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A SYSTEMS ANALYSIS OF ALTERNATIVE CONCEPTS FOR AIRCREW COLD WEATHER CLOTHING

BY

JOAN M. WALKER

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values required to provide thermal protection. Since the results indicated that auxiliary heated clothing items especially for the hands and feet will be necessary, an evaluation of potential power sources is included in the study. The report recommends that either two ensembles or a basic and an augmented version of the same ensemble be designed. The basic system will be worn in cold and intermediate cold regions and should be designed using state-of-the-art technology to protect to -15°F (-26.1°C). The other ensemble will be worn in extreme cold climates where temperatures can fall to -60°F (-51.1°C).

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EXECUTIVE PRECIS

In 1979 the US Army Natick Research and Development Center (NRDC)* was tasked to develop a new clothing system for Army aircrews operating in regions of intermediate cold, cold, and extreme cold weather, that is, where minimum winter temperatures for each region are between 0°F (-17°C) and -60°F (-51.1°C). The primary need was for an ensemble to facilitate the interface between the person, the aircraft, and the environment while providing cold-wet weather protection for three different environments: the ambient conditions experienced during preflight tasks, the cockpit conditions experienced during mission tasks, and ambient temperatures experienced while conducting prolonged survival tasks.

The NRDC Directorate for Systems Analysis and Concept Development** performed an analysis in support of the clothing development effort to assess the feasibility of the conceptual alternatives proposed for the ensemble by the NRDC Individual Protection Laboratory and to recommend a preferred approach.

The proposed clothing system concepts included:

- 1) conventional cold weather clothing, which utilizes the layered principle;
- 2) conventional clothing supplemented by auxiliary heated items, such as gloves or boots;
- 3) clothing fabricated with reflective or other heat retaining fabrics;
- 4) clothing that combines heat retaining fabrics with auxiliary heat; and
- 5) a thermostatically controlled microclimatic system that would maintain comfort by warming or cooling the individual as needed.

Each of these concepts was evaluated to determine its effectiveness in satisfying the essential requirements specified in the Letter of Agreement (LOA) between NRDC and the user community.

Methodology

First, the detailed requirements for cold weather aircrew clothing were defined by identifying: 1) the major tasks aircrews perform; 2) the typical time, temperature, and physical activity level profile for each task; 3) the implications of these roles for the operational capabilities of the clothing; 4) the hazards aircrews could encounter; and 5) the needs that are or will

*Formerly, the U.S. Army Natick Research and Development Laboratories.

**Formerly, Operations Research and Systems Analysis Office.

be met through other clothing or equipment items. From the lengthy list of detailed requirements, five categories of critical performance parameters were identified to evaluate the feasibility of the proposed alternative concepts and to assess their relative benefits. The five categories of critical need are:

- 1) environmental protection for all mission tasks, and some survival tasks, under all climatic conditions occurring in cold regions;
- 2) compatibility with military aircraft and with other aircrew clothing and equipment;
- 3) protection from fire hazards and crash impact;
- 4) provisions for human factors; and
- 5) reliability, availability, maintainability (RAM), and other miscellaneous factors.

In evaluating the importance of these categories, environmental protection and compatibility were judged most critical. TRADOC and DARCOM representatives felt these categories together should contribute between 55% to 80% of the performance goals for the new clothing system.

Next, available research data were collected and analyzed to identify technical constraints and to define the minimal performance criteria against which the proposed concepts would be evaluated. The analyses determined:

- the differences in typical and absolute extreme climatic conditions between the three zones where the clothing system will be worn --cold, intermediate cold, and extreme cold;
- the clothing insulation values (clo) required to provide protection against these climatic conditions;
- the feasibility of using auxiliary heated clothing items; and
- the number of aircraft and aircrew currently deployed in the three clothing zones.

Finally, the feasibility of each proposed concept was assessed, the relative costs of each were estimated, and the most cost-effective solution to the problem of clothing aircrews in cold climates was defined.

Findings and Conclusions

The analysis indicated that it is unlikely that any of the proposed concepts is able to meet all the requirements specified in the LOA, given the current state-of-the-art. The major obstacles are: 1) the physical impossibility of simultaneously satisfying with conventional materials the requirements for both environmental protection and aircraft compatibility,

2) the lack of an adequate and convenient power source for auxiliary heated systems, and 3) the lack of data to determine the feasibility of new alternatives currently in research and development. For example, environmental protection at the specified minimum temperature (-60°F or -51.1°C) at which aircrews must operate may be achievable through the use of auxiliary powered items, but heating elements in existing heated handwear are too bulky to accommodate the manual dexterity needs of aircrews. The achievability of this approach is only conjectured and additional research will need to be conducted to ascertain this fact.

A second conclusion of the analysis is that the goal of a single ensemble is impractical for the environmental temperature range (high to low) over which the ensemble will be worn, that is, from +40°F (4.4°C) to -60°F (-51.1°C). This goal is similar to requiring that one uniform be designed for wear over the more familiar temperature range of 0°F (-17.8°C) to 100°F (37.8°C).

Furthermore, the analysis shows that protection from extreme cold is needed by only a small percentage of all aircrews. While 18,500 individuals (slightly less than half of the total Army aircrewmembers) will wear the new ensemble during the winter months, roughly 95% of these aircrewmembers will be located in areas where the temperature never drops to the -30°F (-34.4°C) to -60°F (-51.1°C) range. These extremely low temperatures occur only in limited regions. Nevertheless, some Army aircrews will experience these temperatures routinely, such as those located in Fairbanks, Alaska where temperatures in this range historically have been recorded on about 26% of the days between December 1 and February 28. The 95% quoted above reflects peacetime assignments. In the event of a crisis, especially one in an extreme cold climate, this percentage could decrease. Since the need exists for thermal protection to as low as -60°F (-51.1°C), the requirement should not be changed. However, the study concludes that the most demanding segment of the environmental protection requirement applies to a very small percentage of potential users, and therefore, is questionable as a general requirement.

To underscore this point, the implications of extending the thermal protection of clothing to accommodate extremely low temperatures should be considered. With conventional clothing, greater bulk generally is required to protect against increasingly colder environments. In fact, 25 percent more insulation is required to maintain an individual in thermal balance at an ambient temperature of -60°F (-51.1°C) than at a temperature of -30°F (-34.4°C), under conditions of no wind. If a comparison of insulation requirements is made between -60°F (-51.1°C) and -15°F (-26.1°C), 43 percent more insulation is needed at the lower temperature. The imprudence of designing a single general clothing system which protects to -60°F (-51.1°C) should be apparent.

Other major findings and conclusions of the analysis are listed below.

- the insulation (4.3 clo) of the Arctic ensemble, which is the warmest ensemble in the Army inventory, offers marginal to inadequate environmental protection for the preflight tasks at the specified

minimum temperature with slight air movement (4 mph). This ensemble also fails to meet the compatibility requirement with the aircraft due primarily to its bulk.

- Unheated boots also are inadequate for satisfying aircrew needs. The warmest boot in the Army inventory (the white vapor barrier boot) cannot keep the toes above the critical temperature of 60.8°F (16°C) when the ambient temperature is -60°F (-51.1°C) and the outdoor preflight tasks exceed 45 minutes. This boot also fails to interface compatibly with the toeholds and foot control areas of the aircraft due to its bulkiness.
- Unheated gloves cannot meet the environmental protection requirements either for routine missions or for survival situations as specified in the requirements document.
- In a cockpit maintained at 32°F to 40°F (0°C to 4.4°C), fingers cannot be kept above the critical temperature for effective use (60.8°F or 16°C) except by heated gloves designed to meet the manual dexterity needs of aircrews.
- Use of reflective fabrics to increase the insulation value of clothing is not currently a feasible approach. Research has revealed that the compression of layers caused by stitching or normal wear of the item limits any potential improvement in clo (insulation) to less than 10 percent for clothing items constructed with reflective layers.
- The power requirement for a microclimatic system exceeds the excess power available on some aircraft and the necessary central heating/cooling unit presents weight and space problems. Moreover, access to both power and the central unit (which will supply the heated air or liquid) while aircrews perform preflight or flight continuation tasks outside the aircraft is an unresolved problem. Current concepts for microclimatic systems would also need to be extended to provide heat to the extremities. This need increases the power requirements for the system.
- Auxiliary heated clothing items, which can supply heat to the body extremities as well as to the trunk, will be needed to meet both the thermal protection and mission capability requirements.
- Auxiliary heated items could be powered by portable batteries, by the aircraft generator, or by either depending on the location of the aircrewmember. For routine situations, rechargeable nickel cadmium batteries are more cost-effective than disposable lithium batteries. However, lithium batteries have properties that make them very useful for certain aircrew situations. For example, because lithium batteries are high energy density sources which can tolerate extreme cold, they could be stored in the aircraft for use in an emergency.

- Although definitive heating power requirements have not been determined for a -60°F (-51.1°C) environment, the experiments which have been conducted indicate that at least 10 watts per extremity will be required to maintain extremity temperatures of 60.8°F (16°C). With thermostatic control, the estimated total power consumption level for both hands and feet is at least 25 watts per hour.
- The average power density of Army type-classified nickel cadmium batteries encased in a safety sealed pack is about 12 watt-hours per pound. Depending on the aircrewmember's role, a completely portable system which supplies heat to the extremities could add up to 8 pounds to the clothing ensemble.
- Aircrew survival kits do not contain clothing. Therefore, additional insulation may need to be provided for survival, especially for the extremities, and should be considered in the final design. Alternatively if auxiliary heated items are used, substitute items should be included in the system to compensate for the lack of power in a survival situation.
- Protection from fire hazards and crash impact is within the state of the art.
- A preliminary cost analysis indicates that a design based on the conventional clothing concept could cost from 1.5 to 2.0 times the price of the current system, a design based on auxiliary heating could increase the cost over that of the baseline by a factor of 1.5 to 4, and a microclimatic design could increase the cost by a factor of 4 to 5.5.

Recommendations

The findings and conclusions lead to the recommendation that either two ensembles or a basic and augmented version of the same ensemble be designed. The basic system would be worn in cold and intermediate cold regions and should be designed using state-of-the-art technology to protect to -15°F (-26.1°C). The other ensemble would be worn in extreme cold climates where the temperature can fall to -60°F (-51.1°C).

The preferred concept for the basic system is a design using conventional layered clothing supplemented with auxiliary heated gloves. The insulation required to meet the suggested minimum temperature (-15°F or -26.1°C) was estimated to be about 3.5 clo. The current Combat Vehicle Crew (CVC) winter ensemble is an example of an existing uniform which provides the required thermal protection. Boots suitable for aircrew tasks must be designed and should provide between 1.6 clo and 2.0 clo. Dual-powered electrically heated gloves which are thermostatically controlled are needed. They should be designed to operate off portable batteries when the aircrewmember is outdoors and to access the aircraft generator for power when the aircraft is operating.

For the extreme cold climates (-60°F or -51.1°C), additional layers or heated components are required to extend the thermal protection of the basic system. More research must be conducted to determine whether all requirements can be met for the temperature extremes. Heated handwear and footwear, which operate similarly to the heated gloves described above, are needed.

For both the basic clothing ensemble and the extreme cold ensemble, a two-layer handwear system is recommended. The inner glove should be designed for flying and other cabin/cockpit mission tasks that require a high degree of manual dexterity. The inner glove should contain the heating capability since heat is needed both inside the aircraft and outdoors. The outer glove would be worn over the inner glove for outside tasks. Under extreme cold conditions, a mitten rather than the outer glove would be worn over the flying glove for outdoor tasks. The function of the outer layer is to provide insulation for the heated glove and to protect the flying glove from petroleum, oil, and other lubricants.

The final recommendation is that additional laboratory research be conducted to answer some of the feasibility questions that have been raised in this report. When testing auxiliary heated items, the appropriate environmental conditions, metabolic rate, and clo of the ensemble to be worn by the aircrewperson should be simulated.

PREFACE

The Directorate for Systems Analysis and Concept Development of the US Army Natick Research and Development Center (NRDC) conducted the systems analysis and prepared this report in support of the aircrew clothing development effort. The work was carried out under Project 1L663747D669, Task 34, Aircrew Clothing System, Cold Weather.

The author wishes to thank Major Phillip Webb, Project Officer, US Army Aviation Center (USAAVNC), Ft. Rucker, AL and Major Allen Jarvis, Aviation Research and Development Command (AVARDCOM), St. Louis, MO for their helpful guidance throughout the project; Dr. Matthew Herz for his editorial contributions; Ms. Lisa Labanca for her editing assistance; and Ms. Mary Ellen Jennings and Ms. Diane Sears for their typing support.

Figure A-2 is reprinted from The Weather Almanac, edited by James A. Ruffner and Frank E. Bair (copyright © 1981 by Gale Research Company; reprinted by permission of the publisher), third edition, Gale Research, 1981, p. 6-7.

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Chapter I

INTRODUCTION

The systems analysis reported in this document was undertaken as part of a larger program to develop a new clothing system for aircrews operating in cold regions. The deficiencies of the current aircrew ensemble have been recognized for many years. Since World War II, Army aircrewmembers have worn clothing originally developed for Air Force and Navy fliers. Because this clothing was designed for cabin temperatures of fixed wing aircraft, it has always been thermally inadequate for persons in Army helicopters flown in the extreme cold. In addition, individual clothing items fail to intermesh and the bulk of the boots, the gloves, and the ensemble in general impair the crewmembers' abilities to exploit fully the capabilities of the aircraft.

Cold injury is generally considered a preventable condition. However, the adverse effects of low temperatures on military operations have been documented since the time of the Greeks. Cold weather has accounted for an enormous number of casualties, deaths, and even has caused military defeat. During World War II, the total time lost for all cases of cold injury has been estimated at over seven and one half million man-days. Although these losses occurred chiefly among the ground forces, the Army Air Force did report some cases of high altitude frostbite. (See Appendix E for technical definitions of cold injuries, the environmental conditions under which they occur, and a brief discussion of the incidence of cold injuries during World War II and the Korean War.)

The reduction in forces and the high medical expenses do not reflect the full cost that low temperatures cause during military operations. Long before the cold causes a soldier to become a clinical casualty, it has impaired the soldier's performance and reduced effectiveness. Penetrating cold distracts an individual's attention and reduces ability to concentrate. Cold has also been found to decrease reflexes, impair judgment, reduce energy, and create apathy.

1. BACKGROUND

The planning process which culminated in the requirements document for a cold weather aircrew clothing system began over a decade ago. In 1971, Alaskan divisions were surveyed to identify the adequacy of arctic survival kits and clothing. Several workshops were held during the 1970's to address the problem areas and recommend solutions.^{1,2,3} From these sessions it became clear that cold weather clothing and materiel development had been relegated to low priority in recent years and consequently serious deficiencies existed. It was recommended that priorities be adjusted to permit timely development/procurement of items critical to successful cold weather combat operations. Throughout the mid to late 1970's, conferences and working groups convened to draft and finalize several requirements documents slated to correct the deficiencies in cold climate clothing and survival equipment.⁴ The Letter of Agreement (LOA) for an Aircrew Clothing System Intermediate Cold, Cold and Extreme Cold Weather (Appendix H) is one of these documents.

2. OBJECTIVES

The objective of the program funded by the LOA identified above is to develop a new clothing system for Army aircrews operating in cold regions where minimum temperatures fall to between 0°F (-17.8°F) and -60°F (-51.1°C). The clothing system will be designed to facilitate the person/machine/environment interface while providing cold/wet weather protection for three different temperature environments: the ambient conditions experienced during preflight tasks, cockpit conditions experienced during mission tasks, and ambient temperatures experienced while conducting prolonged survival tasks. The envisioned clothing system will protect all parts of the body including the head, arms, hands, torso, legs, and feet. The effort reported in this document was conducted by the US Army Natick R&D Center Directorate for Systems Analysis and Concept Development as preliminary analysis for the aircrew clothing development process.

The objectives of the systems analysis were threefold:

- to assess the feasibility of the proposed conceptual alternatives;
- to determine the most cost-effective conceptual approach for improving the aircrew cold weather clothing; and
- to analyze the functional requirements and specify design parameters to be used in the development of the clothing.

The development process evolves from many decisions. This systems analysis addresses the higher level or conceptual questions. Once a clothing concept is chosen, many decisions will still remain to be made concerning clothing design, textile technology, and material science. These fall in the area of the clothing developer's expertise, and therefore are not included in this report.

Questions such as the following were addressed in this analysis: "Is auxiliary heating necessary or will conventional fabrics be adequate? If auxiliary heating is necessary, which items of clothing should be heated? Is there a feasible power source?" These questions were answered from research already conducted and documented. Further laboratory and field testing will need to be completed to answer other questions which have arisen and will arise as the development process continues.

In the past, some clothing items have been developed, sent to the field for testing, and have failed. Although many clothing features cannot be realistically tested anywhere but in the field, other features are amenable to laboratory experimentation. Considerable laboratory work has been conducted in the area of cold/heat stress on the body and the scientific findings have been incorporated into models which can be used to predict the effects of wearing various clothing under different environmental and metabolic scenarios. These models were employed in this analysis to eliminate

infeasible solutions and to quantify some design parameters. The information collected and analyzed for this report serve to narrow the options open to the clothing developers.

3. ANALYTICAL APPROACH

The US Army Natick R&D Center Individual Protection Laboratory proposed several distinct conceptual alternatives (Chapter V) for meeting the thermal protection requirements. In order to assess the suitability of each both to protect aircrews from the cold and facilitate the person/machine interface, it was necessary first to collect pertinent data, second to analyze this information, and third to draw conclusions and make recommendations.

This technical report begins with a discussion of the requirements for the cold weather aircrew clothing system (Chapter II). An understanding of the mission tasks and problems confronting flight crews operating in cold regions was gained through written material, through discussions with persons in the US Army Training and Doctrine Command (TRADOC), and by interviewing aircrewmembers who have had first-hand experience.

The temperature criteria which must be met by the clothing system are included in the LOA. However, these minimum temperatures represent the worst case and are encountered in only a few locations. The diversity of the climatic conditions in regions of the world which experience cold winters is explained by the data presented in Chapter III.

The properties of clothing and their effect on the thermal comfort of man have been studied in laboratories for over 40 years. The US Army Institute of Environmental Medicine in Natick, Massachusetts researches the interaction between the soldier and i) the physical environment, ii) clothing, and iii) equipment, and assesses the ability of the soldier to accomplish a mission under the stress of these factors. Findings which have resulted from these and other research efforts are directly relevant to the aircrew clothing problem, and are applied in Chapter IV to the task requirements and climatic conditions presented in the preceding two chapters. First the theory of clothing is explained and then the feasibility of conventional clothing to protect from the cold is assessed by applying cooling models.

The results of the analysis of the insulation requirements explain the difficulty clothing developers encounter when attempting to design clothing for comfort and freedom of movement over a wide range of temperatures. Because these difficulties have been recognized for many years, scientists have begun to explore innovative options. Three of the proposed alternatives employ auxiliary heat. Because the lack of a suitable remote power source has terminated development efforts of heated clothing in the past, the requirements for power and the potential sources of supply were addressed in this systems analysis. Past experiments with auxiliary heated clothing items are reviewed and then the feasibility of using one or more of these items in the aircrew ensemble is assessed (Chapter IV).

Chapter II

REQUIREMENTS FOR THE AIRCREW CLOTHING SYSTEM, COLD WEATHER

1. INTRODUCTION

The rational development of an operationally effective clothing system for Army aircrews in cold climates requires an understanding of the roles performed by various aircrew personnel and the operational environments in which they work. For civilians, the function of clothing in cold climates is primarily to protect the individual from the natural environment. For military aircrews, and other soldiers, clothing and specialized equipment worn on the body must also offer protection from combat and operational hazards. In addition, the environmental protection provided by the aircrew clothing system must be suitable both for mission tasks and for survival situations following a crash or other emergency. All these requirements must be met within the overriding constraint that the ensemble interface compatibly with the person, the aircraft, and other equipment.

In the sections which follow, the aircrew's routine duties and potential threats are discussed in light of the factors which influence clothing requirements. However, not all of the clothing requirements for aircrews will be met in this development program. Some essential elements of the total protective system are either being addressed under other requirements documents or currently are provided by existing items of equipment. For reference, these other requirements documents are listed below.

- Letter Requirement for Glove, Flying, Extreme Cold Weather
- Letter Requirement for Aircrew Survival Armor Recovery Vest
- Letter Requirement for Survival Environmental Packet
- Required Operational Capability for an Aircraft Modular Survival System
- Letter Requirement for Insert, 12.7 mm Armor Piercing Small Arms Protective, Torso, Armor with Carrier
- Draft Letter of Agreement for an Aircrew Life Support System, Integrated Battlefield
- Letter of Agreement for a Ground and Air Combat Vehicle Microclimatic Conditioning System (MCS)

A brief description of the goals of each of these development programs is included in Appendix F.

All remaining aircrew clothing protection needs not satisfied by the developmental items identified above will be addressed under the LOA for an Aircrew Clothing System, Cold Weather. The final section of this chapter discusses these principal design characteristics and organizes them into a hierarchy of functional capabilities which is later used (in Chapter VI) to evaluate the proposed conceptual alternatives.

2. MISSIONS AND THE ROLE OF AIRCREWS

Missions

Aircrew clothing requirements can be specified by examining the routine activities Army aircrews perform, the physical and psychological environments in which they work, and the threats they may encounter. The term aircrew includes pilots, copilots, crew chiefs, flight engineers, and some noncrew members. Aircrews operating both rotary and fixed-wing aircraft carry out diverse missions in such broad categories as combat search and rescue, medical evacuation, close air support, air superiority, reconnaissance, target acquisition, airlift, and electronic warfare.⁵

Army aviation plays a vital role in cold climates. Helicopters are used to reduce combat troop exposure to the cold and to facilitate mobility under winter conditions where snow and ice make ground travel difficult. In Alaska, for example, the lack of roads has resulted in a substantial reliance on air transportation. For the most part, aviation in cold climates is employed in much the same manner as in warmer climates. However, the frequency mix of the mission categories is altered.

Special procedures must often be followed when planning aviation operations in cold environments.⁶ In addition, the time to complete most routine tasks is longer than in moderate climates. Often snow and ice must be removed from the aircraft. If the temperature is below -4°F (-20°C), the engine, cockpit, dynamic components, radio compartment and other instruments should be preheated with a Herman Nelson heater in order to avoid subjecting these parts to the extreme temperature differentials which will result upon starting the aircraft. Additional maintenance precautions must be observed during preflight checks. Longer engine runups are required. If the temperature is below -20°F (-29°C), the battery must be removed at the end of the day, stored indoors, and reinstalled the following morning.* When available, protective covers must be placed over the aircraft to protect from freezing rain, sleet, and snow. Also, cold soaking prevents the timely completion of maintenance tasks.

*A battery modification which will eliminate the need to remove the battery is being applied through a product improvement program (AVRADCOM). It is anticipated that the modification will be fielded between 1986 and 1988.

Aircrew Tasks

This section identifies the tasks performed by aircrews working in a cold climate during a typical 10- to 12-hour day. The tasks are grouped into four broad categories: preflight tasks, flight/mission tasks, flight/mission continuation tasks, and post flight tasks. Some tasks, such as those which are necessary to maintain and operate the aircraft, are required for all missions, whereas other tasks are mission and/or aircraft specific.

For each task described below, the factors influencing the clothing requirements of aircrews have been identified. These concerns include the environmental conditions, the level of physical exertion, the average time to complete the task, the degree of manual dexterity required to perform the task efficiently, and the interactions of the clothing with the aircraft and other life support equipment. The time and temperature estimates are presented as ranges since the clothing system is being designed to be worn in Clothing Allowance Zones V, VI and VII for all aircraft and missions. (See Appendix A for a description of these Clothing Allowance Zones.)

Missions vary in length both within and between mission categories. For planning purposes, we have assumed that the inflight time for an average mission is 1 to 1-3/4 hours and that during a typical day three or four missions are completed. The fuel capacity of the helicopters, which ranges from one to three hours, imposes an upper constraint on mission length. Refueling generally is done after each mission.

During a typical day, aircrews are exposed to and must be clothed for two very different thermal environments -- ambient or outside temperatures and cabin/cockpit temperatures. The variation in the ambient temperatures throughout the three clothing zones is discussed in general terms in the next chapter. The upper and lower bounds on temperature for each aircrew task are indicated under the task descriptions in this section.

Cabin/cockpit temperatures also vary since they are affected by ambient temperature, mission profile, and heater efficiency.⁷ The cabin/cockpit temperature design standard for most helicopters is +40°F (4.4°C).^{*} However, at ambient temperatures below 0°F (-17.8°C) this level is reached only during portions of a mission due to cold soaking of the aircraft and the necessity for some missions that the aircraft land one or more times to load or unload passengers or cargo. When the doors are open, the cockpit temperature approaches the ambient temperature within two minutes and rewarming to 40°F (4.4°C) may take as long as 30 minutes. The latest version (draft) of the Army Basic Cold Weather Manual (PM 31-70) recommends that the cockpit temperature in helicopters which carry troops be maintained at 32°F (0°C).⁸ Under extreme cold ambient conditions, cockpit temperatures above freezing create condensation in

^{*}See Appendix B, Section 3 for more information on aircraft heater efficiency.

the troop rifles that later freezes and causes the rifles to malfunction. Although not all aircraft, and therefore not all aircrews, are subject to such frequent cold exposure during routine missions, the worst case has been considered in this analysis.

Descriptions of the aircrew tasks and subtasks follow. These tasks are repeated throughout the day for each mission with the following exceptions: 1) the aircraft inspection tasks take less time than indicated for missions following the first, and 2) the post flight tasks take longer after the last mission of the day than between missions.

(1) Preflight Tasks

a. Briefing/Flight-Planning

Time: 10-30 minutes

Environment: indoor temperatures ranging from 45°F (7°C)
(tent) to 70°F (21°C) (building)

Activity Level: Light - sitting or standing

At the conclusion of the planning session, the aircrew should be able quickly to don the remaining clothing items required for the subsequent tasks.

b. Aircraft Inspection

Time: 30-90 minutes* outdoors, and
5-10 minutes in the cockpit

Environment: -60°F (-51.1°C) to 60°F (16°C)

Activity Level: Light to moderate - walking, climbing on top
of aircraft, sitting in cockpit

Before the engine is started, the pilot, the co-pilot, and the crew chief together conduct a complete inspection of the outside of the aircraft, the engine, the rotary blades, the transmission, the landing gear/skids, the hydraulic system, and the electrical system. These tasks are performed while outside the aircraft. Some can be accomplished through visual inspection alone; others require use of the fingers to test fittings and connections. For all rotary aircraft, the aircrewmembers must be able to climb on top by inserting their

*The CH-47 takes the longest amount of time to ready for flight, and under certain extreme environmental conditions this time may exceed 90 minutes. The CH-47 has an extensive hydraulic system which should be preheated during extreme cold weather.

boots in the toe holds and pulling themselves up with their hands. Once on top of the UH-1, the UH-60, or the CH-47, the crewmembers are required to traverse the length of the aircraft to check systems located in the rear. This task is dangerous under icy or windy conditions, because neither the vapor barrier (VB) nor mukluk boot provides sufficient traction.

Sometimes these outdoor preflight tasks must be completed in the vicinity of a hovering aircraft or while the rotors of the aircraft undergoing inspection are turning. The latter case occurs, for example, when checking for leaks. The windchill factor created by the rotorwash can exceed -60°F (-51°C) and sometimes approaches -100°F (-73°C). (See Wind Chill Chart - Table 5).

Additional preflight tasks must be done inside the cockpit before the engine is started. Pilots must have unrestricted manual dexterity to check such items as the radio, the instruments, and the circuit breakers, as required by a checklist.

c. Run-up

Time: 10-35 minutes

Environment: ambient to start; heater functional within 10 minutes

Activity Level: Light - sitting

Engine run-up time varies with outdoor ambient temperature. It is necessary to bring the engine up to operating temperature to avoid possible engine damage caused by water vapor condensing and freezing.

(2) Flight/Mission Tasks (in-flight)

Time: 1 to 1-3/4 hours each

Environment: cabin/cockpit temperatures ranging from 10°F (-12°C) to 40°F (4.4°C)

Activity Level: Light - sitting, but under mental stress

For the duration of the flight, the pilot and copilot perform their flying activities while seated and secured by the safety harness. Life support equipment necessary for protection or for operating the aircraft must interface with the cold weather clothing. These include the helmet, the survival vest and armor, the interior communication system, chemical/

/biological protective gear, the oxygen system, and the Aviator's Night Vision Imaging System (ANVIS). The flight gloves must provide the manual dexterity and touch sensitivity required to manipulate efficiently toggle switches, circuit breakers, the throttle, the cyclic and the collective. The boots must interface well with the foot controls and not be so thick as to reduce the pilot's sensation of critical vibrations which are communicated through the foot pedals. The bulkiness of the clothing must not inhibit access to controls reached by stretching.

The tasks of the crew chief and the flight engineer and their concomitant levels of physical exertion vary according to the mission. Generally, these two crewmembers are more mobile than the pilot and copilot and need greater freedom of movement, especially for their upper torso, in order to perform their functions efficiently. Their duties frequently require that they move around the aircraft. They operate lifts and winches when lifting cargo or rescuing individuals, secure cargo and gear, and supervise passengers. When picking up, dropping off, or carrying suspended cargo, the crew chief assumes a prone position and looks through an open hatch in the floor of the aircraft to guide the pilot. This task requires that his head and face be protected against exposure to the ambient air. The crew chief and flight engineer communicate with the cockpit through the interior communication system. They are connected to this system by an umbilical cord cable which connects to their helmet.

(3) Flight/Mission Continuation Tasks (on ground)

a. Refuel

Time: 5-10 minutes per mission (hot refuel)
30 minutes per mission (cold refuel)

Environment: -60°F (-51.1°C) to 60°F (16°C)

Activity Level: Moderate

If a crew chief is on board, this person generally handles refueling; otherwise this task is performed by the pilot or copilot. A hot refuel where the aircraft engines are not shut down takes less time; however, the rotorwash increases the chill factor for the fuel handler. For a cold refuel, the engines are shut down and the aircraft is secured before it is refueled. This task is often sloppy and very cold as the fuel temperature will be equivalent to the ambient temperature. Fuel spilled on clothing or skin is much more dangerous than water because it does not freeze. Fuel supercooled below freezing point of water will cause instantaneous frostbite contact with bare skin.

b. Cargo Handling or Rearming

Time: 0-60 minutes

Environment: -60°F (-51°C) to 60°F (16°C)

Activity Level: Moderate to heavy

These two tasks are addressed together since each is done outdoors in preparation for the next flight. Cargo handling is required for all aircraft; however, the size, weight and bulk of the cargo varies with the function of the helicopter. The crew chief assists in loading cargo by operating winches, directing vehicles driven onboard, and ensuring that all cargo is securely tied down. Rearming is required for the attack helicopters and consists of loading the following types of weapons: 20 mm and 30 mm turrets, 7.62 mm door guns, TOW missiles (40 lb (18.1 kg)) and Hellfire missiles (100 to 110 lb (45.4 to 49.9 kg)). The AH-1 carries 8 missiles and the AH-64 carries 16 missiles. This task requires 30 minutes to one hour of heavy labor. The pilot and copilot sometimes assist with rearming since attack helicopters do not carry a crew chief.

c. Maintenance and Repair

d. Debriefing/Rebriefing

Time: 10-20 minutes per mission

Environment: indoor temperatures ranging from 45°F (7°C) (tent) to 70°F (21°C) (building)

Activity Level: Light - sitting or standing

(4) Post Flight Tasks

a. Secure and Inspect Aircraft

Time: 5-15 minutes

Environment: -60°F (-51°C) to 60°F (16°C)

Activity Level: Light to moderate

Tasks include inspecting aircraft for cracks and leaks, securing aircraft to ground, and when appropriate, removing battery and/or installing ice and snow covers. All aircrew members participate in these tasks.

- b. Refuel
- c. Rearm
- d. Maintenance and Repair
- e. Flight Logging/Debriefing

See Flight/Mission
Continuation
Tasks - same
procedures

Time: 5-10 minutes

Environment: 45°F (7°C) (tent) to 70°F (21°C) (building)

Activity Level: Light - sitting or standing

3. HAZARD PROTECTION

In addition to facilitating the routine tasks aircrews perform, the aircrew clothing system and associated equipment must provide protection from operational hazards. These hazards include fire, crash impact, and the various forms of weaponry. Although protection from weapons is not an essential characteristic which must be incorporated into the new aircrew clothing system, the LOA requires that the new system must be compatible 1) with the approved chemical/biological (C/B) protective ensemble, and 2) with personal armor protection. Improvements in these two areas of protection are being sought under two separate but concurrent development efforts. The requirements documents supporting these efforts are identified below and described in greater detail in Appendix F. Because of the recent emphasis on improved chemical/biological protection, a separate subsection which discusses the implications of cold temperatures on the C/B threat and protection is included in this section.

Development of a new armor vest to protect aircrews from conventional weapons is proceeding under an approved Letter Requirement.⁹ The vest is a combination armor/survival item and will be worn over the cold weather clothing. The threats posed by technologically advanced weaponry, including antiaircraft, nuclear, chemical, biological, and laser systems, present special problems not easily solved by conventional clothing and equipment. As a result, protection from these threats is being addressed in a separate Letter of Agreement.⁵

Fire Protection

The new aircrew cold weather ensemble must provide the maximum degree of fire protection commensurate with the state-of-the-art. Crashworthy fuel tanks have sharply reduced the number of fires resulting from crashes, and fire protective clothing can serve to reduce further the number of injuries and casualties. The refueling operation presents a triple hazard situation:

1) the individual is in direct contact with the fuel, 2) fuel soaked clothing is a fire hazard, and 3) wet clothing loses its insulation value.

Static electricity creates serious problems in a dry cold environment. The flow of fuel during refueling operations generates static electricity.⁶ Fuel and air mixtures are highly explosive and a single spark of static electricity can cause ignition. Although it is very important that the aircraft be electrically grounded and that individuals discharge static charges from their bodies before engaging in refueling operations, this is not always possible due to the frozen ground.

The flight suit is the only item of the current cold weather flying ensemble which is constructed of Nomex*, a nylon flame-resistant fabric. The Nomex summer weight flight gloves are not adequate for most winter environmental conditions, but are sometimes worn under the leather shells. All items of the new system, including the boots, should offer fire protection.

Crash Impact Protection

Functional cold weather footwear for aviators should not only provide adequate warmth but should also provide impact protection, especially to the toe area. Aircrews currently wear one of several boots in extremely cold regions: the vapor barrier boot, the Air Force mukluk, or the Army ski boot, mountain. As none of these was specifically designed for aircrew use, their provisions are inadequate.

Chemical/Biological Threat and Defense in the Cold

Chemical/biological (C/B) protection need not be directly incorporated into the cold weather aircrew clothing system, but the new system must interface with type-classified and developmental gear. Several recent developments have influenced the decision to include this discussion of the C/B threat and its defense in the cold. These include: 1) increased realization throughout the military of the likelihood of C/B use, 2) parallel research and development efforts which are examining the feasibility of including C/B protection as an inherent property of the flight suit, and 3) the results from a recent study that examined the need for and effectiveness of chemical protection in cold temperatures.

The C/B threat and operational procedures for combating that threat have not been adequately defined for cold, intermediate cold, and extreme cold regions. Current doctrine requires that in the event of a C/B hazard, the standard protective C/B clothing (overgarment, mask, hood, overboots, and gloves) be worn under the parka and associated trousers.¹⁰ In the case of aircrews, the overgarment is worn over the flight suit.

*Nomex is a product of the Dupont Corporation. The use of trade names does not constitute or imply endorsement of a product.

It is generally assumed that the probability of a C/B attack is greater in warm climates than in cold and that the additional layers of winter clothing provide increased protection. Temperatures below 40°F (4.4°C) are unfavorable for a chemical vapor attack; however, other anomalies caused by a cold environment make C/B warfare a real danger.¹¹ Most nerve agents (GA, GB, GD, and VX) and several blister agents (HN-1, HN-2) do not freeze until the temperatures are extremely cold, that is, below -30°F (-34°C) for some and below -50°F (-46°C) for others. Freezing conditions create special problems in combating the C/B threat. For example, if snow or ice cover chemical agents, their effects will be preserved until the snow melts or the chemicals are uncovered. Any frozen contamination carried indoors on clothing or equipment will thaw causing secondary contamination and vapor hazards in heated areas. Existing equipment decontaminants allow chemical decontamination down to -25°F (-32°C). However, decontamination procedures which call for an abundant application of water are impractical because of the subfreezing weather. As of January 1981, no procedures had been defined for decontamination in arctic conditions.¹⁰

A recent study used both simulation and analytical models to examine the threat of chemical agents in cold temperatures.¹² The study compared the relative effectiveness of standard environmental clothing to chemical protective clothing in preventing casualties in a warm 77°F (25°C) versus a cold 20°F (-7°C) environment. The study showed that chemical agents can be effectively deployed at low temperatures. Relative to the warmer temperature, the study found that at 20°F (-7°C) the quantity and volatility of persistent agent vapor decreased dramatically while slightly higher concentrations of liquid agent were deposited over a larger area. These differences combined with the increased protection of winter clothing, resulted in lower casualties relative to a similar attack at a higher temperature of 77°F (25°C). For nonpersistent agents, the vapor quantity and coverage also decreased at the colder temperature, but the significantly greater concentrations of the liquid deposits caused casualty levels equivalent to the warmer temperatures. The inhalation hazard is still present in cold temperatures.

Under the new Air Cavalry Attack Brigade plan and Division 86, aviation will assume a more major role within the total Army mission. In recognition of this, new developments are under way to provide aircrews with improved clothing and equipment which will facilitate their job. One proposed goal is to provide continuous C/B protection. Sufficient tests have not been completed to determine whether this is a feasible goal, but experiments with flight suits which offer C/B protection, and experiments with a microclimatic cooling vest to keep the body in thermal balance have recently been conducted. The possibility of the development of a future C/B flight suit with an inherently higher insulation value should be considered when designing the aircrew cold weather system.

4. SURVIVAL

Aircrew personnel will be faced with a survival situation in the event that enemy action or a mechanical failure causes a crash or unexpected landing. Flight clothing, together with the equipment and rations stored in the survival vests and kits, must provide aircrew personnel with the basic resources to meet successfully the problems posed in performing survival tasks.

The cold regions aircrew survival doctrine is summarized below.²

- 1) Critical Period (0 to 72 hours) - During this period the maximum physical activity will take place. The first concerns of the survivors are to exit the maximum danger area of the airframe, perform life-saving first aid and preventive medicine, and decide upon a plan of action. Second, the survivors must take precautions to prevent cold injury, and third, they must use signaling equipment to alert the rescue team.
- 2) Intermediate Period (72 hours to 14 days) - Gathering sustenance is a major activity during this period because rations will have been exhausted after 72 hours. Other consumable materials (matches, etc.) will last about 14 days.
- 3) Extended Period (After 14 days) - Search and rescue efforts will be discontinued.

In recent years, improved capabilities of search and rescue groups have greatly shortened the duration of survival situations for downed aviators. Data obtained from the US Army Safety Center indicate that there were 90 Class A aircraft mishaps with fatalities between January 1, 1975 and September 30, 1981.* Of these, 78 (87%) of the mishap sites were located in less than two hours, and only 8 (9%) took longer than eight hours to locate. The same source reports that between January 1, 1972 and March 7, 1979, 83% of the 234 downed aviators who survived mishaps were rescued within two hours and 99% of them were rescued within 7 hours. Two aircrews were missing between 30 and 40 hours before they were found.

The draft document, "Survival Equipment Doctrine for Canadian Forces Aircrew,"¹³ indicates that the longest survival stay for a downed Canadian Forces crewmember in the 14 year period between 1965 and 1979 was 15 hours. This report recommends a 72 hour survival provision time frame based on the 15 hour statistic and a five-to-one safety factor. The new US Army aircraft survival kits contain rations to sustain the crew for 72 hours in cold regions and 24 hours elsewhere.

*A Class A mishap is an aviation accident which totally destroys the aircraft, or results in a fatality or fatalities, or causes over \$500,000 worth of damage.

The current US Army survival system for cold regions consists of the SRU-21/P Survival Vest and the Survival Kit, Individual, Cold Climate. This system is inadequate for many reasons, including: 1) the vest is not made of fire-resistant material, 2) the system lacks some items of equipment critical for survival and includes others of limited value, and 3) survival kits are designed for individual rather than crew use, resulting in excessive weight and bulk due to unnecessary duplication of items. As mentioned, new survival equipment for Army aircrews is currently under development. Three requirements documents, one for a survival vest, one for survival supply packets to insert in the vest pockets, and one for modular survival kits, have been approved. (These are described and referenced in Appendix F.)

Although the new survival system will not include clothing, several equipment items can be used to supplement the environmental protection provided by the aircrew clothing system. For example, the new survival kit will provide a tent capable of housing two or five persons. The down-filled sleeping bag provided for each crewmember and passenger in the survival kits is rated at 8.2 clo and can provide several hours of sleep in temperatures as low as -40°F (-40°C). The bag represents a major improvement in environmental survival protection, since the sleeping bag it replaces was only suitable for use in temperatures above +20°F (-6.7°C).

The LOA for the aircrew clothing system includes the requirement that the system provide protection from prolonged water immersion. Hypothermia is a distinct possibility in the event a mishap leads to cold water immersion. For example, a person will lose consciousness in less than 15 minutes if immersed in near freezing water without an anti-exposure suit. In water temperatures from 32°F (0°C) to 40°F (4.4°C), the time until consciousness is lost is 15 to 30 minutes. The specialized nature of cold water immersion protection requires that a separate constant-wear anti-exposure suit be developed. This suit would be more practical for flight crews than the currently authorized quick-don suit because it is impossible for airborne crew members to don a suit quickly in a cramped cockpit.

