MSC-03909

HABITABILITY DATA HANDBOOK

VOLUME 5

GARMENTS AND ANCILLARY EQUIPMENT

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HABITABILITY DATA HANDBOOK
VOLUME 5
GARMENTS AND ANCILLARY EQUIPMENT

JULY 31, 1971

PREPARED BY

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PREFACE

The Habitability Handbook is a collection of data in six volumes which include requirements, typical concepts, and supporting parametric data. The handbook provides an integrated data source for use in habitability system planning and design, intersystem trade-offs, and interface definition. The following volumes comprise the Habitability Data Handbook:

Volume	Title
1	Mobility and Restraint
2	Architecture and Environment
3	Housekeeping
4	Food and Water Management
5	Garments and Ancillary Equipment
6	Personal Hygiene

This volume provides data pertinent to wardrobes and ancillary equipment applicable to extraterrestrial habitats and vehicles.

These data are considered preliminary and are predominantly derived from analytical and terrestrial sources and in general lack zero-g verification.

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1.0 INTRODUCTION

1.1 PURPOSE

The Garments and Ancillary Equipment volume was developed to provide handbook data for use by space system planners, designers, system engineers and habitability system engineers. The handbook presents the criteria by which crew garments, garment support systems, and ancillary equipment may be evaluated for use in manned spacecraft. The document integrates habitability technology in handbook format by presenting wardrobe concepts and garment selections based on crew considerations and material selection criteria. In addition, the impact of wardrobe logistics and laundry system concepts are assessed.

1.2 MAJOR INTERFACE AREAS

The garment system, ancillary equipment, and washer concepts interface with the following habitability areas:

- Architecture and Environment (Volume 2)
- Housekeeping (Volume 3)
- Personal Hygiene (Volume 6)
- Mobility and Restraint (Volume 1)

The Architecture and Environment volume provides data pertaining to design considerations for minimum crew dressing envelopes, laundry facilities, and garment storage areas. The Housekeeping volume provides data concerning the processsing of laundry water to remove impurities.

The Personal Hygiene volume provides data concerning reusable wipes for body washing and drying. The Mobility and Restraint volume defines requirements and concepts for body restraints to be used during dressing and garment washing.

1.3 HANDBOOK USE

Section 2 presents general requirements for determining the type of material to select for garment construction and the number of wardrobe garments. To obtain data concerning a particular garment concept or selection, locate the type of garment under garment style concepts or wardrobe definition in Section 3. Section 3 also provides a method of determining the type of wardrobe (disposable or reusable) required based on the requirements contained in Section 2. Section 4 presents garment restraint concepts and additional fabric items that satisfy requirements outside of the personal wardrobe.

Section 5 presents an analytical approach to fabric selection. The thermal data are based upon the heat transfer and thermodynamic interactions between a man and his clothing. The thermal data are also applicable to bedding materials, or other fabric items that require thermal design. With the general garment body distribution requirements determined by thermal criteria, the elements of garment construction are presented to allow comparison of fabric data, design details, and weight determination factors prior to selection of the appropriate construction methods. Section 5 also provides the results of specific material tests that allow selection of the proper material for a specific garment.

Section 6 presents wardrobe logistic data concerning garment packaging volumes and garment transfer envelopes. The weight and volume of each garment item are determined by the thermal design and construction method as selected by the designer (Reference Section 5).

Hand and automatic laundry system concepts, along with pertinent weight and volume data, are presented in Section 7. In addition, soap and detergent data are presented.

A glossary of terms commonly used in the textile industry, and certain terms used in the presentation of thermal aspects of garment systems, are presented in Appendix A. An illustrative example of how to use the handbook is presented in Appendix B. Various materials have been evaluated for combustion rates, physical characteristics, and outgassing. The results of the evaluations are presented in Appendix C, Fabric Characteristics Summary.

1.4 NOMENCLATURE

A	=	Body surface area (ft^2)
A_{mr}	=	Material Area Ratio (%)
C	=	Crew size
d	=	Major diameter (ft)
D	=	Compressed yarn major diameter (In.)
De	=	Denier
D_o	=	Yarn circular diameter (In.)
E	=	Evaporative heat rate (Btu/ft^2)
h	=	Convective film coefficient (Btu/ft^2-°F-hr)
h_{fg}	=	Latent heat of vaporization of water (Btu/lb)
I	=	Insulation (Clo)
I_a	=	Atmosphere Insulation (Clo)
I_c	=	Clothing Insulation (Clo)
I_t	=	Average Insulation (Clo)
k	=	Gas conductivity (Btu/ft^2-°F-hr)
M	=	Mass (lb) or End density (yarns/In.)
M_{H_2O}	=	Mass H_2O (lb)
n	=	Minimum number of stitches/In.
N	=	Pick density (yarns/In.)
P	=	Porosity factor
PBI	=	Polybenzimidazole
ø	=	Crimp factor
Q	=	Heat load (Btu/hr)
T	=	Temperature (°F)
U	=	Overall heat transfer coefficient (Btu/ft^2-°F-hr)
W	=	Weight (lb)
WI	=	Wear Interval (days)
WR	=	Wear Rate (lb/day)

2.0 GENERAL REQUIREMENTS

The data for the following requirements must be provided prior to garment material selection or garment system definition for a particular mission and crew:

1) Mission Profile
   - Mission duration
   - Number of crew members
   - Atmosphere (with total pressure)
   - Temperature (minimum and maximum)
   - Maximum dew point temperature
   - Gas ventilation velocity

2) Crew Data
   - Metabolic rates during:
     Exercise
     Duty (normal and maximum)
     Sleep
   - Crewmen physical sizes in percentile
   - Garment wardrobe weight and volume limits

3.0 WARDROBE SELECTION

3.1 CREW CONSIDERATIONS

3.1.1 Crew Size Program. A sizing system for flight clothing has been developed from body measurements obtained from approximately 4000 Air Force personnel. Two body dimensions, height and weight, form the basis of this sizing program and were selected due to the high correlation between these variables and other body dimensions. A twelve-size program was selected from the Air Force study for inclusion in the handbook because it contains the largest number of sizes, namely, four categories of weight each having three categories of height. Figure 3-1 presents the relationship of height and weight for this twelve-size program. Superimposed on the size categories depicted in the figure is the distribution of an astronaut and scientist population which consisted of 87 men.*

3.1.2 Crew Size Distribution. A size distribution was obtained from a sample of eighty-seven astronaut/scientist personnel. The data indicate that the largest percentage represented in this survey is in the medium-regular category with the balance of the sample distributed over the entire range. Figure 3-2 depicts the sample distribution of the current astronaut/scientist population. The shaded areas of the bars represent the results of the 4000 man Air Force sizing study which are included for comparison.

