothing keeps a sitting-resting subject (metabolic rate 50 K cal/m.^{2}hr.) indefinitely comfortable in a steady state at 21 C, (69.8 F), 50 percent relative humidity, air movement 20 ft/min.

TEMPERATURE SAFETY CRITERIA

The primary safety directive was to avoid cold injury to volunteers while attempting to define the parameter boundaries of the region beyond which cold injury would occur.

The original safety criterion prevented GAC from exposing Air Force volunteers to ambient temperatures below 4.44 C (40 F) during Phase I testing. In the absence of negative results other than discomfort, shivering, some brief acute pain and occasional evening headache and malaise, GAC was permitted to enter more stressful regions in Phase II. Protocols are reproduced in Appendix I.

The basic safety criteria for volunteers at the beginning of Phase II were as follows:

- No skin point should go below 0 C (32 F).
- Average skin temperature should stay above 21.1 C (70 F). This was chosen because it is a typical voluntary tolerance limit in water immersion studies.
- No specific core limit was imposed though we were aware of problems that begin at about 32.2 C (90 F) (figure 10).

*Subject 1 wore jungle boots for several test runs.

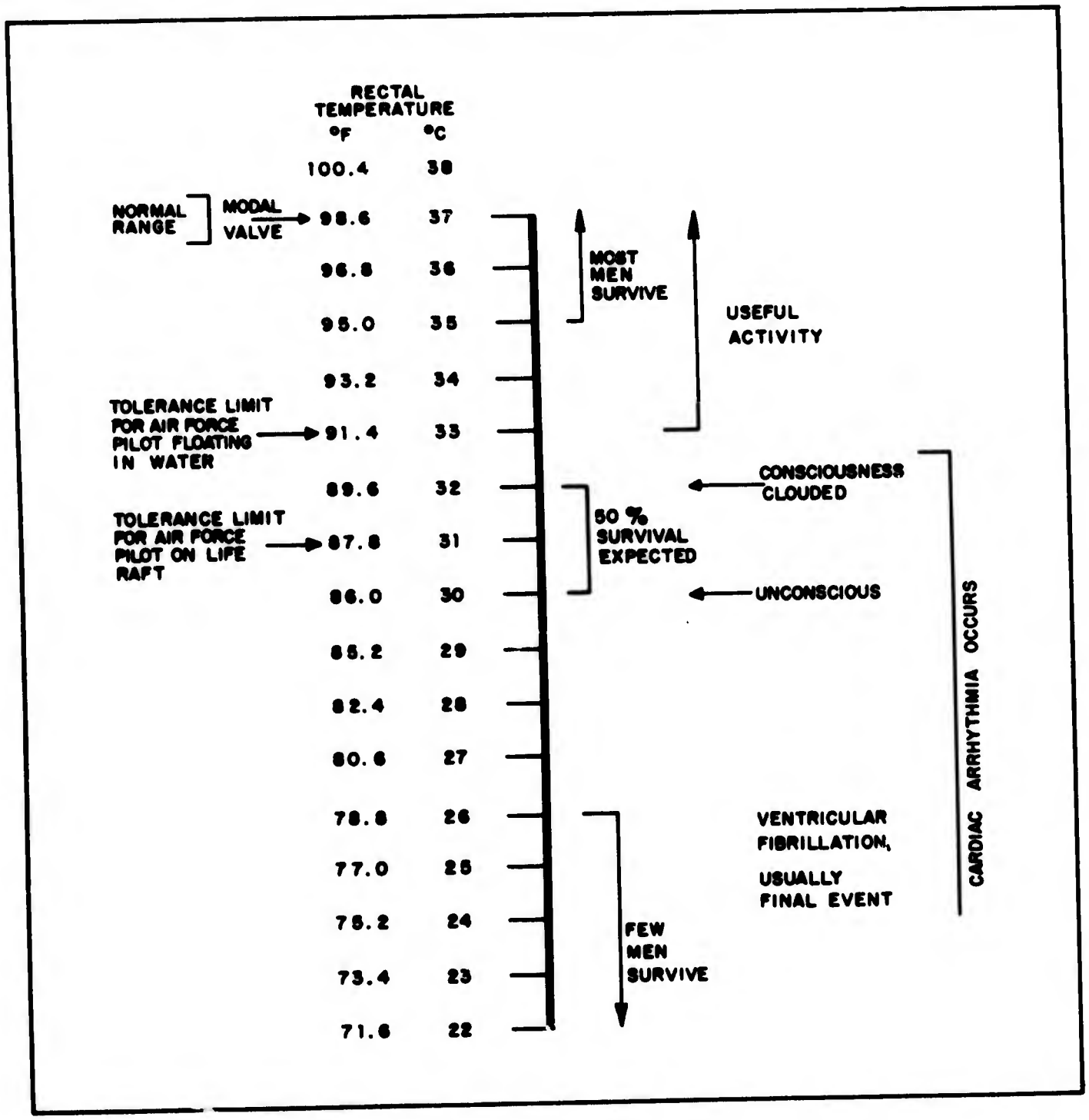


Figure 10. Tolerance to Internal Body Temperatures*

* From AFSC DH 1-3: DN 3M6 - Chap.3 - Biomedical/Life Support
Sect 3M - ESCAPE, SURVIVAL, AND RECOVERY (1 July 69)

Since no subject was monitored at every important body point by temperature transducer, Goodyear Aerospace imposed additional criteria based on subjective responses of volunteers; i.e., at least for the earliest runs at ambients below 0 C (32 F) Goodyear might stop a run and inspect the volunteer following a sequence of verbal reports such as: "The back of my neck is coldest. . . . , it's beginning to sting ...., it aches ...., ...no, it's O.K. now (or it feels warm)." Initially such sequences were interpreted conservatively to imply a loss or serious disturbance of local nerve function and perhaps onset of superficial injury. As experience was gained and this was shown not to be true runs were permitted to continue as long as the subject reported normal or at least some topical sensation (often irritation) as a result of touching the area in question. In addition, the "coldest" areas by subjective and objective criteria were later supplied with pasted-on thermocouples to improve knowledge of local conditions.

After obtaining some experience with runs at ambients below 4.4 C (40 F) Goodyear Aerospace requested and was given permission to permit the computed average skin temperature to drop below 21.1 C (70 F) as long as individual local temperatures were held at or above 0 C (32 F). This move was made after it became clear to those present that the indicated 21.1 C (70 F) average skin level provided light to moderate discomfort depending on individual variations but in itself did not define a threshold of danger. Subsequent runs yielded indicated average skin levels as low as 16 C (60.8 F). Even though quite uncomfortable at these levels no subject elected to request run termination nor turn off the tunnel himself. Both of these options were demonstrated to be available to them by our occasionally asking them to turn off the tunnel at the end of a full 30-minute run to which they complied promptly.

Goodyear Aerospace is pleased to report no cold injuries to any subject. This is tempered by the implication that GAC might not have pressed far enough to define safe vs unsafe rescue towing regimes.

By way of validation of the frostbite limits we note that one very superficial but undeniable cheek skin freezing incident was encountered by a Goodyear employee, in summer uniform, precooled and exposed 5 minutes at 100 mph in -6.7 C (20 F) air. This shows that the project safety record was probably due more to care in conducting the experiment than to the distance from freezing danger.

IMPLEMENTATION OF SAFETY CRITERIA

The skin temperature criteria for a subject's safety have been described previously while the means for implementing emergency shutdown are discussed in this subsection of the report. Also, presented are other hazards and their respective safety procedures.

Dr. Lochridge, who was present at the first visit to the Harrison facility, has described in Appendix I certain features of these tunnels which render them unusually convenient and, therefore, relatively safe for the conduct of live wind cooling experiments.

Although a high level of cleaning service maintained free particles in the airstream at a minimum, goggles or helmet with visor were worn by the subjects at all times during the whole body test runs.

Communications were established between subject, test conductor, tunnel operator and medical monitor with the use of headsets and microphones. The communications system was adapted to the HGU helmet headsets so that no special equipment would be worn by the subject other than the standard flight uniform. Stationed by each microphone and each temperature recorder was a stop button which could be used to terminate a test run in the event of an emergency. An additional emergency stop button was attached to the subject during the test run, and instructions were given that a run could be terminated at any time without prejudice. An initial EKG was taken during the preliminary cooling cycle and another at the termination of each test. The medical monitor made certain that the subject was functioning normally at all times. A running account of the comments reported by the subjects was entered directly on the chart paper so that a natural time log could be kept of each comment. Conversation between subject and test conductor seemed to relax the subject during the test runs and added to the overall morale of the subjects.

SECTION III

SUBJECT SELECTIONS

The primary test subjects used in the biothermal testing at Lockport, N. Y. were furnished by the Aerospace Medical Research Laboratory of WPAFB for Phase I and Phase II testing. Subjects 3, 6, and 7 were test subjects for Phase I testing while subject 3 with new subjects 2 and 1 were test subjects for Phase II testing. Pertinent data concerning subject characteristics are provided in Table II.

During Phase I, sixty-five test runs were made of which thirty-four were whole body runs and thirty-one were hand runs. The subjects were exposed to temperatures from 4.4 C (40 F) to 21.1 C (70 F) at wind speeds from 10 to 100 mph.

Subject 7 was an important member of the group in that he had numerous environmental test exposures prior to the trip to the Lockport facility. Although the prior tests were not cold tunnel tests, his knowledge and understanding of test procedures were invaluable during the test runs.

Table II. Subject Characteristics

Subject	Height	Weight (lb)	Unusual Skin Characteristics	Phase
3	5'6"	160	Extremely Tough	I
		151 5/8 (11% fat)		II
6	5'11"	165	Quite Dark	I
7	5'10"	190	Dark	I
2	5'8-1/2"	171 5/8 (13.5% fat)	Not Unusual	II
1	5'10-1/4"	165 1/2 (12.2% fat)	Not Unusual	II

Subject 3 was present for both Phase I and Phase II testing and was a very dynamic individual. He had the most prior experience with parachute equipment and flight assemblies and assisted considerably by describing the operational use of these items. This subject shivered more frequently than any other subject and reported intense local pain more often although his temperature recovered as expected. His subjective readiness to run also required more recovery time than the other subjects. In the last 14 years, his body had become accustomed to a more moderate environment as he had only been exposed to summer

like conditions. He had been recently active in acute heat exposure testing. He is 27 years old and has had excellent health.

Subject 6 was the youngest of the Phase I trio. His wit, general conversation, and competitive attitude were instrumental in the success of the Phase I testing. He also was familiar with the equipment. His spontaneous written interpretation of the coldest spots and sequence of appearance was very useful. He also withstood the boredom and discomforts associated with the hand runs and the whole body runs stoically. This subject's hand temperatures rose notably slower than the other subjects after the tests.

When comparing the Phase I effort with that encountered in Phase II, even though the temperatures were much higher in Phase I, only summer uniforms were used for the whole body runs thus affording less protection against the test conditions.

During Phase II testing, 110 tests were run of which 40 were hand runs and 70 were whole body runs with both winter and summer flight suits. In addition to the subjects supplied by the Air Force, two other members of the crew participated in the testing (subjects 4 and 5). The lowest hand test temperature was -25 F and the lowest whole body test temperature was 0 F.

Subject 1 was a very formidable subject who withstood all test conditions in good humor. He was exposed to temperatures to 0 F with no objection to any test condition. On numerous occasions Subject 1 commented that during his childhood he had felt much colder and had been exposed to more severe conditions during everyday living. This subject had little or no prior experience with environmental testing. Even so, he responded superbly. He was more consistently active during runs than subjects 2 or 3.

Subject 2, age 23, was the youngest volunteer of Phase II and was a diligent individual who made the coldest whole body runs of the program (Run 90) at -17.8 C (0 F) and 100 mph. During his initial exposure, which was the first test run he had experienced as a volunteer, he was very nervous. After his initial difficulties, the response received from this subject was very good. He communicated his reactions to test conditions with great care and enthusiasm. In addition to the -17.8 C (0 F) -100 mph run, he was exposed at -17.8 C (0 F) - 50 mph, thus becoming the only subject exposed to two whole body runs at zero degrees. He moved less than subject 1 during whole body runs and shivered so little that his strong shivering in Run 100 was notable. In his 23 years he had never before been at ambients under -6.67 C (20 F) nor in extreme heat. Childhood diseases included pneumonia, bronchitis and strep throat.

In the Phase I, March-April, testing at Lockport the 65 tests were made at ambient temperatures of 4.4 C (40 F) to 21.1 C (70 F). The volunteers accepted these conditions but with occasional indications of both acute and accumulated stress.

During the Phase II, August, testing only 9 of the 110 tests were above 1.7 C (35 F) ambient but the enthusiasm of the volunteers was notably better than in the Phase I testing. Subject 3 suggested that this may have been due, in part, to the improved outside weather which encouraged outdoor activities after work and which did not contribute to their heat debt stress. During Phase II no run was shut down by a volunteer in spite of obvious episodes of intense pain and shivering. However, the large distance between these conditions and debilitating or lethal ones may be indicated by the fact that the volunteers returned willingly two times a day, 10 or more times each week, for three weeks.

SECTION IV

PROCEDURES

Phase I was carried out with three Air Force volunteers as subjects; these were subjects 3, 6 and 7. In Phase II the Air Force volunteers were subjects 1, 2 and 3 while an Air Force doctor and GAC personnel participated briefly as subjects 5 and 4 respectively.

The procedure for inserting intraepidermal thermocouples required that no pain be experienced nor any blood appear. These signs would indicate that the needle was below the epidermis. Also, we tried to get a continuous tunnel at least 1/4 inch long to avoid end effects. Sterile methods were followed in all cases.

After the subject had been prepared with sensors in a separate room he was taken to a room, adjacent to the test chamber, and his temperature sensors were checked by attaching his sensor cable to the instruments. These checks included identification and sign checks for thermocouples and continuity and shorting checks for all sensors. During this time the cold chamber was brought to the desired ambient temperature, -31.7C (-25 F) to 21.1 C (70 F), and the wind speed was set at 10 mph or another chosen value. Tunnel ambient was held as nearly constant as possible during the entire time a subject was in the test chamber. Figure 5 displays the largest uncontrollable tunnel temperature transient, which occurs when the wind speed is abruptly changed from 10 mph to 100 mph.

For bare hand runs, the subject was dressed to afford him reasonable whole body comfort for the anticipated condition and run duration. The bare hand runs fall generally into two categories:

(1) Direct runs, no precool; i.e., runs in which the hand was inserted directly into an air stream previously set at some fixed wind speed between 10 and 110 mph as indicated on Table III.

(2) Runs initiated by precooling the hand for 5 (Table IV) or 10 minutes (Table V) at 10 mph. If no point had reached 0 C (32 F) at the end of the precool period the wind speed was rapidly increased, within 5 to 20 seconds, to the high value indicated.

The notations on these charts, Tables III and subsequent, are defined as follows:

(1) $t_{50\%}$ is the time at which the temperature of the coldest indicated point had moved 50 percent of the differential between the initial value and the ambient.

Table III. Bare Hand Parameters with No Precooling Period

TEMP F	TEMP C	BARE HAND RUNS	10 MPH WIND	30 MPH WIND	50 MPH WIND	100 MPH WIND
50	10.0	SUBJECT (RUN) ◇ △ Σ	3(P17) 0.33k 52.5(12)k			7(P24) 3(P23) 6(P25) 0.25k 1k -0.25k 52.5(4.5)k 50.5(4.5)k 50(2.5)k
40	4.4	SUBJECT (RUN) ◇ △ Σ	6(P56) 3(P57) 7(P59) 7r 3.13r 2.66r 43.5(19.25)r 46.5(13.25)r 48(0.36)r	6(P58) 3(P60) 7(P61) 2r 1.75 1.92r 42(10.25)r 45.5(14.75)r 48.5(4.75)r		7(P55) 3(P54) 6(P53) 0.25k 0.17r -0.09k 42.5(6)k 43(3.83)kC 40.5(5.75)kC
30	-1.1	SUBJECT (RUN) ◇ △ Σ	4(59) 4(60) 2(56) 1.5p 2.17p 0.7k 38.5(9.33)C,D 38.5(6.83)pC 38.5(6.5)kC,D			
25	-3.9	SUBJECT (RUN) ◇ △ Σ	1(9) 1.33n 36(9.25)n		3(44) 0.17k 2.5nC	4(68) 3(47) 4(48) 0.17q 0.25k 0.58o 1.33q 1.17r 1.33q 27(1.93)
20	-6.7	SUBJECT (RUN) ◇ △ Σ			1(61) 1(67) 2(52) 3(42) 0.25n 0.75n 0.17k 0.17k 1.1nC,D 1.17k,nC 1.5nC 28.5(1.75)nC	2(51) 3(41) 0.17n 0.25k 0.67nC 0.75nC
10	-12.2	SUBJECT (RUN) ◇ △ Σ		4(76) 0.33n 1.25n 27.5(1.75)nC	3(73) 4(81) 4(83) 4(84) 0.38n 0.17p 0.25p 0.26p 0.77nC 0.83p 1.08p 0.78p 27.5(1.17)pC 27(1.37)pC,D 27.5(1.2)pC	3(75) 0.17r 38.5(0.20)rC,D
0	-17.8	SUBJECT (RUN) ◇ △ Σ	1(64) 0.59n 0.75nC	4(78) 0.5p 0.67p 28(1.2)p	3(77) 0.22k 0.44kC	2(54) 0.11r 0.24r 12(0.37)rC 3(79) 4(53) 0.12k 0.08p 0.22kC 0.17p 25(0.25)pC
-25	-31.7	SUBJECT (RUN) ◇ △ Σ	4(70) 1.12p 0.93p 28(1.12)pC		4(71) 0.38p 0.31p 27.5(0.38)pC	

CODE:
- ◇ TIME TO REACH 50 % OF T_o-T_{amb} (MINUTES)
- △ TIME TO REACH 32 F (MINUTES)
- Σ LOWEST TEMPERATURE,T(F),DURING RUN: OCCURRING AT (TIME (MINUTES))

CRITICAL REGIONS:
- k - INDEX FINGER, RIGHT HAND
- n - TIP OF MIDDLE FINGER, RIGHT HAND
- p - SMALL FINGER, LEFT HAND
- q - TIP OF MIDDLE FINGER, LEFT HAND
- r - MIDDLE FINGER, RIGHT HAND

CONDITIONS
- C - REWARMING CYCLE RECORDED
- D - LAMP USED FOR REWARMING

Table IV. Bare Hand Parameters with Precooling for 5 Min at 10 mph

TEMP C	TEMP F	BARE HAND RUN	30 MPH WIND	50 MPH WIND	70 MPH WIND	100 MPH WIND
21.1	70	SUBJECT (RUN) ◇ △ Σ	3(P5) 6(P6) 7(P7) -2k -1k 0k 71(6)k 71.5(8)k 74.5(4.75)	7(P10) 6(P9) 3(P8) 0.25k 4.05k 0.68j 72(8)k 73.5(11)j 72(9)k	3(P11) 6(P12) 7(P13) -1.5k -4k 0j 71(9.5)k 71.5(9)k 72(7.25)j	3(P14) 7(P15) 6(P16) -1k 0j -4.5k 68.5(8.5)k 72(6)j 71(8)k
10.0	50	SUBJECT (RUN) ◇ △ Σ	7(P18) 6(P19) -4.5k -4.5k 51(3)k 51(3.5)k		3(P20) 7(P21) 6(P22) -4.5k -4.25k -4.75k 50(2)k 48(1.5)k 52(0.5)k	
-6.7	20	SUBJECT (RUN) ◇ △ Σ		2(10) 3(11) -3.75n -3.5k -0.5nA 0.87nE -0.16kA 1.16kE		

CODE: ◇ TIME TO REACH 50% OF T_o-T_{amb} (MINUTES)
△ TIME TO REACH 32 F (MINUTES)
Σ LOWEST TEMPERATURE,T(F),DURING RUN: OCCURRING AT (TIME (MINUTES))

CRITICAL REGIONS:
j - LOWER THUMB, RIGHT HAND
k - INDEX FINGER, RIGHT HAND
n - TIP OF MIDDLE FINGER, RIGHT HAND

CONDITIONS:
A - REWARM IN TUNNEL
E - TWO PART TEST RUN IN WHICH HAND WAS REWARMED IN TUNNEL PRECEDING TEST RUN

Table V. Bare Hand Parameters with Precooling for 10 Min at 10 mph

TEMP C	TEMP F	BARE HAND RUN	10 MPH WIND	50 MPH WIND	70 MPH WIND	85 MPH WIND	100 MPH WIND
-1.1	30	SUBJECT (RUN) ◇ △ Σ	3(8) -9.25r 1.5rA 1.33rE	3(1) 1(5) -8.5k -9.84r 1.25k 34.5(-1.25)k	1(2) -9.25k 1.25k	3(4) -9.25k 0.25k	1(6) 2(7) -8.75kA -9.33n 0.33nE 2.25nE 36.5(1)nA 38(1)nA

CODE: ◇ TIME TO REACH 50% OF T_o-T_{amb} (MINUTES)
△ TIME TO REACH 32 F (MINUTES)
Σ LOWEST TEMPERATURE,T(F),DURING RUN: OCCURRING AT (TIME (MINUTES))

CRITICAL REGIONS:
k - INDEX FINGER, RIGHT HAND
n - TIP OF MIDDLE FINGER, RIGHT HAND
r - MIDDLE FINGER, RIGHT HAND

CONDITIONS:
A - REWARM IN TUNNEL
E - TWO PART TEST RUN IN WHICH HAND WAS REWARMED IN TUNNEL PRECEDING TEST RUN

(2) t_{32} is the time at which the temperature of the coldest indicated point had reached 0 C (32 F).