The problem of cold water immersion protection is being assessed in a separate study under the funding for the aircrew cold weather system, and therefore will not be addressed in this analysis. As part of this substudy, two commercially available constant-wear suits were recently evaluated by the US Army Cold Regions Test Center.¹⁴ Both suits were found to be uncomfortable and additional testing was recommended.

5. PERFORMANCE PARAMETERS FOR THE AIRCREW CLOTHING SYSTEM, COLD WEATHER

Aircrew cold weather clothing requirements not satisfied by existing items of equipment or other developmental programs should be incorporated into the new clothing system. This section summarizes these functional capabilities and identifies the key performance parameters which can be used

to evaluate the proposed clothing concepts. These parameters were derived from the mission profiles, the environmental and hazard protection requirements, consideration for human factors, and RAM (reliability, availability and maintainability) requirements.

The strengths and weaknesses of the various proposed clothing concepts could be evaluated by separating the clothing system into its physical components such as gloves, boots, etc., or alternatively, the system could be addressed as a whole and each alternative solution subjectively evaluated on how well it meets the stated functional requirements. The latter approach was chosen since at this stage of development, the clothing items do not physically exist and several of the alternatives represent untested concepts.

Figure 1 graphically displays the primary performance parameters which will be used to evaluate the alternatives. These parameters are arranged in a logical hierarchical framework which starts at the top with an overall objective -- system effectiveness. The functional parameters and subparameters to achieve the overall goals are then identified in successively lower levels. As Figure 1 indicates, system effectiveness is basically a function of five major objectives. These are that the new clothing system should provide environmental protection and hazard protection without introducing incompatibilities with the aircraft or other equipment, take into account human factors, and be reliable, available, maintainable, and durable.

The subcategories of the five major objective areas are identified and discussed below. The discussion follows the order of Figure 1. It covers most of the essential characteristics mentioned in the LOA (Appendix H) but excludes detailed design features which cannot be included in a conceptual evaluation.

Environmental Protection

The ability of the new system to protect aircrews from the cold is a major objective or performance parameter. Protection from two very different sets of environmental conditions must be incorporated into the clothing system --those encountered during routine missions and those encountered during survival situations. These categories represent the first subdivision under environmental protection (see Figure 1). Similarly, while performing routine missions two very different temperature conditions are encountered on a daily basis: inflight cockpit temperatures, and pre/post flight and other ambient temperatures. Survival environments also are divided into two conditions: ground survival and water immersion survival. A special environmental protection requirement exists for the pilot of the fixed wing OV-1 aircraft* who must eject during an emergency.

*OV-1 and other aircraft flown by Army aircrew are described in Appendix B.

PERFORMANCE PARAMETERS AIRCREW CLOTHING SYSTEM, COLD WEATHER

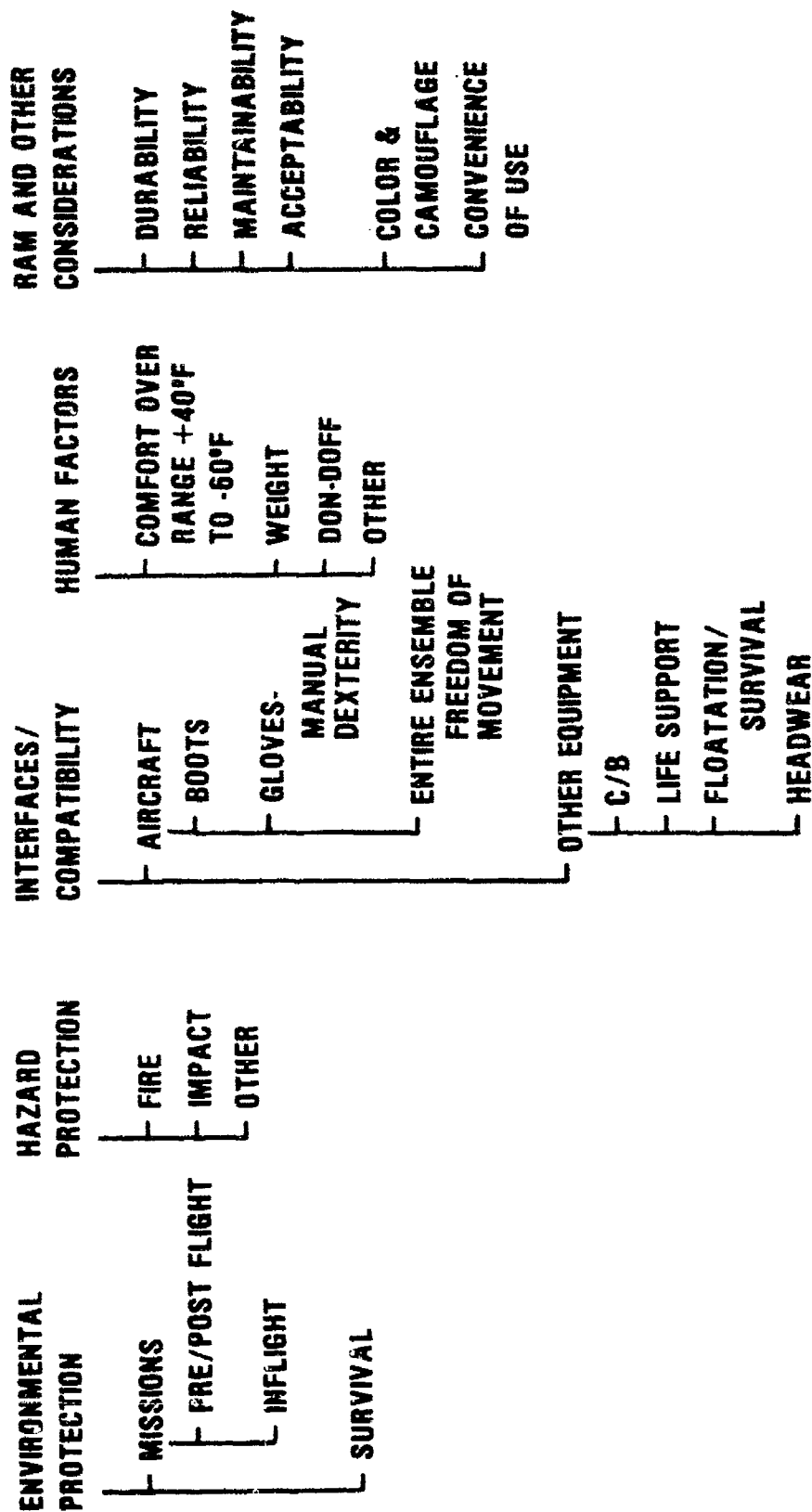


Figure 1. Hierarchy of performance parameters for the Aircrew Clothing System, Cold Weather.

For each environment, the LOA provides guidance concerning minimum temperatures likely to be encountered. For pre/post flight tasks and survival activities, the new ensemble must provide environmental protection including water repellency to -60°F (-51.1°C). For inflight tasks, the minimum cabin/cockpit temperatures for which protection must be provided are specified as:

- 1) -60°F (-51°C) for five minutes
- 2) -30°F (-34°C) for ten minutes
- 3) 1) and 2) above, sequentially, totaling fifteen minutes, then for the duration of a typical aircraft mission at +40°F (4.4°C).

During the total time period, protection for the extremities must be sufficient to maintain a fingertip and toe temperature of 60.8°F (16°C). Research has determined that below this temperature normal dexterity drops precipitously and a pilot's finger function would be seriously impaired.

Hazard Protection

This general category encompasses the ability of the ensemble to protect aircrews from fire and crash impact hazards. It also includes clothing features to facilitate retrieval from a crash.

Interface/Compatibility

The most important requirement of the new system is compatibility with the aircraft and other aircrew equipment. The system should not hinder the aircrew's performance or safety. Items of the ensemble which interface with the aircraft and the key characteristics are listed below.

Gloves must provide the manual dexterity required to perform all pre/post flight and missions tasks.

Boots must fit comfortably into the toeholds and foot control areas. They must provide traction and permit aircraft vibrations to be sensed through the soles.

Jacket and Trousers combined with other layers and the survival/armor vest must not restrict the general freedom of movement required for preflight or flying tasks. Also, the bulk of the clothing must not restrict sight or interfere with easy access and exit.

Many other items of equipment must interface well with the basic clothing system. These include the C/B gear, life support equipment, the helmet, flotation/survival equipment, and the Aviators' Night Vision Imaging System.

Human Factors

This category of parameters measures how comfortably the clothing system interfaces with the person alone without regard for the aircraft. The human factor category includes the flexibility of the clothing system to adjust for temperatures over the range of +40°F (4.4°C) to -60°F (-51°C), the weight of the ensemble, and the ease of donning/doffing. Other human factors design features noted in the LOA are the need for strategically located pockets, the provision of a drop seat, and sizing requirements.

RAM and Other Considerations

The differences between alternatives in their reliability, availability, and maintainability are important performance considerations. Several proposed alternatives involve mechanical parts, such as pumps or heaters, which are more likely to malfunction than conventional clothing. Also included under other considerations are the durability of the proposed system, its acceptability among users, and its convenience of use.

Chapter III

COLD REGIONS: CLIMATIC CONDITIONS AND THE DEPLOYMENT OF ARMY AIRCREWS

1. INTRODUCTION

The new aircrew clothing system for cold weather will be worn in Clothing Allowance Zones V, VI and VII and in the mountainous, plateau and other highland areas of the world. Appendix A displays a map of the geographical areas covered by these zones, lists the countries contained in each, and explains the major differences between the US Army Clothing Allowance Zones and other military climatic classification schemes. As the map of the Clothing Allowance Zones (Figure A-1) illustrates, the three coldest zones and the highland areas (black) collectively extend throughout most of North America, Asia, and Europe. About 48% of the total land mass of the northern hemisphere has been classified as cold regions.¹⁵ Winter conditions throughout these regions vary from cold to extreme cold.

The purpose of this chapter is twofold:

- to present climatic data which quantitatively define the meaning of cold and extreme cold and demonstrate the differences in environmental conditions between various locations in the zones; and
- to identify the geographical distribution of Army aircraft and aircrew personnel in these zones.

The conclusions drawn from these data are utilized in the assessment of the proposed conceptual alternatives (Chapter VI). Appendix A contains much of the climatic data and descriptive material which support this chapter. Similarly, supporting material on Army aircraft is included in Appendix B. These appendices are frequently referenced in the pages which follow.

2. WEATHER CONDITIONS IN COLD REGIONS

In cold regions, many factors interact to create environmental conditions. Such principal factors as temperature, wind, humidity, precipitation, and darkness are constantly changing. Due to the complexity of these interactions and the variability in conditions which result, it is difficult to characterize the climate of a land mass as large as half of the northern (or southern) hemisphere with any accuracy. Also, not all of the parameters are of major significance in the design of aircrew clothing. Therefore, the discussion here is limited to the general effects of the key factors which

affect clothing design--temperature and wind. It is assumed that precipitation, ranging from rain to snow, occurs throughout the three clothing zones (Appendix A) in varying amounts and that the clothing will be designed to accommodate these conditions.

Several relevant questions concerning temperature and wind conditions in the three zones are listed below.

- 1) What are the normal daily minimum, maximum, and average winter temperatures for various locations in the three clothing zones?
- 2) What are the lowest temperatures reached in different areas?
- 3) How frequently do the lower temperatures occur?
- 4) How much variation in temperature exists between locations in the same zone?
- 5) What are the average wind speeds?

Data which answer these questions were collected and analyzed for this systems analysis.

Temperature

Section 2 of Appendix A briefly discusses winter conditions in the continental United States, Alaska, Scandinavia, and Korea. Maps displaying data which answer questions 1 and 2 above are included (Figures A-2 thru A-4). These data indicate that for Clothing Allowance Zones V, VI and VII, the normal daily minimum temperatures for January vary between a high of about 25°F (-4°C) found in the warmer locations in Zone V to a low of around -21°F (-29°C) for Fairbanks, Alaska. Absolute minimum temperatures in the -40°F (-40°C) to -70°F (-56.7°C) range have been recorded in Alaska, Canada, Asia, and even in northern sections of the continental United States. Absolute lows between -20°F (-29°C) and -40°F (-40°C) have occurred in numerous locations in Zone V; however, the probability that temperatures as low as the absolute minimum temperatures will occur is very small and protection to those levels is not an absolute necessity, and therefore, unacceptably expensive given the expected risk. In general, the Army accepts a small risk of having the design specifications violated during periods of extreme weather. For most climatic elements, a level which is exceeded not more than one percent of the time is used.¹⁶ These values are known as the one percent design values.

Figure 2 displays one percent design temperatures for various locations in Clothing Zones V, VI and VII. For each location a temperature range is indicated by a bar. The range indicates the minimum levels, for different sites within the specified state or country, below which the temperature does not drop 99% of the time during the coldest three consecutive months (December, January, and February). All sites listed for a specified state or country in the Engineering Weather Data publication for the Departments of the

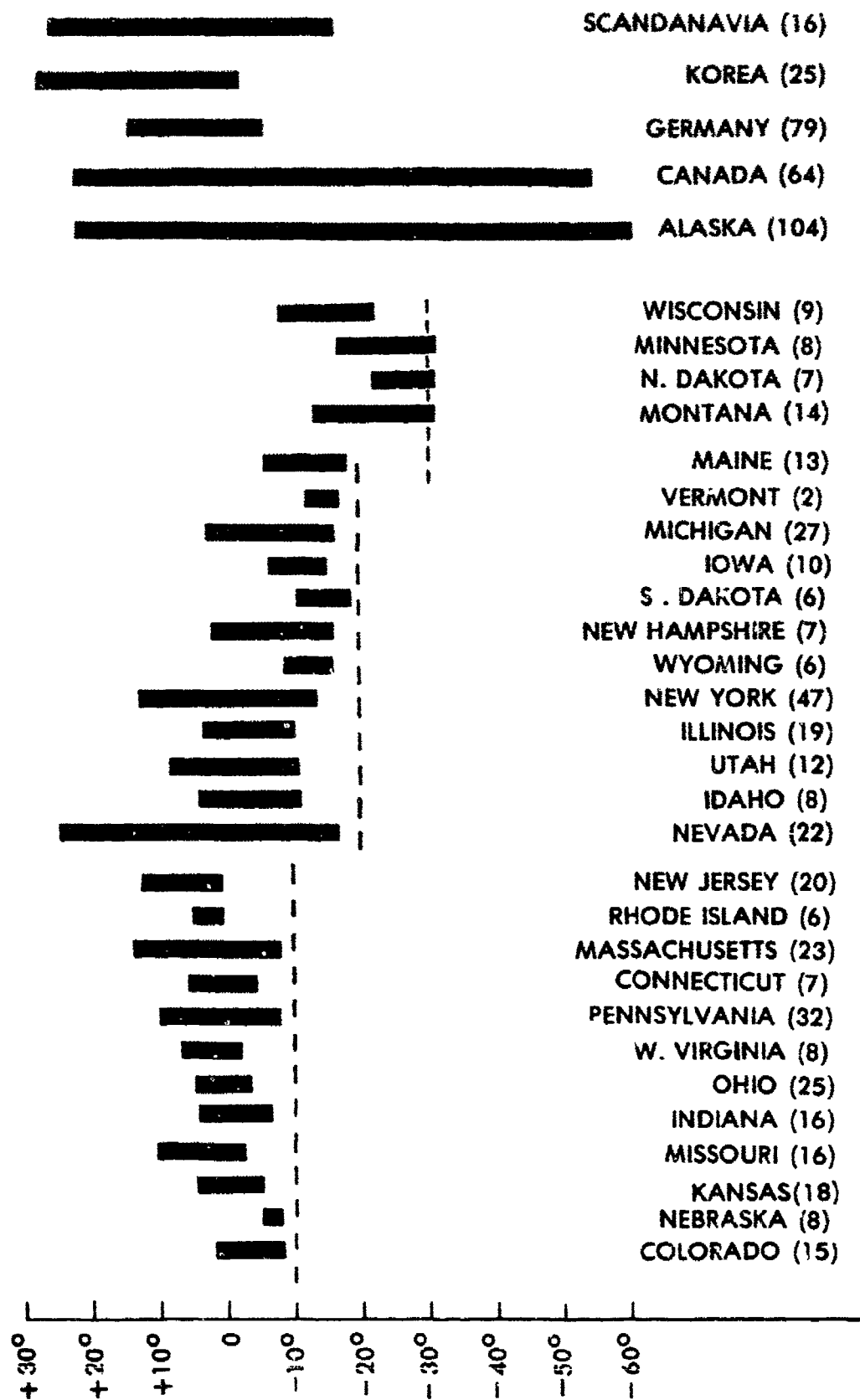


Figure 2. Ranges of minimum temperatures (1% Values) for various states/countries

Note: The number of sites is indicated in parentheses following a location name.

Air Force, the Army, and the Navy are included in the analysis.¹⁷ The number of sites for each location included in Figure 2 is indicated in parentheses following the name of the state or country.* For example, data were available for 15 sites in Colorado and the minimum temperatures at these sites ranged between +2°F (-16.7°C) and -8°F (-22.2°C). For the most part, the data published in the Engineering Weather Data manual were collected at military installations.

With the exception of Alaska, all states shown in Figure 2 are in Zone V. The states have been separated into three groups depending on whether the lowest temperatures are above -10°F (-23°C), between -10°F (-23°C) and -20°F (-29°C), or below -20°F (-29°C). Because of the temperate influence of the sea on the coastal zones and the severe conditions of the interior, both Alaska and Canada have sites whose minimum temperatures differ from one another by about 80°F (+20°F to -60°F).

The bars drawn in Figure 2 to identify ranges of minimum temperatures give no indication of the distribution of sites within each range. For this purpose, several areas were chosen and the frequency distributions of all data points (sites) available for each area were plotted (Figure 3). Michigan represents Zone V, Germany represents Zone VI, and Canada and Alaska represent Zone VII (interior areas) and Zone VI (coastal areas). As can be seen, minimum temperatures in the -30°F (-34°C) to -60°F (-51°C) range occur at numerous sites throughout Alaska and Canada. The USSR, Mongolia, the northernmost part of China, Greenland, the Arctic, and Antarctica are the only other areas of the world with temperatures as low.

Wind

Wind occurring concomitantly with low temperatures creates effectively colder conditions through the wind chill effect. This situation increases human discomfort and adds to operational problems. Wind chill has been defined as the cooling effect of moving air on a body expressed as the amount of heat lost per unit area per unit of time, taking into account temperature and wind speed (Webster's Third New International Dictionary, Springfield, MA, G. C. Merriam Co., 1967). Average wind speeds are presented here for selected locations.

In Alaska, at temperatures below -40°F (-40°C), the wind speed averages about 3-5 knots. At temperatures from 0°F (-18°C) to -40°F (-40°C), the wind speed averages 5-10 knots. Canada is slightly windier. At temperatures below -20°F (-29°C), the wind averages 7-9 knots and at temperatures between 0°F (-18°C) and -20°F (-29°C), it averages 10-12 knots. On the coldest days in Germany, the mean wind speed is 3-8 knots, and in Michigan the mean speed is 7-9 knots.¹⁷

* Since only four sites were listed in the Engineering Weather Data publication for Scandinavia, additional data from the Arctic Institute of North America were included.

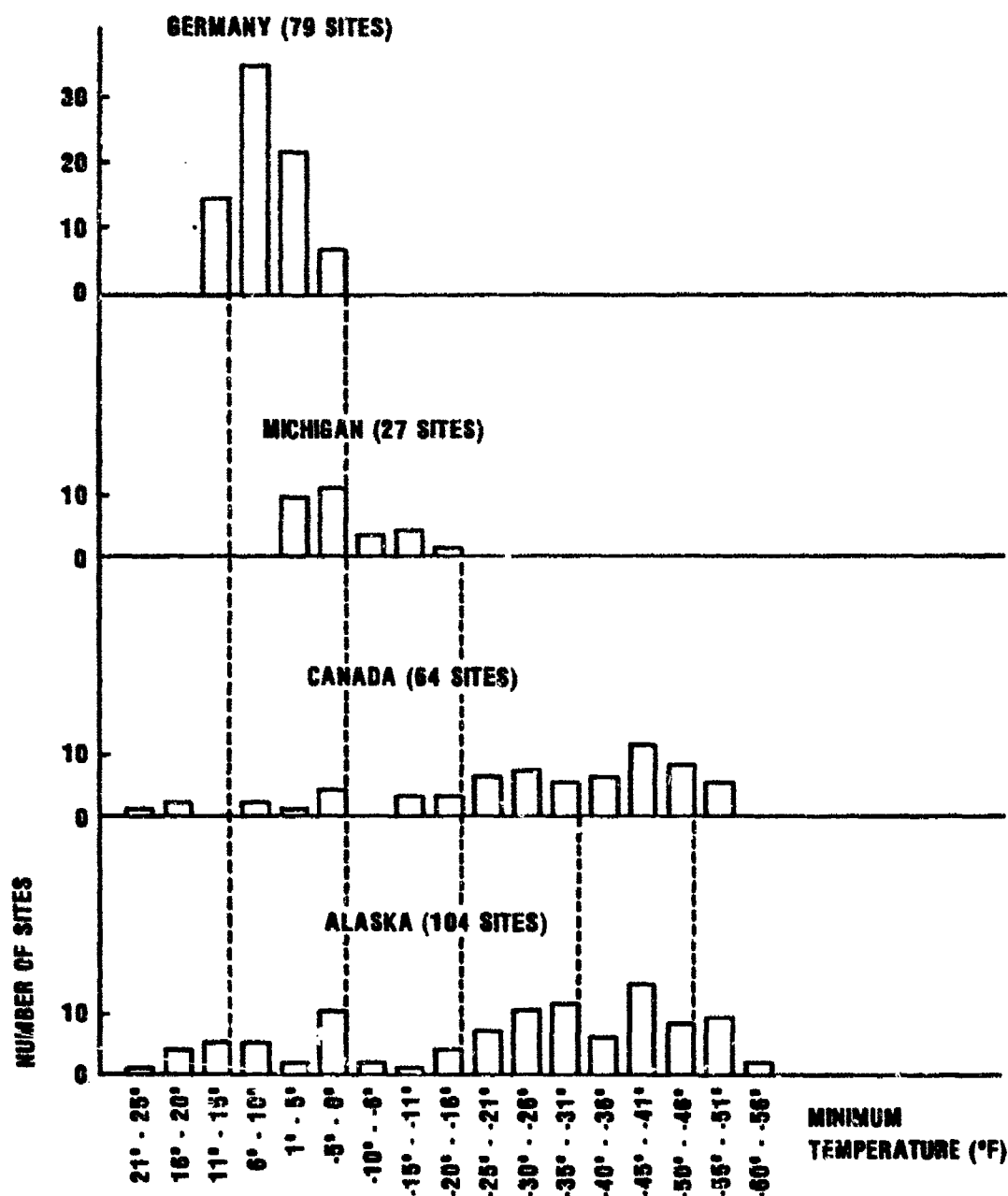


Figure 3. Frequency distributions of minimum temperatures.

Alaska

Thermal protection against extreme cold presents a difficult problem for clothing developers. Due to the inadequacy of the current ensemble under extreme cold conditions, the performance of aircrews in Alaska is greatly impaired. Section 3 of Appendix A presents a brief description of the Alaskan climate and displays climatological data for two Army bases. Table 1 included here conveys an understanding of the severity of the climate in central Alaska.

When designing clothing protection against the cold, the mean temperatures are not as useful as knowing how frequently various lows are experienced or what percentage of the days the temperature drops below various levels. Table 1 presents this data for Fairbanks. This table displays interval data for minimum temperatures recorded over a 20-year period. These data indicate (see first Cumulative Percent Column) that on 42% of the days from December 1 to March 1, the temperature can be expected to drop below -20°F (-29°C). On about 26% of the days, it should fall below -30°F (-34°C) and 84% of the days subzero temperatures occur. The last two columns give summary data for the seven-month period October 1 through April 30. During these months, the temperature can be expected to drop below -20°F (-29°C) about 25% of the days.

3. AIRCRAFT AND AIRCREWS DEPLOYED IN COLD REGIONS

The previous section examined the general differences in climatological conditions between locations in the three cold weather clothing zones without regard for the presence and level of military operations in each area. The purpose of this section is to characterize the extent of peacetime Army aviation activity in cold, intermediate cold, and extreme cold regions.

Types of Aircraft

The new clothing system will be worn by Army aircrews performing aircraft missions under the Alaskan scenario or aircrews engaged in cold region air-mobile combat operations in other areas of the world. These missions are conducted by four types of helicopters (attack series, observation series, utility series, and cargo series) and four types of fixed wing airplanes (VTOL and STOL series, utility, cargo, and reconnaissance series). Army National Guard and Navy/Marine aircrews also plan to wear the uniform.

Section 2 of Appendix B identifies the specific aircraft within each series, classifies them by branch of service, and lists the crewmembers. A brief description of the major Army aircraft and a photograph of each can be found in Appendix B, Section 1. The discussion includes a statement of the function of each aircraft, the capabilities which distinguish them, and some historical notes.

TABLE 1. Frequency Distributions of Daily Minimum Winter Temperatures in Fairbanks, Alaska

Temperature Intervals (°F)	Oct 1 to Nov 30	Dec 1 to Feb 28	Dec 1 to Feb 28 Cumulative Percent*	Mar 1 to Apr 30	Summary Data Oct 1 to Apr 30 Cumulative Percent*
-60°F	-	0.3%		0.1%	0.1%
-50° to -59°	-	3.7%	4.0%	0.8%	1.6%
-40° to -49°	0.8%	10.1%	14.1%	3.5%	4.8%
-30° to -39°	5.1%	11.5%	25.6%	6.8%	7.4%
-20° to -29°	6.1%	16.7%	42.3%	9.6%	10.9%
-10° to -19°	9.4%	22.1%	64.4%	17.9%	14.8%
0° to -9°	15.6%	19.4%	83.8%	19.1%	17.9%
10° to 19°	20.8%	9.8%	93.6%	19.4%	15.7%
20° to 29°	19.1%	5.4%	99.0%	17.7%	13.3%
30° to 39°	20.3%	0.9%	99.9%	4.8%	11.3%
40° to 49°	2.7%	0.1%	100 %	0.3%	2.2%
50° to 59°	0.1%	-	-	-	0.0%
	100%	100%		100%	100%

*The Cumulative Percent columns indicate the percent of days during which the minimum temperature was contained in interval shown or in a colder interval.

Source: Reference 18.

Geographical Distribution of Army Aircraft and Aircrews

The 1981 peacetime distributions of the US Army aircraft and aircrewmembers among climatic zones are presented in Table 2. The purposes of the data are first to compare the number of Army aviators (and aircraft) located in Clothing Zones V, VI, and VII to the total number of aircrewmembers (and aircraft) worldwide, and second to identify the relative size of the cold versus the extreme cold weather operations. This information will serve to identify the total number of aircrewmembers who will wear the new cold weather aircrew clothing system and the subset of this group which requires protection to -60°F (-51°C). (Of course, these numbers would change if a conflict developed in an extreme cold region.) The Army National Guard (ARNG) resources are included in the estimates since ARNG aircrew wear Army clothing and fly Army aircraft.

The US Army has over 8700 aircraft in its inventory; of these, about 8200 are rotary wing aircraft and the remainder are fixed wing. Approximately 38,000 aircrewmembers are required to operate these aircraft. The number of aircraft based in geographical regions encompassed by Clothing Allowance Zones V, VI, and VII is estimated at 4200 (48% of total Army aircraft). By proportion, the number of aircrew stationed in these three zones was calculated to be around 18,500; this figure represents the number of aircrew who will wear the new cold weather clothing system. A small subset of this group will need environmental protection to -60°F (-51°C). As was shown by the climatic data presented in Section 2 of this chapter, few areas of the world regularly experience such low temperatures. Alaska is the major area in this category which supports US Army operations. The total number of aircrewmembers in Alaska, including those in the National Guard, comprise about 3% of all aircrewmembers assigned to regions covered by Clothing Allowance Zones V, VI, and VII. Although Alaska is not the only location at the lower end of the temperature scale, the vast majority of aircrews who will wear the new uniform are located in the Continental US, Europe, and other parts of the world where winters are cold, but not extremely cold.

The lower half of Table 2 displays the data discussed above separated into two components: 1) the National Guard, and 2) the active Army and the reserves. The table also identifies the number of rotary and fixed wing aircraft. A high percentage of the Army aircraft worldwide are Hueys (47%), OH-58s (24%), or AH-1s (12%).

The types and numbers of aircraft at the three US Army bases in Alaska (Ft. Wainwright, Ft. Richardson, and Ft. Greeley) are shown in Table 3. Over 60% of the 103 Army aircraft are located in the cold interior areas of Alaska.

TABLE 2. US Army Aircraft and Aircrew Resources by Climatic Zones*

AIRCRAFT

	<u>Rotary Wing</u>	<u>Fixed Wing</u>	<u>Total Wing</u>
<u>Army (active & reserves)</u>			
All Climatic Zones (worldwide)	5800	430	6230
Clothing Allowance Zones V, VI, VII	2570	175	2745
Alaska	100	3	103
<u>Army National Guard</u>			
All Climatic Zones	2400	140	2540
Clothing Allowance Zones V, VI, VII	1430	55	1485
Alaska	30	4	34
<u>US Army - Total Aircraft</u>			
All Climatic Zones (worldwide)	8200	570	8770
Clothing Allowance Zones V, VI, VII	4000	230	4230
Alaska	130	-	137

AIRCREW MEMBERS

	<u>Total Aircrewmembers</u>
<u>Army (active and reserves)</u>	
All Climatic Zones (worldwide)	27,870
Clothing Allowance Zones V, VI, VII	13,230
Alaska	330
<u>Army National Guard</u>	
All Climatic Zones	10,130
Clothing Allowance Zones V, VI, VII	5,270
Alaska	142
<u>US Army - Total Mobilization Force</u>	
All Climatic Zones (worldwide)	38,000
Clothing Allowance Zones V, VI, VII	18,500
Alaska	472

*Numbers represent 1981 resources. The Clothing Allowance Zone values are estimates.

TABLE 3. US Army Aircraft in Alaska*

<u>TYPE</u>	<u>NUMBER</u>
<u>Active Army</u>	
OH-58 (Kiowa)	29
AH-1 (Cobra)	9
UH-1 (Huey)	46
CH-47 (Chinook)	16
C12	2
U21	1
Total	<u>103</u>
<u>National Guard</u>	
UH-1H	26
CH-54B	4
UV-18	4
Total	<u>34</u>

*Data collected during 1981.

The shaded region in Figure 4 displays the area of the United States included in Clothing Allowance Zones V, VI, and VII. The sequential numbers identify Army National Guard headquarters. The identity of these sites, the number of aircraft, and the number of ARNG aircrewmembers at each site are indicated in Table B-3 of Appendix B. Since the Army National Guard is funded by the states, these data were readily available from the Army Aviation division of the National Guard Bureau. However, active Army forces are organized by commands, and therefore the Army figures (both aircraft and aircrew) presented in Table 2 were derived by subtracting the available National Guard data from the estimates of the total US Army aircraft or aircrew resources supplied by Headquarters, US Army Troop Support and Aviation Materiel Readiness Command. Some error was introduced since the National Guard data represent authorizations and the total US Army data indicate actual resources.

4. CONCLUSIONS

Several conclusions relevant to the development of the new aircrew clothing system can be drawn from the data discussed in this chapter. The first conclusion is that the thermal protection requirements identified in the LOA are reasonable for the coldest regions of Zone VII, but winter

temperatures at the low end of the scale, that is between -30°F (-34.4°C) and -60°F (-51.1°C), occur with regularity in very few regions of the world. These regions are: central Alaska, central Canada, the USSR, the Mongolian Republic, Greenland, northern sections of the People's Republic of China, the North Polar ice cap and Antarctica. Minimum winter temperatures in the -20°F (-28.9°C) to -30°F (-34.4°C) range can be expected in several additional areas of the world. These include: northern United States, southern Canada, North Korea, northern Scandinavia, and other mountainous regions.

The second conclusion is that only a small percentage of the aircrew for whom the new clothing system is being designed presently operate in these severe cold regions where thermal protection to -60°F (-51.1°C) is required. (During a military crisis this situation could change.) Data on the 1981 peacetime locations of Army aircrew indicate that only about 3% of those located in Clothing Allowance Zones V, VI, and VII operate in Alaska. Even in Alaska, temperatures as low as -60°F (-51.1°C) occur infrequently and only in the interior basin or northern sections. For example, over a 20 year period the US Air Force Weather Service recorded only one day when the temperature fell below -60°F (-51.1°C) in Fairbanks, Alaska and 67 days (average of 3 to 4 days per winter) when the minimum temperature registered between -50°F (-45.6°C) and -60°F (-51.1°C). In striking contrast, the lowest temperature recorded in Anchorage, Alaska (the base for most Army National Guard operations) over a three year period was -20°F (-28.9°C).

However, when the effect of wind is considered, temperatures in the 0°F (-17.8°C) to -20°F (-28.9°C) range with 10 mph to 30 mph wind can have the same cooling power as temperatures from -30°F (-34.4°C) to -60°F (-51.1°C) under calm conditions. Similarly, with air movement temperatures above 0°F (-17.8°C) can feel like subzero temperatures.

Although the exact number is not available, the data in this chapter indicate that a large majority (90-95%) of the aircrews who will wear the new clothing system will operate in peacetime in regions where neither the temperatures alone nor the wind chill effect will approach the LOA criteria. However, regardless of how small the percentage, the requirement for environmental protection to -60°F (-51.1°C) is realistic for some aircrews and in a military crisis the number of crews in the extreme cold may well increase.

These conclusions should not be misconstrued as a recommendation to alter the environmental protection requirement as specified. Rather the question raised here is whether it is practical to satisfy all cold weather flying needs with one clothing system. The next chapter analyzes the insulation requirements for various environmental conditions and demonstrates the relationship between bulk and insulation. Since the extra insulation required to protect to -60°F (-51.1°C) appears unnecessary for a majority of the aircrews, the final conclusion is that a more optimal solution to the problem of clothing aircrews in cold regions may be found by relaxing the requirement that one system satisfy such a wide range of protection needs and permit two systems, one for more general cold weather conditions and a second for extreme cold weather.

Chapter IV

CONCEPTUAL DESIGN ANALYSIS

1. INTRODUCTION

A principal question to be answered for each proposed alternative is whether the conceptual approach is feasible considering the mission requirements (Chapter II) and the state-of-the-art of the technology. This chapter presents technical information and the results of analyses performed to answer conceptual design questions related to the development of a new cold weather aircrew clothing system. Physiological knowledge, the principles of clothing, findings from past experience (both in the laboratory and on the field), and other relevant factual information are utilized in the analyses.

This chapter begins with a general discussion of the science of clothing and the human response to cold environments (Section 2). The feasibility of designing a single clothing system to provide adequate protection in the three coldest clothing allowance zones is assessed through modeling. To analyze the specific levels of insulation required to solve the aircrew clothing needs, the climatic data presented in Chapter III are combined with the mission tasks of Chapter II to create typical temperature/activity profiles. These profiles are entered into the body cooling models which are employed in this analysis to simulate the interaction between the aircrewmembers and the environment (Section 3). The results support the longstanding position of the Office of the Surgeon General that the thermal protection requirements cannot be met without some form of auxiliary heating. Section 4 discusses the feasibility of auxiliary heated clothing and analyzes two potential power sources.

2. THE SCIENCE OF CLOTHING

Heat Transfer and Regulation

The thermal regulation of the human body, like any physical system, depends on the maintenance of a balance between heat production, distribution, and loss. Stability of the deep-body (core) temperature is crucial to avoid any heat- or cold-related problems. Even a variation of less than two degrees Fahrenheit from the usual core temperature of 98.6°F (37.0°C) causes discomfort and reduces efficiency. These temperatures refer to the central areas of the body which must be maintained at a near constant temperature in order for the vital organs to function efficiently. Hypothermia is the lowering of the deep-body temperature to 95°F (35.0°C) or below, a critical point for the impairment of vital functions.

The human body, however, is capable of adapting to wide variations in ambient temperature. To explain the mechanisms, the body will be separated into two temperature regions: the core, which represents about 2/3 of the

body's mass, and the shell which consists of the remaining one-third. Although the core temperature remains fairly constant, the shell, or skin temperature, fluctuates according to whether the body needs to conserve or dissipate heat. The physiological processes are complex, but the effect of the body's first automatic reaction to a thermal imbalance is a change in circulatory distribution. Circulatory heat input from the core to the shell is either reduced (vasoconstriction) to conserve heat or increased (vasodilatation) to dissipate heat. If these reactions do not correct the imbalance, the body shivers to increase heat production or perspires to cool the individual.

The regulatory nature of the shell creates wide differences in skin temperature between various points on the body. In a state of thermal comfort, temperatures on the torso are typically about 94°F (34.4°C) while hands are 84°F (28.9°C). The mean weighted skin temperature in a comfortable condition ranges from 91.4°F (33.1°C) to 93°F (33.9°C). In a cold environment, the shell temperature drops abruptly with the finger and toe temperatures declining most rapidly. At shell temperatures below 60°F (15.6°C) the hand is so cold that manual dexterity is seriously impaired.

The Role of Clothing

In cold regions, the limits of the body's automatic regulatory mechanisms are exceeded and additional clothing must be worn to retard the loss of heat. Ideally, the insulation provided by clothing should be configured to balance the heat loss against the heat generated by metabolic processes. In practice, this is not always possible due to the variations in physical exertion and ambient temperature during the day. Fortunately, if the body's self-regulatory mechanisms fail to maintain a temperature balance, moderate amounts of heat debt or heat excess can be tolerated for limited periods of time. The onset of discomfort occurs with a heat debt (or excess) of 25 kcal* per man. Between a loss (or excess) of 25 kcal and 80 kcal the individual is uncomfortable but still able to function without impairment of performance. Shivering begins after a loss of about 80 kcal and progresses to violent shivering at a debt of 150 kcal. Beyond an imbalance of 150 kcal, there is danger of damage as a result of the cold debt or heat storage.¹⁹

The human body loses heat through both evaporative and nonevaporative heat exchanges. For a person at rest, about 25% of the metabolic heat production is lost through respiration and insensible perspiration. The remaining 75% is lost through radiation and convection; the rate of loss of

* Kilocalorie (Kcal) - A unit of heat approximately equal to the quantity of energy necessary to raise one kilogram of water one degree Celsius. (Kcal = 1000 calories).

this latter nonevaporative component can be controlled by the clothing worn. The key to thermal comfort is to match the insulation of the clothing to the heat dissipated through radiation and convection in order to avoid a heat storage or a heat debt.

Achieving a thermal balance may not be possible in extreme cold environments. Clothing does not supply heat; it only reduces the rate of loss of body heat and thereby extends the time one can remain in the cold. Insulation is primarily a function of the thickness of the trapped air both between the layers of clothing and within the clothing fibers. Therefore, the warmth of clothing is limited by the number of layers and thickness of items (especially in the case of gloves and boots) that one can wear and still work efficiently. Even the Army's bulky arctic ensemble does not provide sufficient insulation to keep one warm at +35°F (1.7°C) for an indefinite period if at rest.

The Clo* Unit

The insulation requirements for clothing are directly proportional to the difference between skin temperature and ambient temperature, and inversely proportional to metabolic heat production. The clo unit is a standard unit used to compare the insulation value of various fabrics and clothing items. (A similar approach, the R value, is used for building insulation. ($R = 1.14$ clo)). One clo unit is defined as the intrinsic clothing insulation required to maintain the thermal equilibrium of a resting person at 70°F (21.1°C) in a normally ventilated room (air movement 20 ft/min with air and wall temperature equal).²⁰ If we assume that the mean skin temperature of such a person is 33°C, then one clo unit is the intrinsic insulation of the clothing (I_{clo}) plus the insulation of the overlying still air layer (I_A) that is required to restrict the dry heat transfer to 5.55 kcal/m² of surface per hour for each degree Celsius difference between skin and air temperature.

To compute the number of clo units necessary to maintain equilibrium under various environmental conditions and metabolic rates, the following formula is used. It was derived from the classic work of Gagge, Burton and Bazett.²⁰

$$I = \frac{I_{clo} + I_A}{M} = \frac{5.55 (\bar{T}_s - T_a)}{M} \quad (\text{Equation 1})$$

where,

I = total insulation value in clo units of protective clothing and overlying air layer

\bar{T}_s = mean skin temperature (°C)

*The metric equivalent of clo is kelvin square meter per watt (K.m²/W).

T_a = ambient temperature ($^{\circ}\text{C}$)

A = area of surface generating heat (m^2)

M = metabolic heat production (kcal/hr), per unit surface area specified as A , which is dissipated through radiation and convection.

The importance of the air layers can be seen by examining the insulation components of a long-sleeved shirt and trousers which together have a clo value of 1.4. The still air layer surrounding the clothing contributes an overall average of 0.8 clo, while the air layer trapped between the cloth and skin contributes about 0.3 to 0.4 clo. Of the remaining 0.2 to 0.3 clo, about 0.1 clo is due to the fiber, and the rest is contributed by air trapped within the fibrous mesh.¹⁹ This example helps to illustrate the paradox presented by the inherently conflicting requirements that the new ensemble be both warmer and less bulky.

The clo values required to maintain thermal equilibrium under various metabolic rates and ambient temperatures can be computed by using Equation 1. Some calculated values are shown in Table 4. Aircrew activities generate metabolic heat in the range of 75 to 175 kcal/hr- m^2 . Clo values in the shaded area of the table represent unrealistically high values in light of the fact that the full six-to-seven-layer arctic uniform offers only an overall value of 4.3 clo at rest.

The Effect of Wind

The cooling of the body is not only a function of the ambient temperature but also of wind velocity. The wind disturbs the still air layer which overlies clothing and thereby reduces the total insulation value attributed to the clothing. Figure 5 illustrates that the effectiveness of the overlying air layer is reduced from about 0.7 clo units in still air to about 0.2 clo units in 30 mph winds.