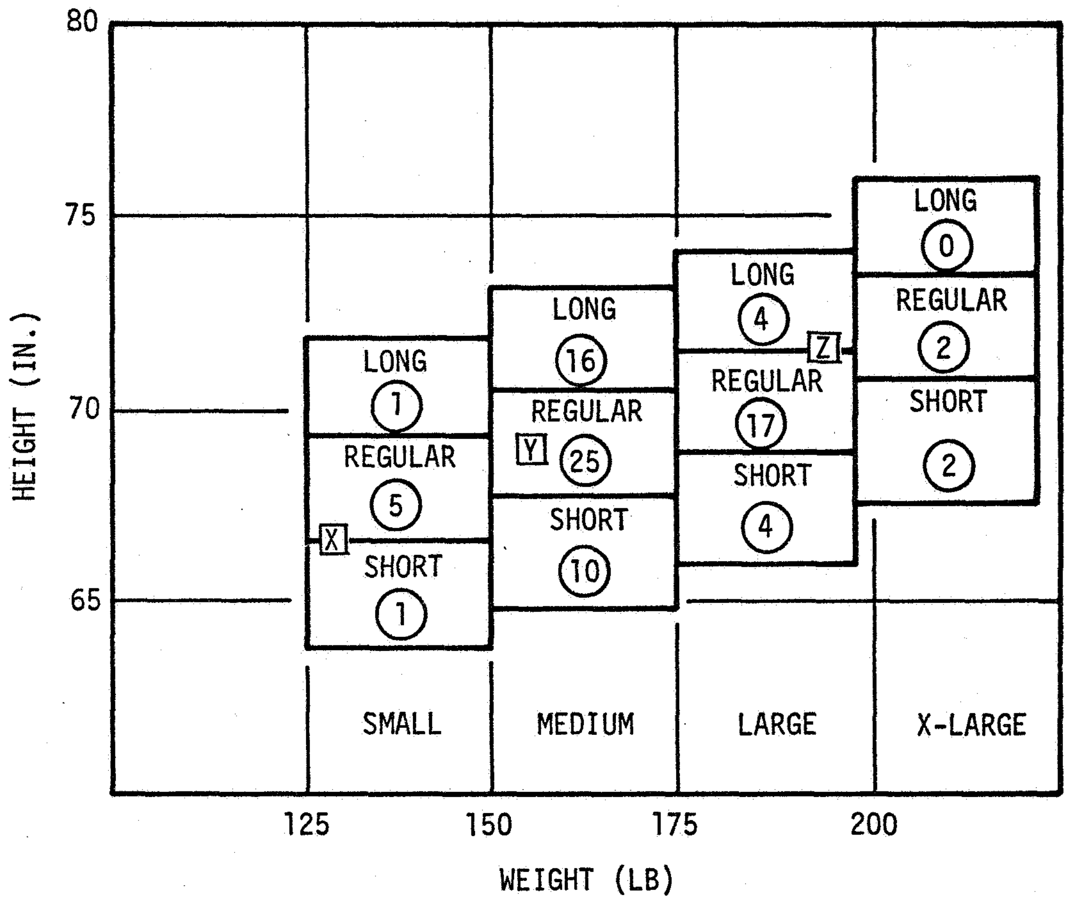
3.2 GARMENT STYLE

The style of a garment must have the combined elements of proper function, minimum weight, and aesthetic appeal. One of the prime considerations of garment design is the decision to use a single-piece or two-piece coverall. Both types of coverall garments have been employed by each branch of the military service for specialized tasks and general wear. Criteria for one or two-piece selection are provided in Table 3-1.

3.2.1 Single-Piece Coveralls. Single-piece coveralls currently in use in the military are shown in Figure 3-3. The users of these coveralls range from a pilot to a crew member of an atomic submarine. The primary configuration differences are the type and location of the pockets, the adjustment

*Data extracted from Reference 2

(Text continued on Page 3-6)



NOTE:
- SIZE CATEGORIES ARE FOR 12-SIZE PROGRAM
- CIRCLED NUMBERS INDICATE NUMBER OF ASTRONAUTS/SCIENTISTS FITTING THAT PARTICULAR CATEGORY OUT OF A TOTAL OF 87.

X - 5TH PERCENTILE
Y - 50TH PERCENTILE
Z - 95TH PERCENTILE

Figure 3-1. Crew Size Program

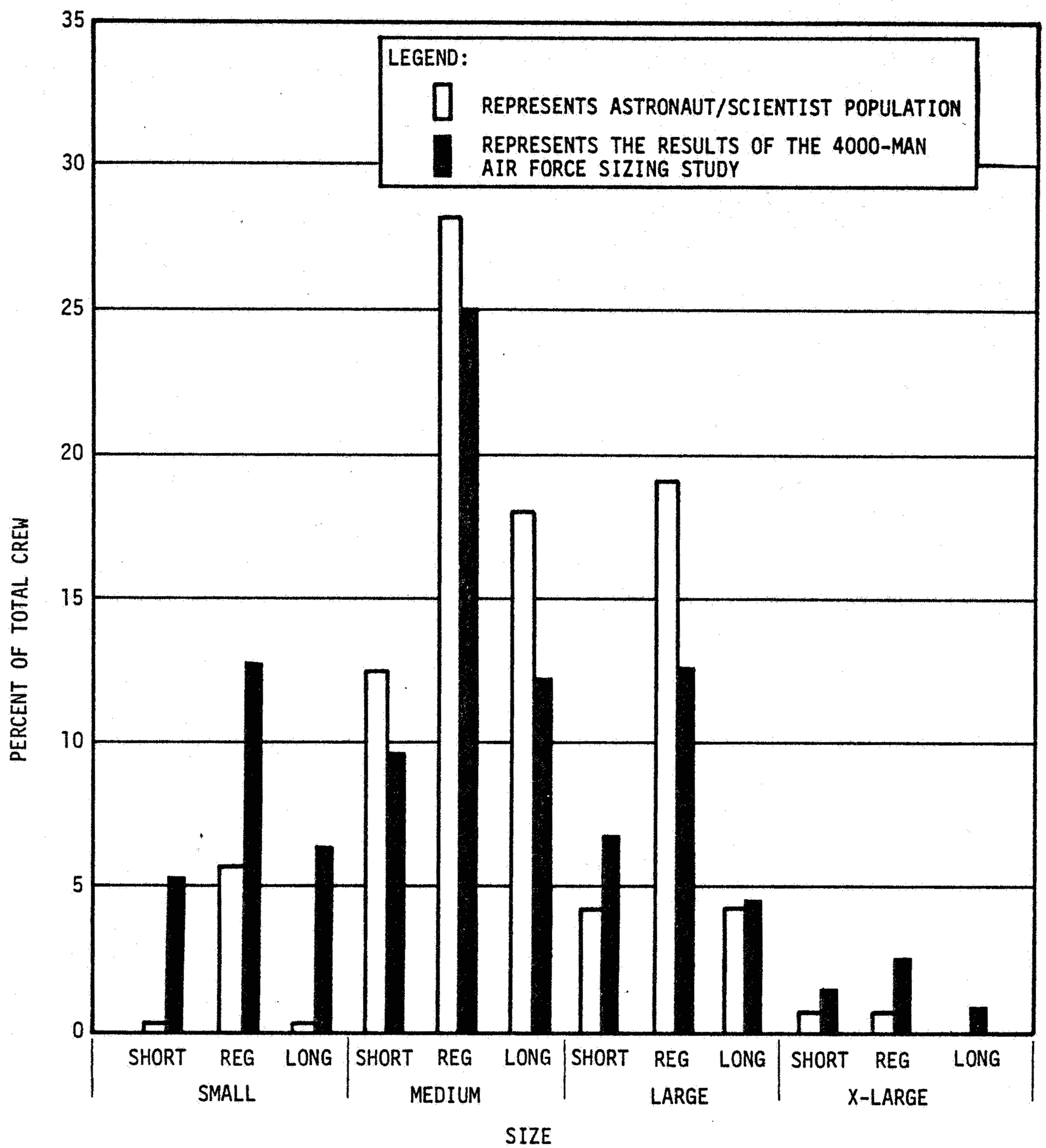
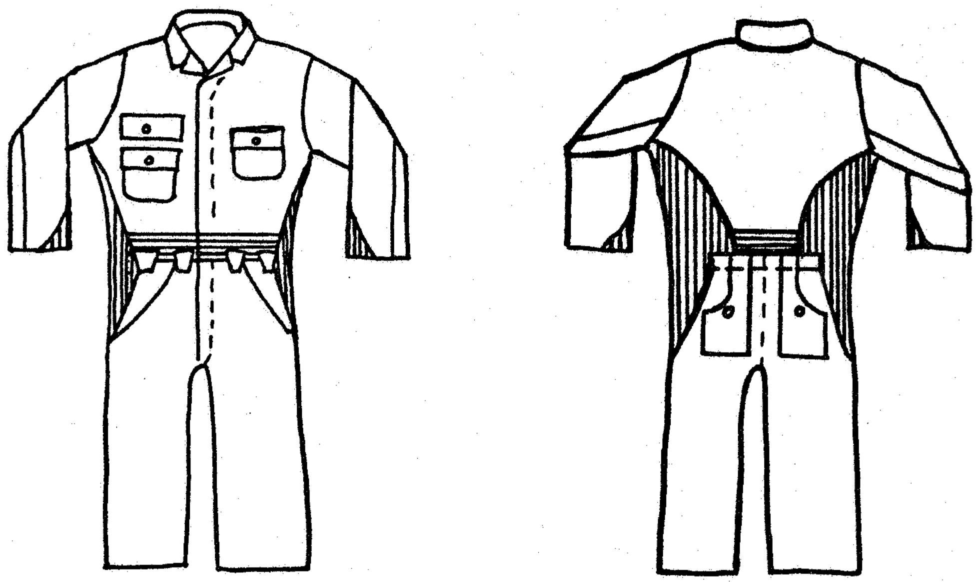