(3) $T_{min}(t)$ is the minimum temperature in degrees F reached during a run with the corresponding time noted in parentheses. All times are in minutes and time zero is taken to be the time at which the high wind ($>$ 10 mph) begins or in the absence of precool is the time at which the man enters the tunnel.

The direct runs are GAC's only valid basis for making comparisons of the effects of various high wind speeds on bare skin, and they are the only basis for extrapolations of bare skin data to higher wind speeds, other altitudes, etc. This is true because the precool at 10 mph in bare hand runs brings the bare skin temperature rather close to ambient in many cases. On the fixed temperature recorder scales, there is then very little pen displacement remaining to represent the effect of the onset of high wind speed. The resolution of the effect of high wind from precooled bare hand runs is, therefore, practically impossible.

Secondly, although the ambient temperature transient at onset of high wind, figure 5, is not very important for whole body runs, it does confuse the interpretation of high wind onset in bare hand runs. This is true because the bare hand finger skin time constant is so small that its temperature can be seen to "follow" these ambient transients on our record sheets. Direct bare hand runs permitted the tunnel to be stabilized in ambient temperature as well as speed prior to every test.

At the lower ambient temperatures, the skin temperature approaches the ambient temperature closely, so that safety criteria would not allow precool completion before the increase in wind speed. This limited the bare hand runs at low ambient temperatures and high wind speeds to only direct runs with no precool.

It was frequently necessary to make bare hand runs with less than the intended complement of four thermocouples. This resulted from various kinds of thermocouple failure that the technician could not always repair in time for the next run. However, no runs were made without instrumentation of the coldest known points. Subject 4 was able to maintain without removal two thermocouples on fingers for runs on four successive days. This suggests that the experience gained should permit Goodyear Aerospace to make more reliable bare skin sensor implants for follow-on live work in tunnels or tow tests.

In the full body tests for Phase II the subject was completely attached to instrumentation, prior to entering the tunnel except for EKG and communications which were attached after he was seated in the parachute harness. This provided a better record than plugging in the

thermistor cable after seating the subject as was accomplished in Phase I. The wind was set at 10 mph before the subject walked into the tunnel so that his exposure time was counted from the moment he entered the air stream. The tunnel operator, having the subject always in view, started his interval clock at that time and announced this event to the recorder operators.

A test conductor always accompanied the subject to help him with any harness adjustment and with the quick ejector snaps, also to plug in the EKG lead, etc. The test conductor also checked the subject for zipper closures, etc. and the area for debris. The cables were then taped to the frame supporting the subject in order to lessen any chance of their whipping in the wind as cable whip is a source of recorder noise as well as other inconveniences.

The demountable man support frame had been fabricated at GAC prior to cold tests.

The subjects ordinarily did not wear the hose attached to their oxygen mask.

Records of breathing were taken utilizing a thermocouple in the mask as an additional safety measure during a few runs.

Photographs and movies of selected runs were taken from various locations in the tunnel.

Infrared thermography on bare skin was attempted for correlation with other data. However, for unknown reasons the instrumentation was too sensitive to wind to give consistently good data.

Upon leaving the tunnel the subject was immediately inspected for cold injury on portions of his body expected to be most susceptible. Then he was temporarily released from duty or requested to relax in the recorder room to produce a rewarming record.

SECTIONS V

RESULTS

INTRODUCTION

All wind tunnel test runs conducted during Phase I and Phase II are shown in Tables III through VII. The Phase I tests, run at 4.4 C (40 F) or above in summer flight suits, are numbered P 1 to P 65 inclusively (preliminary) while all Phase II runs are numbered 1 through 110, inclusively. The Phase II runs were made at 1.7 C (35 F) or below in both summer and winter flight suits, except for nine runs which were made at 10 C (50 F) in winter flight suits only. The daily log of these runs is provided as Appendix V of this report.

Table VI. Phase I Whole Body Runs

Temp. -F-	-C-	Whole Body Runs*	WIND SPEEDS 10 mph	30 mph	50 mph	100 mph
70	21.1	Subject	7 6 3	7 6 3	7 6 3	7 6 3
		Run Time xx	14 22 30	20 20 20	20 20 20	20 20 20
60	15.6	Subject			6 7 3 6 3	6 7 3
		Run Time xx			19 20 20 20 20	20 20 21
50	10	Subject			7 6 3	7 6 3
		Run Time xx			15 20 20	20 20 20
40	4.4	Subject			6 3 7	6 3 7 6 3
		Run Time xx				

* All Whole body runs were precooled at 10 mph: Subjects wore Summer Flight Suits.

xx All run times are in minutes.

The data listed in Table VII and several sheets summarizing the primary results were delivered to the Air Force Monitor on September 12, 1969. At that time slides were presented together with an informal discussion. Similar packages and discussions have been provided to various other AF representatives interested in Air-to-Air Rescue Systems. In addition, data have been provided to others conducting a concurrent study of a pilot rescue system. Preliminary extrapolations have been reported in GAC publications generated for the AF Life Support Systems Project office. The pertinent contents of these reports are referenced in Appendix VII, which also contains an extrapolation function for mean skin temperature.

Phase I, in retrospect, looks like a warmup session for Phase II, since significant cooling limits were only being approached in the region between -17.8 C (0 F) and 1.7 C (35 F) ambient. However, Phase I data

Table VII. Phase II Whole Body Runs

TEMP F	TEMP C	WHOLE BODY RUNS *		10 MPH WIND	30 MPH WIND	50 MPH WIND	70 MPH WIND	85 MPH WIND	100 MPH WIND	102.5 MPH WIND
50	10	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION							
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	1 2 3 10 10 10		1 2 3 20 20 20 d a	1 2 3 20 20 20		1 2 3 18* 20 12* a a	
35	1.7	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	1 2 3 11 10 10 a,b		3 20	1 2 3 10.80 10.30 120		1 2 3 20 11.90 20	
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	1 2 3 10 10 10		1 20	1 2 3 20 20 20	1 20	1 2 3 20 20 20	
30	-1.1	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	1 2 3 10 10 10		1 2 3 4.75 5E 9.2 d,e b	1 3 20 20 c		1 3 20 20	
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION RECORD	1 2 3 5 10 10 10 10		1 2 3 20 20 20 f a,f d,g	1 2 20 20	2 20	1 2 20 20 g I,IV	3 5 20 20
25	-3.9	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	2 3 10 10		2 20	3 20		2 11.5D	
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	1 2 3 10 10 10					1 2 1 3 4F 11E 20 20 g d f	
20	-6.7	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	4 10					4 5F h,f	
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	2 3 10 10	2 20	2 3 20 20	2 3 20 200 a	2 20	2 3 15.8F 20	
15	-9.4	SUMME FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION							
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION RECORD	2 1 3 10 10 10		1 3 20 100 a,f	1 12.75D*	1 20	2 20 345.4 HEAT LOSS KILOCALORIES IV,III,I	
10	-12.2	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION							
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	1 3 2 10 10 10	1 3 20 20	1 3 20 130	1 3 4.5A 15D h a		1 4A h	
0	-17.8	SUMMER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION							
		WINTER FLIGHT SUIT	SUBJECT RUN TIME (MIN) CRITICAL REGION	2 1 10 10		2 20	1 3.9A*		2 6.3C a	

CONDITIONS

- A - BARE SKIN <32 F
- B - BARE SKIN <40 F
- C - CLOTHED SKIN <32 F
- D - CLOTHED SKIN <40 F
- E - WARM FEELING
- F - POSSIBLE LOSS OF FEELING
- G - WEIGHTED SKIN <70 F
- * - MALFUNCTION CAUSING UNRELIABLE TEST
- + - ALL WHOLE BODY RUNS PRECOOLED AT 10 MPH (UNLESS NOTED)

CRITICAL REGIONS

- a - LEGS
- b - CHEEKS
- c - BUTTOCKS
- d - NECK
- e - FOREHEAD
- f - HANDS
- g - FEET
- h - JAW

NOTES:

- I - GOOD REWARM DATA (COMPUTER AND/OR TELETHERMOMETER)
- II - FAIR REWARM DATA (GAC RECORDER)
- III - PASTED THERMOCOUPLES
- IV - DATA SUMMARY CHARTS AVAILABLE

does supplement Phase II data for the purpose of comparing 1 and 3 clo flight suits and for extrapolations along the dimension of temperature.

Phase II work concentrated heavily on locating the coldest whole body exposure conditions that could be found under the restraints of reasonable safety precautions. These conditions were explored independently for the 1 clo and 3 clo flight suits. Bare hand runs with intraepidermal thermocouples were continued to provide indications of the time-temperature regimes in which skin freezing might be expected. Bare hand data with a 0 C (32 F) cutoff provided an excessively conservative criterion (Primary Results subsection) which we were able to safely circumvent by using fine thermocouples pasted on critical skin areas during whole body runs.

Also, we accomplished a brief practical test of gloveless hands under full body exposure conditions and found that the common sense method of folding the hands in the lee of the body will greatly reduce their temperature loss. The effects on breathing of the relation of the airway restrictor valve to the airstream at 100 mph were examined. This examination has already suggested a simple method of safely extending the tow speed above 200 mph.

Various difficulties related to clothing design were noted and will be discussed below.

PRIMARY RESULTS

Probably the single most important result can be appreciated best after inspecting Tables VI and VII. Each of these whole body runs was accomplished without objective evidence of thermal injury except in one case where very light first degree frostbite of cheek and jaw occurred after 5 minutes at 100 mph in -6.7 C (20 F) ambient in a summer flight suit. Safe extended runs at lower temperature are presently attributed to the presence of a hood on the winter flight suit which reduces ventilation around the neck and jaw.

Additional whole body runs at or below -6.7 C (20 F) in summer flight suits were not attempted for safety and practical reasons; that is not to say that we were certain of serious human damage at any particular exposure condition. No specific available parameter regions were avoided for safety reasons in any tests performed with winter flight suits.

Indicated temperatures on the bare hand exposed directly to the air stream do decrease quite rapidly. (See, for example, figures 4, 11, 12, 13 and 14.) Table VIII lists some typical times for bare fingers to reach 0 C (32 F). The table also presents Siple's windchill index from a nomogram (ref 2) and the qualitative description of severity for