The graph was drawn using the relationship developed by Winslow, et. al.²¹

$$I_a = \frac{1}{0.61 + 1.25 \sqrt{WV}}$$

where,

I_a = insulation (in clo) of overlying air layer

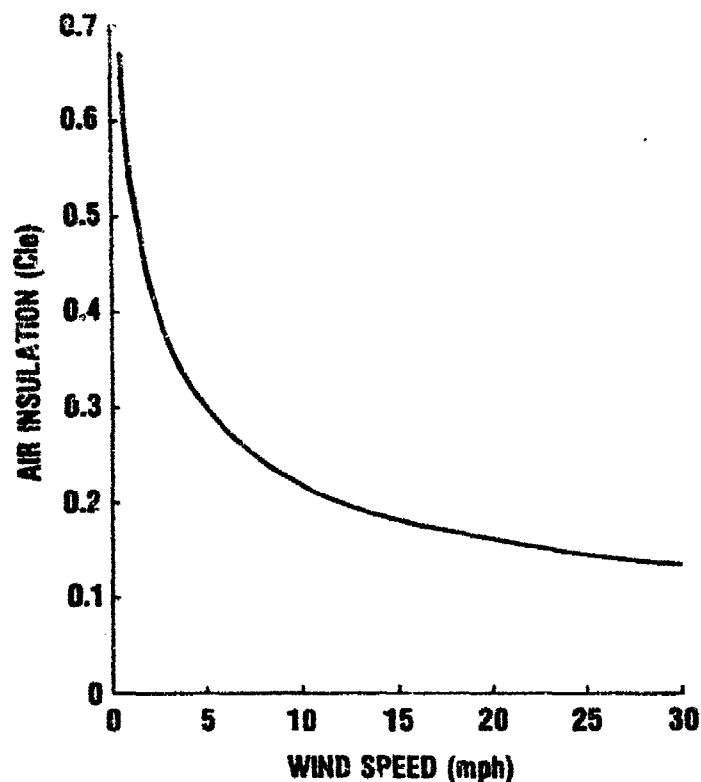
WV = wind speed (mph)

A secondary effect of wind is that it penetrates closures, seams, and porous clothing, thereby disturbing the trapped inner air and further reducing the intrinsic insulation value of the clothing. Thus, to maintain the same

TABLE 4. Clo Units Required to Maintain a Comfortable Mean Weighted Skin Temperature (92°F or 33°C)
Under Different Ambient Temperatures and Metabolic Rates

	-60°F (-51.1°C)	-50°F (-45.6°C)	-40°F (-40°C)	-30°F (-34.4°C)	-20°F (-28.9°C)	-10°F (-23.3°C)	0°F (-17.8°C)	+10°F (-12.2°C)	+20°F (-6.7°C)	+30°F (-1.1°C)	+40°F (+4.4°C)
kcal/hr-m ²											
Sitting at rest	12.5	11.7	10.8	10.0	9.2	8.3	7.5	6.7	5.9	5.1	4.2
Piloting plane	8.3	7.8	7.2	6.7	6.1	5.6	5.0	4.5	3.9	3.4	2.8
Very light activity	6.2	5.8	5.4	5.0	4.6	4.2	3.8	3.4	2.9	2.5	2.1
Walking slowly	5.0	4.7	4.3	4.0	3.7	3.3	3.0	2.7	2.4	2.0	1.7
Light activity	4.2	3.9	3.6	3.3	3.1	2.8	2.5	2.2	2.0	1.7	1.4
Refueling, rearming, walking moderately	3.6	3.3	3.1	2.9	2.6	2.4	2.2	1.9	1.7	1.4	1.2
Severe exercise	2.5	2.3	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	0.8
Running	2.1	1.9	1.8	1.7	1.5	1.4	1.3	1.1	1.0	0.8	0.7

Note: Clo values in the shaded area represent unrealistically high values in light of the fact that the full 6 to 7 layer arctic uniform offers only an overall value of 4.3 clo at rest.



Source: US Army Research Institute of Environmental Medicine, Natick, MA

Figure 5. Reduction attributed to wind of the insulation value of the boundary air layer of clothing.

level of warmth under windy conditions, the decrease in the contribution of the air layers must be balanced by an increase in the total insulation of the clothing in order for the individual to feel as warm.

The cooling power of wind on exposed skin was estimated by Siple in 1940.²² His wind chill chart (Table 5) indicates the equivalent chill temperature, that is, the temperature with low air movement (about 5 mph) which would produce roughly the same cooling effect. This is created by the combination of wind and temperature shown on the chart. One way to incorporate the effect of wind when computing clo values is to substitute the equivalent chill temperature for ambient temperature (T_a) in Equation 1.

The Effect of Physical Activity

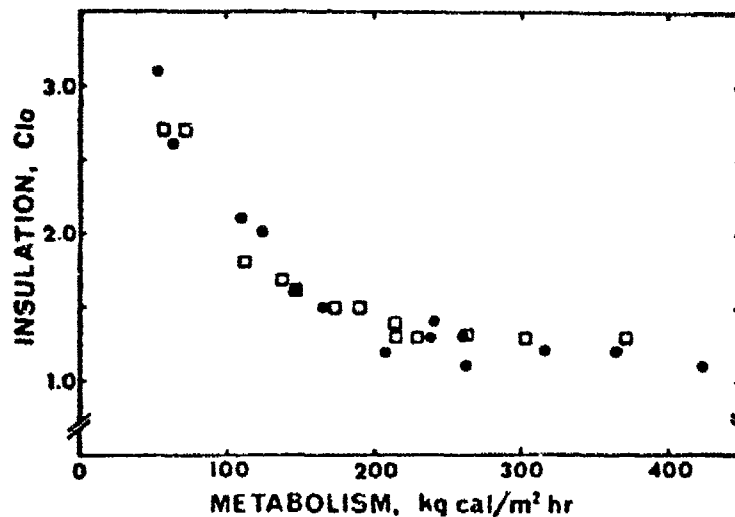
Physical activity is a second factor which disturbs both the still air layer surrounding an individual and the air trapped between the layers of clothing. The wearer generates external air motion and compresses and pumps the trapped air by walking or working. Physical movements reduce the effectiveness of the insulation and necessitate higher clo values for cold protection than the values reported in Table 4. Controlled experiments have

TABLE 5. Wind Chill Effect on Temperature

Cooling Power of Wind on Exposed Flesh expressed as an Equivalent Temperature (under calm conditions)

Wind speed (in mph)	Actual Thermometer Reading (°F)											
	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
	Equivalent Chill Temperature (°F)											
Calm	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
5	48	37	27	16	6	-5	-15	-26	-36	-47	-57	-68
10	40	28	16	3	-9	-21	-33	-46	-58	-70	-83	-95
15	36	22	9	-5	-18	-32	-45	-58	-72	-85	-99	-112
20	32	18	4	-10	-25	-39	-53	-67	-82	-96	-110	-124
25	30	15	0	-15	-29	-44	-59	-74	-89	-104	-118	-133
30	28	13	-2	-18	-33	-48	-63	-79	-94	-109	-125	-140
35	27	11	-4	-20	-35	-51	-67	-82	-98	-113	-129	-145
40	26	10	-6	-22	-37	-53	-69	-85	-101	-117	-132	-148
	<u>Little Danger</u> In less than 5 hrs with dry skin. Maximum danger from false sense of security.						<u>Increasing Danger</u> Danger from freezing of exposed flesh within one minute				<u>Great Danger</u> Flesh may freeze within 30 seconds.	

Source: US Army Research Institute of Environmental Medicine, Natick, MA.



Source: US Army Research Institute of Environmental Medicine, Natick, MA

Figure 6. Decrease of arctic clothing insulation with increased activity (two subjects).

been conducted in the climatic chambers at the U.S. Army Research Institute of Environmental Medicine (ARIEM) to quantify the alterations in both insulation (clo) and permeability resulting from wind and subjective air motion. These effects are expressed as pumping coefficients; they are used to modify the insulation values of clothing which are measured under laboratory conditions without wind or wearer motion. For example, Figure 6 shows the reduction in effective clo resulting from increased activity of two subjects. The data indicate that a clothing system which provides over 3.0 clo of insulation for an individual at rest provides only 1.5 to 2.0 clo at a metabolic rate of 100 to 150 kcal/m²-hr.

Protection of the Extremities

The overall insulation requirements for aircrews in extreme cold climates are high, but the major problem in protecting against the discomforts and injuries caused by cold is to maintain acceptable skin temperatures for the extremities. The clo values presented in Table 4 were estimated by considering whole body cooling. However, long before the mean body temperature drops to the uncomfortably cold zone, the temperature of the extremities will likely have fallen to critical levels.

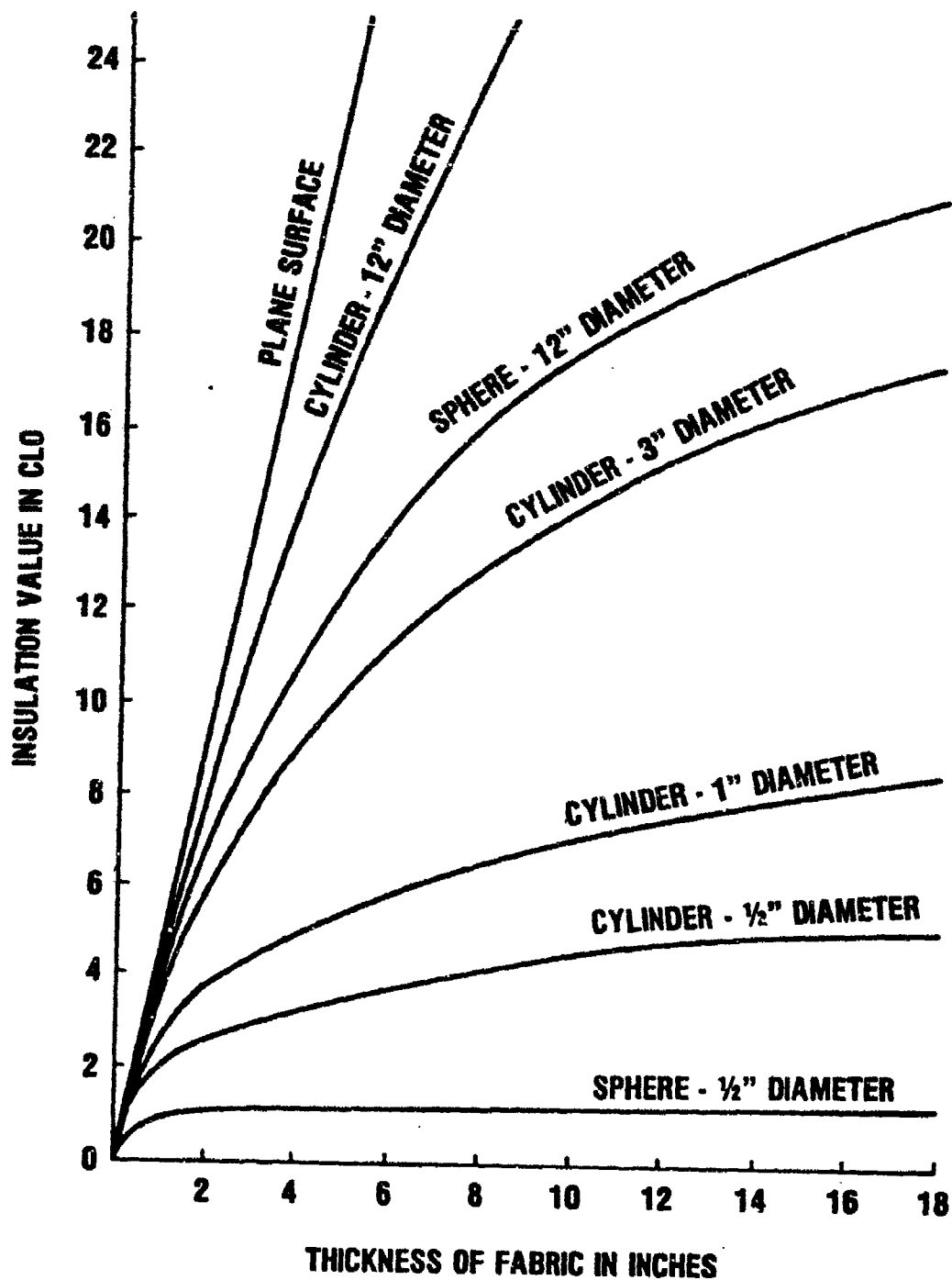
The Extremity Problem. The hands and feet present a special problem in the development of effective cold weather gear and need to be analyzed separately from the body as a whole.^{23,24} Two major differences in the dissipation of heat through the extremities, as compared with the body as a whole, account for the need for a separate analysis. First, due to their shape the hands and feet have a greater surface area to mass ratio than the rest of the body. The second difference is that, unlike the body which produces metabolic heat as a function of the activity level (irrespective of the ambient temperature), the heat input to the extremities is drastically reduced in the cold due to vasoconstriction. Each of these differences is discussed in greater detail below.

In general, the value of insulation placed on a flat surface is a linear function of the thickness of the material. Good insulating fabrics provide approximately one clo of insulation for each quarter-inch of thickness under these conditions. However, when the same fabric is placed over a curved surface, such as the body or a finger, the insulation value is reduced. As Figure 7 shows, the reduction is greater as the radius of the cylinder or sphere decreases. The lowest curve in Figure 7 illustrates the problem encountered in designing a warm glove. Regardless of the thickness of the insulation placed on a small sphere, the clo value never increases much over one because as more insulation is added, the radiating surface area for heat loss by convection and radiation also increases and little or no net is benefit is gained.

Assuming that the average finger diameter is 0.75 inches (1.9 cm), the maximum possible fingertip insulation for a glove is 1.75 clo. However, this implies a thickness which is impractical for glove design since the maximum glove thickness consistent with acceptable dexterity is about one-quarter inch (0.64 cm). A glove constructed of this thickness would provide 0.71 clo to the fingertips, 0.89 clo to the fingers, and 1-1½ clo to the hands as a whole. Although the thickness of this theoretical glove exceeds the bulk limits which would enable aircrews to perform their tasks efficiently, it will be used to illustrate the theoretical limits of glove insulation.

If we assume normal circulatory heat input to the hand (73.3 kcal/hr-m^2), the warmest functional glove (one quarter inch thick) cannot maintain comfortable finger temperatures of 84°F (29°C) for a person at rest in an environment below about 54°F (12°C). However, fingers can and frequently do drop below 84°F (29°C) without seriously affecting performance. Using the critical finger temperature indicated in the LOA (60.8°F or 16°C) as the lower limit, the theoretical glove is inadequate below about 32°F (0°C) under the same heat input assumption.

It is contradictory, however, to assume that the circulatory heat input to the hands would remain at normal levels when the hand temperature is cold, since the body's first physiological response to either whole body cooling or local cooling is vasoconstriction. This process constricts the blood vessels in the hands and feet thus reducing the volume of blood flowing to the extremities and hence the heat. Through this reaction, the body conserves



Source: Reference 23

Figure 7. Insulation of ideal fabric on a plane, cylinders, and spheres.

heat needed to maintain a constant core temperature. Circulation of the blood is the means by which the extremities are warmed, yet only about 10% of the normal heat input is supplied when circulation in the fingers is fully constricted. Circulatory heat input to the fingers can vary from a low of about 7 kcal/hr-m² for extreme vasoconstriction to rates approaching 500 kcal/hr-m² for extreme vasodilatation. The level is largely determined by the state of heat balance of the body as a whole. Some variations also occur in response to local cooling by the environment.

Clo Insulation Requirements for Hands and Feet. Table 6 displays the clo units required to keep fingers comfortable under different environmental and physiological conditions. The values presented in the table were generated using Equation 1 and substituting circulatory heat input for the metabolic rate. These data clearly indicate that it is impossible to keep hands comfortable in the cold by wearing conventional gloves, unless the body has an excess of heat which it must dissipate through the hands. This is unlikely in the case of aircrews working in the extreme cold.

As a baseline, it should be noted that the glove currently issued to Army aircrew in cold climates is a leather shell with a wool/nylon insert. It provides only 0.75 clo units to the hand as a whole and as the discussion above implies, the clo value for the fingers and fingertips is even less. The arctic mitten with its bulky liner only provides 2.2 clo units overall.

To meet the requirement stated in the LOA, it is not necessary to keep the extremities comfortably warm but only to provide environmental protection to the extremities sufficient to maintain a fingertip and toe temperature of 60.8°F (16°C). A skin temperature of 84°F (29°C) for the hand is reported as "comfortably warm," 68°F (20°C) as "uncomfortably cold," 59°F (15°C) as "extremely cold," and 40°F (4.4°C) as "painful," with reports for the foot occurring at 5°F (2.8°C) warmer temperature for each descriptive level.²⁵ A table similar to Table 6 was calculated to determine the clo units necessary to maintain the finger temperature above 60.8° (20°C). Since vasoconstriction can be assumed at this cold finger temperature, clo units were calculated for only two circulatory heat input rates: 23, and 7 kcal/hr-m². The resulting clo values were equally unattainable in a conventional glove. For example, at +10°F (-12.2°C) for the two circulation rates above, the clo units were 6.8 and 22.4, respectively.

The prospects for keeping feet warm in extreme cold using only passive means also do not appear feasible. Even though a higher clo value can be provided in footwear than in gloves, the level is still inadequate for manipulation of aircraft controls and survival in extreme cold. The onset of thermal discomfort affects the feet first, since they are the furthest from the central warm blood supply and since their tolerance level is 5°F less than that for the fingers.¹⁸ The cold dry vapor barrier boot provides 2.0 clo and the mukluk ranges between 2.2 and 2.5 clo depending on the liners worn.

TABLE 6. Clo Units Required to Maintain a Comfortable Finger Temperature (84°F or 29°C)
Under Different Ambient Temperatures and Circulatory Heat Inputs

Circulatory Heat Input (Kcal/hr-m ²)		-60°F (-51.1°C)	-50°F (-45.6°C)	-40°F (-40.0°C)	-30°F (-34.4°C)	-20°F (-28.9°C)	-10°F (-23.3°C)	0°F (-17.8°C)	+10°F (-12.2°C)	+20°F (-6.7°C)	+30°F (-1.1°C)	+40°F (+4.4°C)
Extreme Vasoconstriction	7	63.6	59.1	54.7	50.3	45.9	41.5	37.1	32.7	28.3	23.8	19.4
Moderate Vasoconstriction	23	19.3	18.0	16.7	15.3	14.0	12.6	11.3	9.9	8.6	7.3	5.9
Normal Heat Input	73.3	6.1	5.6	5.2	4.8	4.4	4.0	3.5	3.1	2.7	2.3	1.9
Moderate Vasodilatation	230	1.9	1.8	1.7	1.5	1.4	1.3	1.1	1.0	0.9	0.7	0.6

Other Physiological Phenomena. Two other physiological phenomena which affect heat transfer through the extremities are the precooling of arterial blood and cold-induced vasodilatation. Both are body mechanisms to prevent cold injury.

In the precooling phenomena, heat from the arterial blood entering the arm and hand is extracted by the cooler venous blood returning from the extremity.^{26,27} This exchange of heat occurs in the interest of internal heat economy. It has the benefit of minimizing external heat exchange with the environment while still maintaining needed "nutritive" circulation to the hands and feet.

Cold-induced vasodilatation (CIVD), first demonstrated by Lewis in 1929, is another vascular response to cold. The temperature of fingers exposed to extreme cold normally decreases steadily. However, in most comfortably warm individuals phasic fluctuations (rising then falling) in finger temperatures result from periodically recurring vasodilatation. The onset of this phenomenon occurs only after fingers have been cooled to the painfully cold level of 41°F to 59°F (5°C to 15°C) and, for reasons not well understood, the phenomenon does not occur in all individuals. CIVD is another example of the body's complex mechanisms to prevent cold injury, in this case, frostbite. Once the cyclical fluctuations are initiated, they continue as long as the body is not too cold, thus stopping the declining finger temperature before the freezing point is reached.

Interaction Between the Extremities and the Body

The copper manikin is a device used by the U.S. Army Research Institute of Environmental Medicine, Natick, MA, to measure clothing insulation values. The clo value of a clothing ensemble evaluated on the copper manikin represents a weighted average of the various parts of the body. Twenty-one thermocouples are distributed uniformly over the copper shell to record skin temperatures. The hands and feet together contribute less than 10% to the total clo of an ensemble, while the trunk contributes about 50%. Therefore, the measured clo value of an actual ensemble may meet the required level for comfort of the body as a whole (as indicated in Table 4), but unless the extremities are also adequately protected (as indicated by the clo values in Table 6), the ensemble will not be effective in the cold.

The impact on comfort of placing excessive insulation on the trunk at the expense of the hands, and vice versa, has been studied at the Aerospace Medical Research Laboratory located at Wright-Patterson Air Force Base, Ohio.²⁸ The results underscore the primary importance of extremity protection in the cold, and demonstrate that a large quantity of insulation on the trunk cannot be substituted for a lack of adequate extremity insulation.

Conclusions

In summary, it is clear that conventional gloves and boots cannot keep the hands and feet of aircrews adequately warm in extreme cold environments and adding extra insulation to the torso is not a solution. Auxiliary heat in

some form is needed. Since the major problem of maintaining thermal comfort in the cold is keeping the extremities warm, it is not sufficient to address the body as a whole when analyzing clothing requirements for the cold. The hands and feet must be analyzed separately and both the extremities and the torso must be provided with sufficient insulation to satisfy their different needs.

3. MODELING OF HEAT LOSS AND THE APPLICATION OF CLOTHING THEORY

This section applies the theory of clothing to the environmental conditions confronting aircrews to determine the insulation requirements for their cold weather clothing. The section is divided into two major subsections. The first examines the comfort of the body as a whole under several environmental scenarios. The second employs an extremity cooling model to ascertain the insulation needs of the hands and the needs of the feet. The new clothing system will be worn for both ambient conditions and cockpit temperatures and therefore must be capable of facilitating the interface between the aircrew and widely varying temperatures without creating cold or heat stress which degrades performance. The feasibility of designing one clothing system to meet the crew needs in ambient conditions without over-protecting under cockpit temperatures is addressed in both subsections.

It should be noted that the results presented here are for the average male. The modeling requires assumptions about body weight (70 kg), surface area (1.8 m^2), and heat production. Clearly, there are great differences in these physical characteristics between individuals and also differences in other factors which affect tolerance to cold. Some of these other factors are sex, race, and previous cold exposures, which serve to induce physiological acclimation and provide experience with protecting oneself against the cold. The study of cold injuries during the Korean War²⁹ found that the incidence of frostbite among black soldiers was six times greater than among whites and that blacks had more severe cases of frostbite. As a group, blacks generally exhibit less cold induced vasodilatory rewarming. White soldiers who had lived in warmer climates were found to have a higher incidence of frostbite than those who originated from colder climates.

Very limited laboratory work has been done to determine the difference in insulation requirements between men and women. Most subjects have been men and therefore the findings apply to men. The copper devices (manikin, foot, and hand) have been modeled to simulate heat transfer between a typical man and the environment. Therefore, the theoretical analyses in this study are restricted to men also. On an average, women are more susceptible to cold injury than men, because being smaller, their hands and feet have a greater surface area to mass ratio than men's.

Modeling of Whole Body Cooling

Below, the general approach used in the modeling exercises is outlined and the assumptions are noted. Some of the values chosen for the input

variables are explained and identified here and others are discussed in Appendix C. Appendix C presents a detailed description of the three environmental scenarios employed in the modeling exercises and displays tables of heat debts and recovery times for each set of assumptions. The conclusions drawn from the analysis of each scenario are discussed following the tables of results. The conclusions and results are also summarized at the end of this subsection.

Description of Approach. Equation 1 of Section 2 is the basic equation used in the modeling of whole body cooling. By varying the inputs over time as dictated by the real life situation, the heat transfer process experienced by aircrews while performing their duties can be simulated. The resulting heat debt or excess and assumptions about the body's tolerance for these conditions are used to determine the adequacy or inadequacy of the ensemble selected for each exercise. In order to simulate realistic conditions through modeling, different assumptions were made for the following variables:

- heat production rate,
- ambient temperature,
- cockpit temperature,
- thermal insulation provided by clothing ensembles,
- effective clo value under physical activity,
- time to complete aircrew task, and
- wind speed.

The aircrewmember's heat production level varies according to the task to be performed, the state of anxiety, and individual differences. For the purposes of this analysis the following heat production rates were assumed:

<u>Task</u>	<u>Metabolic Rate</u>
Preflight tasks (outdoors)	125-150 kcal/hr-m ²
Preflight tasks (in cockpit)	75 kcal/hr-m ²
Piloting an aircraft	75 kcal/hr-m ²
Refueling/Rearming	175 kcal/hr-m ²

Table 4 in Section 2 of this chapter indicates that 4.2 to 5.0 clo overall would be required to maintain a thermal balance under a metabolic rate of 125 to 150 kcal/hr-m² at an ambient temperature of -60°F (-51.1°C). These values represent an aviator engaged in preflight tasks in extreme cold. However, Table 4 indicates that while piloting an aircraft, only 2.8 clo units are required to keep a pilot in thermal balance in a 40°F (4.4°C) cockpit. Less insulation would be needed if the aviators were under stress and more would be needed out-of-doors as the wind speed increases. The insulation values in Table 4 do not reflect the reduction in the clo value of an ensemble

created by physical movement or wind. In the modeling exercises, the measured clo value of each ensemble was adjusted to account for these effects. The assumption made for the effective clo of each ensemble during outdoor preflight tasks is indicated in the description of each environmental scenario in Appendix C. In each case it was assumed that no reduction in clo occurred while the aircrewmembers are seated in the cockpit.

When one moves from a comfortable indoor temperature to a cold outdoor temperature, some time is required before the buffer (i.e., clothing) between the warm body and the cold air reaches equilibrium. This effect of moving outdoors with warm-soaked clothing, and conversely of moving to a warmer environment with cold-soaked clothing, is not considered in the model. Therefore, the numbers presented in the tables of results in Appendix C indicate a heat debt which is somewhat large and recovery times which are somewhat short.

In the modeling exercises, three environmental scenarios were assumed and the adequacy of an ensemble chosen for these conditions was examined. The first scenario used the temperature profile as described in the LOA (minimum temperature -60°F (-51.1°C)). The second scenario assumed a minimum ambient temperature of -30°F (-34.4°C) because a large majority of the aircrew currently do not experience temperatures as low as -60°F (-51.1°C). The third scenario analyzed the requirements for a minimum ambient temperature of -15°F (-26.1°C). In all three scenarios, separate analyses were conducted for each of two work rate assumptions (125 kcal/hr-m^2 and 150 kcal/hr-m^2) for the outdoor preflight tasks.

Considerable variation exists between the different aircraft with respect to the cockpit temperatures which can be maintained during a mission. The mission profile included in Annex A of the LOA describes a typical mission. The profile estimates that it may take 30 minutes to bring the cockpit temperatures up to standard whereas the LOA requirement specifies 15 minutes.

The variations in cockpit temperatures and the variations in the length of time to complete the preflight tasks are represented as separate cases under each scenario. The time assumptions for the three cases are given below.

- Case 1 1) 1 hour to complete preflight tasks outdoors
2) 15 minutes for cockpit heater to reach design standard
- Case 2 1) $1\frac{1}{2}$ hours to complete preflight tasks outdoors
2) 15 minutes for cockpit heater to reach design standard
- Case 3 1) 1 hour to complete preflight tasks outdoors
2) 30 minutes for cockpit heater to reach design standard

For each case, the whole body cooling equation (Equation 1) was applied to each segment of time in which either the temperature, the heat production level, or the effective clo value changes. The heat debts for each time segment were summed to yield an estimate of the cumulative heat debt an

aviator will experience before the aircraft heater becomes effective and reverses the situation.

Results and Conclusions. The results of the whole body cooling analysis show that when the ambient temperature is -60°F (-51.1°C) aircrewmembers would need to wear ensembles with insulative values equivalent to that of the arctic ensemble (5-6 layers), they would need to complete the outdoor preflight tasks within one hour, and the heater would need to raise the aircraft cockpit temperature from -60°F (-51.1°C) to $+40^{\circ}\text{F}$ (4.4°C) in 15 minutes in order for the aircrewmember to avoid a heat debt condition which would impair performance. One and one-half to two hours (recovery time) would then be required in a 32°F to 40°F cockpit for the aircrew to return to a heat balance condition. Since the arctic ensemble is too bulky and the other conditions cannot always be met, it can be concluded that the environmental criteria specified in the LOA cannot be satisfied with a conventional (layered) clothing concept given existing insulation materials.

In the second scenario examined in the analysis, a minimum ambient temperature of -30°F (-34.4°C) was assumed. The results show that a heavy, bulky ensemble would be required to meet the temperature profile as identified in Appendix C. The recovery times in the cockpit range from about one-half hour to four hours for different sets of assumptions concerning average metabolic rate, cockpit temperature, and time required to complete the outdoor preflight tasks. It was concluded that the bulkiness of the clothing required for environmental protection will prevent proper interface with the aircraft.

In the third scenario (minimum ambient temperature of -15°F (-26.1°C)), a clothing system comparable in insulation value to that provided by the new Combat Vehicle Crew uniform for cold weather was found to be adequate for aircrews. Under windy conditions a higher metabolic rate than normal for preflight tasks would need to be maintained to avoid discomfort. The recovery times are so lengthy that under most of the cases examined the mission will have been terminated before a heat balance situation has been regained in the cockpit. The individual is then required to perform outdoor flight continuation tasks during which further cooling may result. However, it is preferable for an aircrewmember to be somewhat cold rather than too warm in order to avoid perspiring, thereby creating damp clothing which accelerates the loss of heat.

Modeling of Extremity Cooling

The LOA requires that the extremities be protected to maintain a fingertip and toe temperature of 60.8°F (16°C) or above. It has already been established that gloves cannot keep the hands comfortable under the arctic scenario described in the LOA. The analyses reported in this section were conducted to answer questions such as:

How long can the fingertips be maintained above the critical temperature while protected with gloves or mittens in different ambient conditions?

Can gloves be designed which are slim fitting yet provide the warmth needed for the cockpit?

How much thermal protection does the arctic mitten worn over a glove provide for hands in extreme cold?

What is the minimum ambient temperature in which a glove can be worn for preflight tasks without violating the minimum fingertip temperature specified in the LOA?

Is auxiliary heating needed for boots out-of-doors? In the cockpit?

An analytical extremity cooling model was used to predict the temperature of the fingers and toes over time during exposure to cold ambient temperatures. A description of the model is included in Appendix C, Section 2.

Analysis of Hand Cooling - Description and Conclusions. First the extremity model was employed to determine analytically the tolerance times for fingers while performing preflight tasks under different ambient temperatures and wind conditions. The tolerance time is defined as the time required for the temperature of the fifth finger to drop to 60.8°F (16°C), the point at which manual dexterity begins to decline sharply.

Three circulatory heat input rates were used in the analysis: 73 kcal/m²-hr to represent normal blood flow, 23 kcal/m²-hr for moderate vasoconstriction, and 7 kcal/m²-hr for extreme vasoconstriction. The results for the middle value are not reported since they differed only slightly from the other two rates. It is unlikely that the blood flow would increase over the normal rate due to the light to moderate activity level required for preflight tasks and the cold ambient temperatures.

To answer the questions posed above, four cases were analyzed as described below.

Case 1 - Leather Shell with Wool Insert. For this case it was assumed that the current issue cold weather aviator glove (leather shell with wool insert) was being worn and that the fingers were assumed to be comfortably warm (84°F (28.9°C)) to start. The clo value of the fifth finger of the glove, as measured on the copper hand by the US Army Research Institute of Environmental Medicine, is 0.67.

The tolerance times for the four ambient temperatures and two wind conditions examined are shown in Table 7. The graphs from which these data were read are displayed in Appendix I as Figures I-1 and I-2. The graphs display the decline in finger temperature as a function of time.

TABLE 7. Tolerance Times (min) for Hands Wearing Leather Shell with Wool Insert While Performing Preflight Tasks

<u>Fifth Finger Tolerance Times</u>				
<u>Ambient Temperature</u>	<u>Wind - 0 mph</u>		<u>Wind - 10 mph</u>	
	<u>7 kcal/m²-hr*</u>	<u>73 kcal/m²-hr**</u>	<u>7 kcal/m²-hr*</u>	<u>73 kcal/m²-hr**</u>
-60°F (-51.1°C)	6 min	8 min	3 min	4 min
-30°F (-34.4°C)	8 min	11 min	3 min	4 min
-15°F (-26.1°C)	10 min	13 min	4 min	5 min
0°F (-17.8°C)	13 min	17 min	5 min	7 min

* Heat input under extreme vasoconstriction

** Heat input under normal circulation heat input

Conclusion - The clo value for the fingertip of the leather shell with wool insert glove (0.67) is close to the clo value (0.71) of the hypothetical $\frac{1}{4}$ inch insulation glove discussed in Section 2. One quarter inch is considered the practical upper limit of fabric thickness consistent with reasonable dexterity. The additional tolerance time gained by 0.71 clo over 0.67 clo is negligible. Therefore, we can conclude on the basis of the physical laws of insulation that no practical glove can be designed to fulfill the preflight requirements of the LOA without the use of auxiliary heating. In fact, the results show that auxiliary heat is necessary at all ambient conditions included in the analysis.

Case 2 - Arctic Mitten over Glove. To prevent the rapid loss of heat through the extensive surface area of a glove, it was assumed in this case that the arctic mitten was worn over the glove. In practice, it would be removed when manual dexterity is required for a preflight task, but for this modeling exercise the tolerance times were calculated by assuming that the mitten would be worn constantly to provide a clo value of 1.5 for the fifth finger. Since this assumption is unrealistic, the actual tolerance times for a glove and mitten alternative will be substantially less than those shown below in Table 8. The graphs from which these times were read are displayed in Appendix I as Figures I-3 and I-4.

TABLE 8. Tolerance Times (min) for Hands Wearing Arctic Mittens over Gloves While Performing Preflight Tasks

Fifth Finger Tolerance Times

<u>Ambient Temperature</u>	<u>Wind - 0 mph</u>		<u>Wind - 10 mph</u>	
	<u>7 kcal/m²-hr*</u>	<u>73 kcal/m²-hr**</u>	<u>7 kcal/m²-hr*</u>	<u>73 kcal/m²-hr**</u>
-60°F (-51.1°C)	23 min	30 min	8 min	11 min
-30°F (-34.4°C)	30 min	44 min	11 min	17 min
-15°F (-26.1°C)	35 min	56 min	13 min	22 min
0°F (-17.8°C)	42 min	80 min	16 min	31 min

* Heat input under extreme vasoconstriction

** Heat input under normal circulatory heat input

Conclusion - The results show that the arctic mitten and glove combination cannot meet the LOA requirements even under the unrealistic assumption that they are both worn constantly.

Case 3 - Hypothetical Glove, $\frac{1}{4}$ inch Thickness. Next the feasibility of designing a glove to be worn in the cockpit which will meet the temperature conditions listed in the LOA was examined. These conditions are -60°F (-51.1°C) for five minutes, -30°F (-34.4°C) for ten minutes and +40°F (4.4°C) for the remainder of the mission. The tolerance times for the hypothetical $\frac{1}{4}$ inch (0.64 cm) thick glove (fingertip clo of 0.71) were computed to be 10 minutes if the circulatory heat input were normal (73 kcal/m²-hr) and 8 minutes if the fingers were severely vasoconstricted. In all cases in this analysis, the finger temperature to start was assumed to be a comfortable 84°F (28.9°C). This will not be the case unless a solution can be found for keeping the hands warm during the preceding outdoor preflight phase. A second environmental scenario was also analyzed for the same glove. It assumed that the cockpit temperature was -30°F (-34.4°C) for five minutes, 0°F (-17.8°C) for ten minutes, and +40°F (4.4°C) for the remainder of the mission. The tolerance times increased to only 22 minutes and 12 minutes, respectively.

Conclusion - The results above indicate that no glove can be designed to meet the LOA cockpit temperature specifications for the duration of the mission without some form of auxiliary heating. The $\frac{1}{4}$ inch (0.64 cm) glove is much too bulky for flying, yet a glove designed to provide the dexterity needed for flying would yield even shorter tolerance times.

Case 4 - Hypothetical Glove, $\frac{1}{8}$ inch Thickness. In this case the question of whether a glove which is thin enough to facilitate performance in the cockpit could keep the hands comfortable after the heater had warmed the cockpit to +40°F (4.4°C) was analyzed. This scenario ignores the ambient temperature and merely examines the tolerance time under a constant cockpit temperature of +40°F (4.4°C). A glove with a fabric thickness of slightly over $\frac{1}{8}$ inch was chosen; it has a fingertip clo of

about 0.5. A still air layer has a clo of about 0.3. The cockpit tolerance time for this hypothetical glove was calculated to be 30 minutes for normal circulatory heat input and 18 minutes for extreme vasoconstriction. Since the cockpit temperature cannot be maintained at +40°F (4.4°C) for certain missions and aircraft, the tolerance times for a constant +30°F (1.1°C) temperature were also computed. They are 18 minutes and 13 minutes, respectively. The graphs for these results are displayed in Appendix I, Figure I-5.

Conclusion - The model predicts that no glove can be designed without auxiliary heating which will keep the fingertips above 60.8°F (16°C) in a 40°F (4.4°C) cockpit for the length of an average mission (1 to 1-3/4 hours) under the assumption of normal circulatory heat input. If moderate vasodilatation occurs because of body overheating, the circulatory heat input will triple, thereby warming the fingers. However, as stated earlier, overheating should be avoided because the resulting perspiration will compromise protection offered by the cold weather ensemble.

Analysis of Foot Cooling - Description and Conclusions. Similar analyses were conducted to examine the rate of cooling of the feet in cold environments. The toe cap of a boot can be constructed to contain more insulation than gloves. Three representative cold weather toe cap clo values (1.2, 1.6, and 2.0) were used in the analysis to illustrate the additional tolerance time gained by increasing the insulation. The toe cap insulation of the white vapor barrier boot has been measured at 2.0 clo on the copper foot. Several Canadian and Japanese mukluks have been evaluated on the same device and the insulation of their toe cap areas range from 1.6 to 2.0 clo. The new cold weather CVC boot with overshoe has a toe insulation of 1.2 clo.

Table 9 displays the theoretical tolerance times for four ambient temperatures and two circulatory heat input rates for each of three clo values. The tolerance time for feet is defined as the time for the toe temperature to drop from 79°F (26.1°C) to 60.8°F (16°C). The graphs of these results are displayed in Appendix I, Figure I-6.

TABLE 9. Tolerance Times (min) for Feet During Preflight Tasks

<u>Ambient Temperature</u>	<u>Toe Cap 1.2 clo</u>		<u>Toe Cap 1.6 clo</u>		<u>Toe Cap 2.0 clo</u>	
	<u>7 kcal/ m²-hr*</u>	<u>73 kcal/ m²-hr**</u>	<u>7 kcal/ m²-hr*</u>	<u>73 kcal/ m²-hr**</u>	<u>7 kcal/ m²-hr*</u>	<u>73 kcal/ m²-hr**</u>
-60°F (-51.1°C)	20 min	25 min	26 min	34 min	30 min	42 min
-30°F (-34.4°C)	27 min	36 min	34 min	53 min	40 min	63 min
-15°F (-26.1°C)	32 min	46 min	40 min	70 min	55 min	140 min
0°F (-17.8°C)	38 min	62 min	50 min	104 min	60 min	170 min

* Heat input under vasoconstriction

** Heat input under normal circulatory heat input

The data indicate that very limited time is gained at either of the two lowest ambient temperatures (-30°F and -60°F) by increasing the insulation from 1.2 clo to 2.0 clo. The range of gain is from 10 minutes at the lower ambient temperature under extreme vasoconstriction (i.e., from 20 minutes to 30 minutes) to 27 minutes at the higher ambient temperature under normal blood flow (i.e., from 36 minutes to 63 minutes). Even the warmest boot cannot meet the performance specifications listed in the LOA--toe temperature maintained at 60.8°F (16°C) or above in ambient temperatures as low as -60°F (-51°C). In addition, to be practical for flying, the bulk of the new boot should be much less than the arctic boot. Therefore, auxiliary heating is required for outdoor preflight tasks to meet the LOA requirements.

The adequacy of each of the three boots under constant cockpit temperature conditions was analyzed next. The data are shown in Table 10.

TABLE 10. Tolerance Times (min) for Feet in Cockpit

<u>Cockpit Temperature</u>	<u>Toe Cap 1.2 Clo</u>		<u>Toe Cap 1.6 Clo</u>		<u>Toe Cap 2.0 Clo</u>	
	<u>7 kcal/ m²-hr*</u>	<u>73 kcal/ m²-hr**</u>	<u>7 kcal/ m²-hr*</u>	<u>73 kcal/ m²-hr**</u>	<u>7 kcal/ m²-hr*</u>	<u>73 kcal/ m²-hr**</u>
+40°F (4.4°C)	100	a	126	b	150	c
+30°F (-1.1°C)	70	300	92	a	110	b

* Heat input under vasoconstriction

** Heat input under normal circulation

^atoe temperature maintained above 60.8°F (16°C)

^btoe temperature maintained above 77°F (25°C)

^cboot too warm; toe temperature increases above comfortable level

The data indicate that if the feet can be kept warm with auxiliary heat until the cockpit temperature reaches 30°F (-1.1°C) to 40°F (4.4°C) and the blood circulation returns to normal, a boot with 1.6 clo of toecap insulation should be adequate.

Conclusion - Auxiliary heating for footwear appears to be necessary for the outdoor preflight tasks to achieve the desired performance levels. In fact, since the boot with 2.0 clo is too warm at 40°F (4.4°C), a boot with clo high enough for exterior use may be unsuitable for the heated cockpit interior.

4. AUXILIARY HEAT FOR CLOTHING

Although few clothing items with auxiliary heat are in use today, the concept has existed for over 40 years. Special military and civilian applications have supported research and development efforts for auxiliary heated gloves, mittens, boots, jackets, vests, pants, and coveralls. Appendix D presents an overview of the historical research efforts in the United States, the Soviet Union, Canada and the United Kingdom and describes the resulting clothing items.