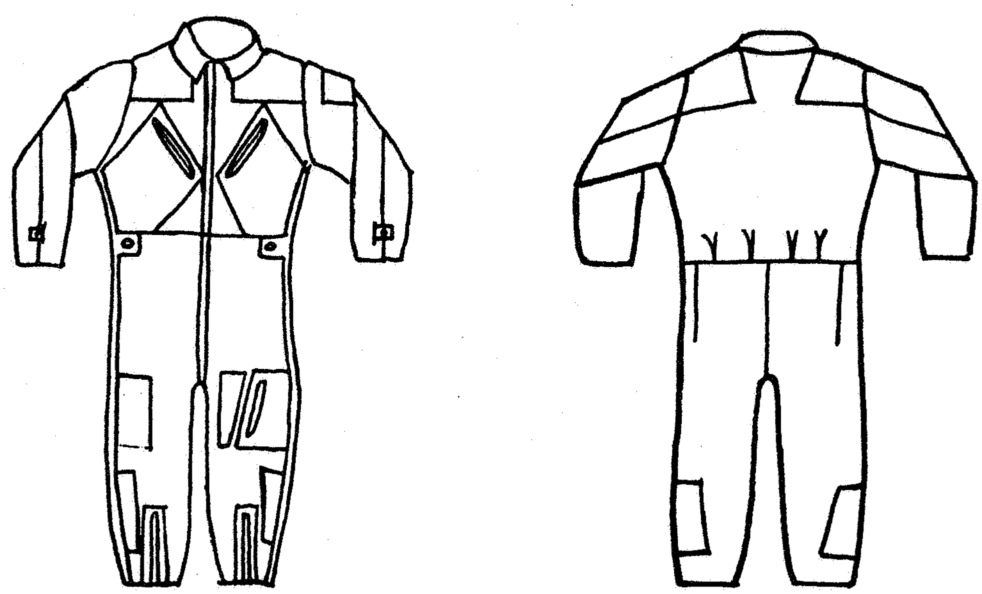
Figure 3-2. Crew Size Distribution

Table 3-1. Comparison of Single and Two-Piece Coverall Garments

Criteria \ Item	Single Piece	Two Piece
Advantages	Total enclosure of body Antisnag	Adapatation to temperature variations Waste management compatibility
Disadvantages	Requires tailoring for proper drape	Some migration
Weight	1.5 - 2.0 lb	1.6 - 2.1 lb
Don/Doff	Can be donned in less time	Familiar donning operation
Cleaning	Cleaned at one time	Articles in wash load may be staggered
Appearance	Utilitarian	Sportswear



UTILITY COVERALLS
(NUCLEAR SUBMARINE)
MIL-C-21897 (S&A)



K2B SUIT

MIL-C-6265E (USAF)

Figure 3-3. Coverall Concepts

provisions, and the type of fasteners used. Size interchangeability has been introduced to a certain extent with the addition of expandable material at the waist and side panels of the submarine coverall garment. In this manner, the drape is also improved as the garment is more conformal. Present use of single-piece garments is generally limited to personnel performing specific tasks requiring environmental or contaminant protection.

3.2.2 Two-Piece Coveralls. Two-piece coveralls and uniforms have been employed in all branches of the service for both general and heavy-duty operations. The advantages of a two-piece garment are launderability and flexibility. The two-piece garment does not require laundering of the trousers and jacket at the same time, thereby reducing the laundry system volume requirements. The flexibility afforded by a two-piece garment is the adaptation to temperature variations by use of the jacket. The major deficiency of a two-piece garment is the migration of the jacket during extreme body motion. Depending upon the degree of confinement, the jacket may not return to the original position. Figure 3-4 presents several styles of two-piece coveralls.

3.2.3 Entry Provisions. The common garment entry methods for both single and two-piece coverall garments are shown in Figure 3-5. For all two-piece coveralls, the entry provision to the trousers is the same as shown in the first concept. In all cases, a front entry is desirable if a crew member is to don the garment unaided.

3.2.3.1 Two-Piece Garments (See Figure 3-5).

Front Entry

This method of entry has the shortest mating surface length and therefore requires the fewest number of fasteners. It is symmetrical, allowing equal pocket distribution and the most common of entrance methods.

Side Entry

The side entry method is advantageous for specialized duties that involve contamination of the frontal area of a garment. Cleaning is facilitated by not allowing stains or contamination into seam and fastener areas where buildup could occur. A second feature of this method is that it allows a degree of conformance to the body for woven materials. The placement of the