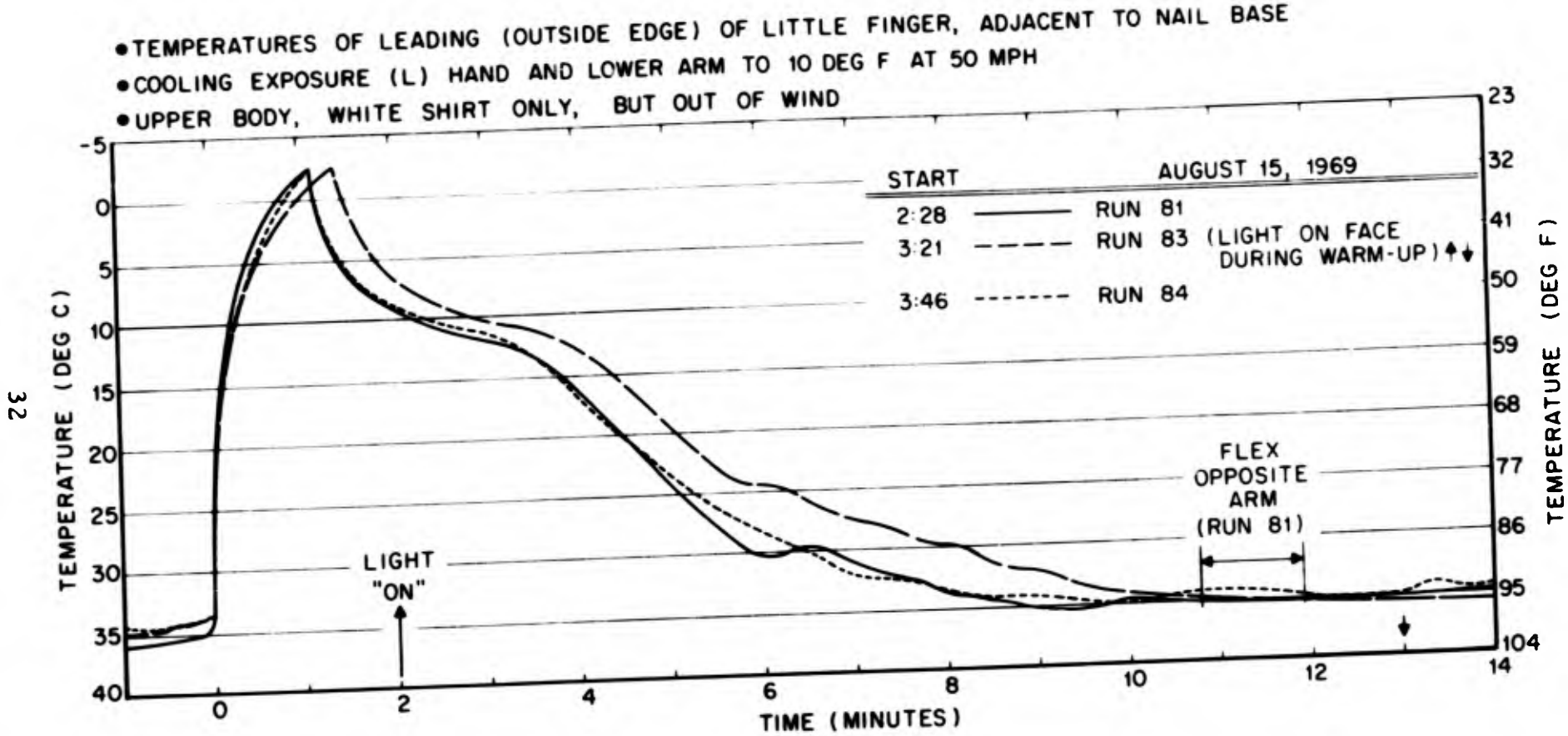


Figure 11. Hand Runs: Showing No Effect of Face Heating During Rewarm

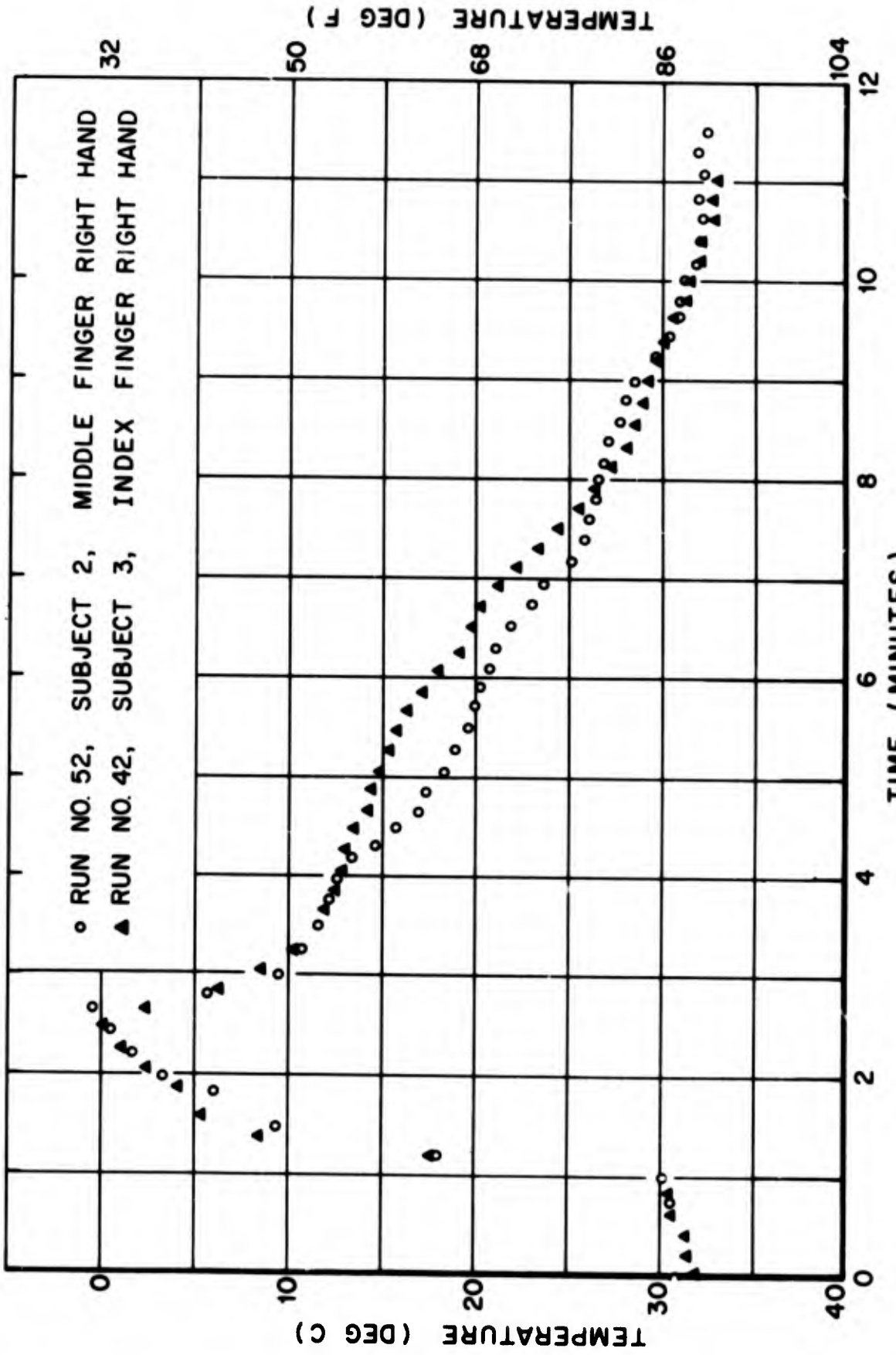


Figure 12. Coldest Hand Temperature: 20 F at 50 mph

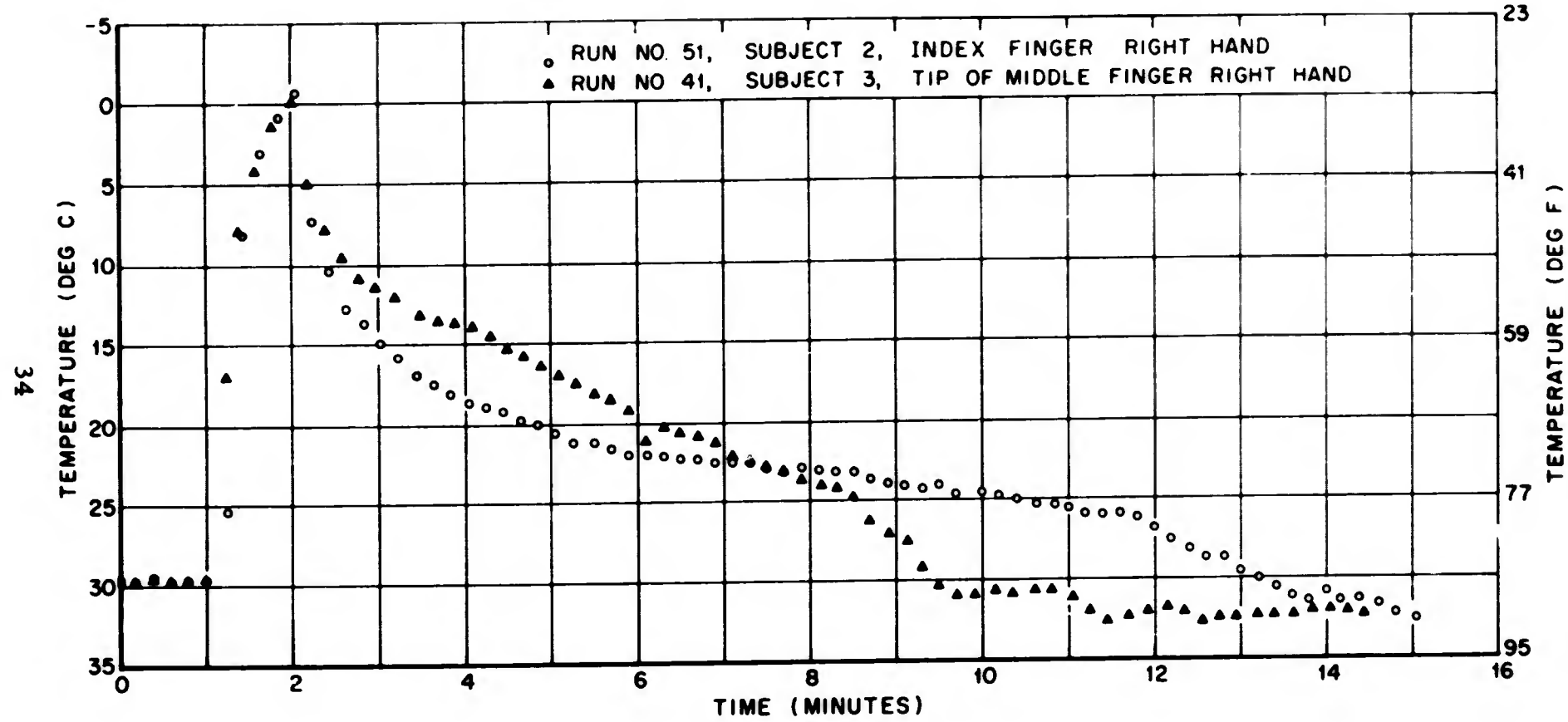


Figure 13. Coldest Hand Temperature: 20 F at 100 mph

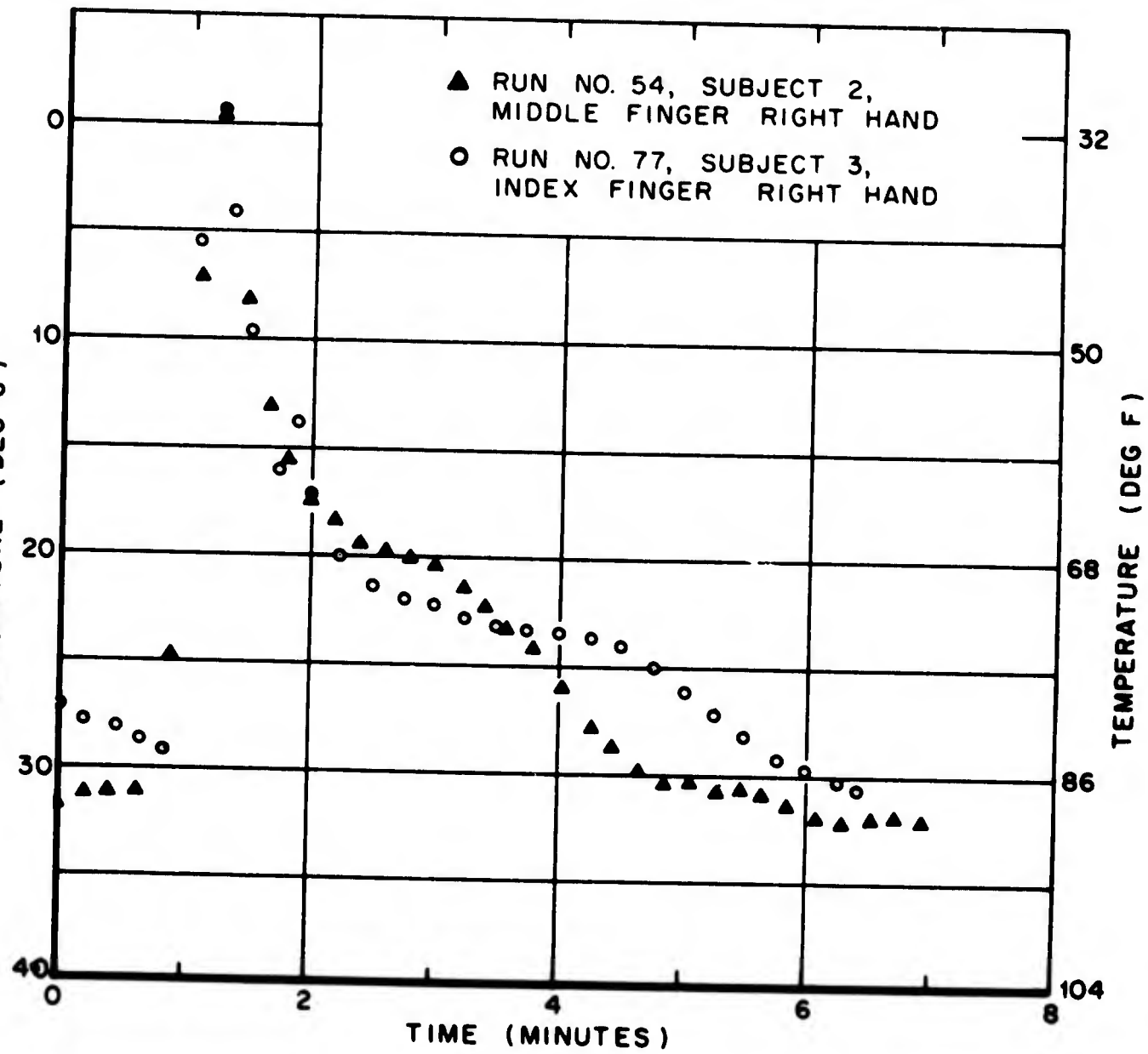


Figure 14. Coldest Hand Temperature: 0 F at 50 mph

corresponding exposures. In addition, it lists a number of whole body runs which were safely conducted for the full standard run duration of 30 minutes under comparable conditions. Clearly Siple's Index is much too conservative to be used as an indicator of significant danger for a well clothed airman towed with his back to the wind.

Table VIII. Comparison of Test Results with Siple's Index

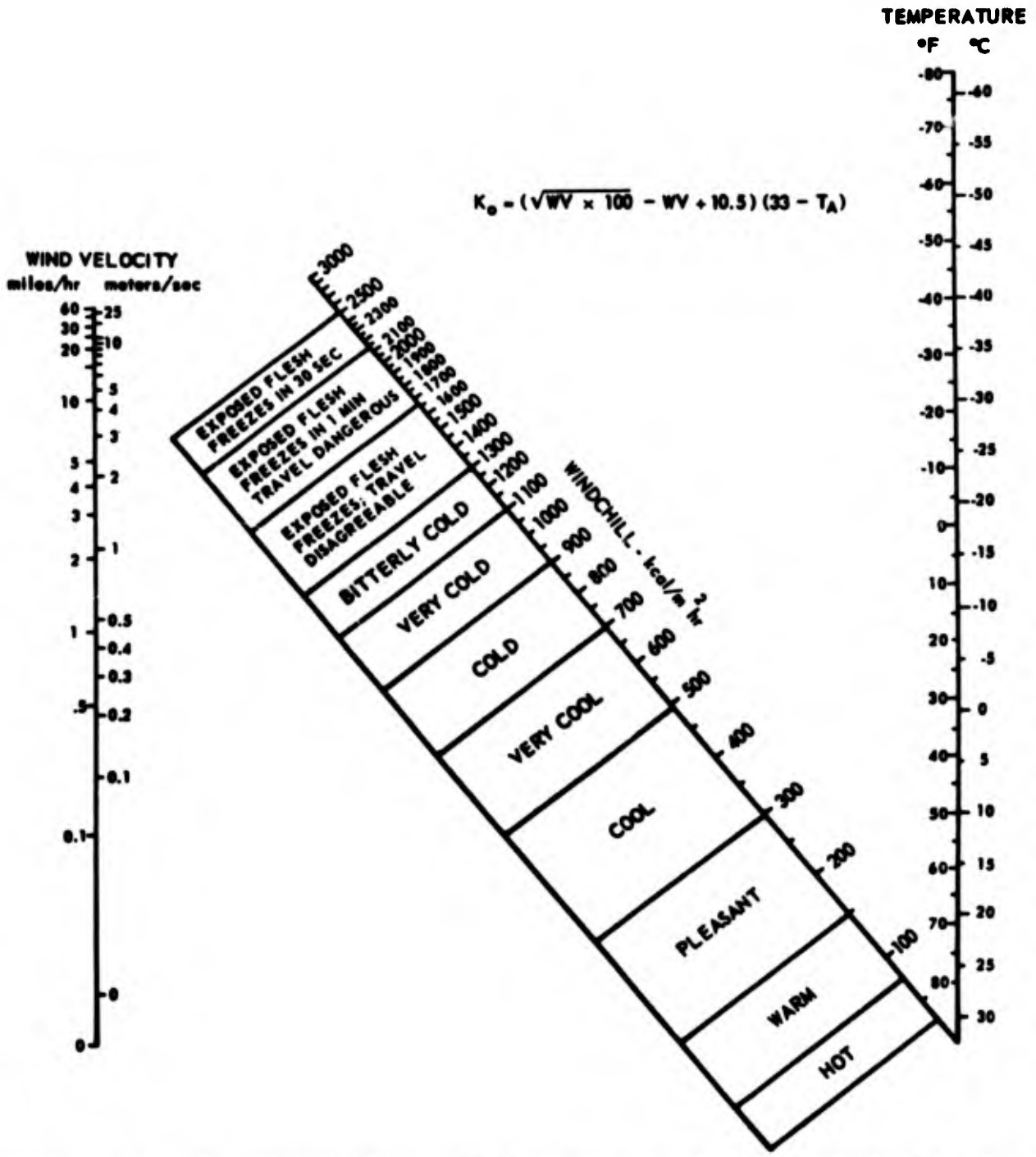
Ambient Temp. F	Ambient Temp. C	Wind Speed (MPH)	Siple Index* and Description (Kcal/M^2Hr)	Time for Bare Hand to Reach 32 F (Min)	Safe 30 min. Whole Body Run Accomplished
25	- 3.9	100	1450 exposed Flesh Freezes	2.25	Yes
20	- 6.7	100	1550 exposed Flesh Freezes	0.75	Yes
20	- 6.7	50	1400 exposed Flesh Freezes	1.50	Yes
10	-12.2	50	1550 exposed Flesh Freezes	1.37	Yes
10	-12.2	30	1500 exposed Flesh Freezes	1.75	Yes
0	-17.8	50	1750 exposed Flesh Freezes in one minute	0.37	Yes

* Windchill nomograph, figure 15, extended by assuming that very high wind speed (∞ mph) at 32 F yields windchill index of 1300, "Exposed flesh freezes."

The bare hand parameter charts shown in Tables III, IV, and V provide additional indications of the speed at which cooling occurs with the arm held out perpendicularly to the wind, palm down.

Since most of the times were measured from the moment of entering the tunnel and not from the moment of entering the air stream, they are a bit longer than would be the case if a man were directly exposed to the airstream from the recorder room. This also generates some unnecessary randomness in the data set which makes certain uses inadvisable; for these uses more suitable data can be read from the records.

Although some clothed areas approached freezing, they did so more slowly than bare ones. This fact allowed instruments to give adequate warning of incipient danger.



In outdoor cold weather, the wind velocity has a profound, sometimes decisive, effect on the hazard to men who are exposed. The windchill concept dramatizes this well known fact by providing a means for quantitative comparison of various combinations of temperature and wind speed. Note for example that -50 F with an air movement of 0.1 mph has the same windchill value, and therefore is predicted to produce the same sensation on exposed skin, as -15 F with a wind of only 1 mph or +14 F with a wind of 5 mph. The windchill index does not account for physiological adaptations or adjustments and should not be used in a rigorous manner. It is based on field measurements by Paul Siple during World War II of the rate of cooling of a container of water.

Source: Consolazio et al. [11].

Figure 15. Windchill Index

Comparison of the relative protection of summer and winter flight suits is made on figure 16. On this figure the initial temperatures indicated from all thermistors and computer outputs, of the subject before precool, are seen across the top of the graph. The final values, read 30 minutes later and connected by lines, are much lower for both suits. Figure 17 shows the effect of running the same subject, number 1, at 50 mph rather than 100 mph. and also shows that at 100 mph subject 2 cools very similarly to subject 1. Figure 18 compares the cooling of subject 2 illustrated previously with his greater net cooling under two more severe conditions.

Rectal temperature generally increased slowly during the entire whole body exposure (figure 6 provides an example). On some runs it started to drop again slowly within the last 5 minutes of the 30-minute run. It continued to drop for about an hour after the run terminated; i.e., during rewarm in 23.9 C (75 F) room as shown in figure 6.

PECULIARITIES OF CLOTHING

Some peculiarities noted in the flight suits during the test run are as follows:

(1) The summer gloves tended to separate from the flight suit sleeve and occasionally threatened to come off entirely in the high wind tests.

(2) The flight suit pants rode up on the subject's legs leaving a two-to-three inch strip of underwear exposed at the boot top. This caused noticeable excess local cooling.

(3) On at least one occasion the wind action completely loosened the lower pants leg zipper allowing even more ventilation of the lower leg. Wind can also untie carelessly made shoelace knots.

(4) During the first phase of the runs in the Lockport facility a considerable sensation of cooling was noted "around the mask." This was interpreted to indicate that the mask was conducting heat away from the face. However, during the second phase tests with the thermocouples, it was shown that the mask in fact insulates the face beneath it. The sensation of cooling is more likely attributable to the physiological Mach effect exaggerating the temperature drop from the mask-protected skin to the nearby exposed skin (Refer to Appendix VI). It is still quite probable that the pressure of the mask will significantly disrupt blood flow in nearby skin and increase its susceptibility to injury from freezing.