In order to meet the requirements of the LOA, auxiliary heat will need to be supplied to the hands and feet. Not only are these extremities more vulnerable to the cold, but insulation to protect them presents a greater problem when interfacing with the aircraft than insulation on the remainder of the body. To reduce the bulk of the present aircrew ensemble, auxiliary heat may also need to be added to other parts of the body to compensate for the reduction in insulation. However, for several reasons this section will concentrate on the feasibility of electrically heated handwear and footwear.

First, as the last section demonstrated, heated gloves are needed both inside the cockpit and for outdoor preflight tasks even at temperatures as high as 0°F (-17.8°C). This implies that the gloves will have much wider geographical application than other heated items. In theory, the cockpit temperatures used in the analysis are typical for all three Clothing Allowance Zones (V, VI, and VII) and the extremity model showed that auxiliary heated gloves are needed for all cold weather flying. In contrast, conventional clothing and boots/socks can meet the insulation requirements of all but a few geographical locations. A second reason for concentrating on the extremities is that some work has been done to determine power requirements for hands and feet and the data which are available will be used in this power analysis.

On the basis of the time requirements for individual aircrew tasks presented in Chapter II, the total time aircrews spend outdoors per day or in an unheated cockpit ranges from one hour to four hours. For example, the crew chief is responsible for refueling and consequently spends more time outdoors than the pilot. The total time spent in a heated cockpit ranges from 4 to 8 hours. However, for certain missions and certain aircraft many hours are spent in inadequately heated cockpits. Therefore, the requirement for protection against the lower temperatures may exceed four hours.

Power Requirements

To design heated clothing, it is first necessary to establish the power requirements and then determine the preferred source of power. Several experiments discussed in Appendix D identified the power consumed by the experimental electrically heated clothing; however, more research will need to be completed before the power requirements for cold weather aircrew clothing can be stated with confidence. Because auxiliary heat alters the circulatory blood flow and adds heat to the body's natural heat production, the effect of auxiliary heated clothing on the individual's thermal comfort currently cannot be modeled with the same confidence as conventional insulation. Laboratory

experiments will need to be run in which the variables are manipulated. After carefully controlled laboratory studies are carried out under constant temperature conditions, it will be important to simulate the ambient temperature changes that aircrews experience in a typical day. All experiments described in the literature were conducted at a selected constant temperature.

One of the experiments conducted in the climatic chambers at the US Army Natick Laboratories in the early 1960's found that electrically heated gloves and socks consumed an average of 24 watts per hour to maintain the comfort of inactive subjects in an environment of -65°F (-54°C) with a 10 mph wind. (A similar experiment in a -40°F (-40°C) environment with a 10 mph wind resulted in 20 watts per hour being consumed to heat the hands and feet.) Since the temperature was thermostatically controlled, power consumption was not constant. Another experiment in this series of tests found that a power level of 10 watts per hand or foot were required to rewarm an extremity which fell below 60°F (16°C). In all three experiments the subjects wore the full arctic ensemble including the arctic mittens and boots; these items provided excellent insulation for the heating elements. However, aircrews will be unable to wear such bulky gear and therefore, may require more power to maintain similar comfort levels outdoors.

Experimental battery-powered gloves tested in the same climatic chambers in early 1981 more closely approximate the handgear to be worn by aircrews. No mittens were worn over the gloves. However, two conditions which render the experimental situation unrealistic for the aircrew LOA requirements are that the arctic ensemble was worn and the experiment was conducted in an environment of -33°F (-36°C). Four nickel cadmium batteries of 1.25 volts each, wired in series, powered each glove. At 1.28 amps, each hand was supplied with a continuous power level of 6.4 watts; the gloves did not contain thermostats. This power level was adequate to maintain the fifth finger temperature above 60°F (16°C) for a period of one hour at which time the batteries expired. The one test subject alternately walked and rested.

From these experiments it will be assumed that the required power level for each hand and each foot is 10 watts per hour. With thermostatic control about 25 watts per hour are required on average to power gloves and boots/socks used to perform tasks in the extreme cold. The power source analysis which follows is based on these assumptions; however, it should be recognized that the actual requirements may differ. In particular, unless better insulators are designed for the elements inserted in the fingers of gloves, more power would need to be supplied at the lowest ambient temperatures -60°F (-51.1°C) to compensate for the heat lost to the environment. On the other hand, the time spent in ambient conditions between missions is relatively short (<30 minutes). If the extremities were kept comfortable in the cockpit, the stored heat would postpone the demand for auxiliary heat during these short exposures to ambient conditions. This is especially true for the feet, which take a longer time to cool down.

Since no experiments have been conducted which simulate cockpit conditions, no estimate will be made for the power requirements to heat thin,

flying gloves in a 30°F (-1.1°C) to 40°F (4.4°C) environment. These temperatures are considerably warmer than those used in past experiments, but since flying gloves must be close-fitting, the amount of insulation which can be placed around the heating elements is restricted.

The great temperature variations experienced within a day, as well as between days, make it mandatory that thermostats be included in the design of heated items. Use of thermostats will maintain more even temperatures and conserve energy.

If clothing items other than gloves and boots/socks were to be developed, the total power requirement would be increased by the watt-hours consumed by the additional items. The extremities would still need to be protected. The microclimatic cooling system which was developed originally to dissipate excess body heat by circulating cooled water through a vest, uses about 600 watts per hour per person. A modification of this system, which will both heat and cool as the conditions demand, is being considered as a solution to the aircrew clothing problem in cold climates. The power requirements for this system have not been determined; however, Appendix D discusses the power requirements for several clothing items developed by foreign countries. The Soviet "Pingvin" vest and boot liners consume 60 watts. The Soviet Yenot suit (jacket and pants) uses 35 watts and the one-piece coverall developed by the United Kingdom consumes about 100 watts.

Power Sources

A major consideration in developing auxiliary heated clothing is the source of power. Many past development efforts have been terminated because no acceptable solution could be found for this problem. Often the recommendation was that lighter portable batteries would need to be developed. This section reviews the options available today and is included in this systems analysis because the lack of feasible source of power presents a constraint that will influence the evaluation of the proposed cold weather clothing systems.

Two potential sources of power for heated clothing are the aircraft generator and portable batteries. A preliminary study was undertaken as part of this research effort to determine the feasibility of using one, or the other, or both of these sources. The factors considered were the types, weight, size, cost, and capacity of portable batteries, and the availability and compatibility of excess power on the various aircraft.

Aircraft Generator. The aircraft generator could be employed to power some auxiliary heated clothing. However, it is not feasible to use the generators to aid in accomplishing the outdoor preflight tasks since these must be completed before the aircraft engine is started. Also, the umbilical cord would interfere with efficient operations. These drawbacks restrict the use of the generator as a power source to mission tasks undertaken with the aircraft in operation.

All Army aircraft have 28 volt dc generators which have sufficient excess power to operate electrically heated gloves and boots for a two- to four-member crew. (See Appendix B for a discussion of the technical characteristics of aircraft, which affect the feasibility of using auxiliary heated clothing.) To eliminate the need for a voltage converter, it is desirable that items be designed to operate off the voltage of the aircraft. A power cable would need to be installed to make the generator power available in the cockpit or cabin. Those aircraft which are designed with outlets are identified in Appendix B, Section 3. The connection between the aircrewmember and the generator power cable should be located where it will not interfere with the aircrewmember's performance.

The availability of sufficient excess power to heat additional clothing items will need to be investigated after the power requirements for such items or microclimatic cooling heating systems have been established. On several aircraft, very limited excess power is available. Most aircraft cannot accommodate a system which draws an additional 600 watts per hour per crewmember, that is, the power required to operate the microclimatic cooling vest.

The possibility of using the aircraft generator to recharge nickel cadmium batteries was also explored. At present, all chargers in the Army Supply System are designed to operate off ac current at 110 volts. If a charger were designed to be installed in an aircraft, it would consume valuable space, add weight and therefore, would be unacceptable.

Batteries. Small portable batteries suitable for heating clothing are available in two general categories, rechargeable and primary (throw away). Of the types manufactured, the two most appropriate batteries are the nickel cadmium battery and the lithium battery.* Other types will not be included in this analysis for various reasons. For example, the development of silver cadmium batteries has been abandoned and alkaline batteries have inadequate capacity.

Nickel Cadmium (or ni-cd) batteries are low energy density rechargeable batteries. They are currently available from the Army logistic system in voltages of 6, 12, and 24 at various amperages. Since Army ni-cd battery packs were originally developed for specific items of equipment, their size, cell configuration, and power capacity reflect their original purpose. For economic and logistical reasons, it is desirable to use these standard batteries in new applications. However, a review of the batteries in the Army supply system suitable for this application indicates that the required battery weight and bulk could best be carried by an aircrew if the total battery capacity were subdivided into smaller cells. This suggests that a new configuration would need to be engineered considering human factors. The weight could then be distributed in a vest or belt, which would be worn under the parka and thus protected from the cold.

*The information presented on the availability and costs of batteries either presently in or to be added to the US Army logistics system was obtained from phone communications with Stuart Shapiro of the Electronics R&D Command, Ft. Monmouth, NJ.

The electrically heated items could be designed to operate at 6, 12, or 24 volts. A 24 volt system has several advantages. First, it could operate off the aircraft generator without the use of a converter. Second, a battery pack of 24 volts could be designed so the item would have dual power sources. Third, the higher voltage implies a lower amperage and a higher resistance. With lower amperage, less heat will be dissipated enroute to the extremities. Also, the maximum capacity of ni-cd batteries is achieved at lower currents. It is even more desirable to keep the current as low as possible with lithium batteries since they have a higher resistance. A heating element with a higher resistance will be thinner than one designed for a higher current and thus create less bulk around the fingers. For these reasons, and to simplify the analysis, the power source comparison was made for a 24-volt system.

In general, the power density of ni-cd batteries which meet the power requirements specified in the last subsection is 12 watt-hours per pound.* Based on a consumption level of 25 watts per hour to heat both hands and both feet, two pounds of ni-cd batteries would be necessary for each hour in extreme cold conditions. At this weight, ni-cd batteries would be impractical for a totally portable system which is powered exclusively by batteries throughout a 10 to 12 hour day. An alternative is a system which operates off either portable batteries or the generator, where the choice depends on the aircrewmember's location.

Lithium batteries are high energy density sources. Of the types manufactured, lithium sulfur dioxide batteries are the most appropriate for this clothing application because they are lightweight and provide superior cold temperature performance. However, lithium batteries are not rechargeable which makes their use for heated clothing very expensive. At the rates of use indicated by the analysis below, several batteries per aircrew would be expended each day. Other problems are that misuse can result in potentially hazardous conditions and disposal of spent batteries may present a problem.

Lithium sulfur dioxide batteries have an energy density in the range of 90 to 120 watt-hours per pound. Therefore, one pound of lithium batteries is equivalent in power to about 8 pounds of ni-cd batteries. From the standpoint of weight, the use of lithium batteries to power a totally portable auxiliary heated handwear/footwear system is feasible.

Two other types of lithium batteries, the lithium sulfural chloride cell and the lithium thionyl chloride cell, are now under development and may be suitable for a clothing application. Under certain conditions these could have as much as 50% more capacity than the lithium sulfur dioxide battery, but the actual amount is a function of the temperature and the rate at which the power is used. Both of these batteries can operate at low temperatures, but neither performs at -65°F (-53.9°C) as does the lithium sulfur dioxide battery. At present no lithium

*Higher power densities can be achieved. For example, the US Army type classified battery BB-541/U measures about 15 watt-hours per pound. It was developed to be used for clothing items and thus has about the maximum wattage of any small ni-cd battery. It is also sealed and has a cable connector. Characteristics: 6 volts, 7 amp. hr @ 1.4 amps, 2 lb. 13 oz., recharging time 14 hrs.

battery is rechargeable, but research is being conducted to enable lithium batteries to be reused.

The uniform annual costs (in FY81 dollars) per man of powering gloves and footwear in extreme cold by either ni-cd or lithium batteries were estimated and are presented in Appendix G. In addition to the initial purchase price, the ni-cd alternative will incur expenses for recharging, including the cost of a charger, labor to manage the operation, physical space to perform the task, and the cost of electricity. Only the cost of the charger was included in the cost comparison. The costs were derived from an existing general purpose Army charger.

The analysis indicates that the use of throw-away lithium batteries to power heated handwear and footwear for about four hours a day under extreme cold conditions is five to six times more expensive than using a rechargeable nickel cadmium battery source.

Conclusions

Using both battery power and the aircraft generator, it may be possible to meet the thermal protection requirements demanded by the temperature scenario in the LOA, although this conclusion is tentative since to date no laboratory experiments of auxiliary heated gloves (without mittens) have been conducted at -60°F (-51.1°C). Lithium batteries would be light enough to supply power to keep the extremities acceptably warm throughout the day without the aid of the generator. Additional heated items could even be added to the system without exceeding the aviator's tolerance for weight. However, due to the high cost of lithium batteries, their use is not recommended for regular use, although they may be suitable for emergency use.

The high power requirements of auxiliary heated clothing will limit the heated items in the aircrew clothing system to gloves and boots/socks or just gloves. The hands are the most critical to efficient performance and have the highest priority. Technically, it is easier to supply heat for the feet, because the insulation provided by the boot reduces the power requirements. Also, the heating elements will not be subjected to as much flexing as heating elements in the gloves.

The power analysis indicates that the most feasible solution is to design gloves and boots/socks to operate off ni-cd batteries while aircrewmembers are outdoors and alternatively to operate off the generator when they are in the aircraft. The weight of the ni-cd batteries limits the number of items which can be provided with heat. Since the new clothing ensemble and the new survival/armor vest have not yet been designed, the extra weight in batteries an aircrew could carry cannot be determined.

The system could be designed to accommodate either type of battery as well as the generator. The cheaper ni-cd batteries could be used for normal conditions and the lighter lithium batteries could be used in the event of failure of the standard system, during emergency crash situations, and for extended periods in the field where the ni-cd could not be recharged. Because lithium batteries tolerate extreme cold, they could be stored in the aircraft.

Chapter V

ALTERNATIVE AIRCREW CLOTHING SYSTEM CONCEPTS

1. CURRENT COLD WEATHER AIRCREW CLOTHING (BASELINE)

Description

The US Army does not have a standard ensemble for aircrews operating in cold climates. Much of the clothing worn by aircrews today was originally developed for Air Force fliers or for ground troops, and therefore does not function adequately for Army aircrews. The requirements document for a new cold weather aircrew clothing system was generated to fill this critical need.

The Common Table of Allowances (CTA 50-900) authorizes the clothing items to be worn by Army personnel in various climates. Commanders have discretionary authority to augment the basic allowances by authorizing additional items which are essential to the mission of their commands. From the authorized items, individuals have the freedom to choose a combination of items appropriate for their individual mission and their personal thermal comfort under local climatic conditions. A lack or an excess of type-classified items at a base can cause different clothing to be worn between sites in a climatic zone or even within sites. For all these reasons there are currently several cold weather clothing systems for aircrews rather than a single baseline ensemble.

The large fluctuations in weather conditions in Alaska on a day-by-day and even hour-by-hour basis require that clothing be flexible. Figure 8 shows a picture of three different winter flight ensembles worn in Alaska. Each aircrewmember in the photo is wearing a different jacket and all are authorized. Aircrews in parts of Clothing Allowance Zone V often wear a fourth jacket, the Army Nomex Flyer's Jacket.

In lieu of describing each possible winter flight ensemble, all items authorized for flight wear in Zones V, VI, and VII are listed in Table 11. In addition to these articles of clothing, aircrews in Alaska are also issued the standard arctic ensemble and wear it at their discretion.

Deficiencies

Many problems exist with the items of clothing currently worn by flight crews, because the items were developed in a piecemeal manner for other uses rather than through a systems approach which considered the aircrew tasks, the environment, human factors, and the aircraft. For example, the vapor barrier boots (VB) do not interface well with the recessed aircraft steps or the cockpit footspaces; they provide insufficient traction for walking on top of the aircraft under icy, wintery conditions during the preflight tasks; their bulk makes efficient manipulation of the rudders and the brakes difficult; and critical pedal vibrations cannot be sensed through the thick soles. Specifically, the vapor barrier boot is too wide to permit proper pedal operation in



Source: Reference 2

Figure 8. Current cold weather aircrew clothing.

Shown is a three man aircrew with flight clothing and survival equipment currently required for flight during the winter season in Alaska. Aircrewmembers are wearing different ensembles of authorized outer clothing. The aircrewmember on the right is shown wearing the long N3B parka with the N1B "fatboy" trousers; the aircrewmember in the center is wearing the short N2B parka with winter weight CWU-1P coveralls; the aircrewmember on the left is wearing the parka shell with its hood and liner and field trousers with liner. Both the cap, cold weather, and the optional balaclava headgear are shown. All have vapor barrier boots, arctic mittens, sleeping bags arctic and mountain with cover and survival kit, cold climate, individual. Worn, but not visible, are aviator mukluk footwear, long underwear 50 cotton-50 wool and nomex flight uniform. Note flight helmets and nomex flying gloves which remain a part of the winter uniform.

TABLE 11. Current Aircrew Clothing, Cold Weather

Basic Items

One-Piece Flight Suit - Nomex, olive green
Underwear, Cold Weather

Jackets

AF Flyer's Jacket, N2B-nylon, sage green
AF Parka, N3B-nylon, sage green
Army Flyer's Jacket, cold weather - Nomex
Parka, extreme cold weather with hood - olive green

Other Clothing

AF Fat Boy Trousers, F-1B - nylon, sage green
Coveralls, CWU-1P - nylon, sage green
Field Shirt, wool - olive green
Field Trousers with Liner - olive green

Boots

AF Mukluks, N-1B
Combat Boot, Leather, Black
Vapor Barrier Boot, White
Ski Boot, Mountain

Gloves

Leather Shells with Wool Inserts
Nomex Flight Gloves

Headwear

Cap, cold weather
Balaclava
Flight Helmet, SPH-4

the following aircraft: OH-6A, UH-1, OH-58A, and OV-1. The weight of the boots (5.5 pounds per pair) also add to their cumbersomeness. Since one pound of weight on the foot is equivalent to 5 pounds on the back, the VB boots are equivalent to nearly 30 pounds of weight carried on one's back.

The Air Force mukluk is preferred by aircrews in Alaska since it is lighter in weight. However, the mukluk does not offer wet cold protection and, as a result, moisture from melting snow penetrates the shell and destroys the insulation of the inner layers. Other problems are that the muklucs are not fire retardant and they wear out quickly. Due to their shortcomings, both the VB boot and the mukluk are safety hazards and neither boot has impact protection in the toe area. The ski boot is more flexible for flying, but it offers limited thermal protection. The clo values for the four cold weather boots are: AF Mukluk - 2.2 clo; Combat Boot - 1.11 clo; VB Boot - 2.0 clo; Ski Boot - 1.24 clo.

A major problem with all winter flight uniforms is that they are thermally inadequate for the Alaskan climate. As a result many aircrewmembers purchase commercial items such as down vests and down gloves to supplement the clothing they are issued. The outer clothing provides no protection from wet precipitation. The N2B jacket is too short and rides up during the extensive bending required by preflight tasks. On the other hand, while on alert in the ready room the clothing is too warm.

With the exception of the Nomex flight suit and Nomex flight gloves, the clothing items do not offer fire protection. For this reason, the Air Force has discontinued use of the nylon jackets (NB2 and NB3) still worn by the Army aircrews and has issued jackets fabricated from Nomex. The combination of a Nomex flight suit and a nylon jacket increases the buildup of static electricity in the cold dry climates.

The bulkiness of the clothing is a problem for all personnel, but especially for those aviators who fly in cramped cockpits. The shoulder harness is difficult to buckle around both bulky clothing and the survival vest. The lack of a zipper in the hood of the N3B parka causes the hood to bunch behind the neck and press against the helmet, making it difficult to hold the head erect. The thickness of the gloves makes manipulation of the toggle switches and circuit breakers difficult. In general, the bulkiness of the clothing interferes with efficient performance and can cause flight hazards by decreasing reaction times or by snagging on equipment.

Other problems include the lack of a drop seat, lack of protection for the throat area from fire or cold, the inconvenient location of some pockets, and the poor fit of the garments.

2. DESCRIPTION OF ALTERNATIVES

Five alternative concepts have been proposed by the US Army Natick Individual Protection Laboratory (IPL) for the new aircrew cold weather clothing system. Within each conceptual area numerous designs of individual items and combinations of these items are possible; however, each concept is technologically distinct from the others. The five alternative concepts are:

Concept 1 - Conventional cold weather clothing.

Concept 2 - Conventional clothing supplemented with auxiliary heated items (gloves, boots, etc.)

Concept 3 - Clothing fabricated with reflective fabrics or other heat retaining fabrics.

Concept 4 - Clothing which combines heat retaining fabrics with auxiliary heat.

Concept 5 - A thermostatically controlled microclimatic system.

The term conventional clothing is used here to mean clothing constructed from materials currently used to fabricate military clothing or materials readily available commercially. The properties of these materials are known and no testing would be required before they could be utilized. Warmth would be provided through the layered principle. One physical example of an ensemble representative of the first concept is the new Combat Vehicle Crew (CVC) uniform. It was designed with the intent that it would provide dual service and a modification of this clothing system has been proposed for aircrews. (The jacket included in this ensemble was originally designed as a cold weather jacket for aircrews). The entire CVC uniform is fabricated in olive green Nomex. The new cold weather aircrew system must provide the optimum camouflage compatibility with the geographical area. For certain areas this requirement implies an olive green camouflage pattern. To date, no successful method has been found for printing camouflage on Nomex without increasing the flammability of the fabric, but the problem is currently being researched and for this analysis we have assumed that camouflage printing is feasible.

The second concept includes designs which extend the thermal protection of standard clothing systems by supplementing the intrinsic thermal protection of one or more clothing items with auxiliary heat. The list of potential items includes gloves, boots, socks, vest, flight suit, and various combinations of these. The heat could be supplied using hot air, hot water, or through electrically heated elements.

The third category includes designs which employ new fabrics designed to retard heat loss through radiation. A review of recent research was conducted to determine the effectiveness of these fabrics and is presented in Section 4 of this chapter. The fourth concept combines heat-retaining fabrics with auxiliary heat, that is, a combination of Concepts 2 and 3.

The fifth category employs the microclimatic concept which represents the ultimate in thermal comfort. In principle, the clothing system would be thermostatically controlled to warm the individual when heat is needed and alternately cool the crewmember when body temperature rises above a specified level. Comfort would thereby be maintained despite temperature changes in the crew's environment. Modifications to several existing items originally developed to cool the individual and prevent heat stress have been proposed. One vest circulates cool water or other liquid; another circulates cool air under the clothing. These systems would be modified to heat as well as cool. In addition, auxiliary heated items may need to be employed to protect the extremities.

When an alternatives analysis is performed, the current system usually is evaluated on its merits in comparison with the proposed approaches. However, the current aircrew clothing ensembles are not specifically included in the list of alternatives above because clothing configurations currently worn by aircrews are subsumed under Concept 1. In the assessment of the alternative concepts (Chapter VI), only the most effective solutions of all possible designs within a conceptual category are considered. Although no data on the clo values of the current aircrew cold weather clothing were available for this analysis, it was assumed that improved ensembles could be fabricated from conventional materials. These hypothetical, more effective solutions were used as representatives of Concept 1.

3. FEASIBILITY ISSUES

The LOA identifies several feasibility issues to be examined during the development process. Other tradeoffs have been raised by this systems analysis. This section discusses some of these issues and draws conclusions based on the information which is presently available.

One Ensemble for Intermediate Cold, Cold and Extreme Cold Regions

For economic and logistical reasons, the Army tries to limit the number of items in the Army supply system. Thus, it would be desirable to introduce a single aircrew cold weather clothing system which will be authorized in Clothing Allowance Zones V, VI, and VII as stated in the LOA. However, a single basic system would need to be thermally suitable over the range of -60°F (-51.1°C) (lowest ambient) to +40°F (4.4°C) (cockpit). This is equivalent to requiring that one clothing system be designed to be comfortable over the more easily grasped range of 0°F (-17.8°C) to 100°F (37.8°C). An 80 to 100 degree temperature span is realistic for those aircrews who must perform preflight tasks in extremely cold ambient temperatures and start the

mission before the cockpit temperature has risen much above the ambient temperature. Aircrews are unable to remove layers of clothing once the cabin temperature rises because they are already airborne and secured by the harness. (If overheating occurs, a lower cockpit temperature can be maintained through heater controls).

Conventional clothing systems do have a comfort range, but the ranges do not extend over 100 degrees Fahrenheit; different clothing is generally required for different seasons. Through the use of auxiliary heated items or a complete self-contained microenvironment, the comfort range of conventional clothing can be extended. But, just as a warmer conventional clothing system requires additional weight and bulk to be carried by the wearer, auxiliary powered articles also burden the wearer. For this study it was assumed that auxiliary powered items would only be utilized if the insulation requirements could not be met by conventional clothing.

If only one clothing system were designed, it would need to provide environmental protection for the coldest temperatures experienced in the three zones. However, the climatic data presented in Chapter III revealed that extreme cold temperatures occur in few areas of the world where the Army functions in peacetime. More importantly, less than 5% of the aircrews who will wear the clothing are located in these extreme cold regions. Of course, if a conflict developed in an extreme cold region, the distribution of aircrews would change.

All of these facts suggest that it is impractical to design a single cold weather uniform to be worn by aircrews in all three clothing zones. A system environmentally adequate for the arctic will be too bulky and too warm for parts of Clothing Allowance Zone V. One suitable for Zone V will be inadequate for the arctic and a compromise will not solve the problem at either end of the range. A microclimatic system could satisfy the thermal range while keeping bulk at a minimum. However, this solution carries both monetary and other costs and is unnecessary for a vast majority of aircrews.

Technological Feasibility of Proposed Alternatives

Although laboratory experiments and prototypes have demonstrated that certain innovative approaches are within the state-of-the-art, the feasibility of applying these solutions to the aircrew clothing problem has not been fully determined. For example, various auxiliary heated items have been evaluated in the laboratory for applications which were studied in the past, but the experimental conditions did not simulate those specified in the LOA. Many questions remain which can be answered only through appropriate exploratory development. The results will provide needed detailed answers for design engineers. These questions include: How effective will heated gloves be at -60°F (-51.1°C)? How much power will be required at that temperature? Will another glove or mitten need to be worn over the heated glove to serve as insulation? Which fabrication allows the most even heat distribution? Can the gloves be designed to be slimfitting and flexible? Can the battery weight be tolerated? Are thermostatic devices small enough to be inserted in gloves? These questions must be addressed under the experimental part of this project.

Similar questions will need to be answered for other heated items. The relative advantages of heating socks versus heating boots or insoles will need to be assessed. If socks are developed, they will need to be durable enough to withstand frequent laundering. Although comfort can be achieved through auxiliary heat, the number of items which can be powered from batteries will be a function of the power demand of each and the additional weight an aircrewmember is able to tolerate.

Theoretically, the increased extremity temperatures which occur with the application of electric heat do not result from the electric heat being absorbed by the blood. Recall the small difference shown on the graphs of finger cooling rates (Appendix I) between the 7 kcal/hr-m^2 circulatory heat input rate under extreme vasoconstriction and the 73 kcal/hr-m^2 rate with normal blood flow (a difference of 66 kcal/hr-m^2). Yet, the recommended power level for the auxiliary heat to maintain comfort was about 10 watts per extremity or only about 11.6 kcal/hr-m^2 . Instead of the heat being absorbed, the application of electric heat to the extremities has been found to maintain comfortable finger and toe temperatures primarily through altering the blood flow to the extremities. The electric heat thus reverses the natural mechanism of the body, which reduces the blood flow to the extremities when heat must be conserved for the core. Laboratory research will need to measure the effect of applying heat to the extremities while the subjects are wearing proposed aircrew clothing to insure that the higher blood circulation rates do not pull too much heat from the body, and thereby, reduce the core temperature.

The microclimatic proposals likewise present many unanswered questions. They were originally conceived as cooling systems to alleviate heat stress, and to date counterpart prototypes which circulate warm water or air to alleviate cold stress have not been built. Until this step is completed, the effectiveness of microclimatic systems to maintain thermal comfort under extreme cold ambient temperatures cannot be tested and validated. At certain temperatures, heat applied to the torso should keep the blood flowing normally through the extremities. In this case, auxiliary heated gloves and boots would not be needed. However, at the lower temperatures specified in the LOA, this probably would not be the case and heated handwear/footwear would also need to be supplied. Since prototypes do not exist, power consumption levels to operate these systems as heating units or as both heating/cooling units have not been determined. A hand portable unit to power the proposed system has been suggested. The acceptability of this solution for aircrews will need to be determined. A major area of concern for all innovative solutions is the cost. Once some feasible alternatives have been developed, the costs can be compared to the benefits.

For the last four decades, researchers have experimented with reflective materials in an attempt to increase the intrinsic insulation properties of fabrics. Their efforts met with little success and between 1955 and the late 1960's most work in this area was abandoned. Recently, the latest developments in the field were evaluated for their application to military cold weather clothing. The results of this study are reported in the next section.

In conclusion, the findings of research designed to answer the questions raised in this section are essential input to the decision-making process of identifying the most effective solution to the problem of clothing aircrews in cold climates.

One Glove or Two

The feasibility of designing one glove which will be used for all tasks was considered in this analysis. The preliminary research with auxiliary heated handwear indicates that a two-layer handwear system is preferable. A glove of the desired thickness for flying would not provide sufficient insulation for the heating elements in extreme cold ambient temperatures. Also, the power requirements for the two environments may be very different.

The use of a second conventional glove to be worn over the thin auxiliary heated glove, although less convenient for the user, has several advantages. First, it allows the inner glove to be designed to provide the flexibility needed for flying. Less dexterity is needed for preflight tasks or for refueling. Second, the power consumption should be less, since the overglove will provide a layer of insulation. Third, the overglove can have built-in protection from petroleum, oil, and other lubricants; this will extend the life of the more expensive, electrically heated underglove. Not only will the heated glove be protected from damaging substances, but the wear and tear will occur on the overglove. If the use of the heated glove without a cover is confined to the cockpit, it will need to be cleaned far less often.

4. EFFECTIVENESS OF REFLECTIVE FABRICS

Body Heat Lost Through Radiation

For several decades scientists have been interested in developing more effective heat-retaining fabrics through the use of reflective metallized layers. In general, the efforts have not been successful. These fabrics do reflect a high percentage of the radiated body heat. However, heat loss from the body by radiation varies with air movement, activity level, and ambient temperature and often represents a small percentage of the total heat loss.

Radiation is only one of four channels through which the human body loses heat to the environment. The other three channels are convection, evaporation, and conduction. The conduction component is small unless the individual is in contact with a cold object without sufficient insulation to prevent an exchange of heat. For example, heat can be conducted from the body through the bottoms of the feet, through sitting on a cold aircraft seat, and through manual contact with the aircraft or other cold equipment. For an individual at rest, evaporation accounts for the loss of about 25% of the metabolic heat through the involuntary process of respiration and insensible perspiration. The remaining heat must therefore be lost through the remaining two channels, radiation and convection.

Table 12 illustrates the effect of air movement and temperature on the relative percentage of the remaining heat which is lost through radiation and convection. Under high winds, the convection loss rate increases significantly, and since the radiation rate is unaffected by the wind, the radiation percentage decreases dramatically.

TABLE 12. Heat Loss Through Metallized Fabrics

<u>Air Movement</u>		<u>77°F (25°C)</u>		<u>-40°F (-40°C)</u>	
		<u>% Heat Loss Due To</u>		<u>% Heat Loss Due To</u>	
<u>Cm/sec</u>	<u>miles/hr</u>	<u>Radiation</u>	<u>Convection</u>	<u>Radiation</u>	<u>Convection</u>
9	.21	52%	48%	32%	68%
36	.81	35%	65%	19%	81%
121	2.69	23%	77%	11%	89%
1024	22.9	9%	91%	4%	96%

Source: Reference 30

The military abandoned research in the area of reflective fabrics between 1955 and the late 1960's due to the lack of progress. However, the development and use of low density polyester batting about 1968 revived the efforts, since the laws of radiant energy transfer indicate that reflective layers are the most effective in reducing heat loss through open-structured materials and are least effective in combination with densely-packed fibers.

Over a six year period in the 1970's, the US Army Research Institute of Environmental Medicine (ARIEM) conducted experiments to evaluate commercial reflectives and determine their effectiveness for clothing.³¹ The results of those experiments are reported in the following three subsections.

Reflective Materials

A variety of metallized reflective layers were incorporated into fabric systems and the insulation values were measured on an electrically heated guard ring flat plate, an apparatus used to measure clo and permeability. These reflectives included thin-film plastic layers with metallic coatings deposited on one or both surfaces, conventional aluminum foils, and special metallized fabrics produced by depositing foil on a fabric under pressure. This latter process bonds the foil to the fabric without destroying its vapor permeability. These metallized layers were arranged in various combinations with polyester battings and measurements were taken.

The results for uncompressed batting were encouraging. Layers of batting with reflectives facing each other across every batt were found to be most effective. An arrangement consisting of two 68 g/m² polyester batts with a metallized film placed on each of the four surfaces measured 6.1 clo showing an improvement of 85% over the insulation provided by the two batts without reflective layers.

On the other hand, combining reflectives with dense foam showed less than a 10% improvement since radiation is not a major avenue for heat loss in foam or other densely-packed fibers. In fact, it was shown that uncompressed batting without reflectives provides about 70% as much insulation as a comparably thick dense fabric. The effect of the reflective is merely to minimize the radiation heat loss thus rendering uncompressed batting closer in insulation value to a dense fabric of the same thickness.

The effect of various stitching patterns sewn through the layers of batting and reflectives was also studied. The compression caused by stitching drastically lessened the insulation quality of the unstitched layers. With the moderate to heavy compression required to join pieces of material, the addition of reflectives increased the total clo value by only about 16%. The study concluded (p. 23):

It is obvious that, if reflectives are to be successfully applied in cold weather clothing, some method of joining and stabilizing the fabrics which will not compress them will have to be found.

Reflectives Used in Clothing Items

As part of the research conducted by ARIEM, actual clothing items were fabricated with reflective layers and measured on the copper man, copper hand, and copper foot.

Arctic Uniform. The liners of the standard arctic uniform were constructed with reflective films and the entire six layer ensemble worn with the reflective liners was compared against the control uniform. The total insulation value of the ensemble with reflective liners (4.58 clo) was only 5.7% greater than the clo value for the uniform with no reflectives (4.33 clo).

Handwear. Reflective films were added to the polyester liner of the arctic mitten system, which consists of a polyester batting liner, a wool mitten, and an arctic shell. Measurements on the sectional copper hand revealed that the overall clo was only increased by 3-10%. The fingertip area, however, increased by close to 10%. The benefits for gloves were not tested in this experiment, but they probably would be negligible due to the compression of the batting caused by the extensive stitching around the fingers.

Footwear. The use of reflectives in conventional footwear is not recommended since dense materials are used and reflectives have been found to be ineffective in combination with materials where radiation exchange is not a major factor. Experiments with polyester batting booties showed promise. Further experiments are being conducted to determine if the insulation of mukluks can be enhanced with booties designed with reflective layers.

Conclusions

ARIEM's research has demonstrated that the thermal protection of clothing items fabricated with reflective fabrics (Concept 3) is not substantially better than the protection offered by conventional fabrics, that is, a nearly equal amount of bulk (trapped air) is required to achieve the same insulation value. However, some benefit may be gained by combining reflective fabrics with auxiliary heat (Concept 4) since reflectives may retard the loss of heat and thereby reduce the power requirements. This hypothesis will need to be tested in a laboratory. As mentioned, a footwear application (booties/mukluks) may also prove beneficial.

Chapter VI

ASSESSMENT OF ALTERNATIVES

1. BENEFIT ASSESSMENT

A systematic evaluation of alternative solutions generally includes: 1) the determination of the objectives and requirements for the system, 2) the identification of the critical parameters and their relative priority, and 3) the comparison of the relative merits of each alternative with respect to each critical parameter. The objectives and requirements for the new cold weather aircrew clothing system were defined in Chapter II. This section describes the method used to rank the requirements, presents the results of the ranking, and assesses the alternatives.

Ranking of the Parameters

Six individuals from TRADOC and DARCOM who are involved with the development of aircraft and aircrew clothing and equipment independently judged the relative importance of the performance parameters displayed in Figure 9. Their relative ranking of the objectives for the new clothing system varied, because these individuals represent different groups and interests within the Army aircrew community. Included in the sample were the TRADOC project officer for the cold weather aircrew clothing development effort, the DARCOM project officer for the aircrew integrated battlefield life support system, and DARCOM project officers for several helicopters. Some of these Army officers had flown under the most extreme cold weather conditions and some had not.

The five performance categories at the highest level of the hierarchy in Figure 9 were ranked and weighted first. Even at this level there was some disagreement among the project officers, but it was clear that Environmental Protection and Interfaces/Compatibility were the two objectives judged to be of greatest importance. Three of the judges chose one objective and three chose the other as the most critical area; for their second choice, four of the six judges chose the other half of this pair not picked as their first choice. This result is understandable since environmental protection and compatibility interact.

The weights each judge assigned to these two major areas varied greatly, but for each judge the sum of the weights assigned to these two areas ranged from about 55% to 80%. On the basis of these survey results, the decision was made to allocate about half of this range to Environmental Protection and half to Interfaces/Compatibility for the purposes of this analysis. Similar subjective approaches were used to combine the survey data for the other performance areas and derive a weight or range for each. The intent of the ranges, therefore, is not to span the recorded judgments (some votes fell outside the indicated ranges), but to reflect the opinion of the majority.

PERFORMANCE PARAMETERS

AIRCREW CLOTHING SYSTEM, COLD WEATHER

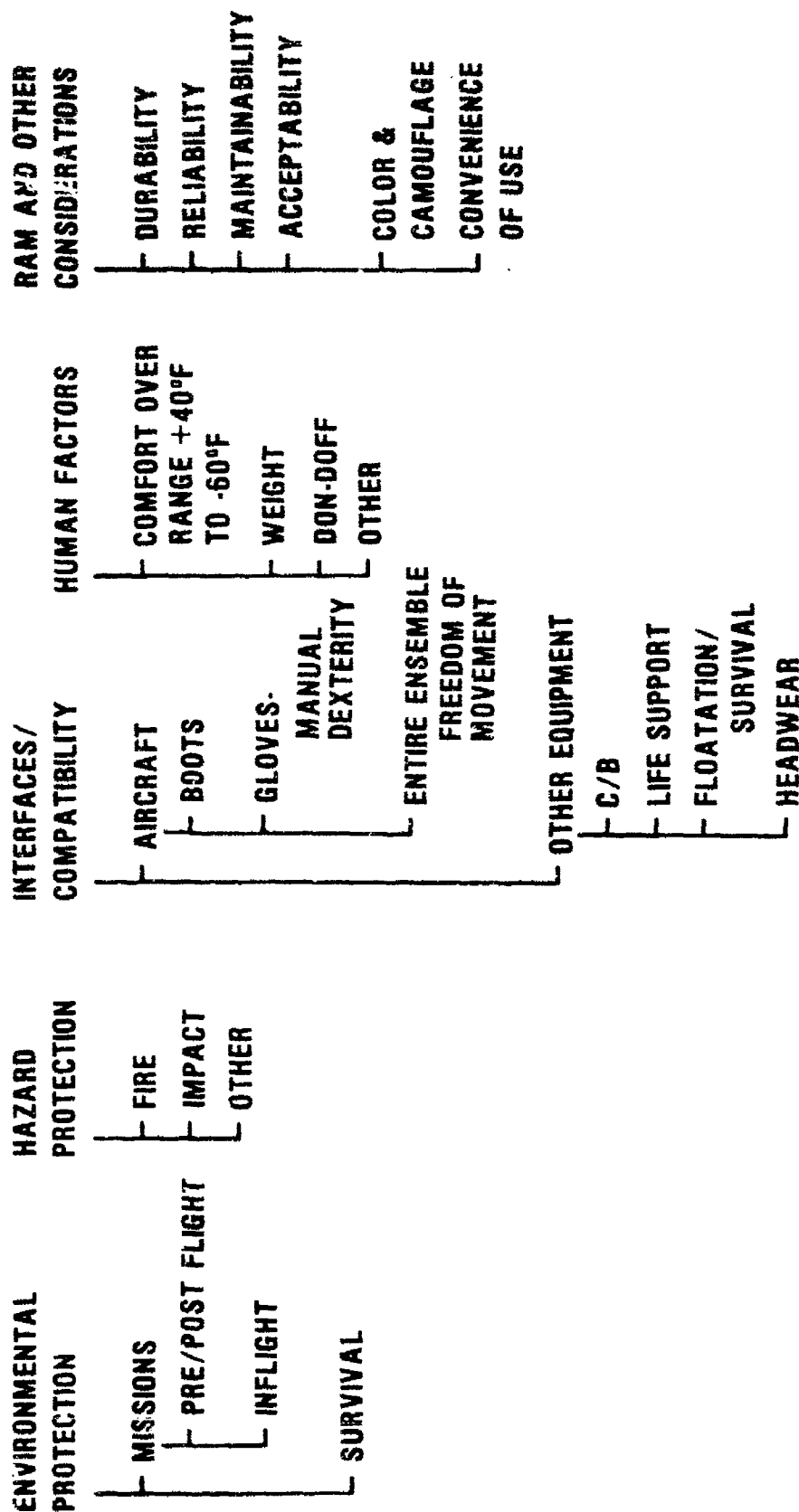


Figure 9. Hierarchy of Performance Parameters for the Aircrew Clothing System, Cold Weather.