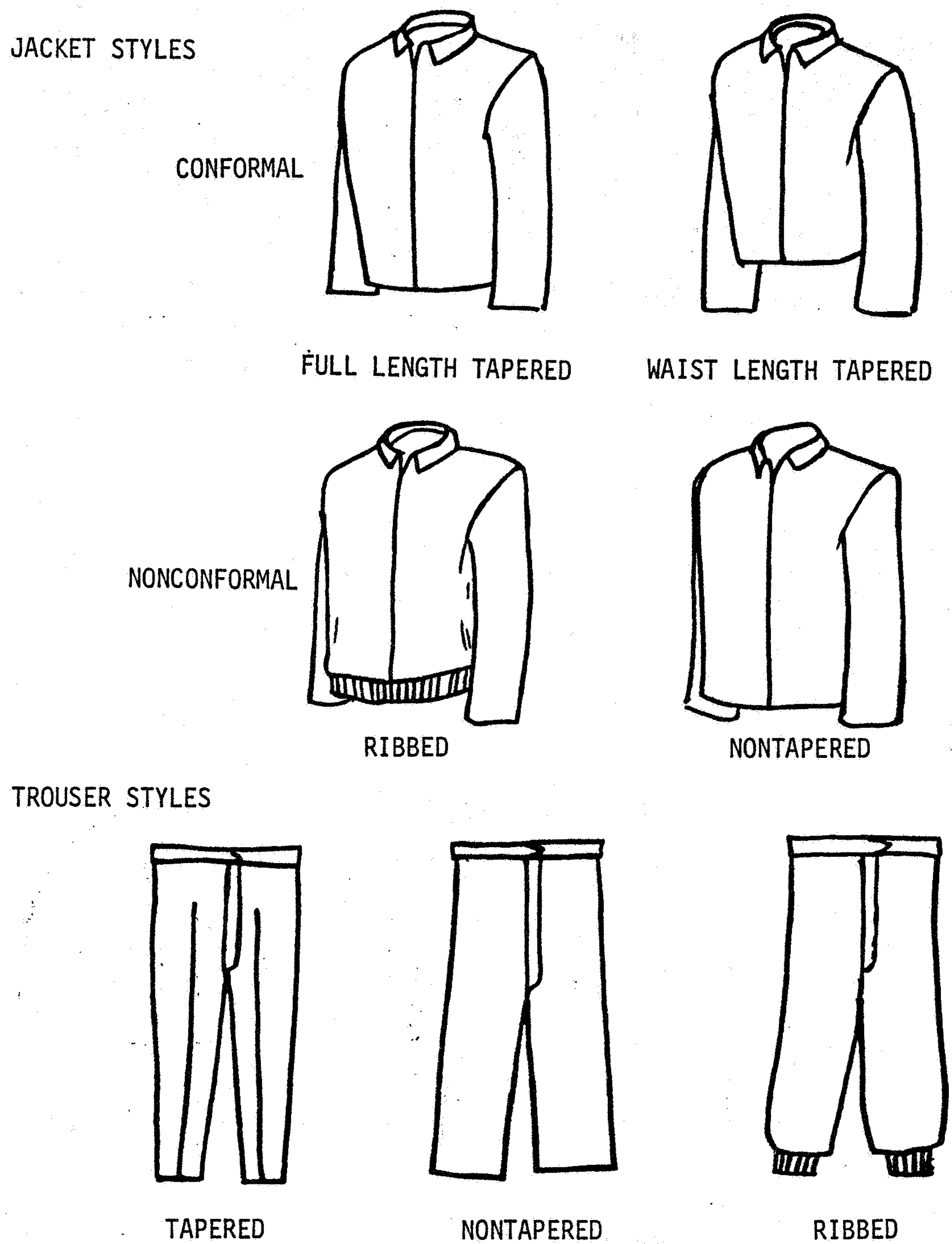


Figure 3-4. Two-Piece Coverall Garments

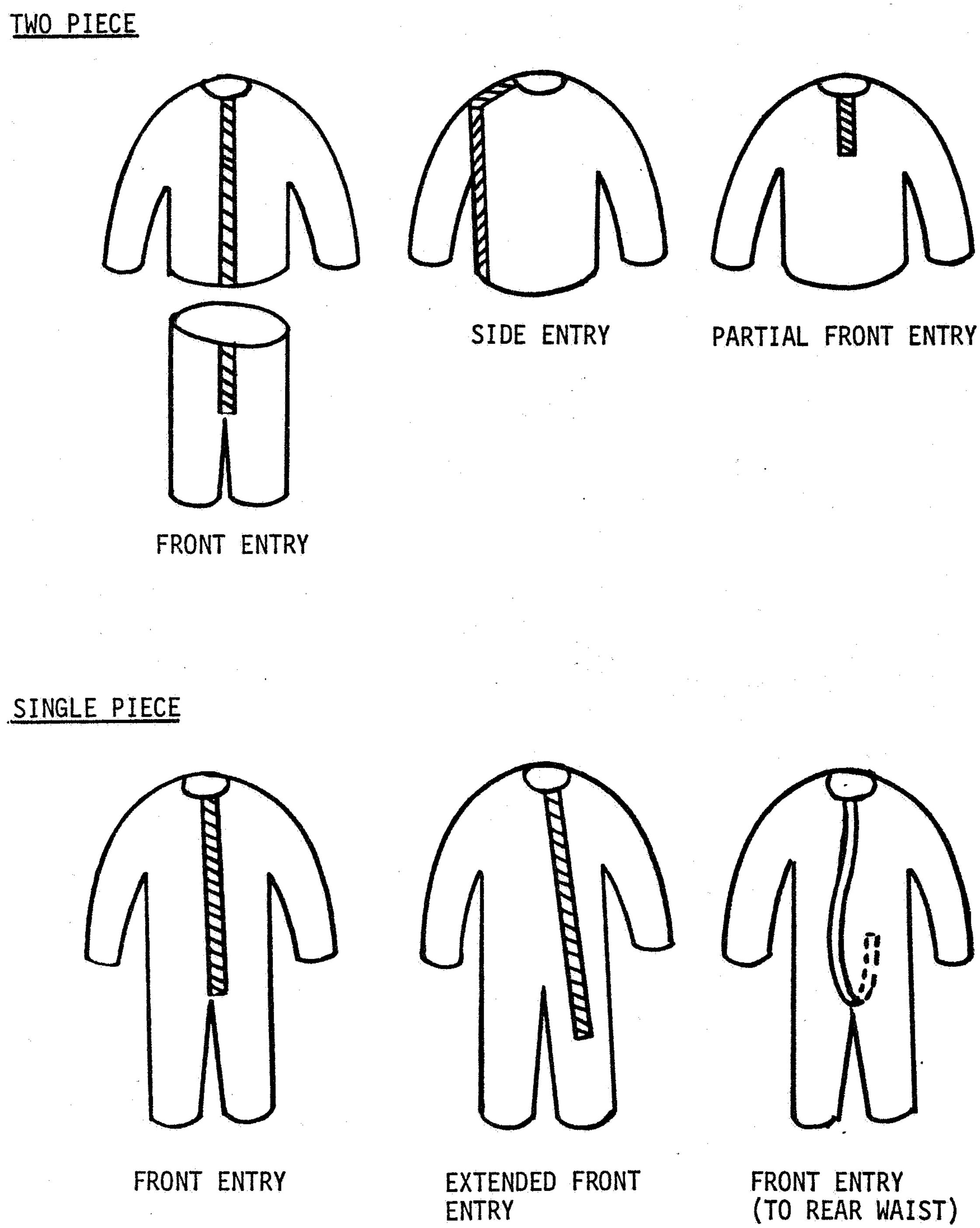


Figure 3-5. Garment Entry Provisions

relatively stiff fastener seam is at an area of least length change during body bending.

Partial Front Entry

This method is used primarily with stretchable materials such as knits and requires overhead donning.

3.2.3.2 Single-Piece Garments (See Figure 3-5).

Front Entry

This method is the combination of the front entry method for two-piece garments. The primary disadvantage is the lack of proper interface with the Waste Management System.

Extended Front Entry

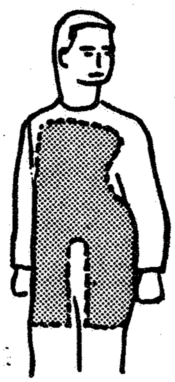
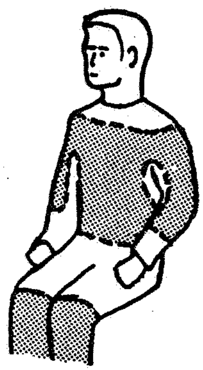
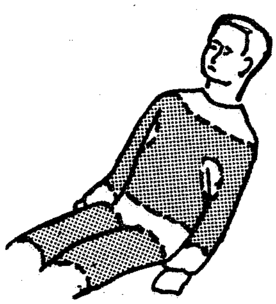
This method is advantageous for extremely cramped donning areas. It allows a fixed position of the body on the garment while putting limbs into sleeves and legs. However, this concept has the same disadvantage as the previous concept.

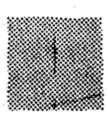
Front Entry (single piece - alternate)

In this method, the entry seam is extended to the rear waist. This concept allows for crew interface with the Waste Management System without removing the garment.

3.2.4 Pocket Location. The location of pockets in a garment is a function of the items to be contained and the working position of the crewmen. With the availability of increased workspace, the task oriented items such as checklists and manuals may be stored at the work stations. The use of pockets in the wardrobe shall be concerned with the items presented in Table 3-2. Two styles of pockets are available, the internal and external types. The internal, or slash pocket, conceals the material within the garment and is hidden from sight. The capacity of the pocket is limited due to garment drape requirements. In the external pocket, increased space is available with the use of folded sides; however, a utilitarian style results.

Table 3-2. Pocket Location Criteria

Major Activity Position	Area of Pocket Location	Style/Contents	Applicable Personnel
Standing		Internal Keys Handkerchief Pencil/pen Wallet Nailcleaner Comb Sliderule	Executive Medical
Sitting		Internal/External Pencil/pen Checklists Manuals Tools	Computer operators Navigator Experiment monitors
Reclining		Internal/External Checklists Manuals Tools	Pilots Maintenance Technicians Monitors

 = Applicable Areas

3.2.5 <u>Garment Openings</u>. The appearance of a garment is determined by the design of the openings at the neck, wrists, ankles, and waist. The configuration of each opening and its relative merits are presented in the following paragraphs.

3.2.5.1 <u>Collar Designs</u>. One of the functions of a collar is to prevent chafing of woven materials against the neck. Collar configurations and their derivatives are presented in Table 3-3.

3.2.5.2 <u>Cuff Designs</u>. The purpose of a cuff is to strengthen the fabric of a garment around the ends of a sleeve or pant leg. A desirable cuff quality is to be conformal with the ankle or wrist, thereby avoiding encumbrance and increasing the garment's insulating properties. Since the cuff area must also be sufficiently large to accommodate donning, a stretchable material or split material with fasteners must be used. Cuff configurations are presented in Table 3-4.

3.2.6 <u>Shirt and Brief Styles</u>. The clothing worn underneath the coverall consists of a shirt, briefs, T-shirt (optional) and socks.

3.2.6.1 <u>Shirt Styles</u>. Knit shirts are considered to be most applicable for long-duration missions due to their minimum storage requirements and thermal characteristics. The disadvantages of a knit shirt are lack of rigidity for storing items in pockets and low abrasion wear resistance. However, if the shirt is covered by an outer garment, neither of the disadvantages are as important as the advantages afforded. Shirt styles are depicted in Table 3-5.

3.2.6.2 <u>Brief Styles</u>. The same relative merits of shirt styles apply to a lesser degree to the briefs. Selection of the knit or woven brief should be based on personal preference and fit; however, the weight and thermal characteristics favor the knit briefs. Brief styles are depicted in Table 3-6.

3.2.7 <u>Socks</u>. The function of a sock is to transfer moisture from the foot for evaporation. In this manner, the insulating qualities of the sock keep the foot warm while the moisture is evaporated through the shoe.

3.2.8 <u>Footwear Concepts</u>. The combination of station restraints, mobility aids, and shoe design must be considered for proper footwear selection.