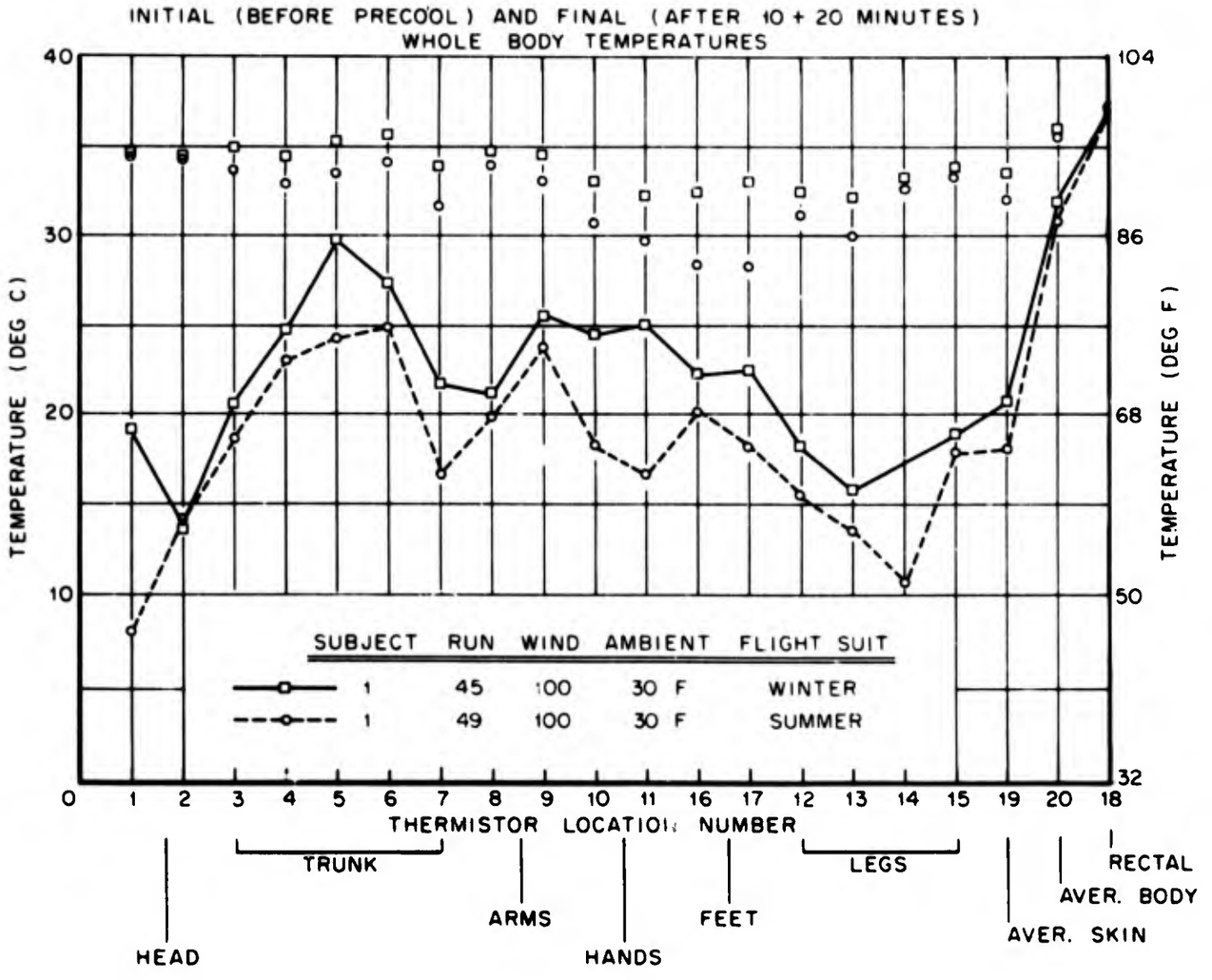


Figure 16. Initial and Final Body Temperature vs Summer and Winter Flight Suits

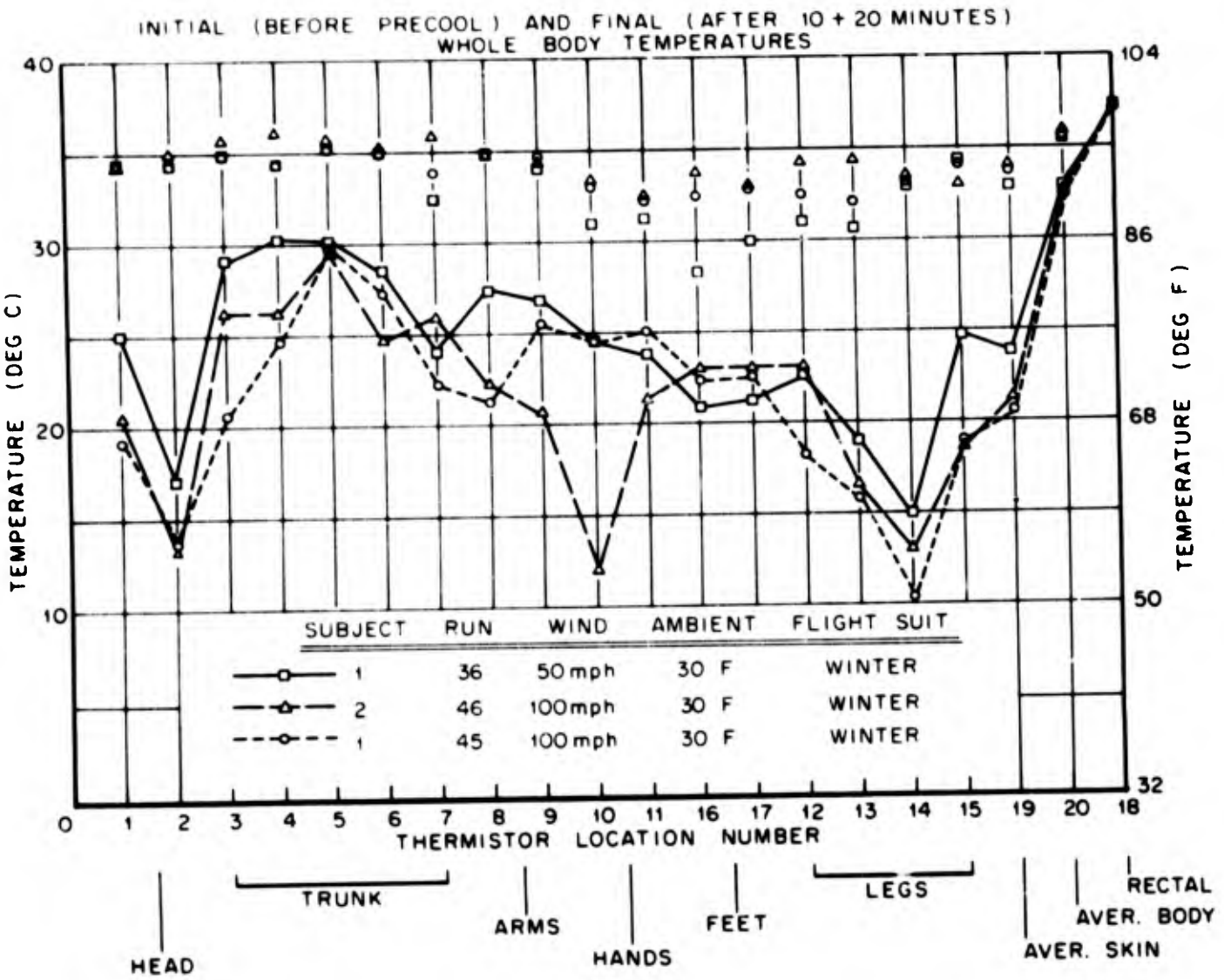


Figure 17. Initial and Final Body Temperature at 50 and 100 mph

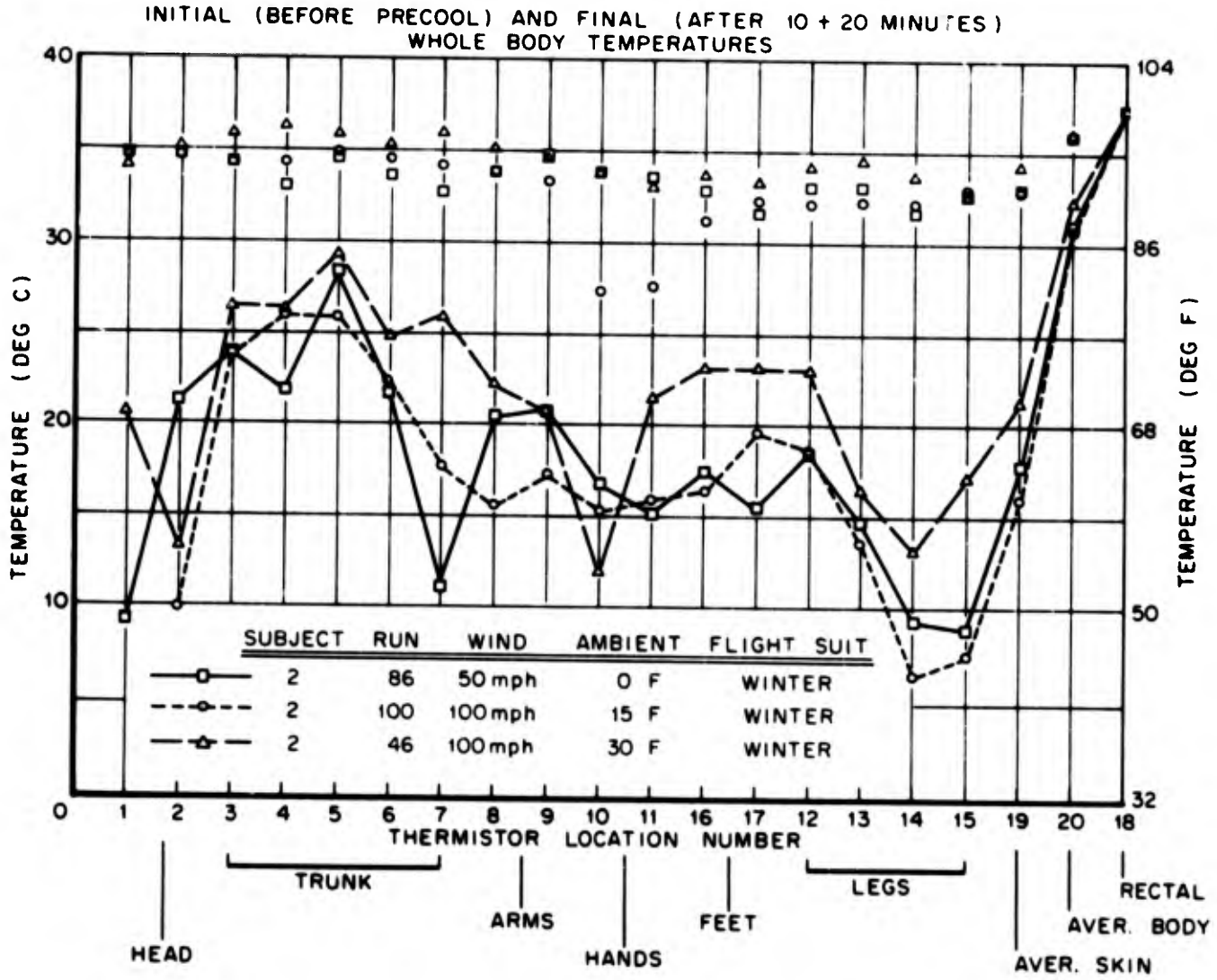


Figure 18. Initial and Final Body Temperature vs Three Ambients

(5) The hood on the winter flight suit served two useful functions. First, it reduced drafts around the neck and chin and, in fact, did prevent frostbite in notable instances. Second, when stretched over the helmet, it plugs holes in the visor shield which otherwise strongly ventilate the forehead and eyes. However, the hood is difficult to stretch over the helmet.

(6) The fitted padded helmet kept the wind out of the subjects' eyes quite effectively without the hood.

(7) At least one subject was considerably bothered by his chin being pushed against the very cold buckle on his parachute harness chest strap.

(8) The soles of the boots form a significant heat sink for a long period after the subject enters a warm room. If it is operationally safe, after the man has been recovered, boots should be removed to avoid any unnecessary discomfort or body heat loss.

(9) All of our full body runs were made with wind impinging on the back. In this attitude the parachute back pack provides significant protection. Also, the helmet protects the face and the body protects the hands.

(10) Subjects were encouraged to put their collars up during the coldest 1 clo runs.

COMMENTS

Additional data concerning the test runs are as follows:

(1) Run 86. Eyes focused slowly after run. No other similar reports.

(2) A subject ingested ice from his mask. This probably would not happend with hose attached, but exhalation valve might freeze.

(3) No difficulty in breathing was reported by any subject when questioned.

(4) Heat lamp on face stopped shivers of one subject. When lamp was extinguished, his shivers immediately returned (Appendix III). (Refer to Appendix V, Phase II, Run 63.)

(5) Right side colder than left; scattered subjective and objective reports.

(6) The only episode of superficial frostbite gave absolutely no warning.

(7) Subjects frequently reported feelings that 100 mph runs were warmer; e.g., on legs, than 50 or 70 mph runs. These reports are not supported by temperature records. Mechanical stimulation of clothing flapping probably caused the misleading perception. Similar reports were made relative to the cold breeze ducted from above into the eyes, of persons wearing standard helmets lacking custom padding.

(8) Cheeks were observed to ripple at 100 mph.

(9) Relative humidity was generally around 40 percent for runs above freezing. On colder runs the tunnel tended to become relatively saturated with moisture.

(10) Some individual differences have been noted in Section III. In addition, Subject 3 who shivered most frequently and heavily had the greatest amount of reported pain especially in bare hand runs. Also, his hands tended to remain blanched during extended runs and even during rewarm in the tunnel. This is in contrast to the experience of the other subjects, 1 and 4 in particular, who exhibited reddening after 5 to 8 minutes of moderately cold exposure or tunnel rewarm; the reddening was followed closely by reduction of both pain and tingling and by increased comfort to the extent of relative warm feelings which would stabilize for extended periods. No clear evidence of Cold Induced Vasodilation (CIVD) oscillation has been noted on the thermocouple records.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Eagan's study (ref 3, pp 822-830) and our limited frostbite experience shows that our tests erred, if at all, toward the side of safety. Reasonably safe human tests could be conducted with care in the areas of lowered skin and rectal temperatures. Superficial but recoverable frost bite, precluding further work with an individual, would impose a greater hardship on the source of volunteers than on the persons affected. Heatherington (ref 9) and Eagan (ref 3) provide precedents. It would be reasonable to estimate that, with other conditions fixed, ambient temperatures could be dropped about 5.6 C (10 F) below our test cutoff points before a group of typical exposures would yield a significant percentage of temporary hospitalizations. This could be approached cautiously.

Since we stopped near -17.8 C (0 F) and 100 mph this would imply the reasonable possibility of favorable rescue conditions in 3 clo down to about -23.3 C (-10 F) and 100 mph. One should note in addition that higher altitude with reduced air density will reduce cooling rates to some degree. This permits us to assume that a sufficiently safe tow for a few minutes, with the same clothing, might be available down to -26.1 C (-15 F) which is the cold atmosphere temperature at 6000 feet as indicated by MIL-STD-210A (ref 11).

Very little, impermeable, material would be required to permit tow at higher speeds and/or for extended periods. These considerations deserve further study.

Since rectal temperatures tended to peak near the end of 30 minutes, longer tow times may induce conditions similar to critical cold water immersions, leading to significant whole body cooling. This is an area suitable for further human testing, preferably with good facilities for at least indirect calorimetry.

Unconscious persons, if not able to shiver, presumably would cool much faster. But air-to-air rescue in such a case, however dangerous, may be preferable to the alternatives.

The hood on the winter flight suit will probably not be used by airmen. This is a bit of practical advice provided by an Air Force officer who is an experienced observer of men flying under winter conditions. This agrees with our observation of the difficulty in using the hood. The result would probably be a higher incidence of cheek and neck frost bite, which from our own experience, is not necessarily significant to an individual being rescued. However, all available data are inadequate in

determining the degree of damage. The same AF advisor suggested that a summer flight suit supplemented by quilted underwear might be selected by men flying under certain winter conditions.

Different clothing combinations yielding equal clo values under standard clothing test conditions should not be expected to provide equal protection under conditions of high speed towing. Permeability to air and ducting between layers will be important parameters. To obtain relevant data, tests must be performed on various combinations on men or thermal dummies at various wind velocities as suggested in the GAC proposal (ref 1, Option A). Facilities for dummy tests will probably be more easily available than for live human tests.

Dummy tests would also provide certain data of value for man rating the same facilities. For example, the same dummy test set up could be used to monitor wind induced pressure differentials between nose-mouth area and the chest as well as other local skin patches. The significance of these pressures to cold responses are treated briefly in Appendix IV, while their relationship to other aspects of "pressure" breathing is the subject of a separate data collection being assembled at GAC.

In addition, certain dummy tests relative to drag, torques, and stability of towing, as well as tests of clothing integrity pertinent to man rating the tunnel and the tow condition could be made, if a realistic dummy, such as Dynamic Dan*, were available.

From the local skin temperature changes and the weights shown in Table I, the temperature computer determined a final mean weighted skin temperature $\overline{T}_s$ of 16 C (60.8 F) at the end of run 100. This was 16.8 C (30.3 F) below the value that the subject had when entering the tunnel 30 minutes earlier. In the meantime, the rectal temperature had risen 0.28 C (0.5 F). If the rectal (core) temperature represents 67 percent of the body mass and the mean skin (shell) temperature represents 33 percent, the resulting net heat loss over the 30 minute run is found to be 345.4 kilogram calories. This is quite large when compared with other experiments in which men have withdrawn after the mean skin temperature reached 70 F with 150 Kcal loss (ref 2). Three possible reasons for the implied discrepancy, are:

(1) The ratio of the core to shell is incorrect for the high wind exposure.

(2) The heat loss is real but distributed differently, in such a manner that the result is tolerable, if adequate rewarm is promptly supplied.

(3) The thermistors, many of which were well covered by clothing, are reacting somewhat too much to the air streaming through the clothing.

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* Impact and Vibration Branch, Biodynamics and Bionics Div., AMRL, Wright-Patterson Air Force Base, Ohio.

GAC cannot resolve these three possibilities at the present time. However, studies are suggested to do so. Other weighted mean skin losses were generally less than 16.7 C (30 F). For example, the blocks of runs(Table VII) including summer and winter flight suits at -3.9 C(25 F) and -1.1 C(30 F) from 70 mph to 100 mph show mean skin losses from 12.8 to 14.4 C (23 to 26F) during 30 minutes. The run at -17.8 C(0 F) and at 50 mph shows a 15.2 C (27.3 F) change in weighted mean skin temperature.

The curves on figure 2 show mean skin temperatures from several experiments with the same subject in the 3 clo assembly. Curves B, D, and F show effect of ambient temperature, in runs for which the wind speeds were the same. Additional reduction of ambient temperature, curve G, did not have a large effect on $\overline{T}_s$, but it did bring about enough change in the local calf skin temperature, under the pant leg, to require shutdown after only 6.3 minutes of running at 100 mph.

Pairs of curves curves such as A and B, both from runs at 10 C (50 F), or E and G, both from runs at -17.8 C (0 F), clearly demonstrate that $\overline{T}_s$ is depressed much more rapidly by 100 mph wind than by 50 mph wind. This suggests that aerodynamic heating is not significant at wind speeds up to 100 mph.

The curves shown in figure 19 were generated by averaging the results obtained from two subjects (figures 12 and 13). These results confirm that for patches of bare skin directly exposed to the stream, a 100 mph wind cools more rapidly than a 50 mph wind and much more rapidly than a 10 mph wind.

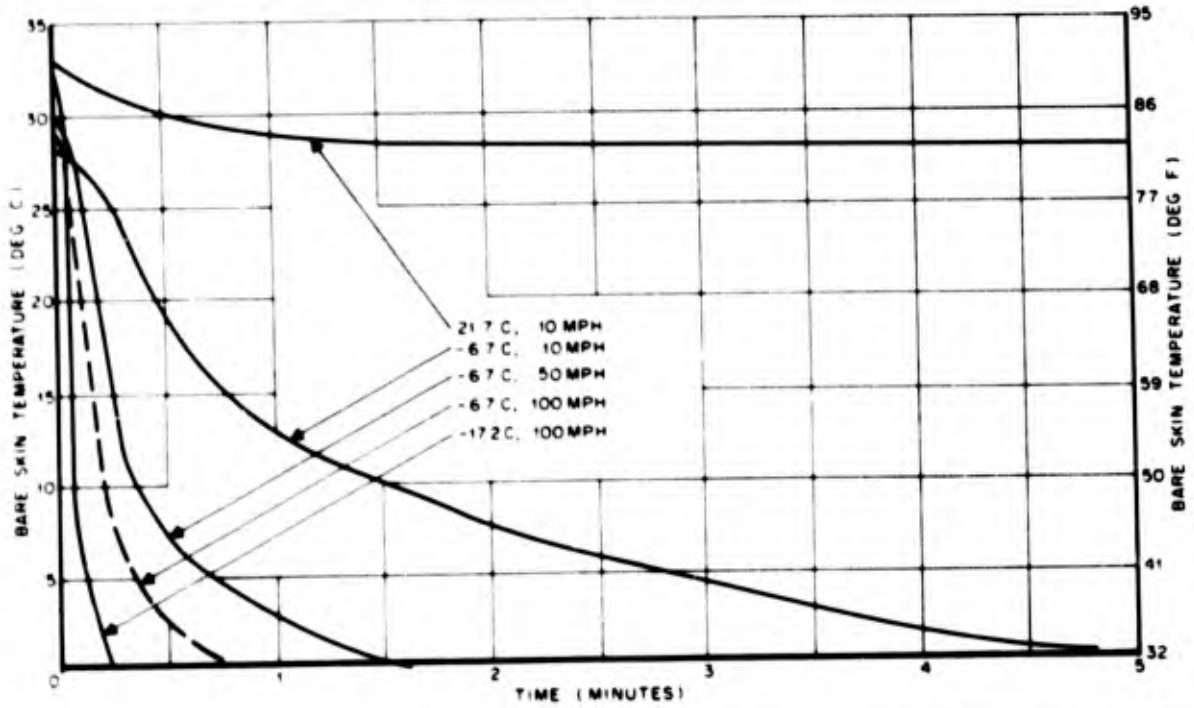

Figure 19. Cooling Curves for Fingers of the Bare Hands of Subjects 2 and 3

There are specific effects of high altitude on the cold responses of men. These may affect more the details of rescue system design than the decision to rescue. T.R.A. Davis, et al. (ref 3, part 1, pp 191-198) examined the effect of altitude on the cold responses of six low and five high altitude acclimatized Jats, Hindu villagers, and also tested 5 Tibetans who had lived their entire lives at 12,000 to 17,000 feet. The Jats, all soldiers, had been raised and were tested at 700 feet, near Delhi, India. The high altitude acclimatized Jats had spent the previous 11 months at 12,000 to 17,000 feet and been exposed to cold there but protected themselves more than native Tibetans.

All cold exposure tests were performed with subjects dressed only in shorts and reclining on a stretcher at 2 C (35.6 F) air temperature for 60 minutes. At 700 feet both Jat groups completed the test with no difficulty. The high altitude acclimatized Jats showed decreasing rectal temperature and less cold induced shivering, electrically recorded, than the low altitude ones.

At 13,000 feet two of the five Jats accustomed to this altitude terminated their tests at 45 minutes because of unbearable pain in the lower extremities, all complained of greater discomfort. Two of the low altitude acclimatized Jats finished the test but with strong complaints of pain in the lower extremities. Two terminated at 35 minutes because of unbearable pain in the same region; and two stopped at 35 minutes because of cramps associated with hyperventilation.