Figure 10 displays the results of combining the judgments of the six individuals. Given the small sample and the differences in opinion reflected by the results, the weights in Figure 10 should be used only as general guidelines. At each level shown, the range of percents has been subdivided into ranges for the parameters at the next lowest level. For example, Missions (15-20%) is subdivided into Preflight (10-15%) and Inflight (5-10%). For the most part, percents smaller than 20% were not subdivided at the next lowest level. Hence, not all the subparameters shown in Figure 9 are represented in Figure 10.

Qualitative Evaluation

The facts, data, and analyses included in Chapters II through V show that, for various reasons, none of the proposed state-of-the-art alternatives can satisfy all of the major requirements for the system. In particular, there is a problem in meeting the environmental protection criteria stated in the LOA and environmental protection is a principal goal of the clothing system. Without several competing feasible alternatives (that is, alternatives which meet all requirements to a varying degree), it is pointless to apply a quantitative methodology to choose the preferred approach. Instead a qualitative assessment of the feasibility of each concept to satisfy the requirements of the LOA is presented below.

- Concept 1 (Conventional Materials) - The most obvious weakness with Concept 1 is the inability of unheated gloves to protect the aircrew's hands at -60°F (-51.1°C) or even at considerably warmer temperatures. As explained earlier, this problem is caused by the physical shape of the fingers and the laws of heat transfer and therefore is not a problem that can be solved through further research on materials. If a warm mitten were worn over the glove and removed for tasks which require manual dexterity, the glove/mitten combination would most likely still be inadequate, since the tolerance times for the hands are so short.

The feet, likewise, cannot be protected at -60°F (-51.1°C) by any unheated boots currently available. The extremity model predicts that in 42 minutes or less the toes would cool to 60.8°F (16°C). A boot with a higher clo could be developed, but it would be too bulky to allow the aircrews to function properly.

The clothing required to restrict the cooling of the whole body to a tolerable loss is equivalent to or exceeds the insulation of the arctic ensemble. This system would fail the requirement that the ensemble interface well with the aircraft and other equipment.

In a survival situation, the individual can be more active physically than when flying an aircraft. Under light to moderate activity, a conventional clothing system could be designed which would meet the survival needs. However, when less active or when at rest, the heat generated will not match the heat lost and cold injury could occur. At the extreme low temperatures, it would be difficult to keep

WEIGHTS ASSIGNED TO THE PERFORMANCE PARAMETERS

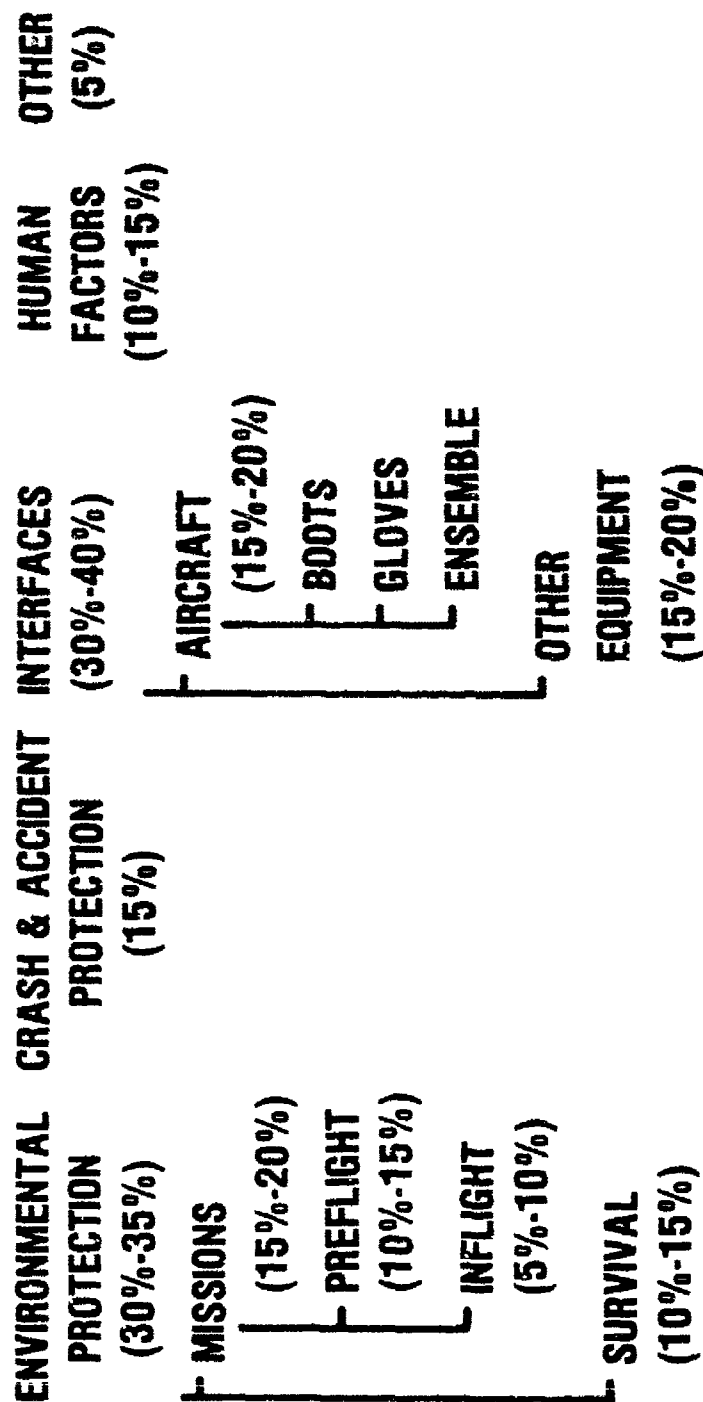


Figure 10. Weights assigned to the performance parameters.

the extremities warm unless the body is overheated; this situation is neither desirable nor likely. The arctic mittens will need to be added to the survival gear to substitute for flying gloves. The historical data on rescue times reveals that most downed aircrews in peacetime have been recovered in a few hours. Clothing without auxiliary heat would be adequate for this period. For longer periods, the tent, the sleeping bag, and auxiliary heat sources could be used to supplement the protection offered by the flight clothing.

Concept 1 can satisfy most other requirements. The use of Nomex or another high temperature-resistant fabric will provide fire protection. The human factors requirements can be satisfied through proper design.

- Concept 2 (Auxiliary Heated Items) - The feasibility of this concept for solving the aircrew clothing problem cannot be stated with certainty until further laboratory research has been completed. It is clear that auxiliary heated items are needed in order to meet the temperature criteria and that these items are within the state-of-the-art. However, it is still unclear whether this approach will solve the aircrew problem, and if so, how the solution will be designed. Section 3 of Chapter V discusses these feasibility issues. To review, it has not been determined whether heated gloves can be developed which will keep hands warm at -60°F (-51.1°C). The analysis suggests that gloves, boots or socks, and torso items may need to be heated, but the impact of combining two heated items has not been thoroughly explored. Also, the power requirements for a -60°F (-51.1°C) scenario have not been established. The power level is affected by the conducting material, and to date, not all options have been analyzed for this application.

Without knowledge of the power requirements, it is difficult to state whether an adequate power source is available. On the basis of prior experience, it appears that the portable batteries to power gloves and boots for outdoor tasks can be carried without burdening the aircrews with excessive weight.

The comments made for Concept 1 concerning the adequacy of the clothing in a survival situation also apply to Concept 2. Additional items would need to be included in the survival kit to supplement any flight clothing powered by auxiliary heat. These items merely convert the Concept 2 ensemble to a Concept 1 ensemble in a survival situation.

Concept 2 can satisfy most other requirements. The use of Nomex or another high temperature resistant fabric will provide fire protection. Auxiliary heat will allow the system to be designed with considerably less bulk, and therefore, the current aircraft incompatibility problems can be eliminated. Auxiliary heat will also provide greater comfort over the wide range of temperatures an aircrew experiences.

- Concept 3 (Reflective Fabrics) - Testing of reflective fabrics without auxiliary heat have demonstrated only small benefits in insulation qualities when these fabrics are used for clothing. The increases in clo values are insufficient to meet the temperature requirements of the LOA. In all other respects, this concept is similar to Concept 1.
- Concept 4 (Reflective Fabrics and Auxiliary Heat) - Several combinations of reflective fabrics and auxiliary heat are possible. Reflectives and heat could be used separately, that is, one clothing item in the ensemble could employ auxiliary heat and another could be constructed from reflective fabric, or heat and reflectives could be combined in the same item. The literature search revealed no evidence that the effectiveness of the latter combination has been tested. Since research has shown that stitching reflective fabric greatly reduces a garment's insulating effectiveness, one suggestion is to use reflectives for articles of clothing which cover relatively flat, smooth parts of the body such as the back and chest, and reserve auxiliary heat for gloves and/or boots.

Concept 4 is not substantially different from Concepts 2 and 3 with regard to how well it can meet the requirements other than environmental protection.

- Concept 5 (Microenvironmental) - This concept potentially offers the greatest benefits for inflight aircrew mission tasks. In theory, it will maintain comfort by supplying heat when needed or alternatively cooling the body if overheating occurs. The interface problems and lack of freedom of movement experienced with the current clothing can be eliminated, because warmth is provided through electric power rather than through bulk insulation. However, a feasible micro-climatic prototype has not been developed and much research remains to be done. Some feasibility problems with Concept 5 are discussed in Section 3 of Chapter V.

The lack of an adequate power source for all aircraft may present the greatest obstacle. Preliminary work indicates that a micro-climatic system consumes more power than some aircraft generators have available as excess (See appendix B, Section 3). The aircraft generators cannot be utilized as a source of auxiliary power for the preflight tasks, yet auxiliary heat is needed most for these outdoor tasks. The high power needs of anticipated versions of a micro-climatic system seem to preclude the use of portable batteries worn by the aircrews. A hand-carried portable battery system is inconvenient. In addition to the power source problems, the central heating/cooling unit presents weight and space problems for some aircraft.

Another major problem with Concept 5 is that the ensemble would be limited or non-existent and the clothing alone would be considerably less warm than clothing developed under Concept 1 where

warmth is achieved through bulk insulation. This problem needs to be addressed and an acceptable solution found before development work proceeds. The microclimatic concept is also completely unacceptable for the OV-1 pilot who must eject in an emergency.

A New Approach - Description and Assessment

The information collected for this study, the analysis of the information, and the assessment of the proposed alternatives all suggest that a new approach should be taken to the aircrew cold weather clothing problem. The temperature range in winter between the coldest locations in Clothing Allowance Zones V, VI, and VII and the warmest is too great to satisfy with one uniform. The requirement that the system provide environmental protection to -60°F (-51.1°C) also poses a difficult technical design problem, and as a result, clothing developed to meet this requirement will probably be more expensive than clothing developed to meet the warmer temperature criteria for cold and intermediate cold areas. Of overriding importance is the fact that clothing adequate to -60°F (-51.1°C) is needed by only a small percentage of the aircrews for whom this system is being designed, unless a crisis develops in an extreme cold climate.

All these facts suggest that it is neither practical nor effective to design just one cold weather aircrew clothing system for all three clothing zones. Instead a two- or multi-ensemble concept is recommended. A basic cold weather aircrew clothing system should be designed which will satisfy the environmental conditions experienced by the vast majority of aircrews operating in cold climates. This system should be adequate for cold and intermediate cold regions (Zone V and VI). The minimum temperature limit for this ensemble will need to be established through further work, but it probably will be in the -10°F (-23.3°C) to -15°F (-26.1°C) range. For colder locations (Zone VII), such as Alaska and northern parts of the United States, additional layers or components should be designed to increase the environmental protection of the basic ensemble. The multi-ensemble concept will enable one or more items to be added to the basic system in accordance with the thermal protection needed. (Alternatively, a second system which utilizes a different concept could be designed for the extreme cold areas, if it is determined that this solution is more practical.)

A major advantage of this approach is that one of the proposed concepts can be used to satisfy the clothing problem for the majority of the aircrews. Further research will need to be conducted to develop the items which will supplement the basic system and extend its thermal protection to -60°F (-51.1°C). Each of the proposed concepts is briefly assessed below on its potential to satisfy the modified requirements for a proposed basic cold weather aircrew ensemble. For this exercise, -15°C (-26.1°C) was chosen as the lower temperature limit for the basic ensemble.

- Concept 1 - An ensemble could be fabricated from conventional materials which would offer adequate environmental protection for the torso to -15°F (-26.1°C) (see Table C-5), but conventional gloves still are inadequate for the hands (see Table 7). A boot with a clo value between 1.6 and 2.0 would be sufficient at normal circulation levels but marginal under vasoconstriction (see Table 9). It is not clear whether a boot in this clo range can be designed without auxiliary heat to meet the requirements for flyers and overcome the deficiencies of the current footwear (see Chapter VI - Section 1). The recessed aircraft steps and foot control areas will need to be measured to determine the maximum outer dimensions of a boot which will interface well with all aircraft.
- Concept 2 - A system consisting of auxiliary heated gloves, conventional clothing rated about 3.5 clo, and boots with a clo between 1.6 and 2.0 would meet the proposed environmental requirements. The new CVC uniform offers sufficient insulation, but several features will need to be redesigned. In particular, the jacket does not offer adequate protection to the neck and head area. In discussions with flyers, a hood was considered necessary for windy conditions. Also, full length leg slide fasteners on the outer layer were recommended so that this layer can be easily donned/doffed without interference from the boot. The gloves should be designed to operate from both portable batteries and the aircraft generator as heat will be needed both outdoors and in the cockpit.

In a survival situation with a minimum temperature of -15°F (-26.1°C), the individual would need to be engaged in light activity to sustain a thermal balance overall. The arctic mittens will need to be included in the survival gear to compensate for the lack of power.

- Concept 3 - The statements made regarding the effectiveness of reflective fabrics for extreme cold apply to this environment also.
- Concept 4 - No benefit can be gained by combining heat with reflective fabrics since it has been ascertained above (Concept 2) that auxiliary heat is needed only for the gloves and that stitching causes compression, thereby reducing the efficacy of reflective fabrics. Conventional fabrics can meet the insulation requirements for the remainder of the ensemble, although reflective fabrics may have value for parts of some items.
- Concept 5 - A microclimatic solution is unnecessary for a -15°F (-21.1°C) environment since conventional clothing is thermally adequate. If the microclimatic concept were employed, the lack of a suitable power source is as much a problem at this temperature as at the -60°F (-51.1°C) level, although the power requirement would be less. Also this solution most likely would be inadequate to protect under survival conditions.

To summarize, Concept 2 (Auxiliary Heated Items) is the preferred solution for the basic cold weather clothing system. The preferred concept which will extend the thermal protection of the basic ensemble to -60°F (-51.1°C) cannot be determined until feasible alternatives have been proposed.

Several ideas for meeting the -60°F (-51.1°C) requirement are suggested below and will need to be explored.

- 1) Concept 3 could be used to design a heated vest which requires lower power because reflective fabrics are included.
- 2) An additional parka could be worn over the basic ensemble or a down vest could be used to provide extra insulation.
- 3) The use of impermeable fabrics to retain heat should be explored. A local manufacturer has designed clothing which includes an impermeable layer for warmth near the skin. Under ambient conditions in which the suit is too warm, zippers can be used to control cooling.
- 4) Dr. Ralph Goldman, formerly of ARIEM, has proposed the use of a vest filled with warm water which would act like a hot water bottle to extend one's staying time in the cold. Heat would not be supplied continuously as in the microclimatic concept to avoid requiring a portable power source. Instead, the water would be heated in the ready room before the aircrew begins the preflight tasks and then could be reheated by the aircraft generator before the aircrew exited the aircraft following each mission. Since water has a specific heat approximately 1000 times greater than air, the warm water would extend one's staying time in the cold.

2. COST ESTIMATES

This section presents some rough cost estimates in order first to rank the proposed alternative concepts by cost, and second to determine the relative cost differences between them. Because numerous clothing systems incorporating different designs, materials, and technical approaches can be configured to represent a concept, the cost of clothing systems within a concept can vary substantially. This is particularly true of Concept 2, Auxiliary Heated Items, where the number of heated items and the type of power source employed can influence the cost by as much as a factor of two. The variables which affect the cost of sample clothing systems within each concept are considered in the subsections below.

Table 13 presents a cost summary of the examples discussed in the subsections which follow. When available, the actual cost of an item similar to one which could be included in a clothing system was used to derive the cost estimate of the total system. For example, the actual cost of the CVC system

TABLE 13. Cost Summary of Alternative Concepts

	UNIFORM ANNUAL COST
<u>Current Cold Weather Aircrew Clothing (Baseline)</u>	\$280 - \$380
<u>Concept 1 - Conventional Materials</u>	
Example - Combat Vehicle Crewman (CVC) System	\$600
<u>Concept 2 - Auxiliary Heated Items</u>	
Option a. CVC with heated gloves and insoles Dual power capability: battery power (non-standard) for 4 hours; aircraft generator	\$1150
Option b. CVC with heated gloves and insoles Battery power (standard) only for 3½ hours	\$825
Option c. CVC with heated gloves Dual power capability: battery power (standard) for 3½ hours; aircraft generator	\$850
Option d. CVC with heated gloves and insoles Battery power (standard) only for 1 hour	\$700
Option e. CVC with heated gloves Battery power (standard) only for 1 hour	\$625
Option f. CVC with heated gloves Dual power capability; battery power (standard) for 1 hour; aircraft generator	\$685
Option g. CVC with heated gloves and insoles Aircraft generator only	\$700
<u>Concept 3 - Reflective Fabrics</u>	
Various designs	\$350 - \$450
<u>Concept 4 - Reflective Fabrics and Auxiliary Heat</u>	
Options from Concept 2 constructed with reflective fabric	\$700 - \$1200
<u>Concept 5 - Microenvironmental</u>	
Microclimate conditioning system with battery powered gloves for 1 hour	\$1500

was used as the cost basis for several options. The procurement cost of developmental items had to be estimated. Cost ranges are not presented for each example because it was felt that the cost data available did not adequately bracket the range of design possibilities.

Unless otherwise noted, all cost estimates are given in FY81 dollars. Development costs of new items were assumed to be included in the funding for NRDC's R&D Program and therefore were treated as sunk costs.

Current Cold Weather Aircrew Clothing (Baseline)

The various baseline cold weather aircrew clothing configurations, excluding the helmet, goggles, underwear and other items which will not differ between alternatives, range in cost from \$250 to \$350 each. These configurations assume that each aircrewmember is issued one type of boot, one type of ensemble, and two types of gloves -- Nomex flight gloves and the leather shells with wool inserts. In Alaska, items from the arctic ensemble can be authorized by the Commander to supplement the aircrew clothing; these items increase the clothing cost per man by \$150 to \$200. However, these costs are not included in the estimated cost of the baseline system since arctic items are not issued to most aircrews in Clothing Allowance Zones V and VI.

The useful life of the various aircrew clothing items varies between 6 months and 18 months. If we assume a useful life of six months for the gloves and one year for the remaining items, the annualized cost of cold weather clothing per aircrewmember is between \$280 and \$380.

Concept 1 (Conventional Materials)

Among other factors, the cost of a conventional clothing ensemble is affected by the fabric, its durability, the number of items, and the innovation in the design. Since the new CVC uniform (excluding the gloves and boots) is an example of an existing clothing system which could be modified to meet the needs of the majority of the aircrews, its cost will be used as an estimate for Concept 1.

The procurement cost of the cold weather CVC clothing system, excluding the helmet, goggles, and body armor is \$570. This configuration includes the overall, the coverall liner, the coverall, the face mask, the balaclava, the cold weather jacket, the cold weather gloves, the insulated boot, and the overboot. If it is assumed that the life expectancy of this uniform is similar to that of the current aircrew uniform, the annualized cost of this uniform per man is about \$600.

The CVC clothing items are fabricated from various Nomex materials. The Nomex fabric used for the jacket is a spun Nomex which costs about \$12 per yard; comparable fabrics without the flame resistant quality are one-third to one-half as expensive. Other high-temperature resistant fabrics could be used to fabricate the new aircrew clothing system. Filament Nomex, used in Air Force jackets, costs about \$14 per yard. PBI, a fabric which provides better fire protection than Nomex, and hence may cost more, is being developed by a commercial firm.

Concept 2 (Auxiliary Heated Items)

The cost of an ensemble representative of Concept 2 will be affected by such factors as the number of auxiliary heated items included in the final design, the technology used and the power source(s) employed. The procurement cost for the CVC uniform quoted above can be used as the cost basis. For various combinations, the CVC cost can be adjusted by substituting the cost of the heated item or items for the cost included in the CVC total for similar unheated items.

Auxiliary heated gloves are estimated to cost between \$75 and \$125 per pair without batteries.* These estimates do not include thermostatic control which will increase the cost of the item. The battery pack, power cords, connectors, etc. are estimated to cost several hundred dollars for four hours of capacity and proportionally less for fewer hours.** A second battery pack and a recharger are necessary. The cost of portable battery power (non-standard battery pack) to heat both hands and feet for four hours under the most extreme cold is estimated in Appendix G in this report to be about \$450 per year per man. Heated insoles to warm feet are being commercially marketed with self-contained battery packs for about \$100 per pair retail. Electric vests for motorcyclists which operate off the battery of the motorcycle are available for \$70 without thermostatic control and \$90 with a thermostat.***

If the heated items for an aircrew are to operate off the aircraft generator, most aircraft will need to be modified. The cost of this operation would vary between aircraft, but on an average it could cost several thousand dollars per plane. One modification will serve items for several aircrew-

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- *Sources: (1) Draft Letter of Agreement (LOA) for Heated Handwear, 1979.
(2) Phone conversation (10/12/81) with Eric Giese, Comfort Products, Inc., Aspen, Colorado.
(3) Widder Enterprises, Oxnard, California.

- **Sources: (1) Draft Letter of Agreement (LOA) for Heated Handwear, 1979.
(2) Electronics R&D Command, Ft. Monmouth, NJ.

- ***Source: Widder Enterprises, Oxnard, California.

members and will have a useful life equal to that of the aircraft. Since this expense will be incurred whether one or more than one clothing item is heated, economies of scale result from adding more than one auxiliary heated item to the clothing ensemble.

No data were available on the useful life of auxiliary heated items, and therefore the following assumptions concerning the useful life were made for this analysis: one year for the outer glove shell, two years for the glove heating elements, one year for the insole, and six years for the rechargeable battery pack. Cost analysts assign a useful life of 17 years to rotary aircraft.

Using these assumptions, the uniform annual cost for auxiliary heated gloves and insoles with a capability of operating off portable batteries or the aircraft generator is around \$625 per man. The cost of the CVC cold weather glove is about \$38 per pair and the useful life is six months, which implies an annual cost of \$76 per man. If the cost of the auxiliary heated gloves and insoles were substituted for the cost of the CVC gloves in the CVC ensemble, the total ensemble cost would be about \$1150 (see Table 13 - Option a.).

The sample design costed above includes heating both hands and feet through dual power sources. This is the most expensive option. If only the hands were heated or if only one power source were employed or if the battery pack supplied only one hour of power, the cost would be lower. The use of commercial battery chargers would also lower the cost.

If we start with different assumptions, for example, that two standard six volt Army battery packs BB-541/U are used to supply 3½ hours of power, and that a charger can be purchased commercially for \$300 which will charge two batteries at a time and have a useful life of three years, the uniform annual costs quoted above could be reduced from \$625 (heated items and power sources) to \$300 and from \$1150 (total ensemble) to \$825 (see Table 13 - Option b.). In this option, the aircraft modification costs were omitted and power was assumed to be supplied only through portable batteries. A large portion of the cost savings results from the use of the Army battery pack BB-541/U. It is a standard battery which is available as a stocked item, whereas the battery described in the previous option was a non-standard battery. If the standard battery pack were combined with power from the aircraft generator to heat only gloves, the uniform annual cost would be about \$850 (see Table 13 - Option c.).

The most costly components in the above options are the portable batteries and charger. If heat were supplied for only one hour instead of 3½ hours, fewer batteries and charging terminals would be needed and the uniform annual cost for battery powered gloves and insoles could be lowered to \$700 (see Table 13 - Option d.). If only the gloves were heated, the total cost of the one hour battery option would be \$625 (see Table 13 - Option e.). Another choice is to heat the gloves by battery for one hour during the preflight tasks and then supply power while in the aircraft through the generator. The total cost for this option is \$685 (see Table 13 - Option f.).

Another alternative is to supply heat to the hands and feet in the aircraft only. This option eliminates the high cost of the batteries and the charger as well as the logistical costs of supplying the batteries and the operational costs of recharging them. The uniform annual cost of the heated gloves and insoles and the aircraft modifications would be about \$175 per man and the annualized cost of the total ensemble would be \$700 (see Table 13 - Option g.).

Concept 3 (Reflective Fabrics)

The cost of an ensemble fabricated partially with reflective fabrics would be similar to but somewhat higher than the cost of a conventional ensemble. The amount of the increase would be a function of the type of fabric used and the extent of its use. The uniform annual cost is estimated to be \$350 to \$450.

Concept 4 (Reflective Fabrics and Auxiliary Heat)

The cost will vary with the design. Since Concept 4 designs include elements of Concepts 2 and 3, the cost of Concept 4 designs can be estimated from costs already discussed. Combining the costs of the options in Concept 2 with those in Concept 3 yields a range of \$700 to \$1200.

Concept 5 (Microenvironmental)

The investment cost for a microclimatic conditioning system has been estimated to be \$8000.⁵⁵ This cost includes vests for four individuals and the heating/cooling unit to serve those vests. Of this amount, the clothing is estimated to cost about \$300 per vest and the hardware will consume the remainder (\$6800). The cost of modifying the aircraft to accommodate the hardware has not been estimated, but we will assume a cost of \$4000. This configuration of the system does not include a provision for supplying power to the aircrews while outside the vehicle. The cost of the basic clothing and the cost of auxiliary heated handwear or footwear will need to be added to the cost of the microclimatic conditioning system.

To estimate the cost of the microclimatic system, a useful life of one year was assumed for the vest and five years for the hardware. Using these estimates and the procurement cost figures given above, the uniform annual cost of the microclimatic system was estimated to be about \$750 per man. The aircraft modifications would cost about \$125 per man per year. Since the microclimatic system does not supply heat for the preflight tasks, Option c. of Concept 2 (see Table 13) which includes auxiliary heated gloves, battery powered for one hour, was chosen as the basic clothing system to be worn with the microclimatic conditioning system. The total costs of the microclimatic vest, the power unit, the aircraft modifications, and the basic clothing, results in an estimate in the neighborhood of \$1500.

In summary, the costs of all concepts except the third are substantially higher than the baseline cost. The microclimatic conditioning system is the most costly of the five alternative concepts. However, as discussed in other chapters of this report, it is not a feasible alternative for aircrew at this point in its development. The system identified in the Executive Precipis as the preferred concept for the cold and intermediate cold regions is a design using conventional layered clothing supplemented with auxiliary heated gloves. This concept not only is technically feasible, but as shown in Table 13, battery power to heat gloves for one hour (Concept 2 - Option e.) can be supplied for a small additional charge (\$25) relative to the cost of a new conventional layered system (Concept 1). Dual power (Concept 2 - Option f.) can be added for \$85 and total coverage throughout the day (Concept 2 - Option c.) can be made available for an additional \$250.

This document reports research undertaken at the US Army Natick Research and Development Command and has been assigned No. NATICK/TR 84/045 in the series of reports approved for publication.

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APPENDIXES

- A. CLIMATE INFORMATION
- B. ARMY AIRCRAFT
- C. MODELING
- D. AUXILIARY HEATED CLOTHING
- E. COLD INJURY
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Appendix A

CLIMATIC INFORMATION

1. Military Regulations and Climatic Classification Systems

2. Temperature Data for Selected Cold Regions

United States
Scandinavia
Korea

3. Alaskan Winter Climate

Four Climatic Zones
Site Data

1. MILITARY REGULATIONS AND CLIMATIC CLASSIFICATION SYSTEMS

Several classification systems and military regulations have been developed to establish uniform climatic criteria for use in materiel development and distribution. Three frequently referenced classification schemes are identified below.

Army Regulation AR 70-38 provides planning guidance for research, development, test and evaluation of materiel to be used in extreme climatic conditions.¹⁶ It covers most items of materiel developed for use in combat by the Army, but it excludes clothing. Eight climatic categories established by international agreements (QSTAG 360 and STANAG 2831) are grouped in AR 70-38 into four climatic design types. These four design types, which are primarily based on temperature, are labeled: hot, basic, cold and severe cold.

MIL-STD-210B is a Department of Defense standard which provides sets of extreme climatic design conditions under which military materiel may be required to operate.³² One difference between this standard and AR 70-38 is that MIL-STD-210B applies only to materiel developed for worldwide use. Both policies incorporate design values which accept a small risk of failure. AR 70-38 was adopted partially because items not intended for worldwide use can usually be designed according to less stringent climatic criteria.

The Common Table of Allowances (CTA 50-900) prescribes clothing allowances for Army personnel in accordance with various Army regulations.³³ For clothing purposes, the world has been divided into seven Clothing Allowance Zones. These zones, identified in Table A-1, were designated primarily on the average temperature of the coldest and warmest months. Their geographic extent is shown in the map in Figure A-1.

Since individual countries are not outlined on the Clothing Allowance Zone map (Figure A-1), the major territories included in the three zones of interest for this analysis are listed below.

Zone V

United States - Northern two-thirds of lower states

Canada - southern part of Ontario, Quebec and New Brunswick

Europe and Asia - Balkan States, Turkey, Southern USSR, central China, western Korea, northern Japan and parts of India

Zone VI

Canada - Newfoundland, Nova Scotia, Prince Edward Island, Magdalen Islands, Vancouver Island, coastal regions of British Columbia

TABLE A-1. Ranges of Average Monthly Temperatures, Coldest Month and Warmest Month for Clothing Allowance Zones

<u>Zone</u>	<u>Description</u>	<u>Coldest Month</u>	<u>Warmest Month</u>
I	Warm or hot all year	above 68°F (20°C)	above 68°F (20°C)
II	Warm or hot summers, mild winters	50-60°F (10-15.6°C)	above 68°F (20°C)
III	Warm or hot summers, cool winters	32-50°F (0-10°C)	above 68°F (20°C)
IV	Mild summers, cool winters	32-50°F (0-10°C)	50-68°F (10-15.6°C)
V	Warm or hot summers, cold or very cold winters	below 32°F (0°C)	above 68°F (20°C)
VI	Mild summers, cold winters	14-32°F (-10-0°C)	50-68°F (10-15.6°C)
VII	Mild summers, very cold winters	below 14°F (-10°C)	below 68°F (20°C)

Source: Reference 33

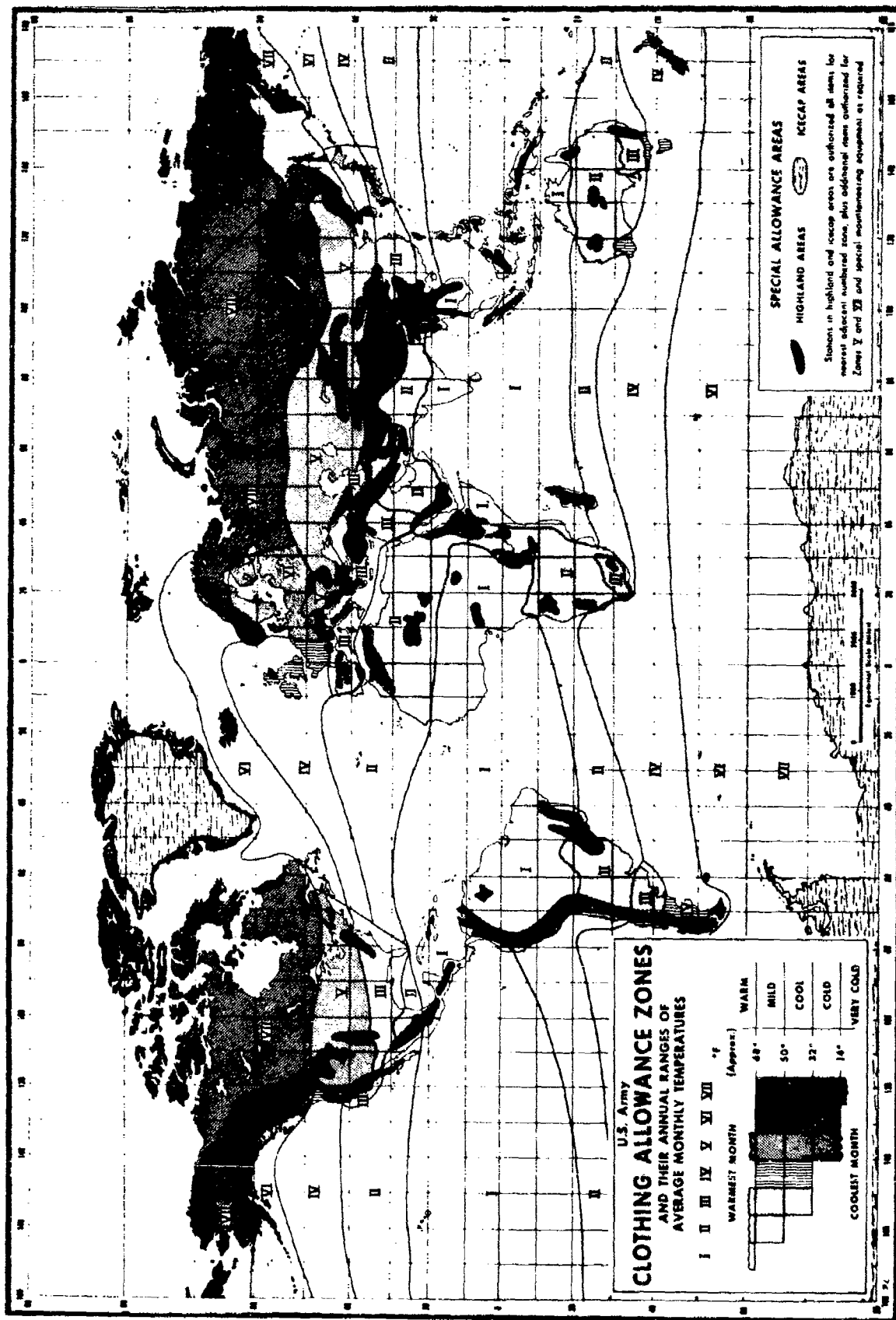


Figure A-1. US Army Clothing Allowance Zone map.

United States - north and south coastal regions of Alaska, Aleutian Islands

Europe - Germany, Denmark, Luxembourg, Switzerland, Liechtenstein and portions of Norway, Sweden, Finland, Austria, France, Belgium and the Netherlands

USSR - western part

Zone VII

United States - central Alaska, northern portions of Minnesota, North Dakota, Montana and Maine

Canada - central, generally north of latitude 47°N

Europe - northern Sweden and Finland

USSR - central and eastern

China - northern

Korea - northeastern coastal regions

Greenland

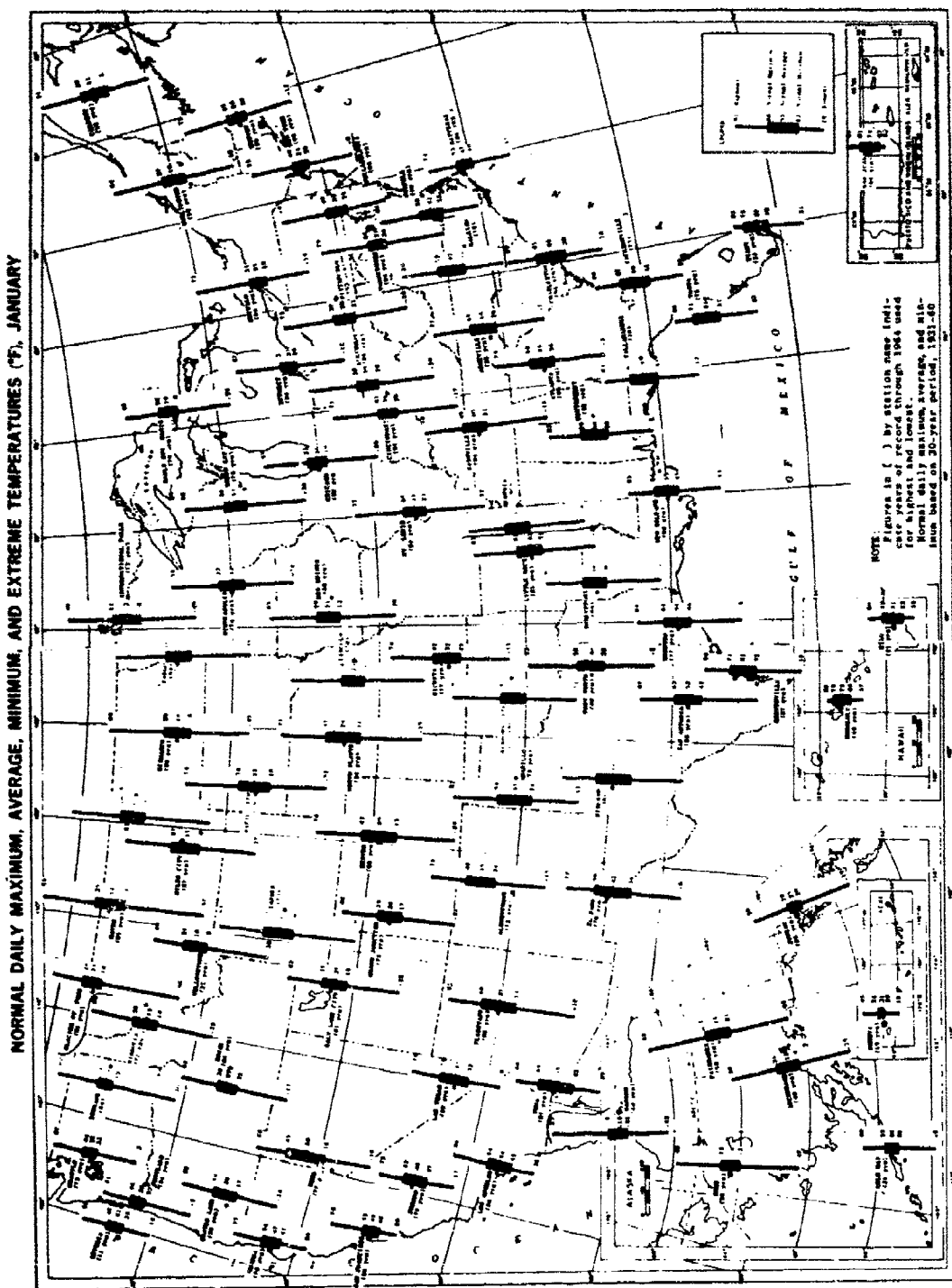
Arctic - north of Arctic Circle

Antarctica

2. TEMPERATURE DATA FOR SELECTED COLD REGIONS

United States

Figure A-2 displays January temperature data for numerous locations throughout the continental United States and Alaska. For each site, five statistics are given: normal daily maximum temperature, average temperature, minimum temperature, and the maximum and minimum extremes. The first three statistics represent the value of that particular element averaged over many years. The actual number of years used to derive the statistics is indicated at each site. Only one displayed site for the continental United States has a daily average minimum temperature below 0°F (-17.8°C). The site is in Minnesota near the Canadian border. Several other sites in the northern states have daily minimums near 0°F (-17.8°C). In contrast, Fairbanks Alaska has a daily minimum of -21°F (-29°C).



Source: Reference 34

Figure A-2. Temperature data for the United States - January (of).

The absolute minimum temperatures reached at various locations are useful for planning since they establish a reasonable lower bound. The data in Figure A-2 include this information for each labeled site in the United States. However, the information is more effectively displayed by the isotherms drawn on the map of the United States in Figure A-3. The second half of Figure A-3 displays similar data for the eastern hemisphere.

Scandinavia

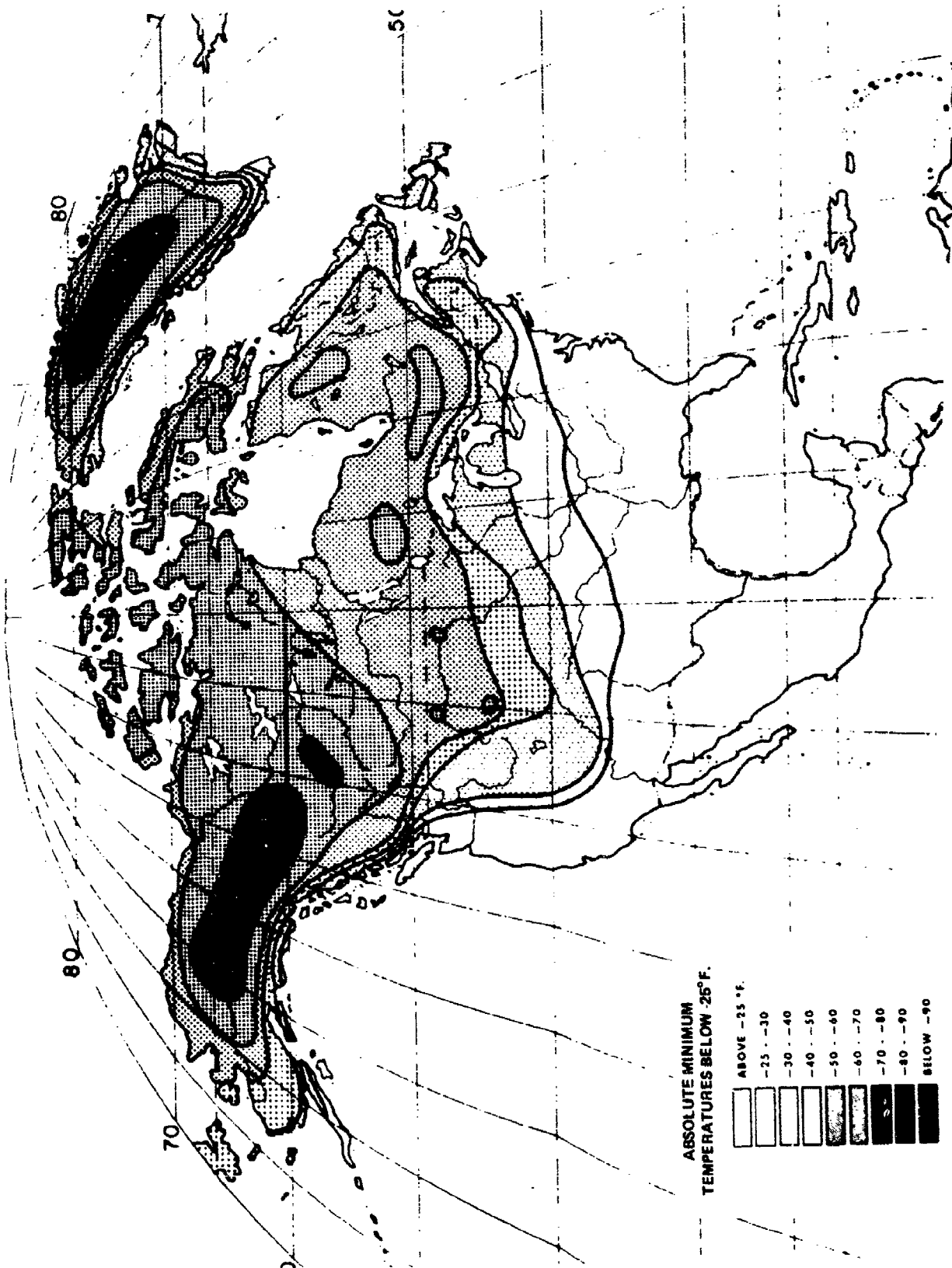
Figure A-4 displays the mean maximum, mean, and mean minimum January temperatures for several locations in Scandinavia. The statistics for Bergen, located in southern Norway, are similar to those for New York City. The temperatures in northern Norway are much warmer than would be expected for a latitude above the Arctic Circle. Locations on the western coast have remarkably high temperatures in winter because of the Gulf Stream and the prevailing westerly winds. For example, Tromso which is above the Arctic Circle has January temperatures comparable to Chicago, Illinois. The climate in northeastern sections of Norway is much colder (similar to northern Minnesota), but is considerably warmer than a typical arctic climate. The minimum temperature experienced in Karasjok, Norway during the 30-year period preceding 1960 was -60°F (-21.1°C). However, Scandinavia's location in a semipermanent trough of low pressure, the unequal heating of land masses, and the adjacent seas create monsoonlike circulation. In the winter, north of the Arctic Circle the winds frequently exceed gale force and produce severe squalls.