(Text continued on Page 3-15)

Table 3-3. Collar Configurations

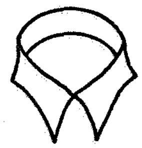
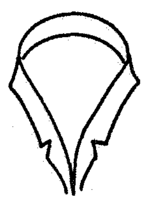
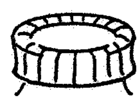
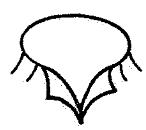
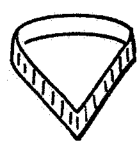
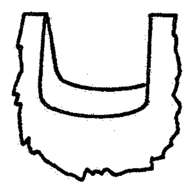
Type	Standard	Rib	Boat Neck (Collarless)
Configuration:			
Application:	Formal and informal, used with woven or knit material	Informal, used with shirts	Informal, used with knit material
Construction:	Fabric plies	Rib knit	None
Sizing:	Snug fit, requires separate measurement	Sized for head passage during donning, requires no special measurement	Allows head to pass through
Derivatives:	 Jacket	 Turtleneck  Combination  Vee Neck	 Undershirt
Weight and Volume	Heaviest, cannot be flattened and retain appearance	Easily packed, weight dependent upon derivative	Lightest and easily packed

Table 3-4. Cuff Configurations

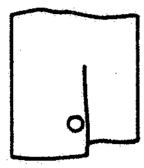
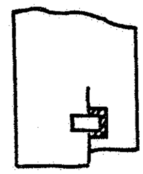
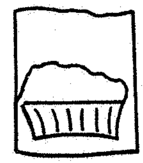
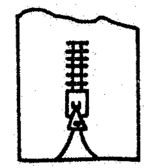
Types	Snap	Hook and Pile	Ribbed	Slide
Configuration				
Application	Street clothes	Apollo coverall	Outdoor jacket	Flight suits
Operations	One hand	One hand	None required	Two hands
Weight	0.1 oz	0.06 oz	0.3 oz	0.2 oz
Advantages	Lightweight	Quick release Lightest	Simple snug fit No sleeve wrinkles	Tight fit Strong
Disadvantages	Loose Some puckering	Wrinkled sleeve Loss of grip with lint	Relatively heavy	Relatively heavy Awkward Requires fitting

Table 3-5. Shirt Types

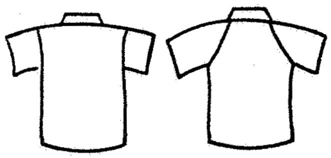
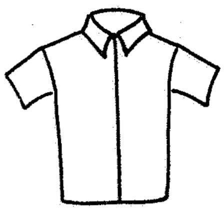
Type	Uses	Advantages	Disadvantages
Knit Shirts 	Conformal shirts T-Shirts	Soft Comfortable Easily stored Absorbent Light weight	Cleaning endurance
Woven Shirts 	Dress shirts Sport shirts	Rigid Favorable for pockets Endurance Loose fitting	Requires collar entry fasteners Storage volume

Table 3-6. Briefs

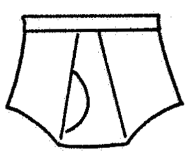
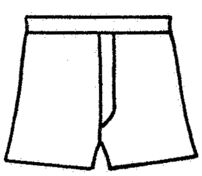
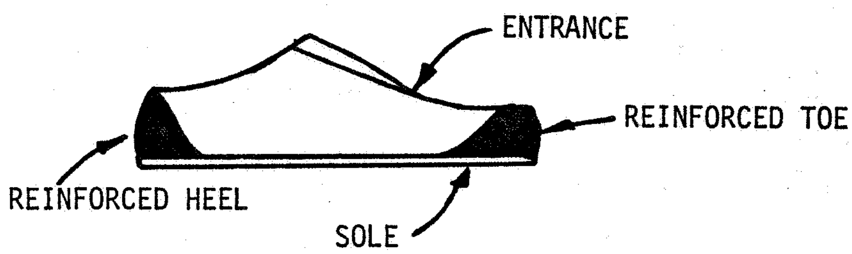
Type	Uses	Advantages	Disadvantages
Knit Brief 	Underwear	Soft Warm Easily stored Light weight Absorbent Conformal	Cleaning endurance
Woven Brief 	Underwear Gym shorts	Loose fitting Porous	Requires more size categories and tear resistance

Figure 3-6 presents several footwear concepts that are compatible with the data contained in the Mobility and Restraint Handbook (Volume 1).

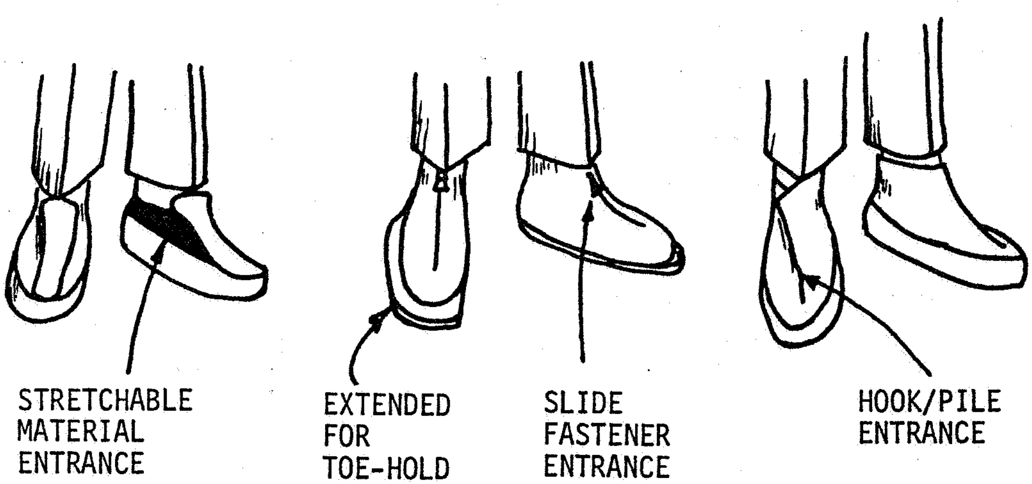
3.2.9 Protective Headgear. The area requiring greatest protection is the area least likely to be covered, the face. The second most critical area consists of the temporal regions of the head. Due to bone thickness and radius of curvature, the frontal and occipital (rear) areas of the skull are the strongest. The requirement for headgear is to transfer an impact force away from a vulnerable area and distribute it evenly over a stronger area. Since the crewman's shoulders tend to block and absorb the direct impact to the temporal regions, less emphasis is placed on this area than facial protection. Table 3-7 provides headgear concepts which are based upon facial protection.

Table 3-7. Headgear Concepts

Type	Protection	Weight	Remarks
Fabric with visor	Foam or inflatable pads-made of polyvinyl, polyurethane, foams	2-4 oz	Foldable, comparable to military style headgear Requires suspension system
Rigid hat with visor	Rigid shell covering head - made of fiberglas, plastic or metal	4-8 oz	Requires suspension system Provides best protection Communications equipment may be incorporated



GENERAL FEATURES



STYLES

Figure 3-6. Footwear Concepts

3.3 WARDROBE SELECTION AND BASIS OF SELECTION

3.3.1 <u>Disposable or Reusable Garment System Determination</u>. The garments will be either disposable or reusable (washed in orbit), depending on the crew size and mission duration. To date, the garments used in space missions have been disposable. However, with an increase in the number of crew members and mission duration, the weight and volume penalty of disposable garments becomes a major consideration. Use of reusable garments requires equipment that is not presently employed in spacecrafts, such as washers, dryers, shape retainer devices, and stain removal provisions.

3.3.1.1 <u>Laundry System Trade-off Considerations</u>. The trade-off between a cleaning system and a disposable garment approach is based upon the following considerations. The weight of disposable garments is a function of the basic item weight and the wear interval. The wear rate (established by dividing the fixed weight of an item by the wear interval) is computed for a total wardrobe for each crew member and multiplied by the number in the crew. This is presented in equation form below:

$$WR_{total} = C \times \left(\frac{W_{shirt}}{WI} + \frac{W_{jacket}}{WI} + \frac{W_{other}}{WI}\right)$$

Where:

WR = Wear Rate (lb/day)

C = Crew Size

W = Weight (lb)

WI = Wear Interval (period between changing - days)

The weight of a cleaning system consists of the fixed weight of the washer/dryer, the weight of water, the weight of the water reclamation unit, and the garment fixed weight. The weight of each of these is a function of the total wear rate, which, on an average basis, must equal the total laundry rate.

Figure 3-7 presents the relationship between the average laundry load and the required size of the washer internal volume. The laundry factor (β) is determined by the following equation:

$$\beta = \frac{CT}{LF \cdot UF}$$

Where:

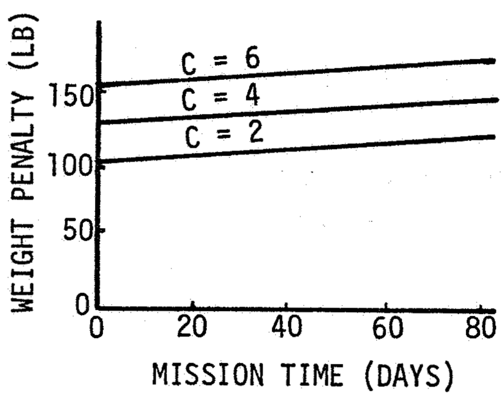
CT - Total Cycle Time (washing and drying)

LF - Loading Factors, the amount of clothing cleaned per cubic foot of washer or dryer (ranging from 2 lb/ft^3 for a dryer to 5 lb/ft^3 for a washer)

UF - Usage Factor, the percentage of hours of operation per day

Since each of these items influences the size and weight of a washer/dryer, the rationale for their selection is an important factor in the cleaning system penalty. The weight penalty for a typical laundry system is shown in Figure 3-8. The weight is based upon the internal volume of the washer of the type shown.