Tibetans exhibited a much greater tolerance to the cold test at 13,000 feet, their only test location, than either Jat group. However, all groups had very similar mean skin temperatures dropping to about 23 C (73.4 F), and rectal temperatures peaking, after a slight rise, at about 20 to 30 minutes of exposure. Foot temperature appears to have dropped a bit faster in Jats; in each group the average stayed above 12 C (53.6 F). Other differences: Tibetans showed much less cold induced change in oxygen consumption than Jats. Also they showed much less shivering than Jats. Jats accustomed to high altitude shivered less (averaged group) than other Jats though both showed increased shivering at altitude. Also both groups of Jats showed a lowered average skin temperature threshold for shivering when at 13,000 feet. The decreased cold tolerance of Jats could not be accounted for by observed values of oxygen consumption nor thermal balance. Davis, et al., concluded that the altitude-induced augmentation of acute responses to cold were probably due to an impairment of non-shivering thermogenesis resulting in a dependence upon shivering thermogenesis and a decrease in cold tolerance, exhibited as pain and discomfort.

The pertinence of these data is enhanced by the fact that the average skin, local, and rectal temperatures have strikingly similar time courses to those in some of our moderate exposures. Also, in run 65, Phase II, the man not previously exposed to cold experienced his first full body

shivers and in the same run had temporary cramps in neck and legs.

Our concern that prompts mentioning this study is not that pain and cramps are an additional source of discomfort. Rather it is that they may indicate physiological changes which will inhibit the person from assisting in his own recovery if needed; but more importantly, pain and cramps may indicate onset of basic physiological changes that could aggravate the man's specific cold injuries. Therefore, a brief review of the physiological significance of these symptoms is one of the proper initial steps of a follow-on biothermal test activity whether in a wind tunnel or in live tow.

RECOMMENDATIONS

Testing under the present contract is now complete, but present data extends only to 102.5 mph and were taken at about 600 feet above sea level. Also, it is apparent that human body temperatures can be lowered further before even light injury occurs.

Tests up to 300 mph and about 3000 feet can be carried out at the Lewis Research Center in Cleveland, Ohio, if we can convince them that reasonable safety can be achieved. We believe that a strong case can be made based on our recent experience at the Lockport facility.

Biothermal study should be extended above 200 knots. Men have sustained dynamic pressures equivalent to 500 knots on bare skin without serious injury (ref 6). Various incidents of difficulty related to wind blast (ref 13) can in part be attributed to unfortunate positions of the body relative to the wind direction or attributed to equipment not designed to function in high wind. High-speed tow during rescue may have several system advantages, including the possibility of using aerodynamic heating to offset heat loss. Figure 20 shows that at 500 knots, the recovery temperature, T_r, the effective environmental temperature, is about 22.2 C (40 F) above the ambient still-air temperature. Whereas, at 200 knots the advantage is only about 4.4 C (8 F). Basic biothermal studies at high speed need not await engineering solutions of buffeting and stability problems.

Certain special clothing problems are anticipated. For example, if an A/P22S-2 full-pressure flying outfit is used (ref 15 and 8), the helmet visor will probably cause difficulties. Goodyear Aerospace understands that when the crewman depletes his emergency oxygen supply, he must open the visor so that he will not suffocate. This would prevent use of the visor for protection from cold injury during towing. Also, the upward jerk induced by the snatch maneuver or the high-speed head-to-foot wind flow during tow would tend to drive the visor shut. Therefore, Goodyear anticipates both recovery system and testing problems relative to the visor. The system problems would be aggravated, if the crewman were injured or unconscious.

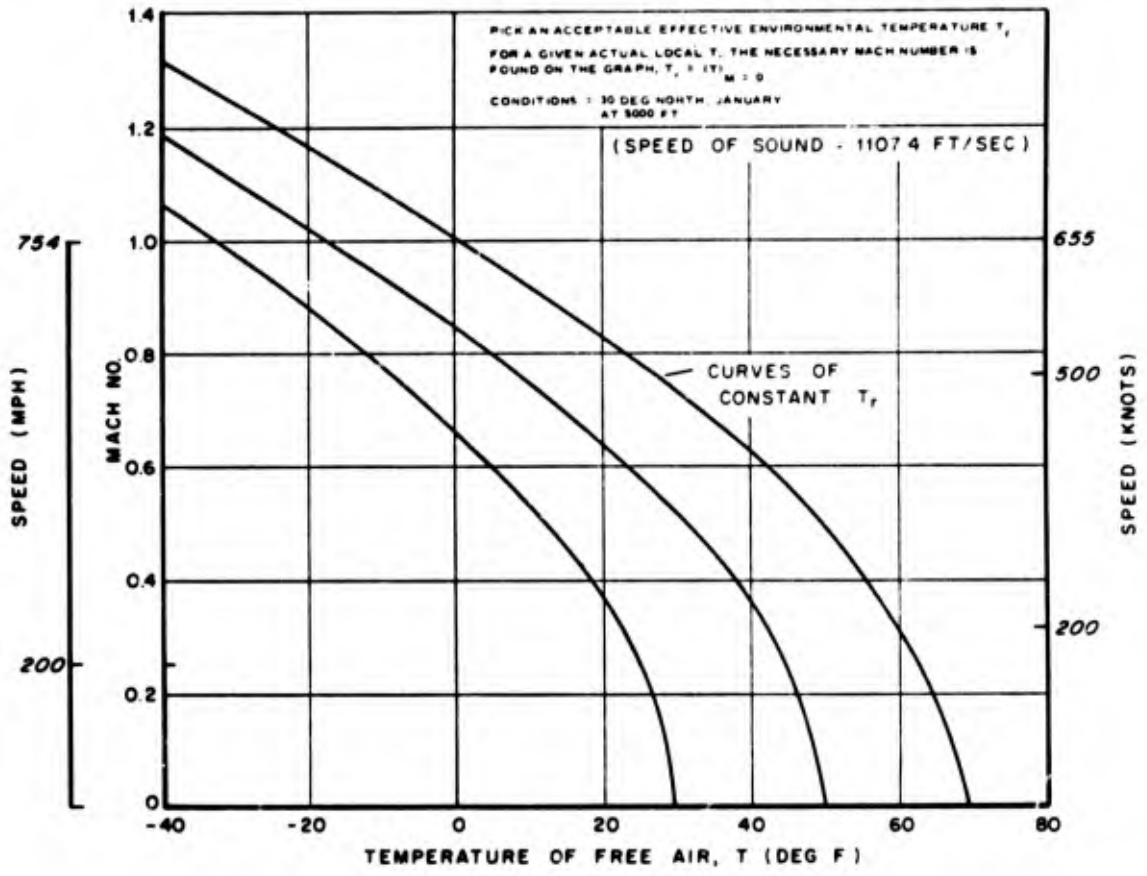

Figure 20. Airstream Recovery Temperature.

GAC can also refine the safety criteria as the tests proceed. Some preliminary animal tests of moderately rapid freezing may be useful for this purpose. These are not essential to the purpose of extending the tests to higher speed but they would help define the distance from a specified danger level.

In addition to and in support of the basic study, GAC may also look at such things as:

(1) Effect of oxygen tension on actual human body temperatures and/or on injury processes in animals.

(2) Probable effects of direct wind pressure on occluding superficial blood flow. This would be a nonlinear effect not properly treated by mere extrapolation.

(3) Testing possible modifications to restrictor valve to allow breathing at very high tow speeds.

(4) Test protective methods for critical areas such as accidentally bared skin.

(5) Study problems of manipulating gear, if needed, in cold wind.

(6) Improvement in the thermocouple technique to improve reliability and reduce the work load related to preparation for tests.

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APPENDIX I

OFFICIAL PROTOCOLS

GENERAL

As a result of experience gained during the tests the basic protocol (17 March 1969, see next page) was changed twice during the test sequence. These changes, increasing the principal investigator's range of choice, were agreed upon during discussion and were formally confirmed by Air Force documents which contained the following statements:

(1) 26 June 1969: Phase II, Line 4 change to read "Tests will explore temperatures approaching tunnel limits (approximately -25 F) ascending by 10 mph increments, with several key locations on the hand continuously monitored and the experiment terminated when any point reaches 32 F, or when mean skin temperature reaches 70 F."

(2) 7 August 1969: Phase II, Line 4 change to "Tests will explore temperatures approaching tunnel limits (approximately -25 F) ascending by 10 mph increments, with several key locations on the hand continuously monitored and the experiment terminated when any hand temperature reaches 32 F; when subjective cold tolerance of subject is attained; or when individual thermistor temperature reaches 40 F."

Data presented in this appendix as "EXPERIMENTAL PROTOCOL" was collected during the span of the contract and is presented as originally reported - together with two "Attachment" pages. The Protocol and Attachments were prepared by the Air Force contract monitors.

EXPERIMENTAL PROTOCOL

I. Title: Windchill Effect on Humans Exposed to Cool Subsonic Airspeeds

II. Project/Task: 7164/716414 (Contract F33615-69-C-1063)

III. Date: 17 March 1969

IV. Principal Investigator: Richard Wilson, Goodyear Aerospace Corp., Akron, Ohio

V. Biomedical Consultant: Webb Associates, Yellow Springs, Ohio

VI. Contract Monitor: Capt. Grant D. Callin, MRET

VII. Medical Monitor: G. Kress Lochridge, Major, USAF, MC

VIII. Purpose: To evaluate the effect of cool subsonic (50-120 mph) airflow on humans. The effect is relative to superficial tissue and deep body temperature changes during prolonged periods (0-30 min) at subsonic speeds. This knowledge will be invaluable in predicting human tolerance in discretionary descent and retrieval operations.

IX. Background: Present day "windchill" charts are of limited value when used for airspeeds of greater than 50 mph. Some of the limitations in the present context are:

1. The "windchill" charts in AFP-161-18 and Gillies' textbook of aviation physiology are based on scientifically questionable assumptions. This is because the tolerance criteria do not define heat loss for various body locations with respect to clo values of a particular clothing ensemble. Furthermore, the windchill charts are mathematically derived, the most valuable human data being anecdotal.

2. For this experiment, the cool air flow will be parallel to the $+G_z$ axis of the body, rather than perpendicular to it as in previous windchill studies. Therefore, the air will flow between the skin and layers of clothing because the air can enter the neck opening; this airflow pattern will increase convective and evaporative heat loss directly in addition to normal core-to-skin conductive loss.

3. The airspeeds to be employed in this study will be substantially greater than any used in previous windchill studies for equivalent time periods. No frostbite predictions have ever been made for humans based on experimental data with windspeeds over 50 mph, and there is evidence that lower speed data cannot be applied with confidence. Iampietro states that an increasing windspeed does not have the same quantitative cooling effect at all air temperatures. For example, at

70 F air temperature and 5-10 mph windspeeds, skin temperature is decreased 1.3 F from still air values; but at 40 F, the decrease with the same airspeeds is 4.5 F. Furthermore, when Hetherington, et al, exposed 79 horizontally positioned subjects to airspeeds of 115-125 mph at -65 F, there were only three minor cases of superficial cold injury at the jacket-glove junctions.

X. Experimental Protocol:

A. Phase I: (At Harrison Division of General Motors, Lockport, N.Y.) Checkout of human reaction and tolerance to normal air temperatures (70 F) at airspeeds of 50 to 120 mph, for times ranging to 30 min. The subjects will be restrained in a fixed cage in a horizontal $+G_z$ orientation to the tunnel airflow. The subjects will be wearing thermal underwear (with skin and rectal temperature thermistors), with summer or winter flight suits, standard flight gloves, HGU-2P helmets, MBU-5 oxygen masks, flight boots, and a B-5 parachute harness system. Respiration, ecg, skin temperatures, rectal temperature, and respiratory rate will be monitored. Air speeds will be increased by 10 mph increments from 50 to a maximum of 120 mph. A suitable number of test runs will be performed to obtain baseline data at each airspeed prior to incrementing the airspeed.

B. Phase II: (At Harrison) Evaluation of reactions to temperature variations at constant airspeeds (airspeed range 50-120 mph). The same clothing, restraint system, and monitoring will be used as in Phase I. These tests will completely fill an experimental matrix of incremented airspeeds and temperatures, with 10 F increments down to 40 F and 10 mph increments from 50 to 120 mph. In all cases, the temperature will be decremented at constant airspeeds; e.g., at an airspeed of 50 mph, a test will be made at 60 F, then another at 50 F, then a third at 40 F, then the process will be repeated at 60 mph, etc. If physiologic monitoring indicates the necessity, the temperature decrements will be cut from 10 F to 5 F or less; if any evidence of pathologic changes in the subject occur, experiment at that stress level will be discontinued. A suitable number of tests will be performed to obtain meaningful baseline data throughout all tolerable areas of the experimental matrix.

C. Phase III: (At Harrison) Evaluation of effects due to loss of personal equipment (simulating equipment loss during ejection sequence). The same experimental ensemble will be used as in Phases I and II, with the exception of certain items which are likely to be lost in a real-life ejection. Thus, the experimental matrix of Phase II will be accomplished with one or both gloves missing, or without an oxygen mask (in this latter case, a throat microphone will be used in

conjunction with the helmet earphones to provide continuous voice exchange between subject and investigator). It is expected that rapid localized cooling will take place on exposed flesh, and intradermal thermocouples will be used to carefully monitor skin temperatures in these instances.

XI. Hazards and Safety Measures: These studies have two aspects not usually encountered in subthermal experiments performed on human subjects: (1) any reactions to the cold ambient temperatures will occur at a rapid pace, and (2) there will possibly be effects due to windblast. In general, the stepwise approach to testing will provide running baseline data on which to build knowledge and make predictions of reactions from one experiment to the next. During the entire study, the subjects will be closely evaluated before, during, and after each test run. The human subjects will notify the investigators of any burnlike feelings on the skin, skin numbness, loss of skeletal muscle control, dyspnea, orthopnea, chest pain, tachypnea, recurrent coughing, or hemoptysis; this includes notification before, after, and during each test. If the stated signs/symptoms occur during a test, the run will be discontinued immediately and care will be administered. Additionally, if the principal or medical investigator see symptoms incompatible with continued homeostasis of the subject, they will immediately discontinue and administer medical care as necessary. Other reasons for discontinuing any test will be as follows: (1) loss of communication with subject, (2) loss of objective readouts of skin or rectal temperatures, (3) desire of subject to withdraw, or (4) opinion of any of the investigators that the subject should be withdrawn. The subjects will be three volunteers from the 6570 AMRL hazardous duty heat panel, and an Air Force physician will always be present as a medical monitor during all tests.

ATTACHMENTS

Attachment 1. Effects of Whole-Body and Localized Hypothermia on Humans

Even though present day "windchill" charts are not useful in this experiment, observations from previous cold experiments can serve as valuable indicators for these tests. The useful observations gathered from the literature are as follows:

The Body Core

a. The conservation efficiency of body heat varies among individuals, whether or not they are cold acclimatized.

b. During cold exposure, metabolism increases to a maximum when core temperature decreases to 95 F (35 C). After this, the body generates heat by shivering, which ceases generally soon after the core temperature gets below 90 F; at this point, thermoregulation begins to fail.

c. Deterioration of cerebration and speech are clinically evident at internal temperatures below 95 F, along with some deterioration of other body functions.

The Body Periphery

a. It is well known that peripheral vasomotor changes occur with cold exposure. Most evident is the vasoconstriction with shunting of blood from superficial tissues; in other words, the body tends to sacrifice the extremities in order to protect the core.

b. The head does not appear to respond to vosomotor control; in cold exposure, it is estimated that the head contributes as much as one-half of the total body heat loss in a resting subject. The head sites which have the greatest potential for tissue freezing are the tip of the nose, ear rims, and cheeks.

c. It has been stated that the human hands, face, and feet can operate without discomfort or visible tissue damage even when the skin temperature in these areas is more than 18 F lower than core temperature. The following observations seem to be rather uniform parameters of human skin cold reaction:

(1) At skin temperatures of 70 F, tolerance is about 2 hours. Below this temperature tolerance time decreases "rapidly."

(2) A skin temperature of 60 F seems to be a "break-off point" below which manual dexterity shows a "serious" decrement; below 55 F, this decrement becomes "severe," and is described as "extremely severe" at skin temperatures below 40 F.

(3) Tactile sensitivity (2 point test) begins to decrease rapidly as skin temperatures decrease below ; this effect is due to the fact that nerve conduction in the body is highly temperature-sensitive.

Attachment II. Physical Features of the Windchill Test Chamber

The General Motors (Harrison Radiator Division) Cold Tunnel at Lockport, New York, can be safely operated for the purposes of human windchill studies. This statement is based on the physical features and setup of the tunnel, to be described as follows:

1. The tunnel environment

a. The Lockport Cold Tunnel is a closed loop subsonic open-throat tunnel capable of maintaining constant airspeeds between 0 and 120 mph. The drive fan is a generator-driven 20-blade aluminum propellor. Between the fan and the adjustable nozzle opening is a steel mesh grating (one-inch openings) and a square-formed louvered grating, used to provide uniform airflow at the nozzle opening. Both gratings form barriers in case of fan blade disintegration during operation.
b. An envelope of uniform air flow and velocity is maintained from the louvered grating to 6 feet aft of the nozzle opening; this makes the volume of uniform flow 12 feet long, 4 feet high, and 5 feet wide.

2. The control room

a. An observation window, 3' x 5', is located opposite the nozzle opening, so that tunnel controllers have vision contact with the test area. The control panel is located adjacent to the window.
b. Printers for multiple temperature recordings are located within the control room. Plug-ins are available for monitoring ecg and other physiological data.

c. Maintenance of constant air velocity is accomplished by control room rheostats; air velocity is monitored by readouts from pitot tubes located within the nozzle throat. Air velocity charts containing corrections for temperature and barometric pressure are located in the control room, and actual velocity can be controlled to within 0.5 mph of that requested.
d. Air temperature is monitored by thermistors situated in the free air stream at the nozzle. Temperature is controlled by three brine tanks (-40, -20, and 120 F) which variably feed into overhead brine coils in the tunnel. Once a required temperature is reached, it can be controlled to within 0.5 F.

3. Safety considerations
a. The airspeed at the nozzle can be changed from 120 to 0 mph in less than 30 seconds, by braking action on the fan.
b. The human restraint cage will be mounted on two permanently fixed steel rails on the chamber floor; these rails are capable of restraining a full sized automobile in high velocities.
c. Altitude variation secondary to specific dynamic pressure is less than 1000 feet, relative, for an airspeed change of 120 mph.
d. Debris in the tunnel is minimal, due to the scrupulous janitorial regime maintained therein; nonetheless, subjects will wear goggles at all times.
e. Relatively little airblast occurs at the sides of the nozzle; therefore observers can comfortably stand as close as three feet from the test subject during a run.
f. We found the overall noise level in operation to be 100 db; to offset this, subjects will wear earplugs and/or the standard HGU helmet ear coverings to reduce sound by 20-60 db.

APPENDIX II

THE FREEZING INJURY: The Medical Aspects of Frostbite

INTRODUCTION

The amount of literature dealing with cold injury is tremendous. Historically, the number of studies in a particular period is in many ways directly related to the increase in incidence of this type of injury during wartime. The number of cases occurring routinely in the civilian populations in the temperate zone is apparently so low as not to free the dollars for or scientifically motivate the medical profession to conduct a progressive research program in cold injury. Research on this problem, whether dealing with human subjects or laboratory animals, has been predominantly clinical in nature - - that is, the results of a more or less controlled trauma have been assessed in terms of the total result at the local or general physiological level. Often this approach ignores between cause and effect myriad influencing factors. Other than those performed in the Nazi concentration camps, few studies have been done with human subjects. In studies available, little emphasis has been placed on defining the environmental-skin relationships.