Korea

Central Korea is located some 35 degrees of latitude further south than central Scandinavia, yet the winter climates of the two regions are remarkably similar. Temperatures vary greatly between the southern coast of Korea, where the mean minimum is around 32°F (-1.1°C) in January, and the northern Chinese border where the minimum mean reaches -20°F (-28.9°C). Korea's cold winters are a result of its position downward from the intense cold of the Siberian land mass. The high pressure area over cold Siberia creates northwesterly winds referred to as the northwest monsoons. They average 6-12 knots during winter months and gusts from 45-50 knots are common.

3. ALASKAN WINTER CLIMATE

Alaska is perceived as a cold region, but in actuality, the climatic range in Alaska is greater than that between Florida and Maine.³⁶ Military clothing for Alaska must provide for the most severe conditions, because distances between different climatic regions are short and missions which begin in one region often extend into another.



Source: Reference 16

Figure A-3. Absolute minimum temperatures below -25°F.

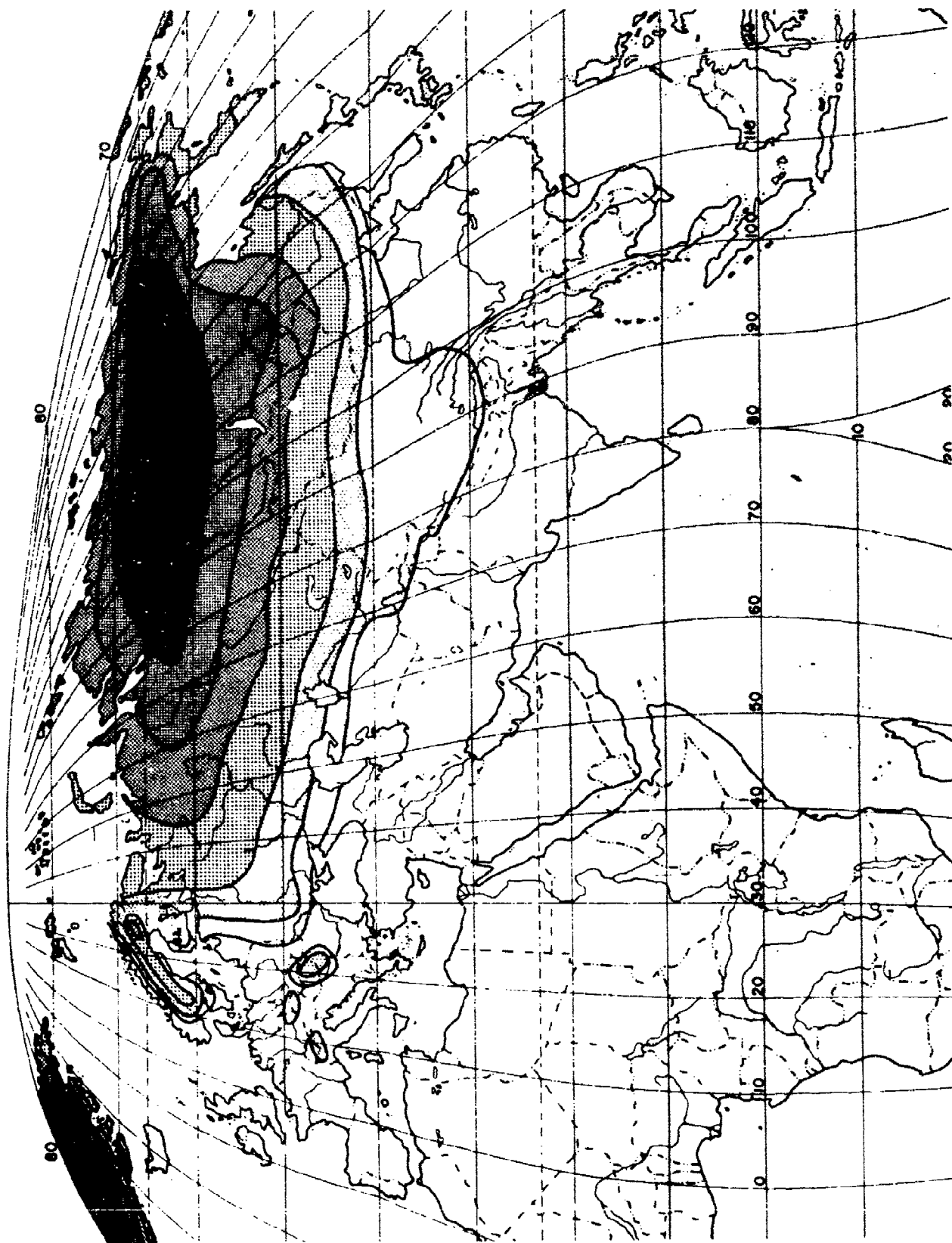
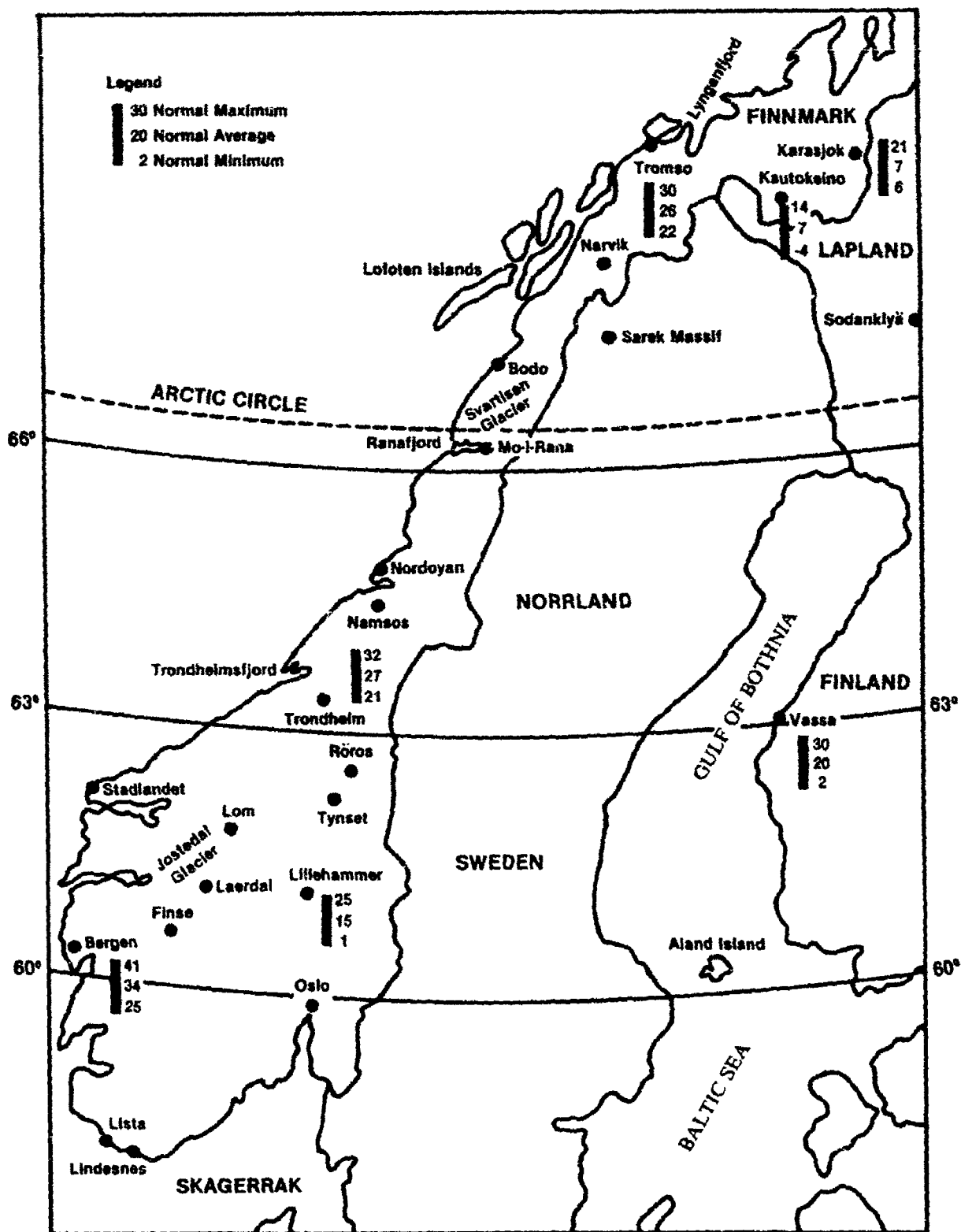


Figure A-3 (Cont'd). Absolute minimum temperatures below -25°F.



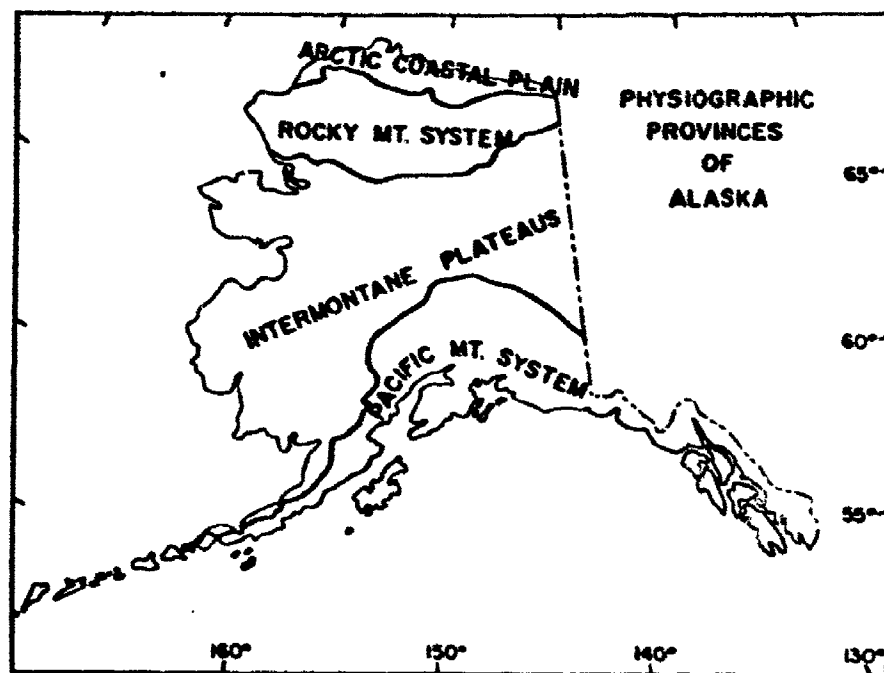
Source: Reference 35

Figure A-4. Temperature data for Scandinavia - January (°F).

Due to Alaska's location near and within the Arctic Circle, summer days are long and winter days are short. At the higher latitudes, short winter days reduce the variation in temperature between night and day since the amount of solar heat received by an area is limited. In Alaska from November to March, the daylight hours range from 10 hours to less than 4 hours. Permafrost, either continuous or discontinuous, is present throughout most of the state.

Four Climatic Zones

Four major climatic zones have been defined for Alaska (Figure A-5). The maritime zone is characterized by small temperature variations, much cloudiness, and abundant precipitation. There is no permafrost, but extensive glaciers emanate from the Pacific mountain system parallel to the coast. This system is composed of several mountain ranges and extends south through British Columbia. The mean temperatures in Alaska on the coast are warmer than in the state's other three zones. Both Anchorage and Juneau are located in the maritime zone. In Anchorage, snow occurs on 20 to 25 percent of the midwinter days, but most of the snow falls in relatively small daily amounts and only two percent of the days have more than four inches. Clear cold weather is frequently accompanied by three and four day periods of fog, caused by the presence of open water.



Source: Reference 36

Figure A-5. Climatic zones of Alaska.

The central continental zone, which comprises half of the state, consists mostly of gently rolling hills and broad basins with extensive major river systems. The mountain ranges which surround this zone prevent inland movement of air and have created a semi-arid region. This area has great temperature extremes which range from around -60°F (-51°C) in the winter to above 90°F (32°C) in the summer. The persistent snow cover during the winter months contributes to the development of the extreme cold, since the white surface prevents the absorption of heat from the limited amount of sunshine received during the short winter days. Ice fog conditions frequently occur during extremely low temperature conditions and tend to persist for periods of a few days to one or two weeks. Fairbanks is located in the center of this zone.

As would be expected, the northernmost or Arctic coastal climatic zone has the most severe climate of any region in Alaska. The winters are very cold, but snowfall is light. Strong winds associated with winter storms create an uneven snow cover which is thin enough to permit great cooling of the ground. The area is characterized by continuous permafrost.

Site Data

Climatological data for two Army bases in Alaska are presented in Table A-2. Ft. Richardson is located near Anchorage and Ft. Wainwright is situated near Fairbanks. The variation in climate between the various regions in Alaska can be seen by comparing the average daily temperatures of these two bases and several other sites. Juneau in the south has an average daily temperature in January of 25°F (-4°C) (average maximum 30°F (-1°C) and average minimum 20°F (-7°C)). These data are similar to those for Buffalo or Detroit. In contrast, the average daily temperatures for Ft. Richardson, Ft. Wainwright and Barrow (site of National Guard Post) are +12°F (-11°C), -10°F (-23°C), and -16° (-27°C), respectively.

TABLE A-2. Climatological Data for Army Posts in Alaska

	<u>Ft. Richardson</u>						<u>Ft. Wainwright</u>					
	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>
Temperature (°F)												
extreme maximum	63°	54°	53°	49°	58°	51°	62°	48°	42°	43°	48°	52°
average maximum	41°	27°	19°	20°	26°	32°	35°	12°	-2°	-1°	6°	23°
average	35°	20°	13°	12°	18°	23°	28°	4°	-9°	-10°	-5°	11°
average minimum	28°	14°	6°	5°	10°	14°	-20°	-4°	-16°	-19°	-16°	-2°
extreme minimum	-6°	-20°	-34°	-36°	-43°	-24°	-16°	-43°	-56°	-62°	-56°	-52°
Precipitation (inches)												
avg. precipitation	1.6	1.3	1.4	1.2	0.9	1.0	0.9	0.6	0.8	1.0	0.8	0.5
avg. snow	7.2	12.9	13.2	12.0	9.3	8.9	7.9	6.2	7.9	10.5	8.2	5.2
Surface winds (mph)												
prevailing direction	N	N	N	N	N	N	ENE	ENE	ENE	E	ENE	ENE
average speed	4	4	4	4	5	5	5	3	2	2	3	4
extreme speed	72	81	64	66	70	54	53	40	34	30	35	42

Source: Reference 37

Appendix B

ARMY AIRCRAFT

1. Description of Army Aircraft

- UH-1 (Huey)
- UH-60 (Black Hawk)
- AH-1 (Cobra)
- AH-64 (Apache)
- OH-58 (Kiowa), OH-6A (Cayuse) and Near Term Scout Helicopter
- CH-47 (Chinook) and CH-54 (Tarhe)
- OV-1 (Mohawk)

2. Tables of Aircraft/Aircrew Data

3. Technical Characteristics of the Aircraft

- Power
- Weight and Space
- Heater Efficiency

1. DESCRIPTION OF ARMY AIRCRAFT*

UH-1 (Huey)

The UH-1 is a utility helicopter whose main function is to carry troops, supplies and equipment. The original Huey was introduced to the US Army in 1959, and although it is in widespread use today (nearly 4000 Hueys are in US service), it is being phased out by the UH-60 (Black Hawk), a new transport helicopter with greater capacity and capabilities. The Black Hawk is now in full production. During the Vietnam War, kits were developed to mount weapons on several models of the UH-1. For example, the UH-1B gunship was equipped with mini-guns, a 40 mm grenade launcher, and rockets. The pilot fired the rockets while the copilot used a ceiling-mounted sight for firing the mini-



Figure B-1. UH-1 (Huey) helicopter.

*Sources of Information:

Ludvigsen, Eric C. "Army Weaponry", Army 1980-81 Green Book, Vol 30, p. 227-288, October 1980.

Communications with US Army Aviation Center, Fort Rucker, AL, July-Aug, 1981.

guns and the 40 mm weapons. The machine guns were operated by a door gunner and the crew chief who sat in the jump seats in the rear of the cargo area in front of the right and left open doors. In the temperate Vietnam climate, the open door arrangement was feasible. However, if a similar capability is ever required in cold weather conditions, the downwash of the rotor and the forward air speed would create serious windchill effects for the door gunners. The open doors would also greatly lower the temperature of the cockpit area.

UH-60 (Black Hawk)

The Black Hawk (UH-60A) is a twin engine, rotary wing aircraft which will carry 11 combat-equipped troops and a crew of three. Its primary mission is to transport troops and supplies over the battlefield. Other missions include aerial medical evacuation (MEDEVAC), combat service support, aerial mine dispensing, and combat support operations. In combat support, 15 Black Hawks can do the work of 23 UH-1s. For example, in one hour and twenty minutes, the UH-60 can make eight trips (16 km) into a hostile landing zone to put 88 persons on the ground, whereas the UH-1 in the same time can make only five trips and deliver a total of 35 troops. Under this mission scenario in a cold climate, the temperature inside the aircraft would be close to the ambient



Figure B-2. UH-60 (Black Hawk) helicopter.

temperature, since the doors would be reopened every five minutes to on or off load troops.

The UH-60 has an external cargo hook rated at 8000 pounds load capacity and provisions for an internal rescue hoist. The Black Hawk has the following performance capabilities: 450 vertical rate of climb, 2.3 hours endurance, cruise airspeed of 145 kts, 16,260 pound mission gross weight and it is designed to operate over 86% of the earth's landmass (4000'/95°F). This aircraft is the first helicopter designed, developed, and produced to Army specifications which have evolved over years of helicopter utilization and combat experiences. It is the beginning of a new generation of Army aircraft.

AH-1 (Cobra)

The AH-1 is a single-engine attack helicopter which was first produced in 1966. By the early 1970's the need for an air-to-ground antitank capability redirected the original emphasis of the helicopter and resulted in an AH-1 fleet that is made up of five different models. The five models reflect the incremental funding and the urgent need for fielded antitank helicopters. The current AH-1 is capable of firing the TOW missile, but artificial illumination must be used to fire the missile at night. Second generation night vision goggles provide limited ability to fly at night, but at this time the Cobra is considered a fair weather/day fighter.



Figure B-3. AH-1 (Cobra) helicopter.

AH-64 (Apache)

The AH-64 (Apache) is the Army's first full scale development attack helicopter. The performance capabilities of the AH-64 far exceed those of currently fielded attack helicopters. In particular, the twin engine, four-bladed AH-64 has the capability of "flight and fight in battlefield obscurants and at night." The target acquisition display sight/pilot night vision sensor (TADS/PNVS) are systems which enable the pilot and copilot/gunner to employ the AH-64 during limited visibility. The TADS incorporates direct view optics, silicon TV, and forward looking infrared sensors. The PNVS provides flight information on the pilot's and copilot/gunner's helmet displays.

OH-58 (Kiowa), OH-6A (Cayuse) and Near Term Scout Helicopter

The OH-6A, the Army's first light observation helicopter, was purchased between 1963 and 1970 and then was replaced by the introduction of the OH-58. (The OH-6A is now mainly used by the Army National Guard.) The main function of both aircraft is to locate targets and work in conjunction with the attack helicopters in combat aviation. Observation aircraft serve as the "eyes and ears" of the commander and hence are nicknamed scouts. Various combinations of light armaments can be carried in externally mounted pods on both helicopters.



Figure B-4. AH-64 (Apache) helicopter.

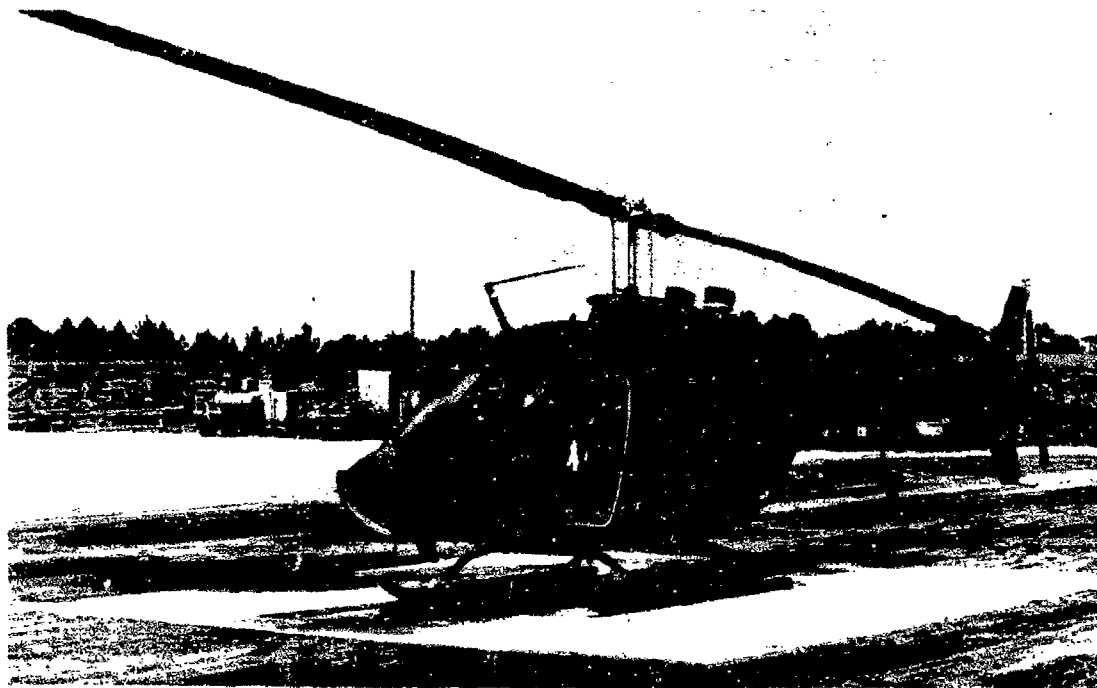


Figure B-5. OH-58 (Kiowa) helicopter.



Figure B-6. OH-6A (Cayuse) helicopter.

The Advanced Scout Helicopter was in the early development stage when funding was terminated in 1979. It was being designed to provide all-weather, day-night command, control, reconnaissance and surveillance capabilities for the AH-64. Subsequently, the Army was directed to use a currently existing airframe to provide the needed capabilities. In September 1981, as part of the Army Helicopter Improvement Program (AHIP), a contract was awarded to Bell Helicopter to convert 57 OH-58As to Near Term Scout Helicopters. The Near Term Scout Helicopter will include a combat support target acquisition/designation system which will operate day and night and in periods of reduced visibility. The contract also requires modifications which will improve the communication and navigation capabilities and provide hover capabilities under most weather conditions for worldwide deployment.

CH-47 (Chinook) and CH-54 (Tarhe)

The Ch-47 is a medium-lift transport helicopter which carries bulky equipment and other cargo both externally and internally. It also carries troops. The CH-47 can transport up to 10 tons as a sling load and has a maximum useful load of 24,414 pounds.



Figure B-7. CH-47 (Chinook) helicopter.

The CH-54 is a heavy-lift helicopter which carries its cargo externally in sling loads or in specially designed pods. Although it was used extensively in Vietnam to recover downed aircraft, it has been phased out of use by the Army and is now mainly used by the Army National Guard.



Figure B-8. CH-54 (Tarhe) helicopter.

OV-1 (Mohawk)

The OV-1 is a reconnaissance/surveillance aircraft and is the main combat fixed-wing plane in the Army inventory. Depending on the model, the aircraft is fitted with side-looking airborne radar, infrared sensors and/or aerial cameras. The OV-1 is the only Army aircraft with an ejection seat; the parachute and survival kit are propelled out of the aircraft with the pilot in the event of an emergency. The descent in cold weather presents special clothing protection requirements due to exposure to extreme environmental conditions. The wind chill factor prohibits any exposed flesh.



Figure B-9. OV-1 (Mohawk) aircraft.

2. TABLES OF AIRCRAFT/AIRCREW DATA

The Army and Navy/Marine Corps aircraft which operate in cold regions are shown in Table B-1, classified by series and military service. These are the aircraft for which the new aircrew cold weather clothing system is being designed. Table B-2 lists the usual crew for each Army aircraft and Table B-3 presents the location of Army National Guard aircraft and aircrew by state.

TABLE B-1. Rotary and Fixed-Wing Aircraft

<u>Helicopters</u>			
	<u>Army</u>	<u>National Guard</u>	<u>Navy/ Marine</u>
Attack Series	AH-1	UH-1C/M	AH-1J
	AH-64	AH-1	AH-1T
Observation Series	OH-58	OH-6A	
Utility Series	UH-1	UH-1	UH-1N
	UH-60		
Cargo Series	CH-47	CH-54	CH-46
	CH-47D		CH-53

<u>Fixed Wing Aircraft</u>			
	<u>Army</u>	<u>National Guard</u>	<u>Navy/ Marine</u>
VTOL and STOL Series	OV-1		
	RV-1		
Utility Series	U-21	UV-18	
	UV-18		
Cargo Series	C-12		
Reconnaissance Series	RC-12		
	RU-21		
High Altitude			A-4, A-6, A-7, EA-6, F-4, F-14, F-18

TABLE B-2. Army Aircraft Crewmembers

<u>Model</u>	<u>Popular Name</u>	<u>Normal Crew</u>
AH-1	Cobra	pilot, copilot/gunner
AH-64	Apache	pilot, copilot/gunner
OH-6A	Cayuse	pilot, observer
OH-58	Kiowa	pilot, observer
UH-1	Huey	pilot, copilot
UH-60	Black Hawk	pilot, copilot, crew chief
CH-47	Chinook	pilot, copilot, crew chief, loadmaster
CH-54	Tarhe	Same as CH-47
OV-1	Mohawk	pilot, operator
RV-1		pilot, IR operator
U-21	UTE	pilot, copilot
UV-18		pilot, radar operator
RU-21		pilot, copilot, 2 operators
RC-12		pilot, observer
C-12		pilot, other

TABLE B-3. Army National Guard Aircraft and Aircrew Distribution Data*

<u>NUMBER</u>	<u>FACILITY LOCATION</u>	<u>WING</u>	<u>WING</u>	<u>AVIATORS</u>	<u>OTHER CREWMEMBERS</u>
1	Spokane WA	20	1	36	30
2	Boise ID	43	1	79	64
3	Reno NV	14	1	35	32
4	Helena MT	42	1	75	66
5	Salt Lake City UT	48	1	77	57
6	Phoenix AZ	41	1	96	81
7	Santa Fe NM	10	1	25	20
8	Denver CO	39	1	74	64
9	Cheyenne WY	15	1	23	34
10	Bismarck, ND	16	1	30	23
11	Rapid City SD	16	2	35	36
12	Lincoln NE	34	2	76	88
13	Topeka KS)	26	1	63	59
14	Tulsa OK)				
15	Lexington OK	50	2	105	67
16	St. Paul MN	37	2	77	60
17	Waterloo IA)				
18	Boone IA)	59	1	128	112
19	Davenport IA)				
20	Whiteman MO)				
21	Jefferson City MO)	62	4	147	178
22	Springfield MO)				
23	Madison WI)				
24	West Bend WI)	44	1	83	57

25	Chicago IL)				
26	Decatur IL)	48	1	91	55
27	Grand Ledge MI	63	1	121	91
28	Shelbyville IN	49	2	92	68
29	Frankfort KY	37	1	78	88
30	Greensboro OH)				
31	Worthington OH)	96	2	186	175
32	Parkersburg WV	20	1	41	38
33	Washington PA)				
34	Annaville PA)	118	2	244	189
35	West Trenton NJ)				
36	Dover NJ)	59	2	112	89
37	Ronkonkoma NY)				
38	Albany NY)	116	2	217	156
39	Niagra Falls NY)				
40	Windsor Locks CT)				
41	Groton CT)	41	6	102	83
42	Davisville RI	28	1	50	46
43	Camp Edwards MA)				
44	Westover AFB MA)	48	2	95	73
45	Concord NH	14	1	26	23
46	Burlington VT	16	1	27	20
47	Bangor ME	33	1	69	77
48	Anchorage AK	30	4	90	52
	TOTALS	1432	55	2815	2451

*Source: Army Aviation Division of the National Guard Bureau.

3. TECHNICAL CHARACTERISTICS OF THE AIRCRAFT*

Power

All Army aircraft have 28 volt dc generators which could be utilized to power heated clothing provided the demand does not exceed the available excess capacity. (Some aircraft also have ac generators). As discussed in Chapter IV, the power requirements for heated clothing have not yet been specified for cockpit temperatures, but we can assume they will be less than the power requirements for outdoor tasks in cold ambient temperatures. The total power requirements per crewmember will depend on the number of heated clothing items and the design of the equipment. Therefore, the power requirements could range from less than 20 watts per hour (to heat just two extremities) to over 600 watts per hour (for a microclimatic system). At 40 watts per crewmember, the total power demand on a 28 volt generator for a 2 to 4 member crew would only be 3 to 6 AMPS. This minimal demand could easily be met on all aircraft.

On the other hand, demands as high as 600 watts per crewmember would be problematic for most aircraft. Numerous systems on board aircraft including instrumentation, weapon systems, communications systems, hoists, de-icers, etc., rely on the aircraft generator for power. These power demands fluctuate over the course of a mission. The worst case scenario would need to be examined to establish the amount of excess power. This exercise was not completed for this study, but discussions with systems engineers for the various aircraft revealed the following information:

The UH-60 has two 45 KVA (kilovolt amps) generators. Adequate excess power exists for heating clothing. A dc utility receptacle is located overhead in the center of the aft cabin.

The AH-1 has a 300 amp generator. A clothing system which drew less than 10% of this current could be readily accommodated. One that drew more current may also be acceptable, but a load analysis would need to be undertaken to verify the level.

The OH-58 has a 150 amp generator and one receptacle located overhead. A load analysis would need to be conducted to determine excess power, but probably 10% would be available at a minimum.

The CH-47 has two 40 KVA generators. One serves as a back-up for the other. It has at least one dc receptacle.

The systems engineers recommended that any electrically heated clothing which will be plugged into the aircraft be designed to operate off 28 volts rather than 6 or 12 volts, because the lower voltage would require that a converter be included in the system to step down the voltage. The use of a con-

*The information in this section was obtained from discussions with systems engineers at AVRADCOM - St. Louis, MO.

verter implies less efficiency since some power is lost in the conversion. It also increases the cost of the system, adds to the weight of the load, and consumes valuable space in the cockpit.

Weight and Space

The weight added to a helicopter by a new system is a critical concern for all aircraft. Ideally, a new system should be designed to be as light as possible. The AH-1 and the AH-64 are already at or above gross weight. For these aircraft, any additional weight will need to be balanced by a reduction in fuel or ammunition. The utility and cargo planes have greater flexibility since they are designed to carry heavy loads.

The microclimatic conditioning system which circulates water requires a central heating/cooling unit which both adds weight to the aircraft and consumes space. The central unit of the current prototype weighs 30-40 pounds.

Cockpit/cabin space available for storage of additional survival items or heating units is extremely limited on most aircraft. The exceptions are the cargo and utility helicopters which by design have ample space in order to accomplish their mission. The AH-1 and the OH-58 have such tight cockpits that there is no room for basic survival equipment. Pilots currently store it in the ammunition bay on the AH-1 and in the passenger area on the OH-58.

One potential problem which could result from the use of auxiliary heated gloves is electromagnetic interference. At the time the gloves are developed, the presence of an electromagnetic field will need to be checked.

Heater Efficiency

One factor affecting the temperature in the cockpit is heater efficiency. Although a cabin/cockpit temperature of 40°F (4.4°C) can generally be used for planning purposes, in extreme cold these temperatures are not achieved in certain aircraft. For example, the OH-53 was not designed for military use, nor was it designed for use below -25°F (-32°C). As a result, a special 100,000 Btu combustion heater has been installed in OH-58s operating in Alaska and an attempt has been made to insulate the doors. Neither solution has solved the problem of a cold cockpit, yet the OH-58 is frequently used for operations in Alaska. The latest solution requires the installation of a Casey heater, which works on a heat exchange principle.

The Black Hawk is another example of an aircraft which is cold for aviators to fly. Its specifications require that an inside temperature of only 15°F be attained when the ambient temperature is -65°F (-54°C). To compound the problem, the plane is drafty since the doors do not close tightly. On the other hand, the CH-47 has a very adequate heater and generally is comfortable for aviators.

Appendix C

MODELING

1. Environmental Scenarios for Modeling

- Environmental Scenario 1
- Environmental Scenario 2
- Environmental Scenario 3

2. Extremity Model

1. ENVIRONMENTAL SCENARIOS FOR MODELING

This section presents a description of each scenario employed in the modeling exercises explained in Section 3 of Chapter IV and displays tables of the results.

Environmental Scenario 1

Description and Results. Scenario 1 simulates the environmental criteria specified in the LOA. The assumptions used for the average time to complete each task were taken from the LOA and from the material collected for the requirements chapter. The time/temperature profile is given below.

SCENARIO 1

	<u>Time (min.)</u>	<u>Temperature</u>
Preflight tasks (outdoors)	60-90	-60°F (-51.1°C)
Preflight tasks (cockpit)	5	-60°F (-51.1°C)
Preflight tasks (cockpit)	10	-30°F (-34.4°C)
Mission	length of mission 1 to 1-3/4 hours	40° to -40°F (4.4° to -40°C)

In the analysis, it was assumed that the aircrews were wearing the warmest ensemble in the Army inventory -- the arctic cold-dry uniform which measures 4.3 clo under laboratory conditions. However, because of physical activity and slight air movement, the thermal effectiveness of this clothing was assumed to be reduced to 3.4 clo for the duration of the time the aircrews work outdoors.

Table C-1 presents the total heat debt that would be incurred by the aircrews under the conditions of Scenario 1 before rewarming begins. The time period over which cooling would continue before the process was reversed by the aircraft heater is 1½ hours for Case 1, 1-3/4 hours for Case 2, and 1½ hours for Case 3.

TABLE C-1. Cumulative Heat Debt for Aircrews under Scenario 1
4.3 clo Clothing System

Metabolic Rate (outdoors) (kcal/hr-m ²)	Cumulative Heat Debt		
	Case 1	Case 2	Case 3
125	-116 kcal/person	-168 kcal/person	-122 kcal/person
150	- 71 kcal/person	-101 kcal/person	- 77 kcal/person

Once the heater becomes effective, the heat debt will gradually be erased. Approximate times required to return to equilibrium are reported in Table C-2 for Cases 1, 2, and 3 for the higher heat production level only (150 kcal/hr-m²). Two constant cockpit temperatures were assumed for this analysis, 32°F and 40°F. The lower temperature was included because a recent recommendation for helicopters which carry troops in extreme cold ambient conditions is that the cockpit temperature be maintained at 32°F (0°C) to prevent condensation in the troop rifles. (The condensation can later freeze and cause the rifles to malfunction.)

TABLE C-2. Recovery Times for Aircrews under Scenario 1

Cockpit Temperature	Metabolic Rate (outdoors) kcal/hr-m ²	Recovery Time		
		Case 1	Case 2	Case 3
+32°F (0°C)	150	2½ hours	3 hours	2½ hours
+40°F (4.4°C)	150	1½ hours	2 hours	1½ hours

Conclusions. Under the assumption of minimal air movement (cockpit conditions) used in the preceding analysis, a clothing system which measures 4.3 clo would be inadequate at a metabolic rate of 125 kcal/m²-hr and marginal at the higher heat production assumed. Under average outdoor wind conditions, the cumulative heat debts would be much greater. A 4.3 clo system clearly would be too bulky for aircrews; however, it was chosen for this analysis since it is equivalent to the arctic ensemble and approaches the maximum insulation for military clothing. The analysis indicates that even 4.3 clo of insulation is not adequate and that some other solution must be found.

Environmental Scenario 2

Description and Results. The tasks and the time profile for Scenario 2 are identical to Scenario 1. The ambient temperature, however, was assumed to be -30°F (-34.4°C) and the cabin temperature after 5 minutes was assumed to have risen to 0°F (-17.8°C). The analysis examined the adequacy of a

system rated at 4.0 clo. The effectiveness of this clothing system was assumed to be 3.1 clo outdoors where the insulation value is reduced through air movement and physical activity. Table C-3 presents the total heat debt incurred by the aircrews under the conditions of Scenario 2 before rewarming occurs. The time periods over which cooling continues before the process is reversed by the aircraft heater are the same as those used in Scenario 1, that is, $1\frac{1}{2}$ hours for Case 1, $1\frac{3}{4}$ hours for Case 2, and $1\frac{1}{2}$ hours for Case 3. Recovery times for Scenario 2 are given in Table C-4 for both heat production levels used and for the two cockpit temperatures.

TABLE C-3. Cumulative Heat Debt for Aircrews under Scenario 2
4.0 clo Clothing System

Metabolic Rate (Outdoors) (kcal/hr-m ²)	Cumulative Heat Debt		
	Case 1	Case 2	Case 3
125	-69 kcal/person	-102 kcal/person	-73 kcal/person
150	-24 kcal/person	- 34 kcal/person	-28 kcal/person

TABLE C-4. Recovery Times for Aircrews under Scenario 2

Cockpit Temperature	Metabolic Rate (Outdoors) (kcal/hr-m ²)	Recovery Time		
		Case 1	Case 2	Case 3
32°F (0°C)	125	2-3/4 hours	4 hours	3 hours
32°F (0°C)	150	1 hour	$1\frac{1}{2}$ hours	1 hour
40°F (4.4°C)	125	$1\frac{3}{4}$ hours	$2\frac{1}{2}$ hours	$1\frac{3}{4}$ hours
40°F (4.4°C)	150	$\frac{1}{2}$ hour	$\frac{3}{4}$ hour	$\frac{3}{4}$ hour

Conclusions. A 4.0 clo clothing system would be adequate for the heat production range from 125 to 150 kcal/hr-m² under the assumption of minimal wind. However, at average wind speeds greater insulation will be required. For example, at -30°F (-34.4°C) winds of 10 mph produce an equivalent wind chill temperature of -58°F (-50°C). Also, for missions which on or off load troops, a 4.0 clo clothing system may not be suitable since additional heat debt may occur before an individual has recovered. These facts suggest that a warmer ensemble is needed, yet a 4.0 clo system is already too bulky to meet the aircraft interface requirements.

Environmental Scenario 3

Description and Results. The tasks and the time profile for this scenario are identical to Scenario 1 with the exception that the ambient temperature was assumed to be -15°F (-26.1°C) and the cabin temperature after five minutes was assumed to have risen to 0°F (-17.8°C). The data in Table C-5 indicate the total heat debt incurred under Scenario 3 conditions for aircrews clothed in a 3.5 clo uniform. The effective clo out-of-doors for this system was estimated to be 2.8 clo. The recovery times are displayed in Table C-6.

TABLE C-5. Cumulative Heat Debt for Aircrews under Scenario 3
3.5 clo Clothing System

Metabolic Rate (Outdoors) (kcal/hr-m ²)	Heat Debt		
	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>
125	-62 kcal/person	-90 kcal/person	-69 kcal/person
150	-17 kcal/person	-23 kcal/person	-24 kcal/person

TABLE C-6. Recovery Times for Aircrews under Scenario 3

Cockpit Temperature	Metabolic Rate (Outdoors) (kcal/hr-m ²)	Recovery Time		
		<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>
32°F (0°C)	125	6-3/4 hours	10 hours	7½ hours
32°F (0°C)	150	1-3/4 hours	2½ hours	2½ hours
40°F (4.4°C)	125	2½ hours	3½ hours	2½ hours
40°F (4.4°C)	150	½ hour	3/4 hour	1 hour

Conclusions. The heat debts displayed here can be readily tolerated. Under windy conditions, the higher metabolic rate will need to be maintained to avoid discomfort. Systems of clothing providing 3.5 clo of insulation have been fabricated from conventional fabrics without creating excessive bulk. For example, the new Combat Vehicle Crewman uniform for cold weather measures 3.55 clo on the copper manikin. This configuration of the CVC uniform includes the overalls and the balaclava, but excludes the vest and face mask.