3.3.1.2 Laundry System Trade Off. The weight of a laundry system as a function of mission time and crew size (C) depends primarily upon the fixed weight since the only time dependent expendable weight is due to the detergent quantities. The weight values include the penalty of the washer and dryer, water storage, and reclamation hardware (see figure below).



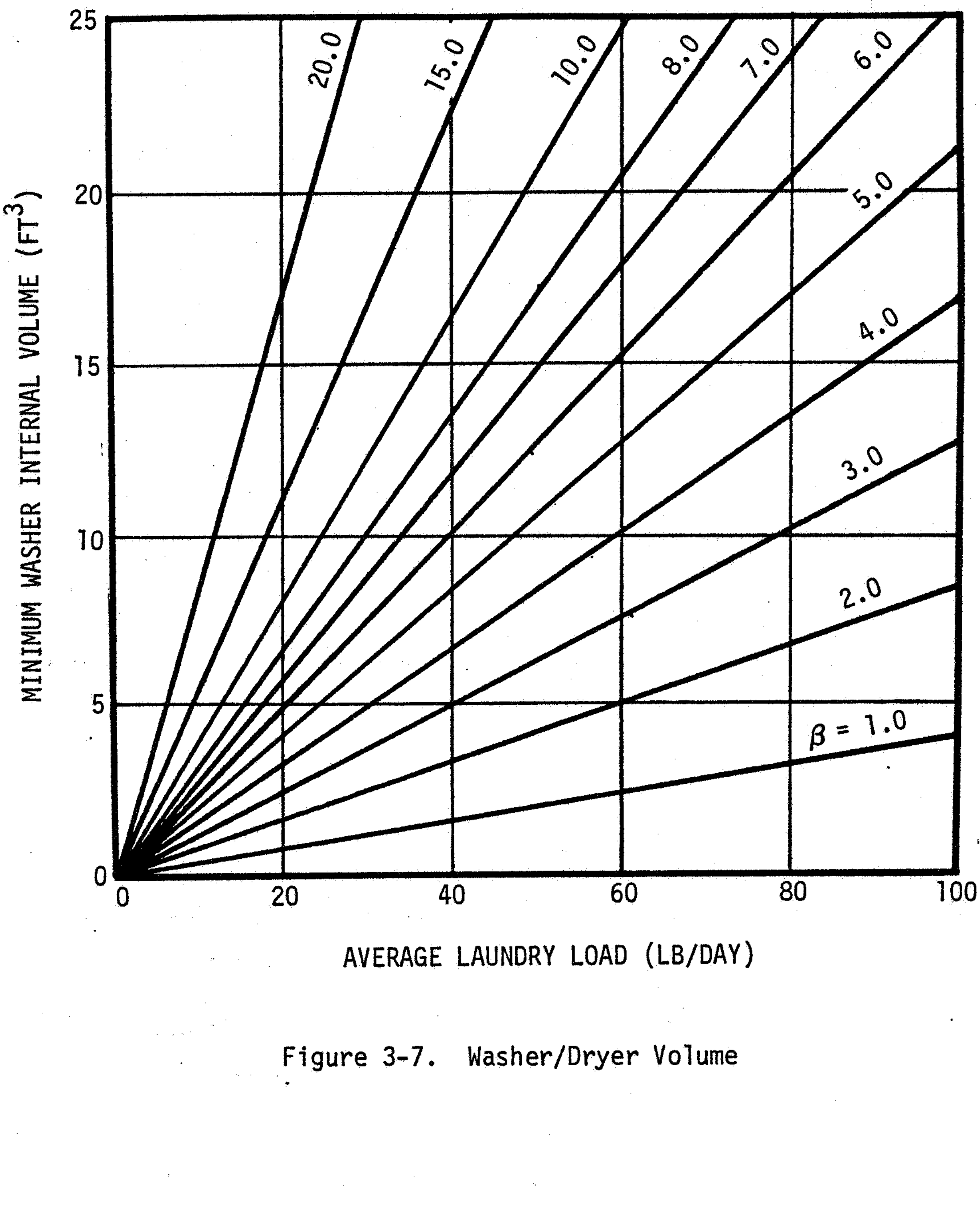


Figure 3-7. Washer/Dryer Volume

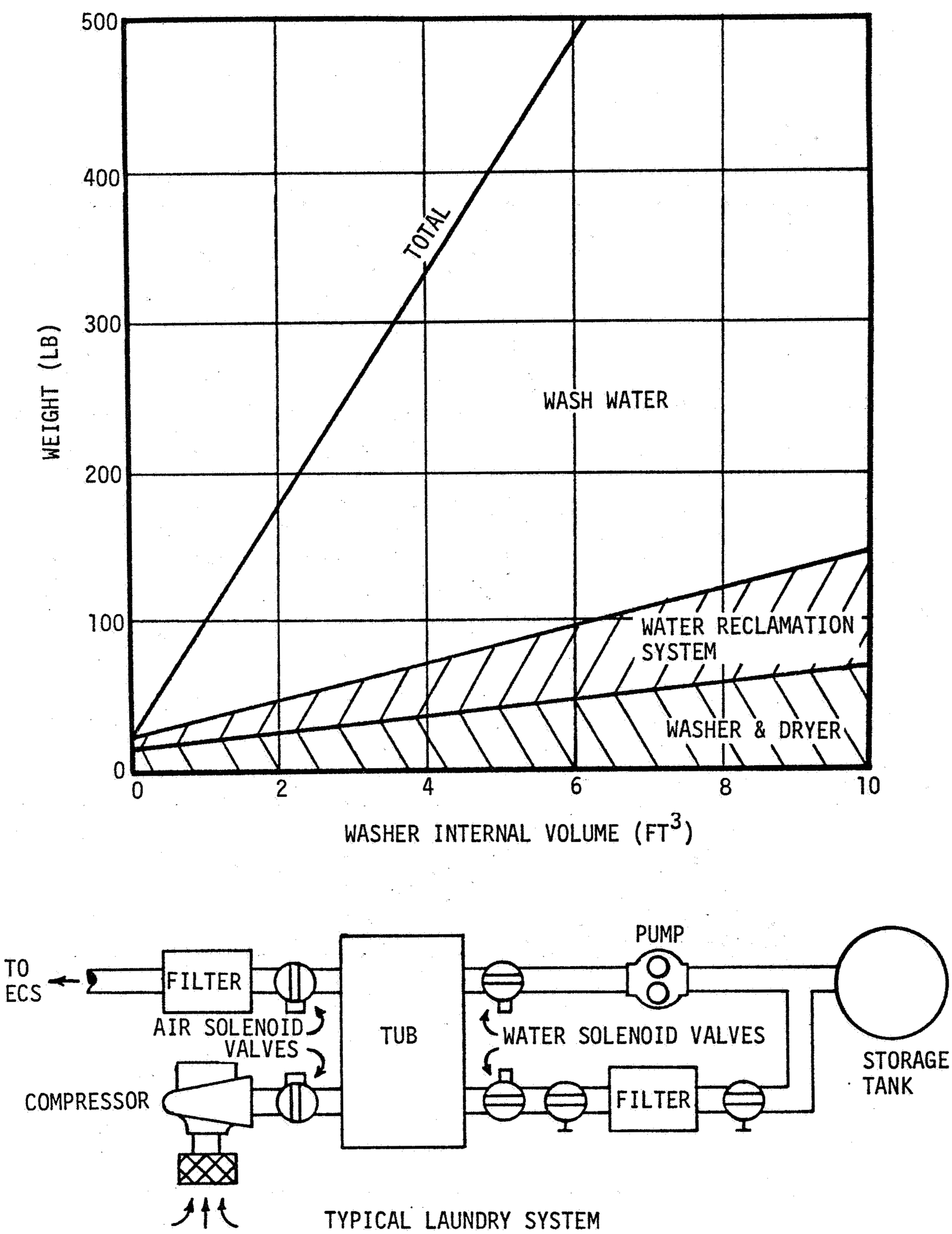


Figure 3-8. Laundry System Fixed Weight Penalty

Figure 3-9 shows a trade-off graph applicable for variable wear rates, crew sizes, weight penalties, and mission times. For a given crew size and mission time, if the point falls to the left or below the wear rate (break even point), a disposable garment system should be employed. If the point lies to the right or above the line, a laundry system should be used.

Example:

Crew size (C) = 6
Mission time = 40 days
Wear rate (WR) = 0.5 lb/man-day

Since the crew size curve and mission time index line intersect at a point below the 0.5 lb/man wear rate, a disposable garment system should be used.