Meryman (ref II-5) has perhaps best summarized the situation in the following statement:

> "In the mammoth literature of cold injury where variations - in temperature, duration, and circumstance of cold injury; variations in species, race, location of injury and motivation; variations in initiation, method and duration of therapy as well as variations in the observer, his criteria and his terminology, all contrive to make it virtually impossible to assemble these clinical data into a clear picture of the injury, its etiology, its mechanism and its treatment."

Nevertheless, this report will, as briefly as possible, attempt to summarize the medical aspects of this information without delving into matters of semantics, etc., particularly with regard to the nature of the freezing injury, its classification, its prevention, and its treatment.

GENERAL

Cold injury due to cold exposure can be divided into two major categories: non-freezing and freezing. The first category generally applies to pathological conditions which result from rather long term exposures to above freezing temperatures. Typical examples of this type of injury are trench foot and chilblains. These are somewhat chronic conditions; however, the mechanisms of injury and the methods of treatment are very similar to those found with the freezing type of injury.

Freezing injury has traditionally been called frostbite, although very mild forms called frostbite may not involve actual freezing of living tissue. Washburn (ref II-7) chooses to call this type of injury "frostnip". Freezing injuries (including "frostnip," since it may be equivalent to what is described as first degree frostbite) are rapid in onset when compared to trench foot and chilblains. They result from varying amounts of exposure to severe environments. Bare areas of the body, particularly the distal portions of the extremities (fingers and toes) and the head (nose tip, chin, cheek, and pinna of the ear) are commonly afflicted. The injury may involve only the very surface layer of the skin (cornified, dead, low H_2O containing cells), in which case it is called first degree frostbite, or it may extend down through the tissues to include bone (fourth degree frostbite).

Since most frostbite injury victims are clothed and the exposure time may be short, general body heat debt (hypothermia) often is not the case. Typical of this type of injury is "high altitude frostbite," a category differentiated by some authors (ref II-7, -1 and -2). The severity of the environmental conditions extant at high altitudes, particularly in aircraft, presuppose very rapid freezing without measurable heat loss from the body core. The mechanisms involved, as far as the freezing process is concerned, appear to be the same as one would experience with slower injuries obtained on the ground. Hypoxia in aircrew victims has been suggested as a possible contributing factor in addition to the windchill and low temperatures for high altitude frostbite.

Shivering, a mechanism to increase body heat production, will occur in cold exposure. However, the heat produced is largely held central to the subcutaneous layers beneath the skin because of the vasoconstriction of the surface vessels in response to the cold stimuli; hence the skin proceeds to freeze. Fingers and toes, despite the fact that they may be used to temperature extremes, and despite their ability to demonstrate the protective phenomenon of vascular "hunting," may be particularly vulnerable to freezing due to their relatively large surface area to mass relationship. Adaptation to cold environments has been shown to improve one's ability to withstand cold injury; however, this factor may be of little significance if the environment is severe enough to freeze exposed skin in a few minutes.

THE NATURE OF THE FREEZING INJURY

Prefreezing Phase

- Visual changes: Visually observable changes in the skin during this phase are extremely variable, depending upon the individual response and the time available for this stage. Generally, however, an initial transient reddening generalized to the exposed area passes into more localized pallor which leads to yellowish patches as the phase ends. If

time allows because the environment is not severe, cyanosis may occur. Cold increases the permeability of vessels, resulting in transudation of fluid which causes swelling.

- Subjective sensations: The exposed subject first will feel the "cold" input from skin thermal receptors. As the body responds to this information, pain develops. Next, a variety of sensations may occur which is best described by the term paresthia. Paresthia ends with numbness which develops into a more localized anesthesia. Distinct separation of these sensations may be time-environment and individual dependent.

- Physico-physiological phenomena: Local peripheral vasculature is probably the first to respond to the cold. Arterioles supplying warm blood to the area constrict, reducing oxygen and heat inputs. Combined with venular dilation, blood flow slows and the resulting erythro-hemostasis lays the groundwork for later thrombosis. Meanwhile, capillary shunts and/or arteriovenous anastomoses are called into play to help protect adjacent areas. Release of epinephrine-norepinephrine in response to cold and/or due to apprehension and excitement may augment the situation in generalizing peripheral vascular shutdown. The cooling blood becomes more viscous (increasing as much as three times), further reducing blood in-flow, resulting in a local ischemic hypoxia.

Even though the cooling tends to reduce the cellular metabolism, anaerobic metabolism goes on with the accumulation of lactic acid which lowers the pH. The acidity in the cells plus the reduced temperature affects enzyme activity and may cause proteins to precipitate. This, by itself may cause irreversible damage. Additionally, the hypoxia may initiate nerve damage, since nerve tissue is particularly susceptible to the lack of O_2. The vasospastic reactions, cold, pH, etc. changes can cause fluid leakage (swelling) and sludging of the red blood cells to further complicate the picture. The multiple cyclic phenomena which started as protective measures seem only to amplify the chain reaction responses leading to ice crystal formation. *

* This paragraph includes several possible ramifications of the pre-freezing phase. It is not fair to imply a fixed sequence of these events or rank them in order of importance as the ultimate main cause of cold injury. Indeed, many additional reactions could be included. Or, if the process of this phase is speeded by extremely severe conditions, such as might occur in wind tunnel tests, many of the responses mentioned may be by-passed or insignificantly developed before ice crystals are formed. These responses obviously involve living cells; hence, I have been talking about tissue below the stratum corneum of the skin. Ice crystals probably would not form in the cornified layer because the H_2O content is low. These cells may be lost without damage in any case.

Freezing Phase

- Visual changes: The pallor of the pre-freezing phase with its yellowish patches gives way to blanched whitish plaques as freezing occurs. (This response is somewhat variable depending on the speed of onset.) The skin takes on a waxy appearance. Small frozen areas (or plaques) may be hard to the touch and independently palpated. The frozen area may be sharply demarcated.

- Subjective sensations: Entering into this phase the freezing area may be anesthetized or numb. At the moment of freezing, most subjects report a "ping" or "prickling" sensation which coincides with the blanching. This reaction subsides and the area is again anesthetized for the remainder of the freezing period. If the exposure continues, joints in the area stiffen and tissue in the surrounding area hardens.

- Physico-physiological phenomena: The first ice crystal to form triggers a chain reaction. Probably, unless the exposure is extreme, these crystals are formed in the extracellular spaces. Water is supplied to the rapidly proceeding process from the cells, causing a concentration of solutes intracellularly (also extracellularly). If the conditions are severe, crystals may form randomly throughout the tissue. Mechanical disruption of the cells by the crystals, once thought to be a major cause of damage, is now considered to have a minimal effect. The concentration of electrolytes and solutes only serves to augment the hemovascular phenomena initiated during the pre-freezing phase. Ice may cause complete blockage of the blood flow to the area, leading to coagulation (thrombosis) in supply vessels adjacent to the frozen area. The combination of factors may cause hemolysis (rupture of the erythrocytes). Anoxic conditions now exist in the area. Supercooling or sub-freezing temperatures may be obtained before crystalization occurs due to the freezing point depression caused by substances in solution plus variable skin factors (oilyness, dryness, etc.) If the freezing conditions continue, the process is progressive, with deeper tissues, tendons, and ultimately bone becoming involved.

Thawing Phase

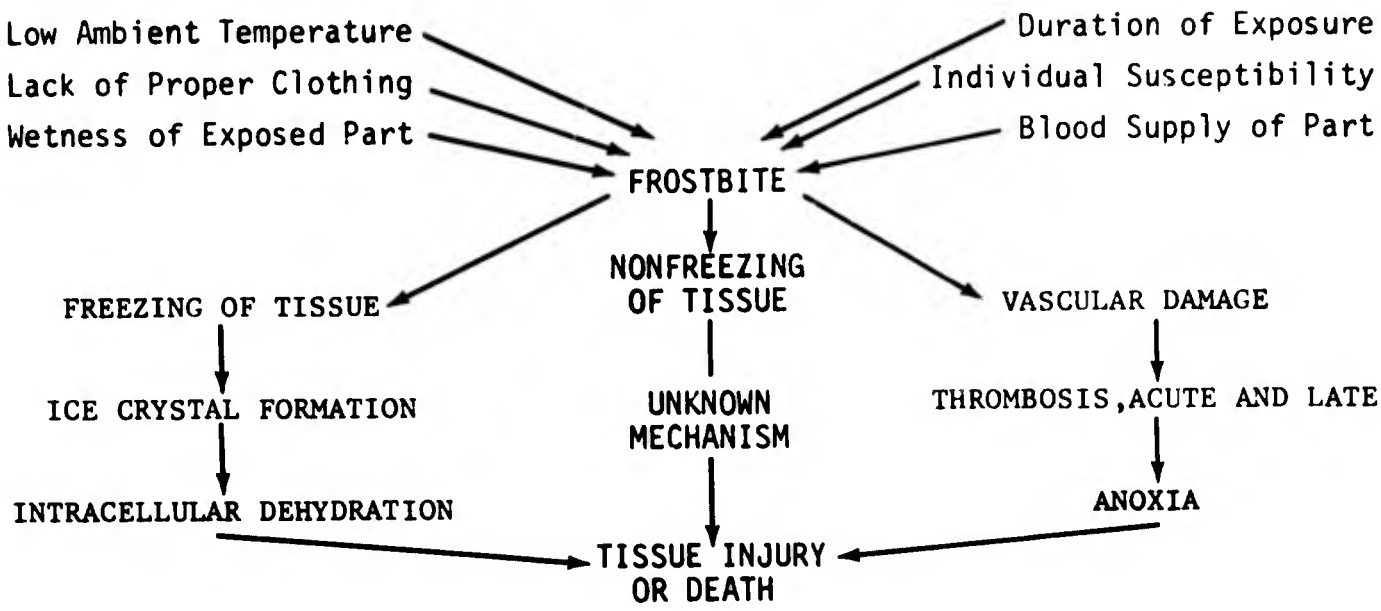
- Visual changes: Upon thawing, the sequence termed "the triple response" by Sir Thomas Lewis (ref II-4) is observed: local skin reddening (reactive hyperemia) followed by a "wheal" at the site of injury and subsequently by a

"flare" in the margin tissues. Depending on the extent of injury and time, the wheal becomes a bleb (bulla) or blister (vesicle) on the skin. The blisters are fluid filled. The yellowness of the fluid may be directly related to the amount of cellular damage. Fibrin-like clots can form in the blisters. If the area dries and darkens, eventually black eschars will form. Necrosis with dry gangrene may follow. Tissue is sloughed in amounts related to the depth of injury. If bone (or periosteum) is damaged, a natural amputation may occur, or surgical intervention may be necessary.

- Subjective sensations: Associated with the reddening response will be the onset of throbbing pain. The pain will persist after thawing is complete and become so intense that the victim will require medication to alleviate it. Periods of time may be pain-free; however, forms of paresthesia will be manifested. The degree of pain experienced may be altered by the thawing method used. Rapid warming by immersion in warm water is usually more painful; however, it is presently believed that less damage will result.

- Physico-physiological phenomena: As the ice melts, a vasospastic reaction causes the area to be perfused with blood. Blood may pour from ruptured capillaries to form petechiae under the skin. Water freed by the melting ice plus additional fluids transudated by changing vascular permeability accumulate under the skin to form blisters. Combined with poor venous return, fluids also accumulate in the tissue to cause edema. Sludging red blood cells may block capillaries causing hemostasis leading to thrombosis. Anhidrosis develops in the area, possibly due to sweat gland damage or nervous damage. This may be followed later by hyperhydrosis. Cells damaged either by mechanical disruption, concentration of solutes, deactivation of essential protein-enzyme systems, or anoxia gradually become necrotic and are sloughed in a gangrenous process.

In summary, the sequence of events in the pathophysiology of frostbite is a series of interrelated and cyclic phenomena. The total picture has not been established at this time. Following the scheme of Hermann (ref II-3), the following simplified picture of the process is presented:



CLASSIFICATION OF INJURY

As with many types of traumatic injuries, an attempt has been made to classify frostbite or freezing injuries into categories of severity. Although experts are not in full agreement how the divisions are made, or if they should be made at all, we shall present one scheme hoping to clarify aspects of the injury not so far made clear. Much like burn injury, frostbite has been divided by some authors into four degrees of injury. Categorization of a given injury into one of the four categories cannot occur until some point in the recovery period, since the severity of an injury cannot be readily determined immediately after the exposure. This judgment may begin, however, after thawing. Persons with fourth degree (most severe) injuries will typically exhibit all the signs of the lesser injuries proximal or surrounding the extensively damaged tissues. Following the description of Orr and Fainer (ref II-6), we have briefly summarized the characteristics of the degrees of injury in the following four paragraphs.

First Degree Frostbite. First degree frostbite is characterized by numbness at the time of injury, reactive erythema, and swelling after thawing followed by superficial desquamation of damaged skin. Stinging and burning pain will accompany rewarming. Swelling begins in less than three hours, and edema may persist for as long as ten days, depending on the effectiveness of the treatment. Only the superficial layers of the skin are damaged, and this tissue is usually sloughed without complications in five to ten days. The only sequelae appear to be persistence of paresthesias, cyanosis, hyperhidrosis, and continuing complaints of cold sensation of the affected area. The underlying skin is apparently undamaged, and it is doubtful that any ice crystals were formed during the exposure.

Second Degree Frostbite. In addition to the hyperema, edema seen in the first degree injury, fluid containing blisters usually appear within 12 to 24 hours after rewarming. Without aspiration the vesicles usually dry in approximately 14 days, forming hard black eschars. Subcutaneous tissue appears not to have been damaged, since the skin underlying the eschars upon their removal is seen to be intact. First degree injury will be observed proximal to the second degree damage. Complications and sequelae for this type of injury are very similar to those occurring as a result of first degree injury.

Third Degree Frostbite. Third degree frostbite is a full skin thickness lesion which extends into the subcutaneous tissue. Vesicles may or may not form; however, the black, hard, dry eschars are present in addition to ulceration. Debridement of this tissue may be necessary to expose granulation tissue. Anesthesia and paresthesias may persist well into the recovery phase. Gangrene may develop, requiring surgical intervention. Complications such as infection are common. As much as two month's time may be required for complete healing. The site of the healed ulcer is scarred and indurated.

Fourth Degree Frostbite. There is destruction of the entire thickness, including bone, which results in loss of the part either through surgical or natural amputation. Dry gangrene with necrosis will invariably be involved. Pain may persist for two weeks, and paresthesias may last for 30 days or more. Gangrene will appear approximately in 36 days. Demarcation extending down to the bone may take 60-80 days. Infections and/or wet gangrene may necessitate earlier surgical amputation to prevent excessive losses of body parts. Sequelae include all of the symptoms of the lesser injuries, only more pronounced, and can develop in tissues proximal to an amputation site.

PREVENTION, FIRST AID, AND THERAPY

Aside from the obvious, not wearing sufficient protective clothing in the freezing environment, there are other factors which should be considered, if severe frostbite injury is to be avoided. Several of these factors are discussed below.

Prevention

- The level of general health should be good. An existing disease state, chronic or acute, increases the chance of cold injury. The level of physical fitness should also be good. Vascular disease or even the vascular lassitude of poor physical fitness from inactivity are particularly strong contributors to the incidence of injury. Fatigue may act similarly.
- Trauma, prior to or during the exposure, particularly, if the

shock reaction phenomenon has been triggered, will predispose one to cold injury. Blood loss is a common initiator of shock.

- Chronic malnutrition or transient malnourishment may be contributory to the injury process in that an injury which might have been minor becomes more severe.
- Heat debt prior to the freezing exposure complicates the freezing injury. Previous frostbite predisposes one to subsequent injury. Also, sweating with subsequent wet clothing should be avoided.
- Whether hypoxia increases the liklihood of injury has not been clearly established. Since anoxia is part of the damaging process in freezing tissue, existent hypoxia is likely to augment the situation. It can be stated that the effects of hypoxia on mental (rational) decision making may pave the way to injury, e.g. failure to put on gloves which are immediately available.
- Physiological factors such as excitement and anxiety may contribute to injury. Physiologically, the release of vasoactive agents, e.g. epinephrine, norepinephrine, associated with excitement probably has an effect. Also increases in heart rate, stroke volume, and respiratory rate will lead to heat re-distribution and loss from the body.
- Tight fitting clothing causing restricted blood flow, particularly to the vulnerable distal portions of the limbs, should be avoided. Medicines and alcohol in the system at the time of exposure are to be avoided. Alcohol causes peripheral vasodilation and also affects the ability to make rational judgments.
- The cold adapted individual may better withstand the freezing injury. It is doubtful if acclimatization, in the usual sense of the term, is beneficial.
- Training of individuals in prevention and first aid measures will help avoid serious injury.

<u>First Aid and Therapy</u>.

Immediate measures are:

- If possible, remove or protect freezing area of the body from the environment immediately upon blanching. Take advantage of body warmth, e.g. place bare hands in armpits. Reorient body with respect to wind to reduce direct bare area exposure. Reduce effective body surface area, e.g. assume fetal position.
- Loosen any tight fitting clothing. Maintain body warmth.
- Avoid traumatizing frozen area. Do not massage or rub with ice or snow. Use care in removing clothing which must pass over the injury site.

- Prevent shock, if indicated, by keeping body warm and administering intravenous solutions, e.g. saline, low molecular weight dextran, etc.
- Administer O_2, if hypoxia exists.
- Initiate rewarming (thawing) of the frozen part. Select thawing procedure:
  a) Rapid: immerse (or bathe) injured area in water controlled at 40-42 C, at least until area reddens from reactive hyperemia.
  b) Slow: re-warm by exposing area to room temperature at 21 to 25 C. DO NOT PACK IN SNOW OR IMMERSE IN ICE WATER.

Early Treatment.

- Give medication for pain, as needed, e.g. meperidine, morphine.
- Cleanse area gently, if required, with a weak antiseptic soap solution.
- Administer a booster dose of tetanus toxoid, if required.
- Administer antibiotics if indicated by open pathway for infection.
  Do not rupture blisters that form.
- Leave injured area exposed to room environment (21-25 C preferred), or lightly bandage, if it is necessary to transport the victim.
- Limit smoking and alcoholic intake.

Later Treatment and Therapy.

The following is a list of medications and treatments which have been used in frostbite therapy with highly variable results. The need for or the selection of a particular regime of treatment is generally dependent upon the extent of the injury and is a judgment which must be made by the attending physician. It is an impossibility to make recommendations, since the literature on frostbite therapy often presents diametrically opposed views on the matter of the use of a particular drug or methodology.

- Bed rest is recommended, particularly if the feet are involved.
- A well balanced, high protein diet is desirable.
- Open exposure of the injury to room environment at 21-25 C.
- Continue administration of analgesics as required, with gradual removal from narcotic forms.
- Continue limitation of smoking, due to vasoconstrictive effects.

- Antibiotic therapy should be continued, especially if debridement, sloughing of eschars, or development of wet gangrene occurs.
- Sterile techniques should be used in all direct contact treatments.
- As early in the treatment phase as a decision can be made, the following therapies may be useful:
  a) anticoagulant therapy, e.g. heparin, Dicumarcol, etc.
  b) vasodilator therapy, e.g. amyl-nitrate, nitroglycerin, alcohol, papaverine, salicylates, etc.
  c) oxygen therapy, including hyperbaric treatments.
  d) ultrasound and/or diathermy treatments.
  e) physiotherapy--exercises and whirlpool paths.
  f) sympathetic block--injection of alcohol into sympathetic ganglion, or sympathectomy.
- If gangrene develops, it should be watched for development of infection and treated accordingly. Surgical debridement may be indicated for eschars or necrotic tissue. Surgical amputation is indicated, if impending natural amputation is likely, to stop progressive necrosis or infection, and to limit the extent of complicating factors.