A second example is the Canadian Aircrew Winter Uniform which was evaluated by ARIEM on the copper manikin in 1975. This uniform with US vapor barrier boots and US wool mittens measured about 3.5 clo.

It is preferable for an aircrewmembers to be too cool rather than to be too warm in order to avoid perspiring. Damp clothing loses its insulation qualities since water is a good conductor. The long recovery periods shown here, therefore, are desirable since they will prevent perspiration which results from overheating.

The explanation for why it can take up to 10 hours for a cold individual to return to thermal balance can be understood by noting the clo requirement for thermal balance in the given cockpit environment. Table 4 indicates that at 30°F (-1.1°C) the activity of piloting a plane would require 3.4 clo for thermal balance. This fact implies that an individual wearing 3.5 clo in a 32°F (0°C) cockpit will generate very little heat which will not be readily dissipated. The actual number of excess calories is 9 kcal/hour/man. At this rate it takes about 10 hours to overcome the heat debt of 90 kcal/man.

Examination of the wind chill chart shows that the temperature and wind combination used in the Scenario 3 analysis is equivalent to many other temperature and wind combinations. The 3.5 clo clothing system, therefore, is adequate for conditions such as -10°F (-23.3°C) and 5 mph winds, or 0°F (-17.8°C) and 8 mph winds, or 10°F (-12.2°C) and 13 mph winds.

2. EXTREMITY MODEL

The LOA requires that the extremities be protected to maintain a fingertip and toe temperature of 60.8°F (16°C). The prediction model described below was used to determine the temperature of the extremities over time after exposure to the cold.³⁸

$$T_t = T_e + (T_o - T_e) e^{-t/a}$$

$$T_e = T_a + 0.18 q_1 \text{ clo}$$

$$a = 10.45 a^1 / (10.45 + 6.69 \sqrt{WV} - .477 WV)$$

where,

T_t = Finger Temperature (°C) at time t

T_e = Asymptotic Temperature (°C)

T_o = Finger Temperature (°C) at time $t = 0$

T_a = Ambient Temperature ($^{\circ}\text{C}$)

q_1 = Heat Flow from Blood ($\text{kcal/m}^2\text{-hr}$)

clo = Insulation Value in clo units

t = Time in Minutes

a_0 = Time Constant in Minutes in still air without insulation

Fingertips $a^1 = 28$

Toecap $a_0 = 31$

a^1 = Time Constant in Minutes in still air with insulation

Fingertips $a^1 = 100 \text{ clo} - a_0$

Toecap $a^1 = 91 \text{ clo} + a_0$

a = Time Constant in Minutes in air at wind velocity WV

WV = Wind Velocity (miles/hour)

Further laboratory work needs to be conducted to establish the reliability of the values specified above for the toe cap area. The values indicated are the best available at this time.

Appendix D

AUXILIARY HEATED CLOTHING: PAST RESEARCH AND FINDINGS

United States

The use of auxiliary heating by the US military is not a new idea. During World War II, the US Army Air Corps developed electrically heated clothing to protect aviators from frostbite. Gloves and boots powered by the aircraft were designed first. Then the technology was applied to develop an electrically heated flying suit which was widely used in military aviation in the 1940's.

Other military personnel also need auxiliary heat in order to work efficiently in the cold, and in the 20 years following World War II numerous research efforts were conducted to explore solutions.^{39,40} US Air Force mechanics and ground crews were provided with electrically heated suits, gloves, and boots. This clothing did maintain comfort, but the power cord restricted mobility. In the late 1950's the US Army at Natick developed experimental heated handwear and footwear for armored vehicle crews. The project was terminated after vehicle designers were unwilling to provide a source of power. Five years later, an effort to develop electrically heated clothing for antiaircraft weapons operators was discontinued because of the lack of a feasible portable power source.

Other experiments have tested the concept of auxiliary heating in various forms and applications including handwarmers for ground soldiers, a hot-air distribution device to supply warm air to the hands of fuel handlers, and chemical heating pads attached to the clothing of inactive soldiers. Handwarmers did not provide enough heat to maintain hand warmth and, in one experiment, they were shown to be only 10 percent more efficient than pockets alone. The hot-air system studied provided poor heat distribution and released too much heat to the body before the air reached the extremities; this caused the subjects to become nauseous and dizzy. Although in principle heating pads can be used to extend tolerance time, the ones tested were entirely impractical from the standpoint of weight, bulk, duration and stability of heat produced.

In the early 1960's, the US Army at Natick conducted a series of experiments under controlled conditions in the cold climatic chambers to study the effectiveness of auxiliary heating and in particular to determine the relationship between the level of electrical power and the skin temperatures maintained.⁴¹ Since the results of these experiments have direct relevance for the aircrew cold weather clothing system, they will be discussed in some detail.

One phase of this study found that a minimum of three watts per hand and seven watts per foot, supplied continuously with adequate insulation, are necessary to maintain the extremities at a temperature above +40°F (4.4°C) in an ambient temperature of -40°F (-40°C) and a 10 mph wind. The subjects were

dressed in the standard arctic ensemble and wore arctic mittens and vapor barrier boots over the electrically heated gloves and socks, respectively. The gloves and socks supplied heat through resistance wires which were knitted into the wool. The subjects were able to remain inactive under these conditions for six hours.

While these minimum power levels were adequate to maintain finger temperatures, they were inadequate to rewarm the fingers once they dropped below the desired level. To rewarm, it was necessary to increase the power to 10 watts for each hand and foot. However, when combined with a thermostat, the study found that when 10 watts were supplied, the total power consumption for a 7 hour period was no greater than that required at the lower wattage levels when power was supplied continuously. That is, at the 10-watt power level the duty cycle, as determined by the thermostat, was only about 50%. Therefore, the power consumption was roughly equivalent to the minimum requirements, about 20 watts per hour. An additional benefit was that at the higher power level, the fingers could be maintained above 60°F (15.6°C). In fact, the study found that extremity temperatures could be maintained at any desired level between 50°F (10°C) and 105°F (40.6°C), as a function of the power supplied. It should be noted that one major difference between the experimental gloves and gloves to be worn by aircrews is that aircrewmembers will be unable to wear arctic mittens over their gloves and still perform their tasks. The mittens worn in this experiment provided a layer of insulation which kept the power requirements low.

The use of a thermostat would enable the gloves or boots to be comfortable over a wide range of ambient temperatures. As part of this laboratory experiment, the feasibility of thermostating was investigated. The web between the thumb and the first finger was successfully used as the thermostat site for the hand. Use of a heated boot rather than a heated sock was recommended by the study, because the thermostat could be located under the fifth toe area in the boot insole. Only slight additional power was required to heat boots rather than socks.

One major finding of the study was that "the electrically supplied heat was grossly insufficient to account for the increased hand temperatures" (p. 418). The researcher concluded that "at the low levels of auxiliary heat being supplied, it is primarily the alteration in blood circulation to the extremities, occurring under the influence of the warmer microclimate produced by auxiliary heating, that accounts for the temperature levels maintained" (p. 418).

In another phase of this study, experiments were run to test the feasibility of applying hot air to the trunk as a means of maintaining normal circulation in the hands and feet. The hot air kept the trunk comfortable, but the extremities cooled to critical levels.

As part of the research program, a portable power supply was developed. It consisted of 11 rechargeable silver cadmium batteries (1.1 volts each, 10 amperes) which were worn in the vest. This 120 watt-hour power pack weighed seven pounds and was designed to supply between 7 and 8 hours of protection for an inactive man in arctic gear at -40°F (-40°C) and 10 mph winds. A few years later the system was modified slightly and sent to the Antarctic in

response to a request for special handwear to protect members of an expedition sponsored by the National Science Foundation.

More recently, battery powered gloves, boots, and jackets have been marketed commercially. These have been developed for skiers, motorcyclists and others whose work or recreational activities require that they be exposed to the cold. At the request of the US Army Natick Laboratories, one glove manufacturer recently modified a pair of gloves to meet submitted specifications. Each glove operates from 6 volts supplied by four rechargeable nickel cadmium batteries (1.25 volts each). The heating element is a printed circuit. When the batteries were located near the body, they supplied power and kept the fingers above 60°F (16°C) for about one hour in -33°F (-36°C).

Soviet Union

The Soviets have been conducting research on electrical clothing, handwear, footwear, and head gear (including facemasks) for the past twenty years.^{42,43} It is reasonable to expect that they have devoted greater resources to the problem than has the United States, given their climate. The need for auxiliary heating exists not only for military uses, but for civilian purposes as well.

Several items have been developed and tested and some may be in use. The Pinguin suit was designed to be worn by operators of various vehicles and machinery working in extremely low temperatures. The suit consists of a sleeveless jacket (to be worn under clothing) and a pair of boot liners. The heated items are lined with graphite strips sealed with polyethylene and operate off the current of a standard 12 volt battery at 60 watts. There is no thermostat. Pravda reported in January 1976 that the Pinguin suit had been approved for quantity production and would be shipped soon to miners.

Another suit, the Yenot, consists of a jacket and pants and requires 35 watts of power which is supplied by a set of nickel cadmium batteries worn in a belt. The batteries supply power for an entire work shift and the temperature is controlled by a heat regulating mechanism.

The Soviets have also developed electrically heated boots which apparently have a dual heating system. A battery fits into a pocket located in the top of the boot. The heating element also can operate from 12 volts of either ac or dc current. It is believed that this footwear is being utilized by military personnel engaged in the operation and maintenance of northern installations.

Research by V. I. Makarov has demonstrated that areas of the body with well-developed cutaneous vascular network and low thermal resistance (back, waist, arm, face, etc.) have the highest capacity to absorb heat. This information was incorporated into the design of a one-piece electrically heated suit which included a helmet, insoles, and heated respirator. The heat

exchangers were located on the 15% of the body surface which was previously identified as being thermoreceptive.⁴²

Several Soviet researchers working independently (R. F. A fanas' yeva, Yevlampiyeva and Kel' shteyn, and Makarov, et. al.) have demonstrated that at lower air temperatures increased body cooling occurs in electrically heated suits relative to conventional clothing. This is due to the greater temperature contrast between the surface of the heated clothing and the ambient temperature. A corollary is that under windy conditions, electrically heated garments lose their thermoinsulating properties faster than unheated clothing.

United Kingdom and Canada

The Canadian and British military establishments also have developed experimental heated handwear and footwear. At the present time, no items are in use but research is continuing and a solution is expected in the next few years.⁴⁴ Canada recently conducted a survey of all military tasks performed in the cold to identify the need for auxiliary heated clothing.

In the early 1970's Canadian tests of an experimental glove, which was constructed from a heating element molded from conductive rubber, established the feasibility of this approach.⁴⁵ The rubber element proved to be a far more rugged product than the earlier solution which employed thin resistance wire. The high power requirement (38 watts) for the heater, however, caused the battery packs to discharge too quickly. The researchers concluded that further work was needed to design a more efficient heating element.

During the last decade, the United Kingdom has been developing electrically heated clothing.⁴⁶ A prototype one-piece coverall, designed for military use was constructed using a heating element made of a new heat conducting fabric. This fabric had the following advantages over the main alternative at that time, resistance wire.

- Punctures and other damage to the element did not interrupt heat flow.
- The heat was more evenly distributed.
- The fabric is flatter and more flexible than one containing wires.
- The fabric could be cut into the desired shape and sewn.

The development of the coverall was eventually discontinued due to the lack of an adequate power supply. It consumed about 100 watts per man.

Electrically heated insoles constructed in an open mesh design that allows some air movement have been developed by the British. Field tests

revealed problem areas that needed further work. Experimental gloves and mittens have also been developed.

In 1978, Canada conducted a comparative evaluation of Canadian and British experimental electrically heated mittens.⁴⁷ Both pairs of mittens utilized heating elements made of thin conductive rubber, however, their shapes differed. The Canadian element applied heat to the back of the hand only, whereas, the British element enveloped the palm and the back of the hand. This factor was credited with accounting for the wide differences in power consumption. No statistical difference was found between the mean hand temperatures of subjects wearing the Canadian or the British mittens, but about 10 times as much power was consumed by the former. At 12 volts, the Canadian element consumed 12 watts and the British element consumed 1.1 watts. These mittens were tested at -40°F (-40°C) while subjects in arctic gear walked on a treadmill.

Appendix E

COLD INJURY

Cold injury is defined as tissue trauma produced by exposure to cold.⁴⁸ The type of injury is a function of the temperature to which the body is exposed, the duration of the exposure, and certain environmental factors. Generally, injuries are classified as freezing and non-freezing. The major types of cold injury and the physiological and environmental conditions under which they occur are identified below.

Frostbite

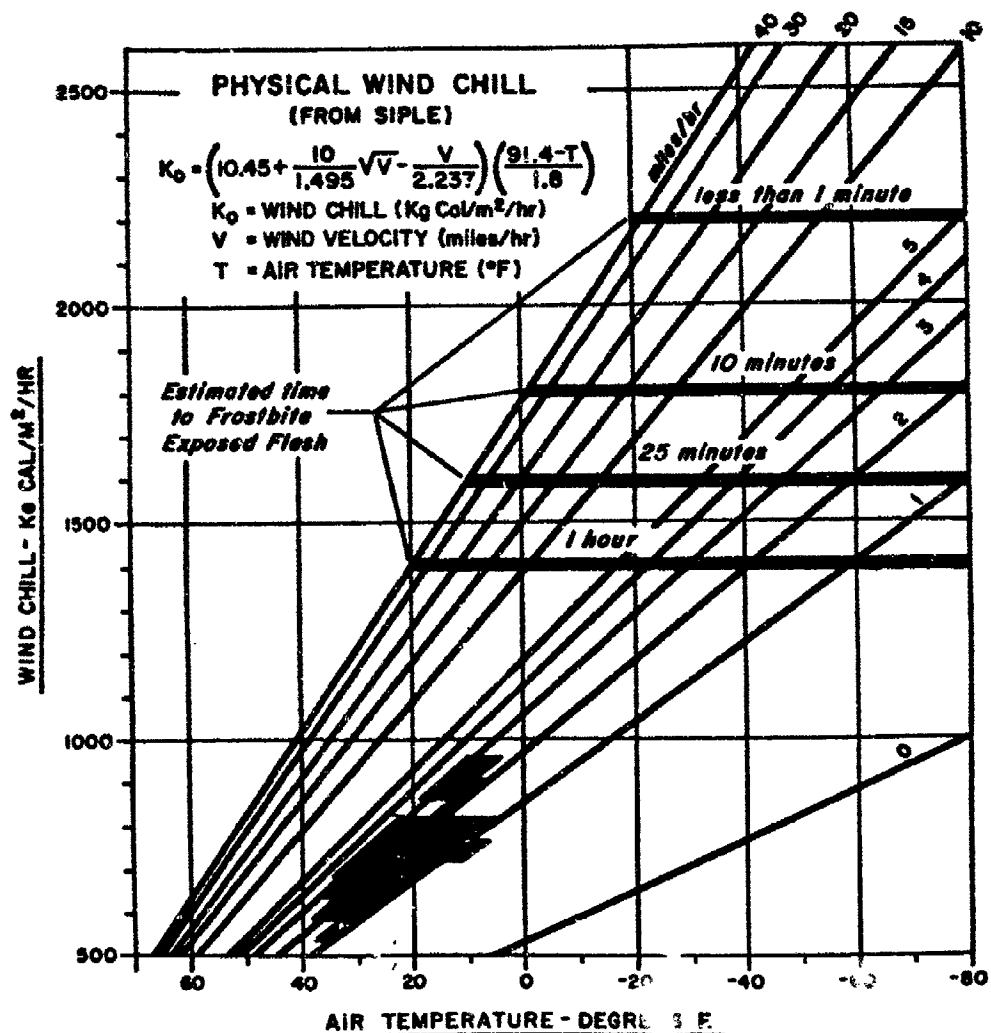
Frostbite is the actual freezing of tissue which results from crystallization of water in the skin. As the ice crystals expand, they cause destruction of the cells either directly or as a result of the higher concentration of all solutes as the water is separated as ice. The resulting hypertonic fluid damages cells. The severity of the injury depends on the duration of the exposure and the wind chill temperature. Under extremely cold conditions, frostbite can occur rapidly. Figure E-1 indicates the estimated time before exposed bare skin can become frostbitten under different combinations of wind and temperature. For example, the graph indicates that frostbite can occur in less than one minute at temperatures near -60°F (-51.1°C) with a 10 mph wind. At the same wind speed and a temperature of -30°F (-34.4°C), frostbite can occur in less than 10 minutes. Frostbite can also develop slowly, even on protected parts of the skin, as a result of prolonged exposure to the cold. The explanation on the graph points out that the epidemiologic cold injury experience during the Korean War is represented by the blocked out area between wind chill levels of 500 and 900 Kg Cal/m²/hr. These levels occur at temperatures above 0°F (-17.8°C) and are much lower than the wind chill levels which occur at temperatures below 0°F (-17.8°C).

Trench Foot and Immersion Foot

These injuries result from prolonged exposure of the feet to cold wet conditions which produce prolonged vasoconstriction. The injury is termed trench foot if the cause was cold wet socks and boots, and it is termed immersion foot if the cause was prolonged contact with cold water. Both of these injuries can occur in temperatures well above freezing.

Hypothermia

Hypothermia is the condition of a low body temperature, specifically a core temperature below about 95°F (35.0°C). The drop in core temperature can occur quickly, as when one is accidentally immersed in cold water, or slowly and can be caused by either the lack of sufficient body heat production or an excessive cooling rate. Once the core drops below about 95°F (35°C), the body's ability to regenerate heat spontaneously to restore the heat debt is reduced, and the application of external heat is frequently necessary to prevent death. Freezing temperatures are not required to produce hypothermia.



A graphic presentation of Siple's wind chill formula (given in the upper left hand corner). The diagonal lines are plotted for wind velocities from 0 to 40 miles per hour. The predicted times to freezing cold injury of exposed bare skin, ranging from one hour at a wind chill of 1400 to one minute at 2200, contrasts with the epidemiologic experience in the Korean war, which is represented by the blocked out area between wind chill levels of 500 and 900.

Source: Reference 49.

Figure E-1. Estimated time to frostbite exposed flesh.

Cold Injuries During Combat

The incidence of cold injury among civilians is limited to sporadic cases of frostbite or hypothermia. When temperatures drop, most civilians spend less time outdoors and those who spend time in the cold, either through necessity or by choice usually have ready access to shelters. Military personnel in training and especially in tactical situations typically do not have the opportunity to escape to a warm environment and as a result, cold weather military clothing must be designed to minimize the risk of cold injury.

Cold injuries have been reported in every major conflict in which the United States has been involved including the Vietnam War.⁵⁰ During World War II, the US Army incurred 90,535 cases of cold injury (2/3 trenchfoot, 1/3 frostbite) severe enough for the soldier to be excused from duty for treatment.⁵¹ Of these, 47,847 were primary injuries which required an average hospital stay of 56 days. The total time lost for all cases is estimated at over seven and one half million person-days or an average of 83 days per case; only 15 percent of these casualties returned to combat. Although these losses occurred chiefly among the ground forces, the Army Air Force did report some cases of high-altitude frostbite.

In the Korean War, over 9000 cases of cold injury (mostly frostbite) were reported. Although temperatures as low as -30°F (-34.4°C) were frequently recorded in Korea during the winter of 1950-51, cold injuries did not increase when temperatures fell, partially due to the fact that during periods of extreme cold, combat activity was reduced.^{29,49} One study found that 80 percent of the cold injuries occurred at temperatures of 0°F (-17.8°C) or higher.²⁹ Inactivity, caused by confinement in trenches, sleeping in the cold, or riding in a vehicle, was found to be a prime factor contributing to cold injury.

Appendix F

AIRCREW REQUIREMENTS DOCUMENTS FOR SEPARATELY FUNDED PROGRAMS

This appendix briefly identifies the goals of several separately funded development programs which are addressing aircrew needs. The new aircrew clothing system should be designed in coordination with these related efforts. It should be noted that several of these programs will correct deficiencies which exist in all climatic zones and are not specifically concerned with the special needs created by extreme cold. For more information, the reader is referred to the actual documents.

Letter Requirement (LR) for Glove, Flying, Extreme Cold Weather⁵²

Work is proceeding under this LR to design handwear for aircrew personnel "which will allow sufficient dexterity to the crew member to perform assigned tasks, provide a measure of safety from the hazards of an aircraft fire and extreme heat, and provide environmental protection from the cold." This glove is intended to be worn only in the cockpit for preflight checks and for inflight duties. It will provide a short-term partial solution to the need for better thermal protection. The broader problem, which includes hand protection for all aircrew tasks performed both inside and outside the aircraft, is the responsibility of the developers of the aircrew cold weather system. The extreme cold weather gloves, developed under this LR, should be considered for inclusion in the aircrew clothing system as one item in a modular glove system.

Letter Requirement for Aircrew Survival Armor Recovery Vest⁹

The new multi-purpose vest will replace two currently issued items: the SRU/21P Survival Vest and the aircrew body armor. It will be worn by all aircrews in all climates. The survival environmental packets described below will be issued according to the environmental conditions. These will be inserted in the storage pockets provided on the vest for that purpose. In addition to the climatically oriented survival components, the vest will have:

- a fragmentation protection carrier containing a body armor insert for front and back,
- an attachment for a life preserver,
- a pickup attachment/harness that will connect to a rescue hoist cable hook, and
- essential survival signal and communication components.

The weight and bulkiness of the vest with all components should be considered when developing the aircrew clothing system. The design goal for the vest is to confine the weight of the vest and its components (excluding the radio and armor) to 8 pounds. The radio will add approximately 5 pounds

and the armor will contribute between 22-24 pounds. The armor, of course, will only be inserted during combat. The remaining items will be worn at all times (AR 95-1). The armor/survival vest will thus contribute about 36 pounds during combat and about 13 pounds at other times. The current armor weighs 28 pounds. The new cold weather clothing system must interface with the new survival/armor vest, and the combined weight and the combined bulk of the clothing and the armor must not impair the aircrew's performance.

Letter Requirement for Survival Environmental Packet⁵³

Under this LR, survival packets are being developed to provide immediate self-aid in the event of an emergency. Each aircrewmember will be issued a basic temperate packet containing survival items required irrespective of the environment, and one or more packets containing items essential for specific environmental conditions: hot, cold, or overwater. These packets will be inserted in pockets on the survival vest. The packets include basic medical supplies, signaling devices, and an assortment of other small, essential items. These packets will supply survival needs for the first six hours, and if required, can be supplemented with items from the survival kit.

Required Operational Capability for an Aircraft Modular Survival System⁵⁴

Under this ROC, four modular survival kits will be developed to complement the survival items that will be carried in the vest. These kits will contain the bulkier, heavier survival equipment, such as sleeping bags, tools and a stove. In order to minimize the weight of the kits, a modular approach similar to that used to design the environmental packets will be used. Each crew will be issued a basic module and one or more supplemental environmental kits---hot, cold, and overwater. The kits will be packaged in two sizes, two-man and five-man, and stowed on-board the aircraft in the configuration which meets the needs of both crew and passengers. The basic module will not include any clothing or equipment (with the exception of matches, fuel, fire starter, rations, and tools to obtain food and water) which offer protection from the environment. However, for environmental protection, the cold module will contain:

- one sleeping bag for each crew member and each passenger (provides 3-4 hours of uninterrupted sleep in -40°F (-40°C)),
- a waterproof, vapor permeable shelter (tent) capable of withstanding 40 knots winds (two sizes: two- and five-man),
- a stove,
- tools (shovel, saw knife),
- snow goggles,
- additional survival rations which will extend the basic module provisions (24 hours) to 72 hours, and

- sufficient quantities of consumables (other than food and water) to last at least 14 days.

Letter of Agreement (LOA) for an Aircrew Life Support System, Integrated Battlefield (ALSSIB)⁵

The goal of this development program is to achieve a totally integrated aircrew clothing and life support system which will combine the capabilities of all aircrew developmental items with the additional characteristics enumerated in the LOA. Ideally, the integrated system will provide protection from combat hazards including ballistic, flame, nuclear, chemical, biological, laser, crash, and environmental/geographical survival protection. Simultaneously, it will optimize all interfaces with the aircraft and mission facilitating equipment.

The program has been divided into two phases. In its first phase (FY 82 to FY 86), the ALSSIB program will coordinate existing aircrew development efforts (6.3 and 6.4) to ensure the highest degree of compatibility between items which interface. The plan is to generate an interim capability by 1986. The list of existing aircrew development efforts includes every requirements document identified in this appendix (Appendix E) and the aircrew cold weather clothing system. In Phase II (FY 87 to FY 92), a new development effort will explore technological alternatives to blend the protective characteristics of individual items of clothing and life support equipment into a totally integrated system.

Letter of Agreement (LOA) for a Ground and Air Combat Vehicle Microclimatic Conditioning System⁵⁵

The purpose of this system is to provide microclimatic conditioned garments for combat vehicle crew and aircrew when operating combat systems. The microclimate cooling/heating system will dissipate excessive body heat generated by wearing CB protective clothing and alternatively provide heat for cold weather operations. Ideally, it will eliminate the need for seasonal clothing systems since the individual's comfort will be monitored and maintained by the conditioning system. Three conceptual solutions are being investigated: a convective ambient air ventilation system, a convective cooled/heated conditioned air system, and a conductive cooled/heated liquid system.

APPENDIX G

COST ANALYSIS OF BATTERIES FOR HEATED HANDWEAR AND FOOTWEAR

Nickel Cadmium Batteries

Assumptions:

1. At least two complete battery systems in the form of vests will be allocated to each man so that one can be recharged while the other is being worn.
2. Power is required about 60-80 days per year.
3. Batteries can be recharged about 200 times before age and cycle life degrade capacity. At 30-40 recharges per year, each battery will last about six years.
4. This non-standard battery pack will cost about \$300-\$325 per 100 watt hours (24V). Note: Standard Army batteries would be cheaper.
5. Battery charger (BB-7286) is estimated to cost \$500-\$10,000 and will have a life span of 5-10 years. Maintenance costs per year are an estimated \$200 per year. It can recharge five vests at one time in 6-14 hours.

Estimated Uniform Annual Costs/Man:

Battery Pack - 2 vests @ \$325 ea for 6 yrs = \$149/yr/man

Battery Charger \$304/yr/man

Electricity Costs)
Labor Costs) not included

Total \$453/yr/man

Lithium Batteries

Assumptions:

1. The equivalent of 100 watt-hours (24V) of batteries will be expended and discarded each day.
2. Batteries are needed 60-80 days per year.
3. A 24V system will consist of 10 cells costing \$6-\$8 each. It would supply about 200 watt-hours of power or the equivalent of two days.

Estimated Uniform Annual Costs/Man

Batteries - \$35/day x 70 days = \$2450/yr/man

Appendix H
LETTER OF AGREEMENT
FOR AN AIRCREW CLOTHING SYSTEM
INTERMEDIATE COLD, COLD AND EXTREME COLD WEATHER



DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY TRAINING AND DOCTRINE COMMAND
FORT MONROE, VIRGINIA 23651

ATCD-S-A

23 October 1979

SUBJECT: Letter of Agreement (LOA) for an Aircrew Clothing System
Intermediate Cold, Cold and Extreme Cold Weather (Short Title:
Aircrew Clothing System, Cold Weather) USATRADOC ACN 36821

SEE DISTRIBUTION

1. Reference: AR 71-9.
2. Attached at Inclosure 1 is the approved TRADOC/DARCOM Letter of Agreement (LOA) for an Aircrew Clothing System Intermediate Cold, Cold and Extreme Cold Weather (Short Title: Aircrew Clothing System, Cold Weather). The following information is applicable to this document:
 - a. System Designation: Non-major.
 - b. Materiel Developer: DARCOM.
 - c. Combat Developer: USATRADOC.
 - d. User Representative: USATRADOC.
 - e. Trainer: USATRADOC.
 - f. Logistician: USALEA.
 - g. CARDS Reference Number: 1409A.
 - h. Operational Test Responsibility: USATRADOC.
 - i. USATRADOC Proponent Activity: Combined Arms Center/US Army Combat Development Activity (Alaska).
3. USADARCOM, in coordination with the USATRADOC proponent activity, will initiate preparation of the Outline Development Plan (ODP) IAW AR 71-9.


ATCD-S-A

23 October 1979

SUBJECT: Letter of Agreement (LOA) for an Aircrew Clothing System
Intermediate Cold, Cold and Extreme Cold Weather (Short Title:
Aircrew Clothing System, Cold Weather) USATRADOC ACN 36821

4. Subject requirement document is forwarded to major Army commands, other services and DOD agencies for harmonization and to all other addressees for information.

FOR THE COMMANDER:



ROBERT W. CHELMER

LTC, GS

Asst AG

1 Incl
as

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USA CD Exper Comd
(see next page)

23 October 1979

ATCD-S-A

SUBJECT: Letter of Agreement (LOA) for an Aircrew Clothing System
Intermediate Cold, Cold and Extreme Cold Weather (Short Title:
Aircrew Clothing System, Cold Weather) USATRADOC ACN 36821

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USACDA (Alaska)

USARJ (ATTN: AJGC-FDA)

USA Log Eval Agcy

USAOTEA

National Security Agcy

USA Foreign Science & Tech Cen,

ATTN: DRXST-PO

USA Avn Cen & Ft Rucker,

ATTN: ATZQ-D

USAICS

USAMPS/TC, Ft McClellan

USAMMCS, ATTN: ATSK-CT

USAOCC&S

USASC & Ft Gordon

USA Training Spt Cen,

ATTN: ATTSC-DS-MSS

Comdt

USAADS, ATTN: ATSA-CD

USAARMS, ATTN: ATSB-CD

USAES, ATTN: ATSE-CTD

USAFAS, ATTN: ATSF-CTD

USAIS

USAQMS

USATSCH, ATTN: ATSP-CD

USAIMA

TJAGSA

Supt, Academy of Health Sciences, USA

ATTN: AHS-COM

Dir, TRASANA

Dir, MTMC, ATTN: MTT-TRG

TRADOC LO:

USAREUR & Seventh Army

ATTN: ATFE-LO-AE

FRG

Eighth USA, ATTN: ATFE-LO-AK

DARCOM

TECOM, ATTN: STEAP-LI

ARRADCOM

MICOM

AVRADCOM

CORADCOM

(over)

ATCD-S-A

23 October 1979

SUBJECT: Letter of Agreement (LOA) for an Aircrew Clothing System
Intermediate Cold, Cold and Extreme Cold Weather (Short Title:
Aircrew Clothing System, Cold Weather) USATRADOC ACN 36821

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Sr Std Rep

USA Std Gp - UK (Assoc)

USA Std Gp - Canada (Assoc)

USA Std Gp - Australia (Assoc)

CNO (OP-98)

CNO (OP 323-E)

Chief of Naval Materiel (NMAT-08T4)

Comdt of the Marine Corps (RD)

CG Marine Corps Dev & Educ Comd (Dev Cen)

HQ USAF (RDQM)

Cdr, US Tactical Air Comd, ATTN: DRP

USA Equipment Authorization Review Activity

ATTN: DRXEA-MC

CINCUSAREUR & Seventh Army, ATTN: ATFE-LO-AE

USA DARCOM Materiel Readiness Support Activity

ATTN: DRXMD-MS

CINCUNC-USFK-EA, ATTN: J-3, USA TRADOC-LO

R&D COORD (Army, DRXSN-E-BN,

US Embassy-Bonn)

LO at TRADOC:

INSCOM

USMC

USAF

LETTER OF AGREEMENT
FOR AN AIRCREW CLOTHING SYSTEM
INTERMEDIATE COLD, COLD & EXTREME COLD WEATHER
(SHORT TITLE: AIRCREW CLOTHING SYSTEM, COLD WEATHER)

1. NEED:

a. A critical requirement exists for a clothing system which will facilitate the man/machine/environment interface for Army aircrews operating in regions of intermediate cold, cold and extreme cold weather (-17.78°C (0°F) to -51.1°C (-60°F)). Existing individual items of aircrew clothing and equipment fail to functionally intermesh, lack critical qualities consistent with environmental protection and are cumbersome to the point of incompatibility with limited cabin/cockpit space of current and future airframes. As a result, environment induced performance degradation impairs the ability of aircrews to fully exploit the capabilities of the machine. Time Frame: 1984-86.

b. CARDS reference number:

2. OPERATIONAL CONCEPT:

a. Role description: The Aircrew Clothing System, Cold Weather, will facilitate the cold dry/wet weather man/machine/environment interface which is characterized by three specific task functions. They are preflight tasks performed at ambient air temperatures; inflight tasks performed in the specific cold weather aircrew micro-environment (to include danger of injury from crash impact and fire during an aircraft emergency), and survival tasks in cold region terrain and climatic conditions. The system will be issued to aircrewpersons operating in climatic zones V, VI and VII of CTA 50-900, and by aircrewpersons operating in highland (para 2, Appendix d, CTA 50-900) and other areas of the world that closely approximate these conditions.

b. The mission profile is attached as Annex A.

3. SYSTEM DESCRIPTION:

a. A systems concept will be followed to insure compatibility of all ensemble components and facilitate the cold dry/wet weather man/machine/environment interface. Standardization of system components with standard and development clothing items will be considered throughout system development. This will eliminate duplication of effort, conserve resources and limit the number of items in the supply system. Coordination/standardization should be effected throughout DOD.

b. Essential characteristics of the Aircrew Clothing System, Cold Weather:

(1) Must allow freedom of movement within the confines of a cockpit/cabin with the least possible restriction in performance of aircrew duties in present and future cockpit/cabin environments.

(2) Must provide environmental protection including water repellancy, to the aircrew member engaged in pre-flight or survival activities in intermediate cold, cold and extreme cold weather regions (-17.7°C (0°F) to -51.1°C (-60°F)).

(3) Inflight environment protection requirements of the aircrew member are derived from tables of probability of frequency of occurrence of minimum temperatures; an extrapolation of actual cockpit/cabin temperatures during run-up and mission performance; from aircraft climatic tests conducted at the Cold Regions Test Center; from studies done by ARIEM at the request of USACDA(AK); and from characteristics of the cold weather aircrew micro-environment. These factors combine to require a clothing system that must:

(a) Provide environmental protection to the aircrewperson from the cold sufficient to perform his duties at the following cabin/cockpit air temperatures and durations:

1. -60°F (-51°C) for five minutes.

2. -30°F (-34°C) for ten minutes.

3. 1 and 2 above, sequentially, totaling fifteen minutes, then for the duration of a typical aircraft mission at $+40^{\circ}\text{F}$ (4°C).

(b) Provide environmental protection to the extremities sufficient to maintain a finger tip and toe temperature of 16°C (60.8°F) (the lowest point of comfort and a point which normally dexterity starts to drop precipitously and at which it could be assumed a pilot's finger function would be seriously impaired) throughout the cabin/cockpit temperature ranges/time period specified in para (a) above.

(4) Must incorporate fabrics and techniques of construction that provide the maximum degree of fire protection commensurate with the state-of-the-art and design functional restraints, excepting components used only during non flying tasks. Fire protection will be no less than that provided by the present system and will provide for small-of-the-back protection during bending/reaching.

(5) Must provide environmental protection to the OV-1 aircrewperson who ejects from a 4.44°C (40°F) micro-environment into a temperature plus wind-chill effect that requires no exposed skin. This protection must be sufficient so that he can function upon reaching the ground well enough to accomplish necessary tasks to insure his survival. The system should also provide protection during prolonged water entry to the aircrewperson who is forced to eject or ditch over water.

(6) Must incorporate a retrieval strap or similar means of quickly extracting an injured crewmember from a cockpit/cabin subsequent to a crash.

(7) Handwear must provide the degree of environmental protection specified in para 3.b(3)(b), fire protection specified in para 3.b(4), yet allow sufficient dexterity and touch sensitivity to effectively perform aircrew tasks. Handwear should be durable and warm enough for use during preflight and survival tasks. Additionally, hardware should not impair the manipulation of closure and release fittings when wet.

(8) Footwear must provide environmental protection specified in para 3.b.(3)(b), be compatible with cramped cabin/cockpit foot/ control spaces, provide protection from fire specified in para 3.b(4), provide the protection/support (including toe protection) required during crash impact and be durable enough for use during performance of preflight and survival tasks. Additionally, footwear must be designed to minimize or provide for evaporation of perspiration and accommodate easy drying to minimize cold injuries.

(9) Must be compatible with existing/developmental protective aircrew headwear (flight helmet) during flight. Headwear for survival situations should consist of the standard cap, cold weather, and/or face masks used in conjunction with the parka hood.

(10) Must provide adjustment for aircrew comfort (prevent overheating as well as protection from cold) during widely varying temperature ranges of 4.44°C (40°F) (upper limit) to ambient (lower limit). The adjustment procedure must be quick and easy so as not to degrade aircrew efficiency.

(11) The color of the uniform will be compatible with existing uniforms or standard within the military service.

(12) Must provide a suitable means of providing the optimum camouflage compatibility with the geographical area and must also include visibility and/or identification/rescue components.

(13) Must be sized to fit the 5th through 95th percentile person.

(14) Must incorporate pockets or other methods with protective closures strategically located to carry flight equipment for inflight accessibility and comfort.

(15) Must provide for easy donning/doffing to allow aircrewperson to quickly change the garment(s), both in warm environment, as on alert status, and in cold environment, while wearing protective handwear.

(16) Must provide for elimination of body waste without unnecessary exposure of body surfaces.

(17) Must provide a method of securing pant cuff to boot leg or other method to minimize exposure of leg during bending/reaching movements to prevent snow from entering boot tops, and provide necessary fire protection.

(18) Must provide for a high wrap around collar to prevent loss of body heat and provide added fire protection.

(19) Resistance to IR or ECM is not required for this item.

(20) Nuclear survivability is not required because the system is not critical to mission accomplishment in a nuclear conflict.

(21) Must be compatible with the approved chemical/biological (c/b) protective ensemble as an integral part of the cold weather clothing system.

NOTE: Potential replacement for current items should also be considered.

(22) Must be compatible with floatation/survival equipment and personal armor protection.

(23) Must be compatible with existing/developmental aircrew life support systems, i.e., oxygen.

c. Technical concepts: Technical risk of the development is considered low and the development within the state-of-the-art. What has been lacking is a systems approach based upon a stated need. Technical concepts considered may include, but not be limited to:

(1) Auxillary heated portions or all of the ensemble: Variations might include heating only undergarments, socks or bootliners and gloves, or a combination of auxillary heating and standard insulated or layered construction.

(2) Reflective fabrics or other heat retaining concepts.

(3) Individual man-portable micro-environments, especially for the OV-1 crewperson who must eject in cold regions and still be capable of accomplishing necessary tasks upon reaching the ground to insure his survival.

(4) Layered construction with insulation injected between layers as needed. A variation might consist of foam filled bottles used to fill the dead space between layers. The equipment could be incorporated into the ejection sequence. If foam injection is used the garment so insulated should be for one time use only.

(5) Standard clothing construction methods consisting of a combination of insulation thickness and layering according to the particular aircrew task function and ambient temperature. A variation might include an inner flight glove used for inflight tasks and as an anti-contact glove during preflight, coupled with the standard arctic mitten readily available for the colder temperatures encountered during extended preflight or survival tasks.

(6) Other technological alternatives and trade-offs to be examined in development of the above technical concepts:

(a) Determination of clothing system design constraints to optimize the human factors portion of the man/machine/environment interface.

(b) Determine feasibility of a clothing system capable of accommodating widely varying temperatures while providing necessary environmental protection.

(c) Determine shortcomings of the system for survival application in a cold environment so that items to compensate for them can be included in a supplemental survival kit.

(d) Feasibility of chemical and biological warfare serviceability/employment.

(e) Feasibility of incorporating means of carrying survival items as an integral part of the system.

(f) Determine specific items of equipment that the system must be designed to carry.

(g) Resolve conflicting impact/fire/cold protection, traction, limited cockpit/control area space, incompatibility with fuselage toe holds, and control touch requirements associated with aircrew footwear.

(h) Determine feasibility of retaining touch sensitivity and dexterity while providing warmth and fire protection in the handwear.

(i) Determine feasibility of an ensemble capable of providing environmental protection in intermediate cold, cold and extreme cold weather regions that will interface with man/machine/environment for every aircrewperson in every aircraft. (Includes the OV-1 aircrewperson who ejects and must take all his gear with him.)

d. Other Service or Allied National Interest: Need for a similar system was expressed by USAF in their (ROC) AAC T-76, Arctic Extreme Cold Weather Flying Coverall, 7 June 1976. USN is aware of the need expressed in this document and the Marine Corps has expressed an interest to adopt the finalized LOA as a Marine Corps requirement. The development program should be coordinated to meet needs of the Army, USAF and Marine Corps. A Joint Services Development Program should be pursued if feasible. Advanced development is to be monitored for incorporation into a JSOR. Available information on foreign systems was considered in the development of this requirement and none were identified which would satisfy US needs.

4. PROSPECTIVE OPERATIONAL EFFECTIVENESS AND COSTS:

a. The aircrew clothing system, cold weather, will facilitate the man/machine/environment for aircrews operating in cold to -51.1°C (-60°F). It will replace existing individual items of aircrew clothing adopted on a piece meal basis over the years beginning with the Army Air Corps in World War II. Some of these items provide inadequate environmental protection, others insufficient fire protection or compatibility with cramped cockpit space and all fail to functionally intermesh. The result, degradation of aircrew effectiveness upon the future cold regions battlefield. The Aircrew Cold Weather Clothing System will be consistent with materiel, doctrine and tactics emerging in the mid 1980-1990 time frame. Quantifiable data to support improved aircrew effectiveness as a result of system adoption is not available since at this time airmobile actual combat operations in cold regions have not occurred.

b. The unit cost is expected to be \$450 to \$550 per clothing set ensemble. (Constant FY79 dollars).