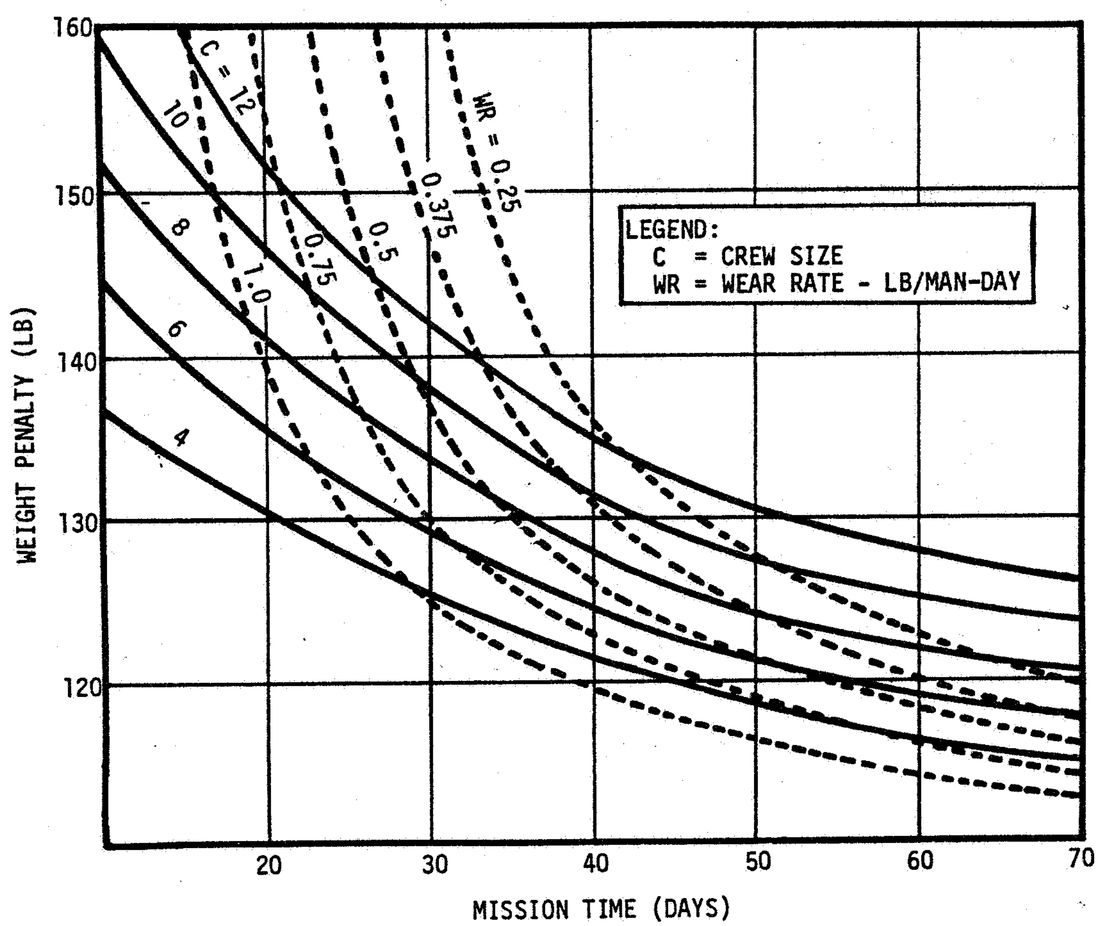


Figure 3-9. Laundry System - Disposable Garment Evaluation (Breakeven Points)

3.3.1.3 Laundry System Power. The power penalty of a laundry system is due to both the operation of the washer and the heat required for evaporation of water from the clothing during a drying operation. Although clothing can be dried with methods other than by heat, heat drying requires the least amount of time. Figure 3-10 shows the breakdown of power required to run a washer/dryer.

3.3.2 Crew Wardrobe Selection Criteria. The number of clothing articles in a basic wardrobe is a function of the following criteria in the order listed:

- Allowable Weight Approach - Knowing the maximum weight allowed per member and the weight of the component garments, the wardrobe may be determined on a relative wear basis. The wear interval/clean period should then be assessed in Figure 3-11.

- Allowable Volume Approach - This approach is the same as the weight approach, however, the transit volume in the shuttle vehicle is the important criteria. Knowing the volume of each item, the total wardrobe volume requirements for the entire crew may be estimated (Reference Section 6).

- Personal Preference - This method of establishing a wardrobe allows selection of a quantity of garments by judgment. It is used only when an excess amount of clothing is allowed by the above two methods.

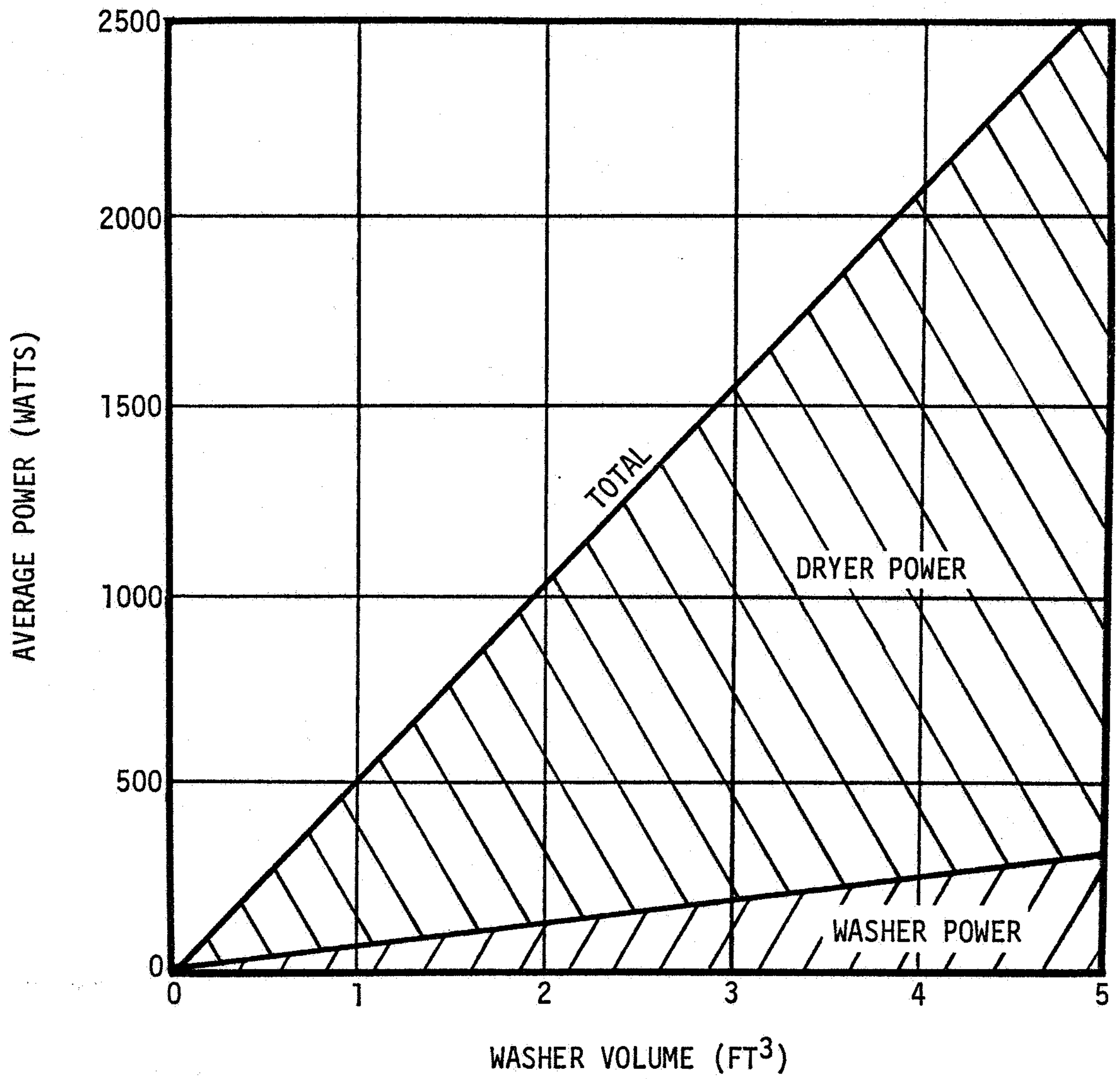
- Hygienic Standards - The soil picked up by the clothing will be due primarily to body oils and contaminants. Although odors will build up, crew perception of odors will decrease and no notice will be made of the level of odor. However, dermatitis may develop after a wearing period of three weeks. If wear intervals beyond three weeks are contemplated, the use of bactericides should be considered.