SEQUELAE

The most obvious complication resulting from the freezing injury is the loss of some body part through amputation. With or without amputation, paresthesias in the area will continue after healing. A feeling of coldness in the area may persist and the area is particularly susceptible to later cold injury. Loss of the sweating response (anhidrosis) may be seen. Arterioles proximal to the site show changes (thickening of the intima) which may persist.

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APPENDIX III

COMMENTS ON FIRST AID FOR CHILLED PERSONS AND RELATED COLD DAMAGE PHYSIOLOGY

GENERAL

First aid development was not a stated objective of this study but it is important from the standpoint of assembling a most effective integrated rescue system; it inevitably appeared in various parts of the literature on cold injury; and it was considered as a part of preparations for the test series. Local cold injury or general hypothermia will provide complications to the treatment of blood loss, shock or central nervous system (CNS) injuries which may otherwise be of primary interest. CNS injuries and respiratory or circulatory problems also tend to aggravate the relative hypoxia of persons who have hanged or been towed at altitude for extended periods. Our discussion centers on prevention rather than correction of overt damage.

Of course, relative to cold injury alone the body core temperature must have priority over local frost bite or discomfort in the treatment protocol. It would appear from our test series that protection from frost bite might be presumed to assure protection from dangerously low rectal temperatures for tow periods of the order of twenty or thirty minutes or less for generally healthy men. This statement deserves deeper consideration and generalization since a rule of thumb of this nature would be quite useful for the attending medical personnel who will need to make rapid decisions regarding rewarming and other treatment procedures. Since our subjects indicated (1) in some cases a peaking of rectal temperature near the end of a full thirty-minute run, and (2) generally a slow steady reduction of rectal temperature for about an hour after removal to a warm 23.9 C (75 F) room, we would expect extended tow up to say an hour or more under stressfully cold conditions to be accompanied by significant reduction of rectal temperature toward a critical level, say 32.2 C (90 F) (see figure 10) even in the absence of frost bite. We have been informed that inadequate rewarming attempts may be more dangerous in this case than none at all. Specifically, persons who may have been immersed for example in cold water, whose core is relatively cool and whose shell (skin and peripheral parts of limbs) is colder and also vasoconstricted, may be rewarmed at moderate speed with disasterous consequences. Their vasoconstriction may be relieved via skin thermal stimulation which is inadequate to strongly rewarm the shell tissues. Then the core is subjected to a deluge of cold blood and it may be cooled enough to carry the person into a distinctly dangerous or fatal condition.

A similar or synergistic phenomenon may occur if appreciable cold blood pooling in the lower limbs has been induced by the subject's extended hanging and/or towing in a parachute harness. During tow the vector

combination of air loads and body weight may press the man into his leg straps with forces considerably greater than his weight alone.

Thus, we are presented with three alternatives:

(1) No specific rewarming attempt except placement in a moderate room, allowing the body to provide its own heat via shivering, etc.

(2) Moderate rewarming efforts which in some cases may be dangerous

(3) Enthusiastic rewarming of periphery and perhaps core directly, which may be designed to prevent significant temperature drop of core.

Unfortunately, we are not prepared to specify numerically the conditions under which Item 2 is dangerous nor the optimum methods by which Item 3 may be accomplished. Operationally, in air rescue work, a person towed more than one-half hour would probably be released to fall near ground facilities rather than being winched into the aircraft. This situation, if confirmed, could help to define the differences in first aid equipment provided in the rescue aircraft and at ground facilities.

In our study combat boot soles, cooled during tow, caused an uncomfortable and presumably significant heat loss after the subject was removed to a warm place. Unless contraindicated by other consideration the subject's cold shoes should be removed immediately after he is recovered from tow.

John H. Talbott (ref III-6, pp 244 etseq) suggests slow rewarming. He suggested initially placing the man in an environment just above 0 C (32 F) for observation and then warming his core at only 1.1 to 1.7 C (2 to 3 F) per hour. His suggestions appear to be based on work with profoundly cooled persons, core down to 75 to 85 F for several hours to days. This long duration of cooling encourages a significant shift of fluid from blood into the tissue; and he recommends that warming should progress slowly enough that the reverse shift of fluid can keep pace with the relaxation of the vascular bed. This may be assured by keeping the systolic blood pressure above 100 mm Hg. Brief recooling may be used to reestablish blood pressure. Administration of fluid intravenously is desirable. Vigilance should not be relaxed until the temperature is normal.

Talbott (ref III-7, p 254) also states that more rapid rewarming may be acceptable if the deep hypothermia has persisted only a few hours. The primary objectives of first aid for deep body hypothermia should be maintenance of respiratory and circulatory functions, the other body systems will then recover except perhaps for a few frostbitten areas.

GAC may extend Dr. Webb's suggestion for our volunteers to recommend that a man in essentially normal condition except for chilling may be encouraged to perform certain exercises to supplement the heat input from shivering. This may be especially beneficial to certain persons who have little propensity to shiver. It is important to remember that we are not dealing with persons who are in a state of profound fatigue, but persons who have in the worst case been exposed at the very most two hours to an

acute chilling experience. But they have quite sufficient reserves, if not mutilated, to replace from inside much of the heat they have lost.

Also, if a man is hanging, especially in a cold situation, for a long period before pickup, he should probably be encouraged to occasionally pull his body up, away from the leg straps, by tugging on his risers. This will supply some heat, but more important will help maintain circulation and reduce blood pooling in his legs. The latter may become a significant factor affecting leg skin cooling during tow and delayed core cooling after retrieval. His action should also contribute to his general physical readiness should he be forced to land by parachute after or in lieu of towing.

Historically, frostbitten areas have been rewarmed in many ways. It does seem agreed now that rubbing or other mechanical stimulation is not advisable due to the potential for aggravating tissue damage. J. D. Nelms (ref III-2, pp 838-839) recommends rapid rewarming via stirred hot water. For convenience we may consider other gently stirred warm liquids or air or the use of heat lamps. These should not be permitted to heat the skin beyond 45 C (113 F) in order to avoid heat damage of tissue. This condition is easily met in practice because 45 C is approximately the point where the sensation on a normal and normthermic man's skin (attending physician, not the patient) changes from "very warm" to "pain." This rapid local rewarm procedure will assure the rapid return of local circulation to the frozen area. Ref III-6, p 198 and 202 recommends not more than 37.7 C (100 F) since ischemic skin burns at relatively low temperature.

R. B. Lewis (ref III-4, pg 3) produced tissue damage in healthy rabbit legs by immersion in water at 42 C (107.6 F) for 3 hours. This suggests that applications of high temperatures for thawing should be terminated as soon as thawing has been achieved.

Hines and Kvale (ref III-6, p 196) observe that the result of ischemia due to cold induced vasoconstriction is in no respect different from that of the ischemia produced by other forms of interference with the circulation. They also remark that oxygen administration has been found valuable in decreasing loss of tissue and extremities after frostbite.

The rapid return of circulation seems to be desirable when one considers that in plants (ref III-8, p 133) and animals (ref III-6, pp 198 and 202 and ref III-3) disturbance of metabolism has been indicated as a principal contributor to eventual tissue damage. Relative ischemia due to immediate freezing, cold induced high blood viscosity or delayed blood sludging and infarction may lead to such disturbance (ref III-9). Moderate heat, in excess of 26.6 C (80 F) may increase tissue metabolism more than it increases the circulation (ref III-6, p 202) which naturally leads to a progressive deficiency of some materials required by the tissue as well as an associated pH change away from optimum levels. In addition to rapid return of circulation, it may be advisable to attempt to preclude the delayed blood sludging and infarction which regularly follow frostbite (refer to chemotherapy, below).

Rapid local rewarming seems consistent also with the general desire to heat the tissue from the outside rather than using core heat to do so. Two

factors must be considered which may require special precautions. Rapid heating of some tissues (at least unfrozen ones) may induce vasodilation in distant ones, which could generate a net cooling effect upon the core. In particular Charles Sheard (ref III-7, p 1123) quotes a 1948 study of Bader, Hacht and Pillion which showed that the temperature of the hand only, and its blood flow, were raised when the face was strongly heated. This occurred if the man had been previously equilibrated to 15 C (59 F) ambient. Ref III-6, pp 198 and 202 refers to similar relations between the limbs.

During our study, Dr. Stenlund, suggested observing the effect of face heating on the recovery of the temperature of a hand after brief bare hand exposures. This was prompted in part by our observation of an interesting plateau at about 11.1 C (52 F) as the finger skin temperature increased from its lowest value of -2.2 or 0 C (28 or 32 F). The curves(see Figure 11) suggest a relatively passive rewarming process up through the plateau region followed by an active phase (vasodilation) which initiates a much more rapid rewarming. However, under these conditions face warming had no perceptible effect.

Also, at least one of our volunteers has reported that a bright light on his face "turned off" his heavy shivering. He had been sitting in the rewarm, 23.9 C (75 F), room in his flight suit when a 650 watt photoflood lamp was turned on his face (eyes closed) from about 2-1/2 feet. The heating intensity was near maximum allowable since the head had to be turned slowly to and fro to avoid pain. It appeared that the shivers were not turned off as a result of the net heating of his body because, first of all, the effect was essentially instantaneous, and secondly, the shivers returned just as quickly when the light was turned off. The shivers, an important though uncomfortable source of needed deep body heating, were eliminated, by a heating method which was not capable, at least immediately, of replacing the lost heat source.

This all suggests that frostbite treatment by application of local heat may have to be either carefully restricted to the frozen areas and maintained only until the circulation obviously returns to the frozen part or applied to a very large portion of the body in order to induce net general heating of the core from outside.

In our observations simply removing the man's body from the wind but keeping him at the same low ambient temperature allows him to subjectively and objectively rewarm.

This event is important relative to determining whether his hanging period (nearly at zero velocity relative to local steady wind) should be interpreted as part of his cooling period. Also, in many situations, he may be seriously cooled but recover spontaneously if merely protected from high wind.

CHEMOTHERAPY

In the event of deep body hypothermia cardiac arrythmia, of specific type described by Talbott (ref III-6, p 244), leading to or followed by ventricular fibrillation are common antecedents of death. There are, of course, mechanical and electrical means which occasionally succeed in halting

fibrillation and permitting the return of a relatively normal heart beat. Emphasizing avoidance of such critical phenomena as fibrillation, we refer to studies which indicate that post-cold-exposure chemotherapy may be effective in preventing that route to circulatory failure.

Hegnauer and Angelakos (ref III-5) report a number of compounds which produced a significant decrease in the average lethal temperature, of pre-anesthetized dogs, in conjunction with a decrease in the incidence of ventricular fibrillation. They caution that the drugs protecting against the spontaneous fibrillation of hypothermia may not be the best group to use in cases where the rhythm has been disturbed by other primary causes such as surgery on the heart. Angelakos (ref III-1) states that ". . . the available evidence, both experimental and clinical indicate that antazoline is (a) useful antiarrhythmic agent in a number of specific arrhythmias including those associated with hypothermia."

Reference III-7, p 252, summarizes animal experiments in which clumping of red cells, intravascular thrombosis and subsequent gangrene were prevented by the injection of an anticoagulant (heparin) before local freezing.

Weatherley-White, et al., (ref III-9) report a reduction in the amount of frozen rabbit ear tissue lost from 100 percent to an average of 54 percent (3 to 79 percent) by injection of a nonionic surface-active agent. This effect was achieved by administering Pluronic F68 (a copolymer of polyoxyethylene and polyoxypropylene glycol) within 30 minutes after re-warming and subsequently maintaining a blood level of 0.6 mg per milliliter blood volume for four days.

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APPENDIX IV

DEVELOPMENT OF PRESENT ATTITUDE TOWARD LOCAL INCIPIENT SKIN DAMAGE CRITERIA

The literature is replete with various suggestions about the minimum skin temperature below which damage may occur. Some of these are:

(1) Feet are injured "quickly" if colder than 10 C to 15 C, i.e., 50 F to 59 F, according to some authors 8 C (46.4 F) according to others.

(2) The 8 C (46.4 F) for 30 minutes is sufficient to damage directly exposed cat peripheral nerve trunks. (Talbott, ref IV-4, p 253). Items 1 and 2 are also quoted by C. R. Spealman (ref IV-5, pp 368 and 369).

(3) The 4 C (39.2 F) is listed as "the point of incipient tissue damage" without mentioning duration of exposure as a factor (ref IV-1, p 24). A 4 C local skin temperature also is claimed to be the local temperature (feet implied) beyond which most men refuse to continue. Accompanying figures show total cooling periods of 1 to 3 hours.

(4) The freezing point 0 C (32 F) of pure water was our skin surface criterion level; 31 F is approximate freezing point of water including biological electrolytes.

(5) Some persons refer to supercooling as though it might be a regular protective mechanism. Specifically, the transition from solid to liquid is said to occur in the range of -10 C (14 F) to -1 C (30.2 F) (ref IV-3, p 7). But freezing of rabbit hind legs (ref IV-3, p 3) has been carried out by immersion for 30 minutes in liquid at -10 ±2 C (14 F ±3.6 F).

(6) In our runs, after "coldest" spots were located (cheek, neck back, jaw, rump, calf of leg), the Air Force volunteers' skin was allowed to reach 0 C (32 F) and remain there for up to five minutes as indicated by fine pasted-on thermocouples.

GAC personnel using intraepidermal thermocouples regularly allowed minimum indicated temperatures of -2.2 C (28 F) on the bare hand runs, with occasional excursions to -3.3 C (25 or 26 F). In one whole body run without gloves bare hand temperatures were cycled many times between 28 F and 36 F over a 15-minute period by moving the hand in and out of the lee of the body.

None of these experiences yielded any post-run evidence of skin injury except one very small hard white spot on a finger at about 25 F; this spot cleared with no other symptoms. Thus, we can say that exposure to indicated local hand skin temperatures of 32 F to 28 F for a few minutes caused no noticeable damage when they were appended to a total cooling period of less than one-half hour.

(7) C. J. Eagan (ref IV-2, pp 822-830) compared the effectiveness of mechanisms which maintain finger temperature of four Eskimos, five mountaineers, and twenty sedentary USAF personnel under conditions of extreme cooling comparable but not identical to those in our experiments. He used cold water at 0 C (32 F) for 10 minutes and cold air for up to 30 minutes at -22 C (-7.6 F), 2.5 mph, which corresponds to a wind chill factor of 1100 k cal/m^2 hr., directed at the volar surface of two exposed fingers.

During Eagan's study the subjects' safety was monitored by visual inspection for superficial freezing and the experiment was stopped when either distal digital pad reached -5 C (23 F), as indicated by a thermocouple taped to that point. Using this criterion only four cases of superficial freezing (presumably 1st degree) were observed although 3 mountaineers and 15 controls each spent 9 to 12 minutes traversing the regime of 0 C (32 F) to -5 C (23 F).

SUMMARY OF FACTORS IN TISSUE DAMAGE BY COLD

The probability of tissue damage by cold and the severity of damage should it occur are, even in the most uncomplicated cases, functions of temperature-time history and tissue type. Temperature-time history is an important factor during the entire exposure event, even during the period of the frozen state, if this occurs.

Specifically, Fuhrman, F. A. and Fuhrman, G. J. (ref IV-3, p 7) suggest that the time that the tissue remains in the region of -10 C (14 F) to -1 C (30.2 F) should be minimized. Transition of small to large, more destructive, ice crystals as well as non-negligible action of freeze-concentrated electrolytes are most serious in this region; see also H. T. Meryman (ref IV-3, p 22). Meryman, p 23, also states that, experimentally, tissues prepared for microscopy by freezing at 1.6 mm/minute are significantly distorted by large ice crystals. He calculates that this would occur under the following approximate conditions -40 C (-40 F) with 40 mph wind, presumably directed onto bare tissue. Whereas tissues frozen at 6 mm/min. are well preserved since only small ice crystals are present.

To clarify the obvious, it is apparent that location of tissue on the body will also affect the response of skin to given local exposure conditions. This is so because the thickness of various skin components varies considerably, for example, from the distal volar pad of an index finger to the abdomen. Also there are large variations in the local "normal" blood supply, the underlying muscular sources of heat, and in the lability of the blood supply relative to internal homeostatic mechanisms and to influence of external pressures.*

*Pressures here is intended to include effects of local wind static pressure, intrapleural pressure as influenced by the nonhomogeneous pressure field around the breathing orifices and chest, local clothing and strap pressure and forces such as strap pressures acting more centrally to limit local blood flow, e.g., potential tourniquet action of parachute harness relative to distal parts of legs and feet.

Nerve is said to be the tissue most susceptible to cold (Meryman, ref IV-3, p 24). Next most easily damaged is muscle, followed in unspecified order by skin, connective tissue, tendon and bone (Carlson and Thursh, rev IV-3, p 18).

THREE REGIMES OF THERMAL DANGER

Two modes of thermal damage were defined as the subjects of investigation of this contract. The following is quoted from Exhibit A, a two page statement of the "Research to Determine Thermal Tolerance in Air-to-Air Maneuvers" dated "68 May 09":

> "The problem as stated divides itself naturally into two parts which the contractor should consider; first is the problem of frostbite, second is that of death." Also the problems of death and frostbite are described in such a way that:
>
> (1) Death is inferred to result from deep body heat loss "during this type of operation," and
>
> (2) Frostbite is inferred to result from "freezing skin temperatures."

But in the light of the preceding discussion of time-temperature-tissue relations we are impelled to hypothesize a third regime of thermal danger: situations may arise in which superficial skin layers reach low temperatures not directly damaging but slightly deeper tissues; e.g., smooth muscle of arterioles and nerves involved in vasocontrol of reflex arcs, do reach temperatures somewhat higher but nonetheless, if prolonged, destructive to them due to their greater susceptibility. These considerations imply, in addition, the possibility of superficial skin damage secondary to interference with its blood supply. This particular syndrome is more likely to occur during prolonged exposures. This hypothetical syndrome is introduced not because it is certain to exist within the context of rescue towing but because at our present level of knowledge it is a distinct possibility. Its recognition will assist us in looking for this possibility in our data extrapolations and providing for this eventuality in the design of further experiments and preparations for prolonged tow as an operational procedure.

Thus, we might revise the problem statement to include three distinct regimes of thermal damage:

(1) Death as a result of deep body heat loss during or following this type of operation (towing). (Appendix III)

(2) Skin and other damage (perhaps called frostbite) due to cooling with or without frank freezing, beginning at the surface and proceeding inward as a function of severity and duration of exposure.

(3) Damage due to cooling beginning subdermally and proceeding inward and, perhaps secondarily, outward primarily as a function of duration of exposure.

The sequalae of 2 and 3 will probably be indistinguishable for exposures beyond some as yet undefined severity and duration.

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APPENDIX V

DAILY RUN LOG SHEETS

This appendix consists of nine pages of tabular material indicating conditions established and experienced results for two phases of testing.