5. SYSTEM DEVELOPMENT: Aircrew clothing system cold weather events to be performed are as follows:

a. Operational Employment Plan: Commander, TRADOC, with input from Commander, DARCOM, will conduct tests and experiments to:

(1) Refine the operational, organizational, logistical, and maintenance concept based upon DT/OT I (or equivalent evaluations) test results and studies or investigations which relate to the Aircrew Clothing System, Cold Weather. Special attention will be given to:

(a) Performance under actual operational conditions in the climatic and terrain conditions encountered in climatic zones V, VI and VII of CTA 50-900 to include highland and ice cap areas and extreme low temperatures.

(b) System compatibility with present and future Army aircraft.

(c) System compatibility with cold climate aircrew survival equipments.

(2) Conduct a cost and operational effectiveness analysis (COEA) or mini COEA for the Aircrew Clothing System, Cold Weather as a basis for evaluating the direction/redirection of the development program, to include an analysis of the technological alternatives.

b. Technical Plan: Commander, DARCOM, with input from TRADOC will:

(1) Develop and validate the Aircrew Clothing System, Cold Weather, technical concepts described in the system description in paragraph 3, above, using contractor, developmental, and operational test and evaluation results and studies relative to the Aircrew Clothing System system/prototypes.

(2) Collect and analyze RAM data if appropriate during conduct of all tests and evaluations for use in determining the potential RAM performance capability of the Aircrew Clothing System, Cold Weather.

(3) Analyze the RAM performance if appropriate relative to the technological potential, developmental risks, operational mode summary, mission profile, failure definition/scoring criteria, and any availability maintainability parameters and prepare baseline analysis of all pertinent RAM data for inclusion in the RAM annex to the LR/ROC.

(4) Provide RAM data and projections if appropriate to be used in conducting the COEA or mini COEA.

c. Logistical Support Plan: Commander, TRADOC and Commander, DARCOM will:

(1) Insure that the Logistical Support Package will be available for evaluation at DT/OT I.

(2) Analyze and determine system cost and effectiveness taking into consideration tri service use, replacement of a multitude of ineffective items currently cluttering the supply system, and consequences of not having a suitable system during combat in a cold environment.

(3) Analyze and determine present standard items of clothing within DOD that will satisfy the requirement and utilize them wherever possible. Modifications to existing clothing will be considered.

(4) Analyze and determine a maintenance and supply concept if any form of auxiliary type heating method is used; i.e., batteries or man portable microclimate.

(5) Analyze and determine the need for support equipment to maintain the system in operating condition.

d. Training Support Plan: Minimal training other than initial aircrew familiarization is envisioned. The materiel developer will prepare the necessary instructions or publications to accompany the individual components of the clothing system upon issue. These publications will be developed based upon a task worksheet mutually agreed on by the materiel developer and the TRADOC proponent. The publications will contain instructions on care and use, and a listing of other compatible systems components and how they are to interface. Maintenance publication will be prepared if any component of the system is considered to be repairable. This materiel will be approved by TRADOC and available for training use and evaluation at first operational test of the clothing system or any user testing. The instructional materiel will be specifically geared to the mental capabilities of the representative aircrew population. The capability of the test player personnel, using the clothing system, to perform those tasks indicated in the task worksheet to specified standards will be made a critical test issue. The Training Support Plan will be available for evaluation at OT I.

e. Personnel Support Plan: The Aircrew Clothing System consists of clothing items that will cause negligible impact upon MOS or current force structure.

6. SCHEDULE AND MILESTONES: Based upon LOA approval 4Q FY79.

6.3

Design Prototypes	1Q80 - 2Q81
Items for DT/OT I	4Q81
DT/OT I	2Q82

7. FUNDING: Constant and Inflated FY79 Dollars (\$M - Millions)

a. Advanced Development (6.3)

		Low	High
Range:	Inflated	1.426	1.930
	Constant	1.250	1.689

Most likely funding profile:

	FY80	FY81	FY82	TOTAL
Inflated	0.429	0.642	0.607	1.678
Constant	0.397	0.565	0.507	1.469

NOTE 1: Quantity of prototype - 60 systems.

NOTE 2: Sunk None
R&D None

b. Engineering Development (6.4)

		Low	High
Range:	Inflated	0.785	1.063
	Constant	0.598	0.810

Most likely funding profile:

	FY83	FY84	FY85	TOTAL
Inflated	0.448	0.401	0.075	0.924
Constant	0.352	0.297	0.055	0.704


NOTE 3: Quantity of prototype - 200 systems

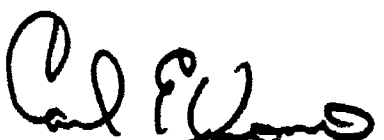
c. Unit Flyaway Cost. Broad based estimates of unit flyaway cost expressed constant FY 79 dollars.

<u>ITEM</u>	<u>UNIT COST</u>	<u>QUANTITY</u>	<u>LEARNING SLOPE</u>
Aircrew Clothing System	\$488	5,000	85%

NOTE 4: Inflation has been incorporated in accordance with DARCOM letter, DRCCP-ER, subject: Inflation Guidance, provided on 17 May 1979.

MARADCOM COST ANALYSIS	
CECDC CONTROL NO.	0713793
VALIDATION LEVEL	I II <u>III</u>
ANALYST	<u>P. J. De Costa</u>
PHONE NO.	<u>955-2698</u>
VALIDATION DATE	<u>13 July 1979</u>
VALIDATION EXPIRATION DATE	<u>13 July 1980</u>

for 
 STAN R. SHERIDAN
 Major General, USA
 Director for
 Development and Engineering


 CARL E. VONO
 Brigadier General, GS
 Deputy Chief of Staff
 for Combat Developments

ANNEX A

OPERATIONAL MODE SUMMARY/MISSION PROFILE FOR AN AIRCREW CLOTHING SYSTEM, INTERMEDIATE COLD, COLD AND EXTREME COLD WEATHER (SHORT TITLE: AIRCREW CLOTHING SYSTEM, COLD WEATHER)

1. BACKGROUND: The tasks and frequency of use presented below are based upon the threat, tactics and doctrine envisioned in the mid 1980-1990s time frame. The tasks are not only typical of those performed in the Alaskan Scenario but also reflect tasks typical of aircrews engaged in cold weather airmobile combat operations anywhere in the world. Typical aircrew tasks to be performed by aircrews wearing the Aircrew Cold Weather Clothing System and to be tested in DT/OT I are listed in paragraph 2 below.

2. MISSION TASKS:

a. Preflight: The aircrew member must be protected from cold during preflight at ambient air temperatures, yet retain sufficient dexterity and ease of movement to touch, feel, see and climb around the various parts of an airframe.

b. Inflight: The aircrewperson must be able to perform specific flying duties in the relatively close cramped confines of a cabin/cockpit, yet be protected from the cold and from fire and crash impact injuries to the maximum extent possible. Cold weather aircrew microenvironments are modified by a combination of ambient temperature, efficiency of aircraft heating systems and specific mission profiles. At ambient air temperatures below -17.78°C (0°F), the cabin/cockpit temperature design standard of 4.44°C ($+40^{\circ}\text{F}$) is attained only during portions of actual mission work. During preflight and runup, cabin/cockpit temperatures are close to ambient air temperatures. Once the aircraft engine heater is started, temperatures are slowly brought up to design standard. This may take 30 minutes. During missions, when doors are opened to on/off load cargo or passengers, cabin/cockpit temperature approaches ambient within two minutes. Once doors are closed, rewarm time may be as long as initial starting. At times, on/off loading occurs before design standard temperatures are attained. In the event of heater malfunction at ambient temperatures -34.5°C (-30°F) to -51.1°C (-60°F), cabin/cockpit temperatures approach ambient within 15 minutes.

c. Survival: The aircrewperson must have the clothing and equipment necessary to survive in the event of emergency in cold regions until a rescue is effected. (This involves, in order of priority: Protection from the environment, ability to repair injuries to the body, interface with potential rescue efforts and sustenance.) Some items of clothing and

equipment that comprise the ensemble will have a purpose when used for pre-flight and flight as well as survival. Shortcomings of the ensemble that relate only to survival application must be compensated for with items included in a supplemental survival kit. The problem is compounded during ejection from OV-1 aircraft in cold regions since the aircrewperson must not have exposed skin because of the extreme windchill effects and must eject together with all his equipment necessary for survival.

3. MISSION SEQUENCES:

- a. Perform preflight tasks.
- b. Perform inflight tasks (includes emergency).
- c. Perform survival tasks.

4. MISSION PROFILE: Mission profile coincides with that of all current and developmental Army and Navy/Marine Corps aircraft transposed into the Alaskan Scenario or engaged in cold region airmobile combat operations in other areas of the world. This includes OH-58, OH-6, CH-54, CH-47, UH-1, AH-1, C-12, U-8, U-21, AAH, ASH, CH-47D, UV-18, UH-60, RC-12, RU-21, OV-1 and RV-1 Army aircraft; and F-4, F-14, F-18, A-4, A-6, EA-6, A-7, CH-46, CH-53, AH-1G and UH-1N Navy/Marine Corps aircraft.

ANNEX B

COORDINATION ANNEX

Agency	<u>Concurrence</u>	<u>Comments</u>	
		<u>Acceptable</u>	<u>Non-Acceptable</u>
USAREUR & 7th Army			
USRDCOM			
USA CINCPAC Spt Gp			
DARCOM	X	2	
FORSCOM			
USACC			
USAINSCOM	X		
USARJ			
Eighth USA			
USA HSC	X		
USA OTEA		1	2
USA CAA			
USA Log Eval Agcy		3	
TAC (DRP)			
Dir, MTMC, TEA	X		
Dir, DMATC			
Comdt of the Marine Corps		9	
CG, Marine Corps Dev Ctr			
CNO			
CSAF			
Sr Std Rep			
USA Std Gp-UK (Assoc)			
USA Std Gp-Canada (Assoc)			
USA Std Gp-Australia (Assoc)			

Assume concurrence from all others when no response was received after 45 days.

Comments not accepted for incorporation into the LOA are as follows:

1. OTEA (CSTE-PON) comment to combine this LOA and the LR for Glove, Flying, Extreme Cold Weather, is not favorably considered.

Rationale for Non-Acceptance. The LR is a short term fix. The LOA may incorporate the LR item if a system approach deems the LR item to be the best solution. The option to develop a follow-on system if needed should be retained.

2. OTEA (CSTE-PON) comment to address flash/heat protection afforded by the uniform is not favorably considered.

Rationale for Non-Acceptance. Para 3b(20) is correct; it is an overall statement as to the requirement of nuclear survivability for the system. The fact that the system provides a degree of heat/flash protection is an essential characteristic for air crash fire protection, para 3b(4) and plus for nuclear survivability.

Appendix I
EXTREMITY COOLING GRAPHS

Cooling Rate of 5th Finger at Various Ambient Temperatures (T_a) Leather Shell with Wool Insert - Wind Speed 0 mph

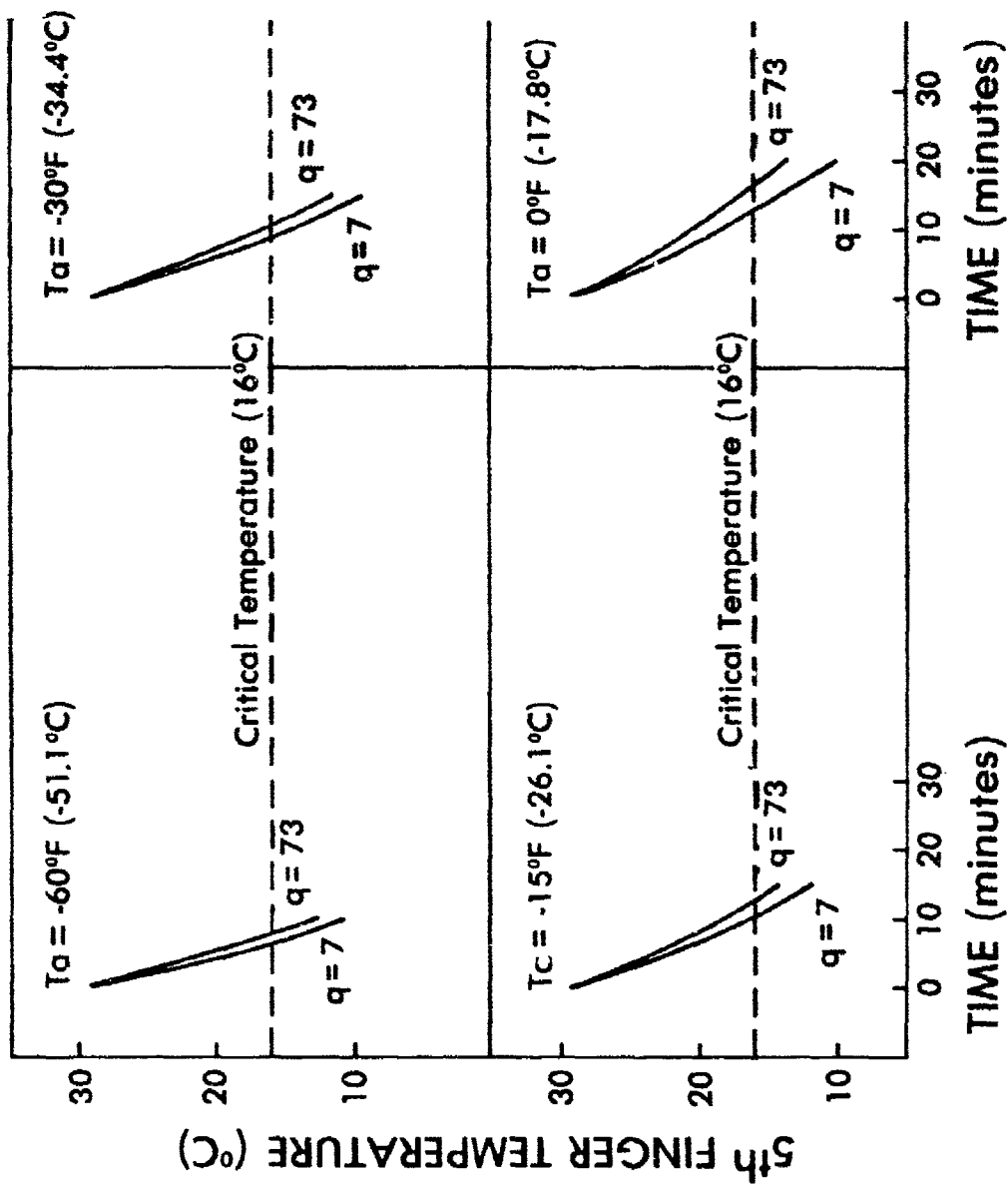


Figure I-1. Cooling rate of 5th finger at various ambient temperatures -
 leather shell with wool insert - wind speed 0 mph.

Cooling Rate of 5th Finger at Various Ambient Temperatures Leather Shell with Wool Insert - Wind Speed 10 mph

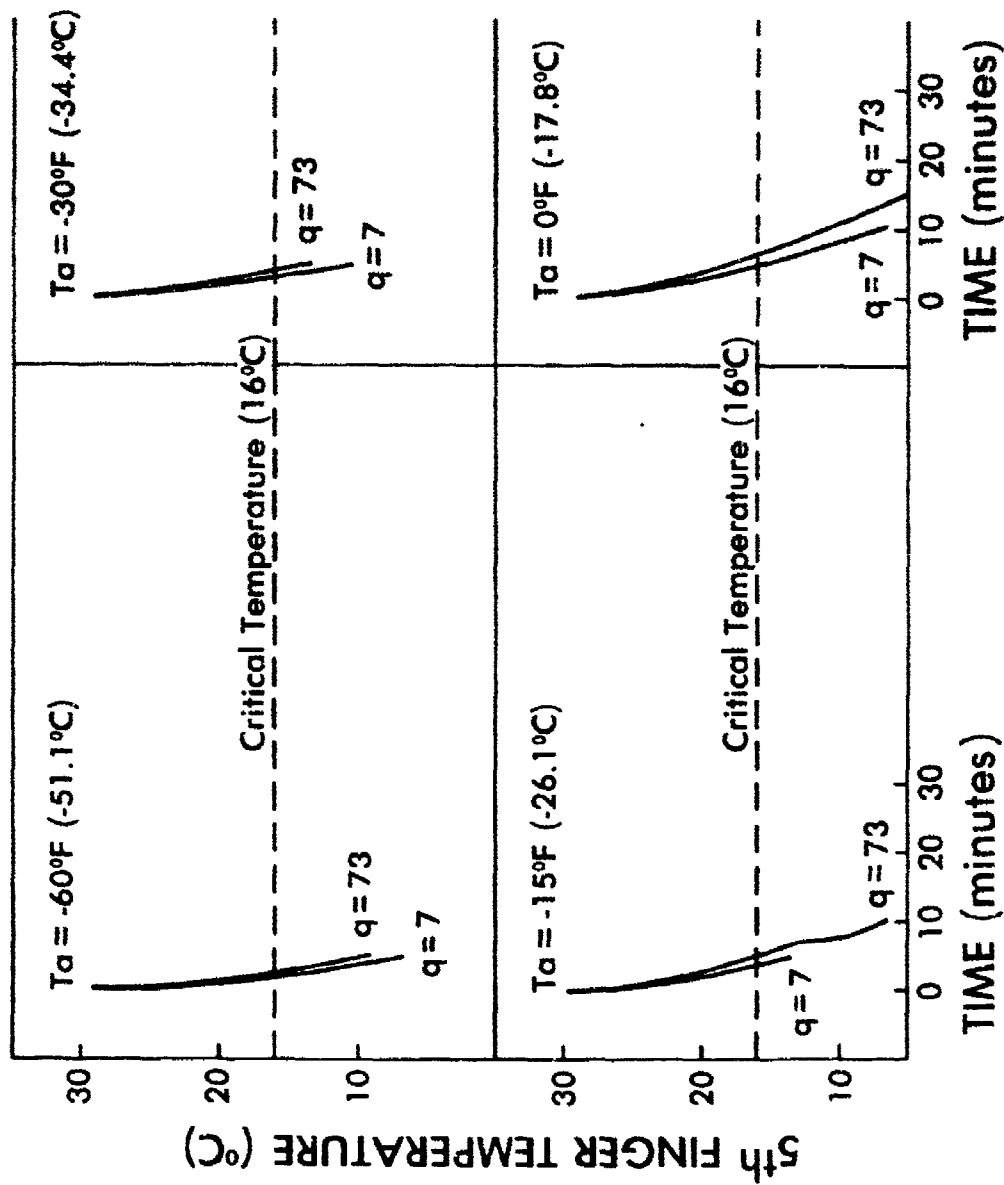


Figure I-2. Cooling rate of 5th Finger at various ambient temperatures - leather shell with wool insert - wind speed 10 mph.

Cooling Rate of 5th Finger at Various Ambient Temperatures Arctic Mitten Over Glove - Wind Speed 0 mph

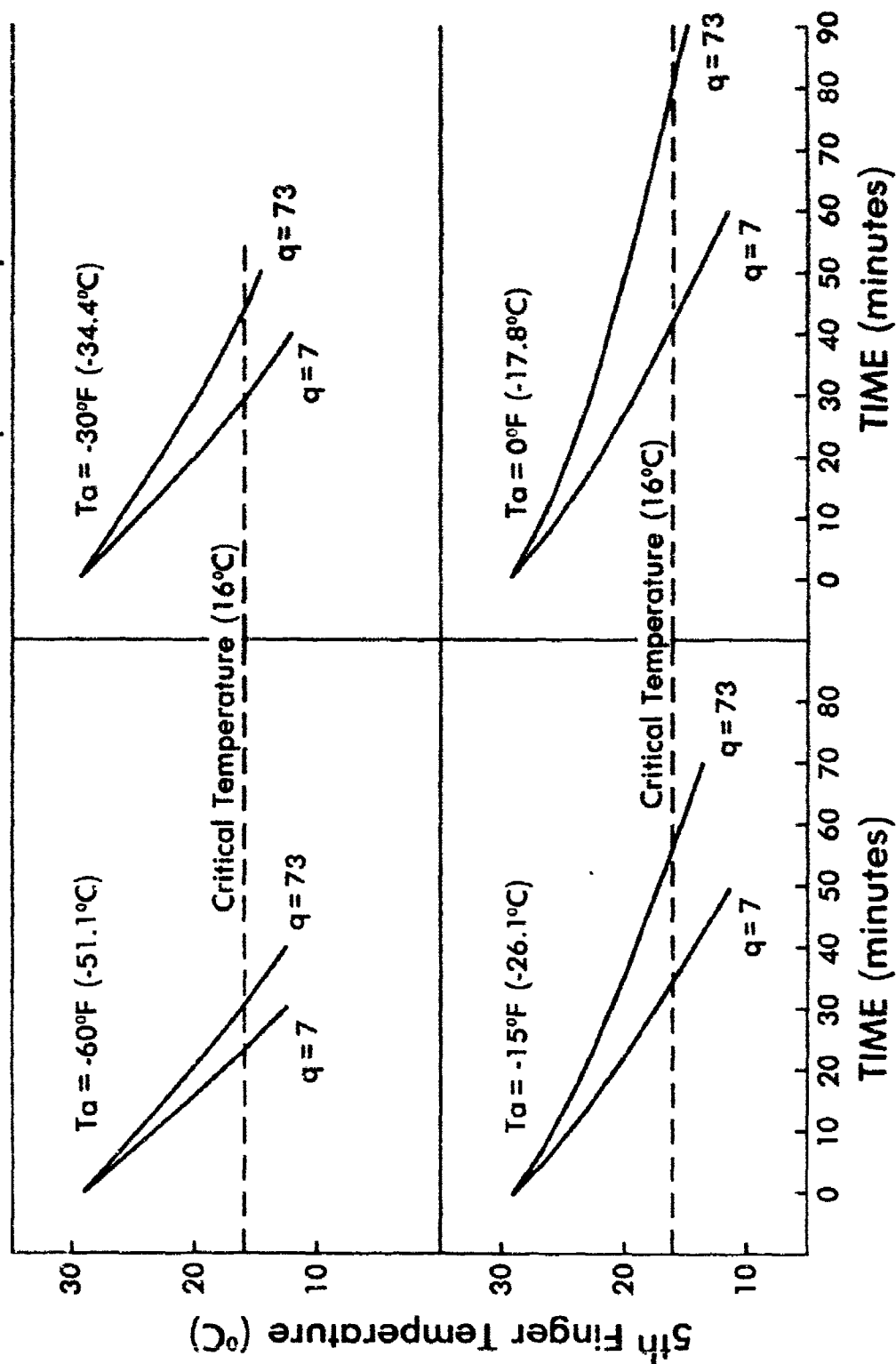


Figure I-3. Cooling rate of 5th finger at various ambient temperatures - arctic mitten over glove - wind speed 0 mph.

Cooling Rate of 5th Finger at Various Ambient Temperatures Arctic Mitten Over Glove - Wind Speed 10 mph

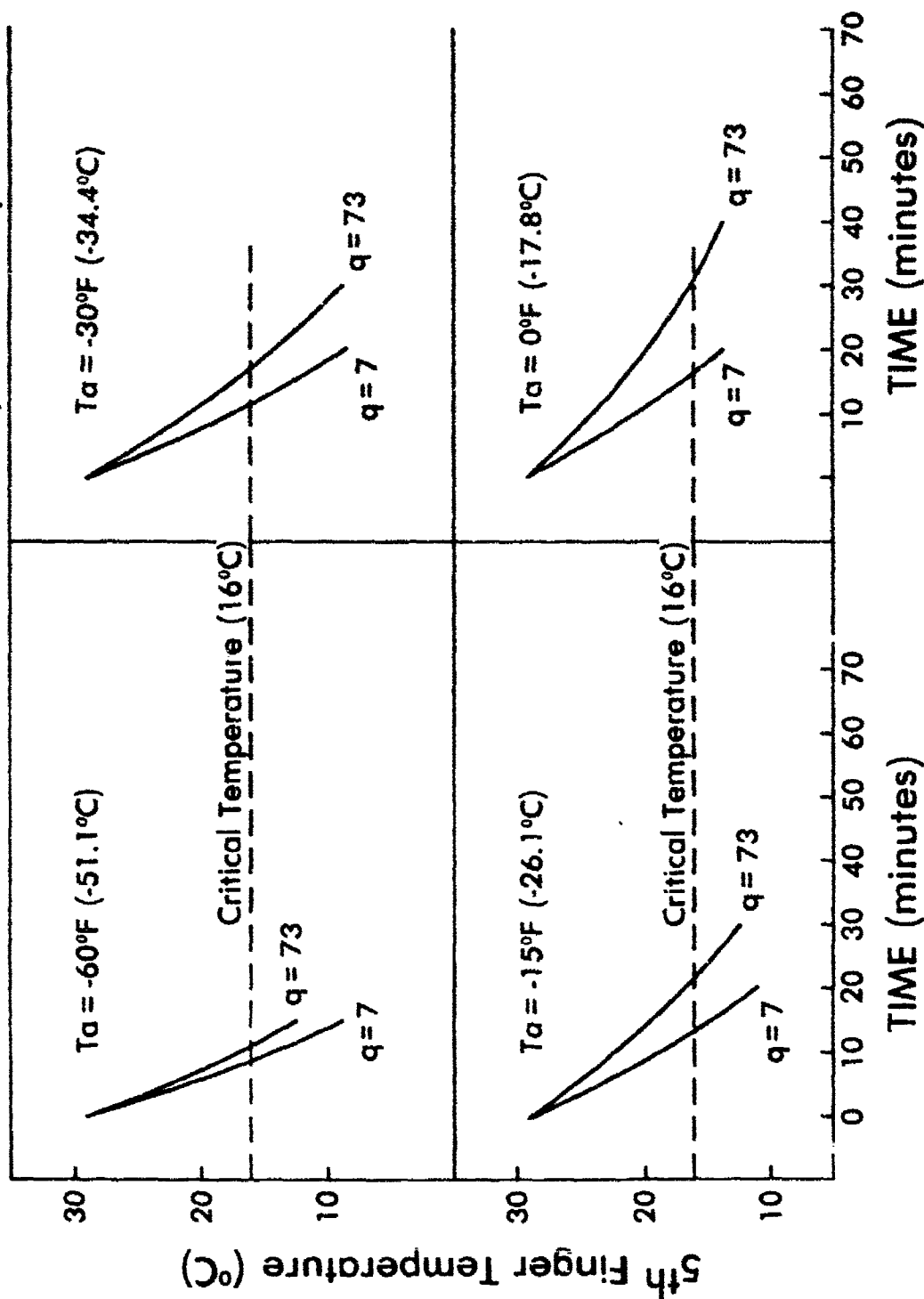


Figure I-4. Cooling rate of 5th finger at various ambient temperatures - arctic mitten over glove - wind speed 10 mph.

Cooling Rate of 5th Finger in Constant Cockpit Temperature Glove with 0.5 Clo Fingertip Insulation

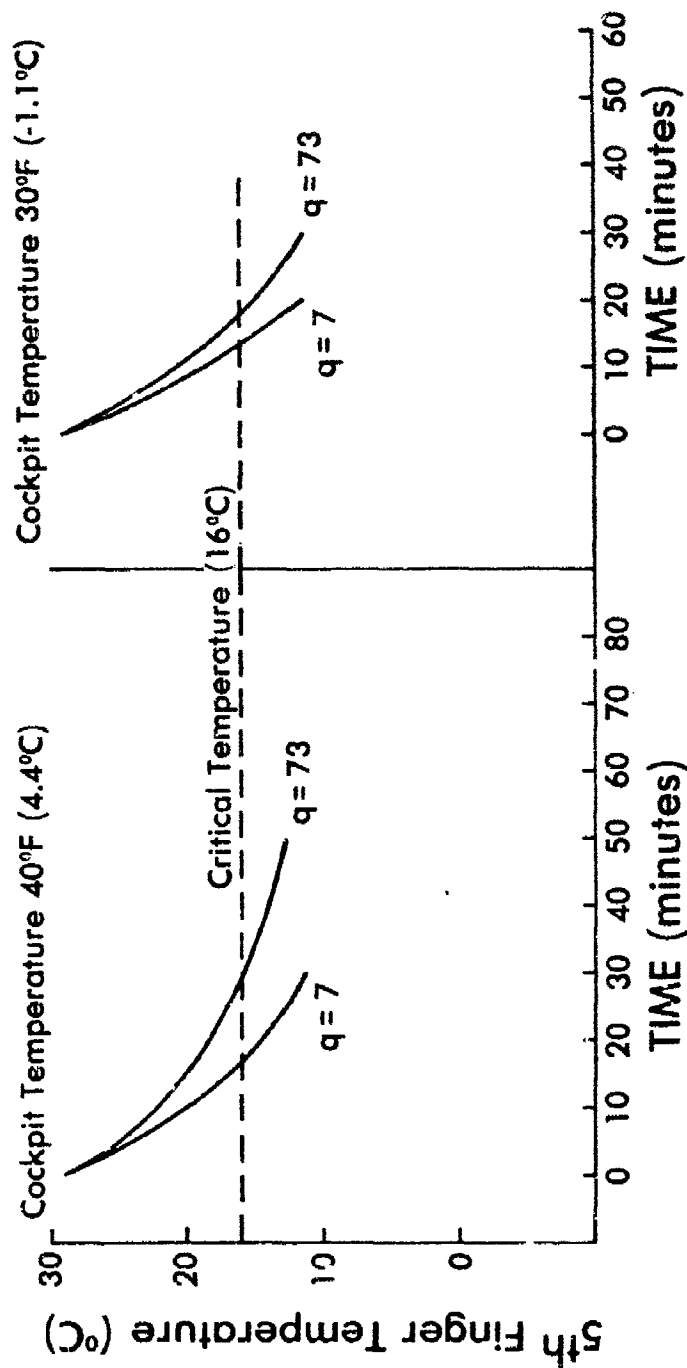


Figure I-5. Cooling rate of 5th finger in constant cockpit temperature-glove with 0.5 clo fingertip insulation.

Cooling Rate of Toes at Several Ambient Temperatures Toecap Clo=1.2

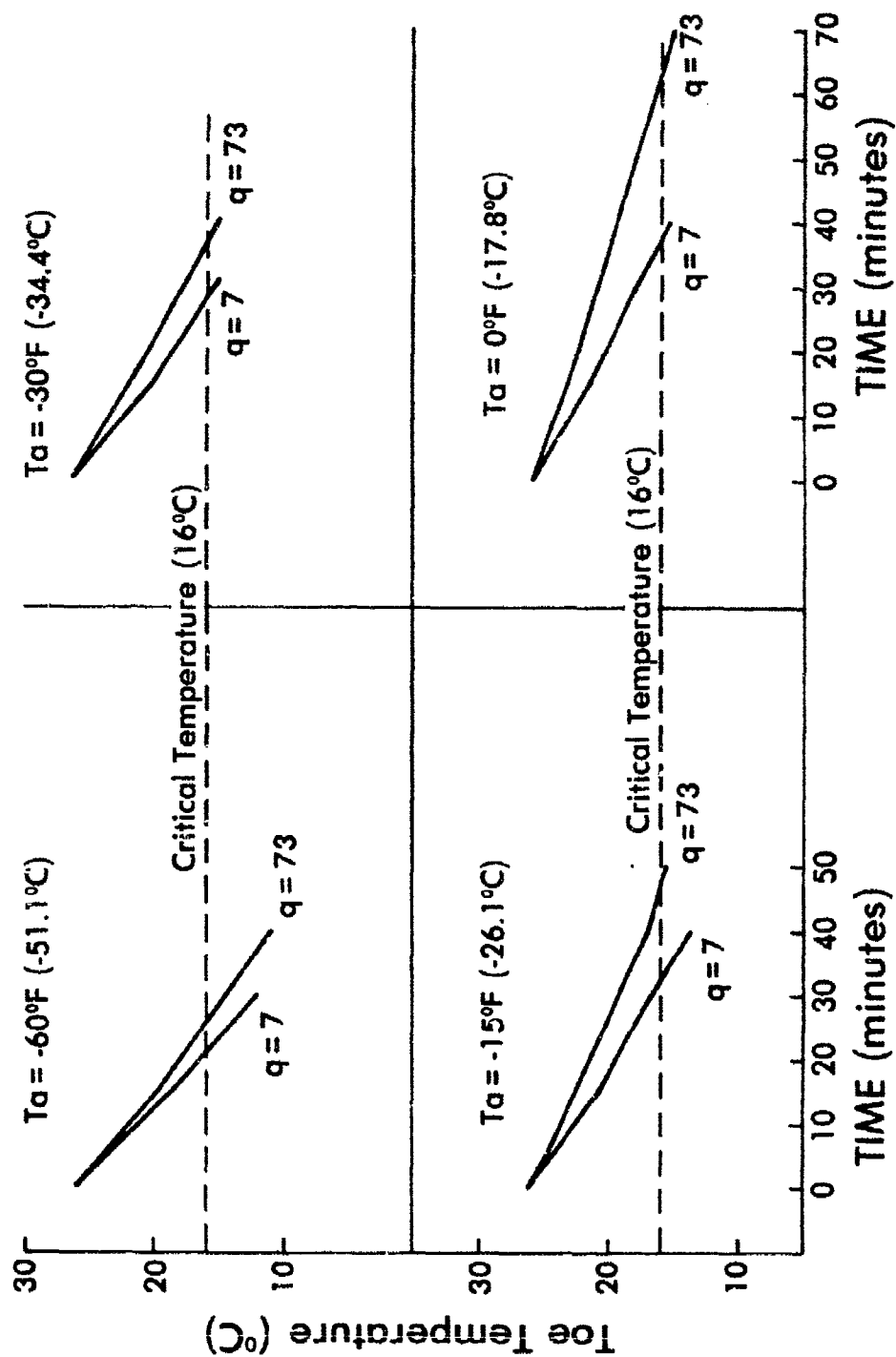


Figure I-6. Cooling rate of toes - several boots and ambient temperatures.

Cooling Rate of Toes at Several Ambient Temperatures Toecap Clo=1.6

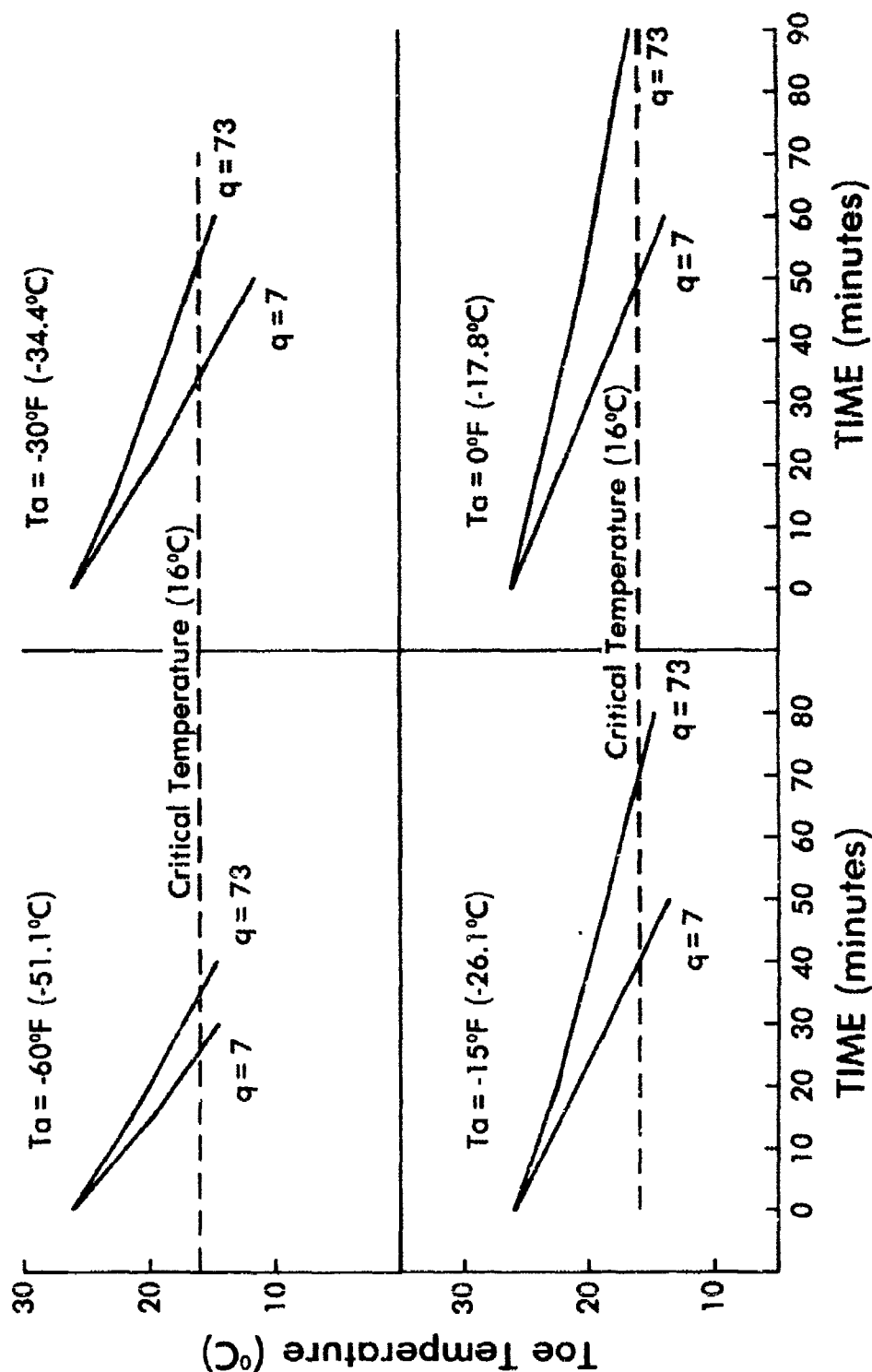


Figure I-6 (Cont'd). Cooling rate of toes - several boots and ambient temperatures.

Cooling Rate of Toes at Several Ambient Temperatures Toecap Clo=2.0

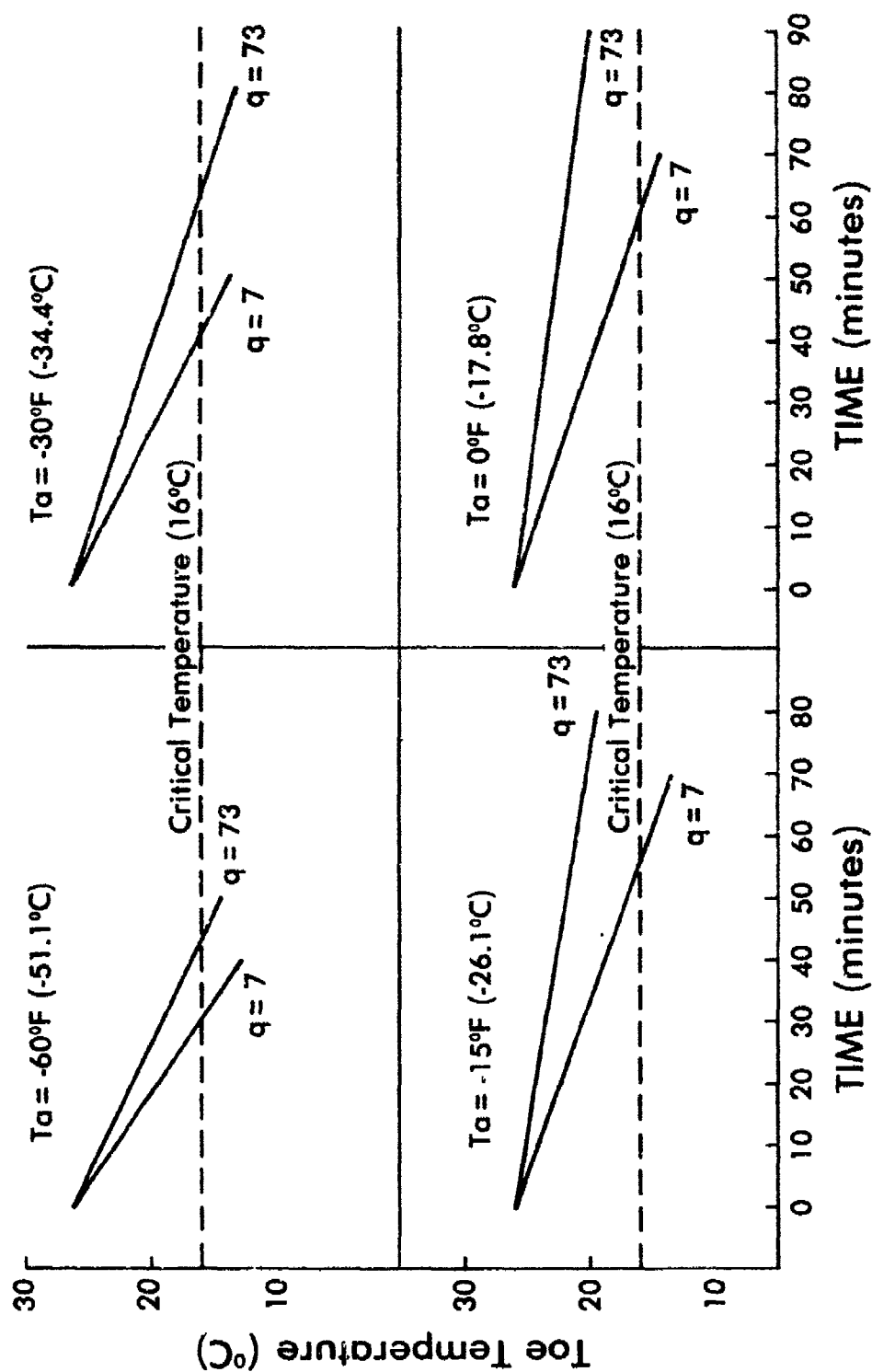


Figure I-6 (Cont'd). Cooling rate of toes - several boots and ambient temperatures.