Phase I - Tests from 24 March through 3 April 1969 - 65 Runs
Runs P 1 through P 65

Phase II- Tests from 4 August through 21 August 1969 -
Runs 1 through 110

PHASE I LOG SHEET: RUNS P 1 thru P21

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	CONDITIONS MPH	HAND SUBJ #	DURATION Min	DURATION Sec	BODY SUBJ #	DURATION Min	DURATION Sec	REMARKS
3/24	4:22	P1	70	10				7	14		1CLO
	4:45	P2	70	10				6	22		1CLO
	5:20	P3	70	10				3	30		1CLO
	5:25	P4	70	10	7	15					
3/25	11:38	P5	70	10	3	5					
			70	30		10					
	12:07	P6	70	10	6	5					
			70	30		10					
	1:14	P7	70	10	7	5					
			70	30		10					
	1:47	P8	70	10	3	4					
			70	50		10					
	2:24	P9	70	10	6	6					
			70	50		10					
	2:49	P10	70	10	7	5					
			70	50		10					
	3:39	P11	70	10	3	5					
			70	70		10					
	4:06	P12	70	10	6	5					
			70	70		10					
	4:33	P13	70	10	7	5					
			70	70		11					
3/26	11:12	P14	70	10	3	5					
			70	100		10					
	11:45	P15	70	10	7	5					
			70	100		10					
	12:16	P16	70	10	6	5					
			70	100		10					
	1:30	P17	50	10	3	20					
	2:06	P18	50	10	7	5					
			50	30		10					
	2:40	P19	50	10	6	5					
			50	30		10					
	3:30	P20	50	10	3	5					
			50	70		5					
	3:59	P21	50	10	7	5					
			50	70		5					

PHASE I LOG SHEET: RUNS P22 thru P37

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
	4:18	P22	50	10	6	5					
			50	70		5	30				
	4:52	P23	50	100	3	5					
	5:04	P24	50	100	7	5					
	5:15	P25	50	100	6	5					
3/27	11:16	P26	70	10				7	10		1CLO
			70	30					20		
	12:07	P27	70	10				6	10		1CLO
			70	30					20		
	1:34	P28	70	10				3	10		1CLO
			70	30					20		
	2:18	P29	70	10				7	10		1CLO
			70	50					20		
	2:56	P30	70	10				6	10		1CLO
			70	50					20		
	3:33	P31	70	10				3	10		1CLO
			70	50					20		
	4:15	P32	70	10				7	10		1CLO
			70	100					20		
	4:50	P33	70	10				6	10		1CLO
			70	100					20		
	5:29	P34	70	10				3	10		1CLO
			70	100					20		
3/28	10:01	P35	60	10				6	10		1CLO
			60	50					19		
	10:36	P36	60	10				7	9		1CLO
			60	50					20		
	11:19	P37	60	10				3	11		1CLO
			60	50					20		

PHASE I LOG SHEET: RUNS P38 thru P52

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
3/28	12:04	P38	60	10				6	9		1CLO
			60	100					20		
	12:37	P39	60	10				7	10		1CLO
			60	100					20		
	1:12	P40	60	10				3	10		1CLO
			60	100					21		
3/31	10:15	P41	50	10				7	10		1CLO
			50	50					15		
	10:50	P42	50	10				6	10		1CLO
			50	50					20		
	11:30	P43	50	10				3	10		1CLO
			50	50					20		
	12:51	P44	50	10				7	10		1CLO
			50	100					20		
	1:28	P45	50	10				6	10		1CLO
			50	100					20		
	2:04	P46	50	10				3	9		1CLO
			50	100					20		
4/1	11:38	P47	40	10				6	10		1CLO
			40	50							
		P48	40	10				3			1CLO
			40	50							
	11:58	P49	40	10				7	10		1CLO
			40	50							
	1:07	P50	40	10				6	10		1CLO
			40	100							
	1:44	P51	40	10				3	10		1CLO
			40	100							
	2:17	P52	40	10				7	12		1CLO
			40	100							

PHASE I LOG SHEET: RUNS P53 thru P65

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
4/2		P53	40	100	6	5	45				
		P54	40	100	3	4	20	Stopped because of "pain", but compare Phase II			
	12:43	P55	40	100	7	3					
		P56	40	10	6	20	20				
		P57	40	10	3	20					
	2:00	P58	40	30	6	15					
	15:22	P59	40	10	7	22					
	15:48	P60	40	30	3	15					
	4:09	P61	40	30	7	5					
4/3	11:07	P62	60	10				6	10		1CLO
			60	50					20		No Helmet
	11:49	P63	60	10				3	10		1CLO
			60	50					20		
		P64	40	10				6			1CLO
			40	100							No Helmet
	1:21	P65	40	10				3	10		1CLO
			40	100					21		

PHASE II LOG SHEET: RUNS 1 thru 6

8/4	3:36	1	30	10	3	10					
			30	50		8	8				
	4:09	2	30	10	1	10					
			30	70		1	15				
	5:02	3	30	10	2	NO TEST					
		3A	30	10	2	1	55	Temp Drop to 31 F			
	5:17	4	30	10	3	10					
			30	85			15	Temp Drop to 31.5 F			
	5:40	5	30	10	1	10					
			30	50		1	15				
8/5	10:32	6	30	10	1	10		Warmed Up In Tunnel			
			30	100			20				

PHASE II LOG SHEET: RUNS 7 thru 22

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
8/5	12:10	7	30	10	2	11		Warmed Up In Tunnel			
			30	100		2	25				
	1:25	8	25	10	3			Warmed Up In Tunnel			
	2:11	9	25	10	1	8	30				
	3:02	10	20	10	2	4	30	Warmed Up In Tunnel			
			20	50			52	(Approx.10 Min.)			
		11	20	10	3	4	50	Warmed Up In Tunnel			
			20	50		1	10				
8/6	10:32	12	35	10				1	11		1CLO
			35	70					10	50	
	11:20	13	35	10				2	10		1CLO
			35	70					10	20	
	1:58	14	35	10				3	10		1CLO
			35	70					12		
	2:15	15	35	10				1	10		3CLO
			35	70					20		
	3:03	16	35	10				2	10		3CLO
			35	70					20		
	3:46	17	35	10				3	10		3CLO
			35	70					20		
8/7	9:26	18	50	10				1	11		3CLO
			50	100					18		Doors Opened
	10:03	19	50	10				2	10		3CLO
			50	100					20		
	10:40	20	50	10				3	10		3CLO
			50	100					12		Doors Opened
	12:17	21	50	10				1	10		3CLO
			50	50					20		
	12:50	22	50	10				2	10		3 CLO
			50	50					20		

PHASE II LOG SHEETS: RUNS 23 thru 42

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
8/7	1:25	23	50	10				3	10		3 CLO
			50	50					20		
		24	50	10				1	10		3 CLO
			50	70					20		
		25	50	10				2	10		3 CLO
			50	70					20		
	3:28	26	50	10				3	10		1 CLO
			50	70					20		
8/8	9:22	27	35	10				1	10		1 CLO
			35	100					20		
	9:44	28	35	10				2	10		1 CLO
			35	100					20		
		29	35	10				3	10		1 CLO
			35	100					20		
	12:47	30	35	10				1	10		3 CLO
			35	100					20		
	1:20	31	35	10				2	10		3 CLO
			35	100					20		
		32	35	10				3	10		3 CLO
			35	100					20		
8/11	9:49	33	30	10				1	10		1 CLO
			30	50					4	45	
	10:20	34	30	10				2	10		1 CLO
			30	50					5		
	10:41	35	30	10				3	10		1 CLO
			30	50					9	15	
	12:34	36	30	10				1	10		3 CLO
			30	50					20		
	1:20	37	30	10				2	10		3 CLO
			30	50					20		
	1:58	38	30	10				3	10		3 CLO
			30	50					20		
8/12	9:35	39	25	10				1	10		3 CLO
			25	100					4		
	10:13	40	25	10				2	10		3 CLO
			25	100					11		
		41	20	100	3		45				
		42	20	50	3	1	30				

PHASE II LOG SHEET: RUNS 43 thru 64

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
8/12	12:49	* 43	20	10				4	10		1CLO
			20	100					5		
8/12	1:25	44	25	50	3	2	30				
	1:45	45	30	10				1	10		3CLO
			30	100					20		
	2:21	46	30	10				2	10		3CLO
			30	100					20		
	2:56	47	25	100	3	1	10				
	3:25	48	25	100	4	2	15				
8/13	9:20	49	30	10				1	10		1CLO
			30	100					20		
	10:05	50	30	10				3	10		1CLO
			30	100					20		
	11:03	51	20	100	2		40				
	11:35	52	20	50	2	1	10				
		53	0	100	4		20	White spot on finger			
	1:47	54	0	50	2		22				
	2:13	55	30	10				1	10		1CLO
			30	70					20		
	2:12	56	30	10	2	9	40	Light Used			
	2:46	57	30	10	2	6					
		58	30	10				3	10		1CLO
			30	70					20		
	3:33	59	30	10	4	10	50	W & WO Lamp Rewarm			
	4:21	60	30	10	4	10	50				
8/14	10:12	61	20	50	1	1	45				
	11:21	62	20	10				2	10		3CLO
			20	50					20		
	12:33	63	20	10				3	10		3CLO
			20	50	Lamp Used on Face				20		
	2:37	64	0	10	1		45				

* Hand thermocouples - NO gloves - also mild frostbite on jaws.

PHASE II LOG SHEET: RUNS 65 thru 86

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
8/14	3:11	65	20	10				2	10		3CLO
	Light	Used	20	100	Cramps & Full Shivers				15	48	
	4:07	66	20	10				3	10		3CLO
			20	100					20		
	4:51	67	20	50	1	1	6	Light Used			
	5:52	68	25	100	4	1	56				
	5:51	69	25	100	4			Light Used			
	6:49	70	-25	10	4	1	7				
	7:02	71	-25	50	4		23				
8/15	10:06	72	10	10				1	10		3CLO
			10	50					20		
	10:46	73	10	50	3		45				
	11:10	74	20	10				2	10		3CLO
			20	70					20		
	11:51	75	10	100	3		12				
		76	10	30	4	1	45				
		77	0	50	3		26				
		78	0	30	4	1	12				
	1:02	79	1	100	3		13				
	1:54	80	10	10				1	10		3CLO
			10	100					4		
	2:28	81	10	50	4	1	10				
	2:43	82	20	10				2	10		3CLO
			20	30					20		
	3:21	83	10	50	4	1	22	Lamp Used for Rewarm			
	3:46	84	10	50	4	1	12				
8/18		85	30	10				1	10		3CLO
			30	70					20		
	10:34	86	·0	10				2	10		3CLO
			0	50					20		

PHASE II LOG SHEET: RUNS 87 thru 101

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
8/18	11:35	87	10	10				3	10		3CLO
			10	50					13		
	1:04	88	10	10				1	10		3CLO
			10	30					20		
	1:43	89	10	10				3	10		3CLO
			10	30					20		
	2:32	90	0	10				2	10		3CLO
			0	100					6	20	
8/19	9:26	91	0	10				1	10		3CLO
			0	70					3	55	
	10:08	92	20	10				2	10		3CLO
			20	85					20		
	10:46	93	20	10				3	10		3CLO
			20	70					20	5	
	11:52	94	10	10				1	10		3CLO
			10	70					4	25	
	12:53	95	30	10				2	10		3CLO
			30	70					20		
	1:35	96	30	10				3	10		3CLO
			30	102.5					20		
	2:13	97	30	10				5	10		3CLO
			30	102.5					20		
8/20	8:59	98	35	10				1	10		3CLO
			35	85					20		
	9:48	99	35	10				3	10		1CLO
			35	50					20		
	10:44	100	15	10				2	10		3CLO
			15	100					20		
	12:28	101	15	10				1	10		3CLO
			15	70					12	45	

PHASE II LOG SHEET: RUNS 102 thru 110

DATE	TIME	RUN NO.	CONDITIONS TEMP(F)	MPH	HAND SUBJ #	DURATION Min	Sec	BODY SUBJ #	DURATION Min	Sec	REMARKS
8/20	12:59	102	15	10				3	10		3CLO
			15	50					10		
	2:10	103	15	10				1	10		3CLO
			15	50					20		
	2:57	104	25	10				2	10		1CLO
			25	100					11	30	
8/21	8:56	105	35	10				1	10		3CLO
			35	50					20		
	9:50	106	30	10				2	10		3CLO
			30	85					20		
	10:45	107	25	10				3	10		1CLO
			25	70					20		
	11:28	108	15	10				1	10		3CLO
			15	85							
	12:40	109	25	10				2	10		1CLO
			25	50					20		
	1:35	110	10	10				3	10		3CLO
			10	70					15		

APPENDIX VI

THE PHYSIOLOGICAL MACH EFFECT: A POSSIBLE THERMAL EXAMPLE

The sensation of coldness on the face next to the volunteers' masks was notable. Initially, this was interpreted to signify that the mask was cooled rapidly and in turn conducted heat away from the face. However, tests showed that the face skin 1/4 inch under the mask edge was in fact much warmer than the skin exposed to air just outside the mask, e.g., typically, 70 and 37 F respectively. Thus, in addition to other possible contributions to the strong cold sensation, the mask provided a discontinuity in the skin temperature.

To quote from Georg von Be´ke´sy* "... I showed that discontinuities in a stimulus distribution are accentuated not only in vision but in all sense organs with a uniform-sensitivity area in which the magnitude of a stimulus can be varied from point to point. The Mach bands (bands of exaggerated perception parallel to the stimulus discontinuity) were demonstrated for shearing displacements and vibratory stimulation, for warm and cold sensations of the skin, and for taste sensations on the tongue. But they can be best investigated for vision, with which they were first discovered."

Thus, in our case of cold skin and adjacent warmer skin, under the mask, we expect an extreme cold sensation just outside the mask with a relatively very warm sensation just under the mask edge. The discontinuity, however, is superimposed upon a general cooling of both areas relative to comfortable skin, at say 90 F. Thus, the warm accentuation is not explicitly noted and the man is left with a very cold sensation just outside the mask and a cool sensation just under the mask edge.

This is one of many such anomalies of sensation which confound the investigator of cold spots concealed by clothing. The work requires much care because the areas are not available for observation at the onset of cold damage and the subjects' senses are unreliable indicators of the local temperature situation. Thus, his reports of discomfort, warmness, pain, etc. cannot be accepted at face value, and the investigator must initially take a very conservative view as we have illustrated in section II on temperature safety criteria.

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* George von Be´ke´sy, "Brightness Distribution across the Mach Bands Measured with Flicker Photometry, and the Linearity of Sensory Nervous Interaction." J. Opt. Soc. Am. 53, pp 1-8, January 1968.

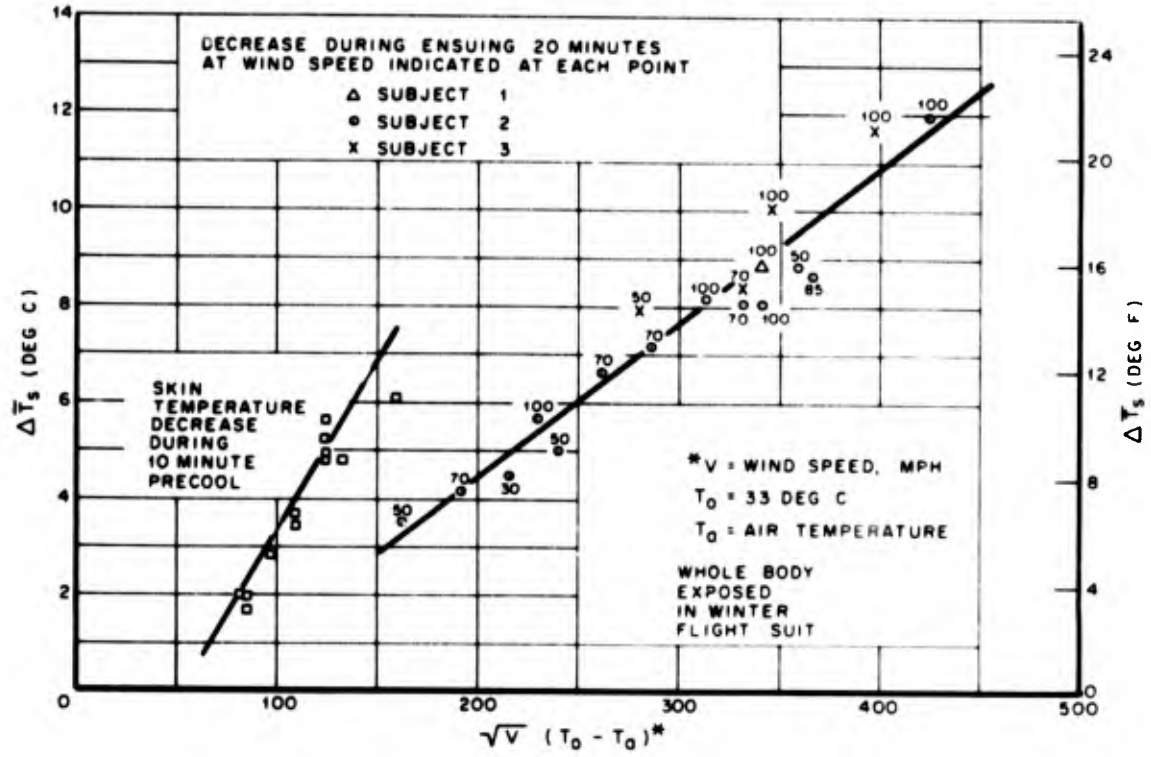
APPENDIX VII

PRELIMINARY EXTRAPOLATION OF DATA

DECREASE IN WEIGHTED MEAN SKIN TEMPERATURE

Using data from full body exposures in winter flight suits, one of us (J. F. A.) has found an empirical expression, $\sqrt{V}\,(T_o - T_a)$, which appears to be linearly related to the decrease in weighted mean skin temperature, $\Delta \overline{T}_s$, during a fixed time interval at constant wind speed, V. T_a is the ambient air temperature and T_o is 33 C, approximately the initial value of $\overline{T}_s$ before a test run.

These data, illustrated below, fall into a remarkably smooth line. Much of the small variation around the line is due to difficulty in specifying precisely the $\overline{T}_s$ value at the time that certain events such as wind speed change occurred. The difficulty derives from the recorder event marking system and the rather sparse sampling of each temperature, 83.8 seconds between samples. These limited data, selected for extensive analysis for other purposes, hint that different subjects may yield distinct but parallel relations. This is not surprising considering subject differences in skin blanching (mentioned in the main text).



Decrease in Weighted Mean Skin Temp. vs Air Speed and Temperature

An equation of a straight line visually fitted to the data of subject 2 giving $\Delta\overline{T}_s$ for the 20 minute interval at high wind speed would have the form:

$$\Delta\overline{T}_s = -2.27+0.0324 \quad \sqrt{V}\,(T_o - T_a)$$

is V is in miles per hour and all temperatures in degrees centigrade. Since $\Delta\overline{T}_s$ for any interval would not ordinarily exceed $(T_o - T_a)$ the equation should not be used beyond 952 mph. There are good reasons to believe it should not be applied even to that high wind speed. In conjunction with our rectal temperature profiles for 30 minutes and a good physiological model of the human body, the above equation would help to estimate core temperature losses in other tow conditions.

DECREASE IN LOCAL CLOTHED SKIN TEMPERATURES

Data were extracted from those collected under this contract to be applied to a synthesis of an integrated rescue system. Extrapolation expressions were derived by Goodyear Aerospace Corporation, Akron, Ohio, under Contract AF 33657-70-C-0235 which was under the direction of Major Richard Steere (ASWLN). These extrapolations of local clothed skin temperatures were a small part of that program administered by the Air Force Life Support Systems Program Office, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The final report on that program, "Pilot Rescue System - Aerial Retrieval Analysis and Definition," by Louis A. Girard, has been reviewed and is being revised for publication. The Goodyear Aerospace document number is GER-14585. The biothermal results are contained in Volume I, Book I - Operational Analysis (unclassified).

An attempt was made to predict the occurrence of potentially dangerous local skin temperatures on typical clothed areas such as kidney, rump and leg. Most work was done with the area we had found to be most often coldest, the calf.

The effort utilized very simple models of the human body, very conservative criteria for skin cold injury and only a part of the available data. Also, the extrapolations attempted to extend our data to 300 mph and to one hour of towing at high speed. This would severely tax the best of extrapolation attempts. Thus, the Principal Investigator of this report considers that, if considerably more effort were applied, more defensible extrapolations could be obtained. However, none of the biothermal calculations in the cited report are known to be incorrect.