The allowable wardrobe of a crew may be determined by each of the above criteria subject to the following general ground rules:

- Outer clothes (jackets, trousers) are worn 5 to 6 times longer than underclothes.

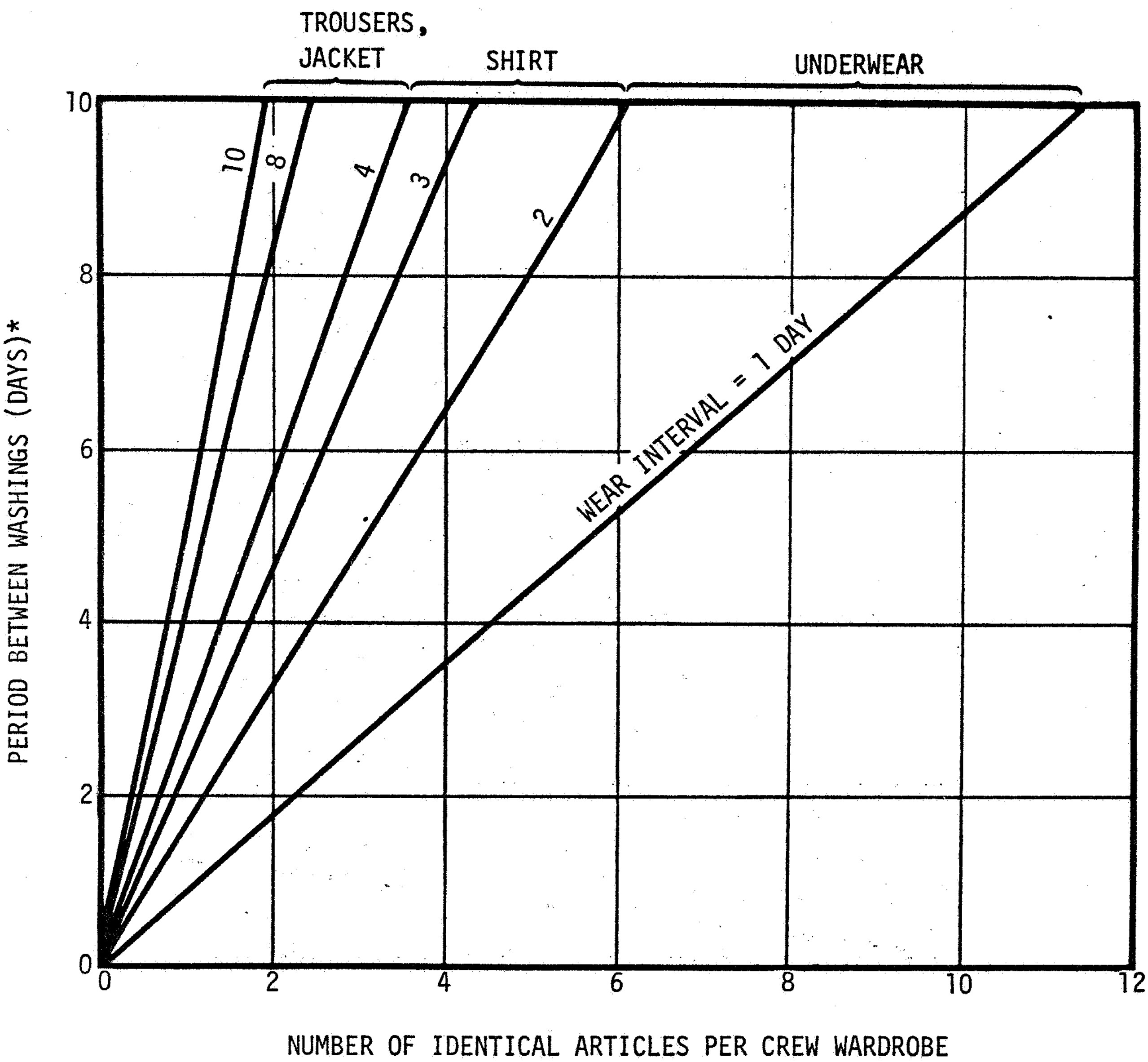
- Underclothes must be changed on a regular basis at the same time, i.e., briefs, socks, and shirt.

- An earth garment change cycle is desirable.



NOTE: TOTAL CYCLE TIME - 1.4 HOURS

Figure 3-10. Power Required for a Washer/Dryer



*For fractions of a day, read the lower whole number value.

Figure 3-11. Crew Wardrobe/Wash Period Requirements

3.3.2.1 Wardrobe Definition.* The basic wardrobe selected consists of garments for normal duty, special duty, leisure, sleeping, and exercising. The following tables depict the candidates, selection, and the basis of selection for various garments and design details.

- Table 3-8 depicts the duty garments selected. The wardrobe consists of a jacket, shirt, trousers, shoes, and hat.
- Table 3-9 depicts the leisure garments selected. The wardrobe consists of trousers, shirt, and shoes or slippers.
- Table 3-10 depicts the exercise garments selected. The wardrobe consists of shorts, T-shirt, socks and sneakers.
- Table 3-11 depicts the specialized duty garment selection which consists of a one-piece clean room coverall, hat, and booties.
- Table 3-12 depicts the sleep wear garments selected. The items selected are a shirt, pants and a robe.

*Data extracted from Reference 3

Table 3-8. Wardrobe Item - Duty Garment (Page 1 of 4)

Design Detail	Candidates	Selection	Basis
		Garment Item = Jacket	
Material	Cotton Cotton-dacron Cotton-nylon PBI X400	Cotton-dacron	Appearance Wrinkle resistance Comfort Absorbency
Construction	Knit Woven Composite	Woven	Strength Rigidity Wear resistance
Entry	Front entry Side entry	Front entry	Least weight Ease of closure
Collar	Standard Rib knit	Standard	Compatibility with woven material
Sleeve	Long Short	Long	Comfort
Cuff	Snap Hook and pile Ribbed Slide	Ribbed	Compatibility with short sleeve shirt Comfort
Pockets	Slash External	Slash	Hidden for style
Pocket closure	Open Fastened-slide Snap Hook and pile	Fastened-slide	Ease of operation Compatible with zero-g environment
Entry fastener	Snap Hook and pile Slide	Slide	Ease of operation Strength Drape
Style	Tapered and fitted Universal	Tapered and fitted	Subjective Appearance
Color	Soft hues	Blue	Subjective

Table 3-8. Wardrobe Item - Duty Garment (Page 2 of 4)

Design Detail	Candidates	Selection	Basis
	Garment Item = Shirt		
Material	Cotton Cotton-dacron Cotton-nylon PBI X400	Cotton	Comfort Absorbency Appearance
Construction	Knit Woven Composite	Knit	Warmth Storage Antisnag
Entry	Pullover Front entry Side entry	Pullover	Least weight Compatibility with knit construction Storage No fasteners required
Collar	Rib knit Standard Combination	Rib knit	Compatible with knit construction Comfort
Sleeve	Long Short	Short	Compatibility with jacket Allows greater insulation variation
Cuff	Rib Fastener	Rib	Compatibility with knit construction Comfort Storage
Pockets	Breast Shoulder	Both	Familiar Pencil containment
Waist area	Ribbed Loose	Ribbed	Compatibility with knit construction Conformal
Color	Complementary hue of jacket color	Blue	Subjective

Table 3-8. Wardrobe Item - Duty Garment (Page 3 of 4)

Design Detail	Candidates	Selection	Basis
	Garment Item = Trousers		
Material	Cotton Cotton-dacron Cotton-nylon PBI X400	Cotton-dacron	Same material as jacket
Construction	Woven Knit	Woven	Same as jacket
Entry	Front entry		Standard
Cuff	Snap Hook and pile Ribbed Slide	Ribbed	Comfort Warmth Appearance
Entry fastener	Slide Snaps Hook and pile	Slide	Strength Ease of operation
Waist provisions	Elasticized Belt Combination	Combination	Size adaptation Style
Pockets	Slash External	Slash	Adequate storage capacity Style
Style	Universal Tapered	Tapered	Subjective Appearance
Color	Soft hues	Blue	Same as jacket Subjective

Table 3-8. Wardrobe Item - Duty Garment (Page 4 of 4)

Design Detail	Candidates	Selection	Basis
		Garment Item = Shoes	
Material	Hide Fabric Vinyl	Hide	Suitable for both zero and one g Porous Strength
Fasteners	Hook and pile Buckle Snaps Slide	Snaps	Subjective
		Garment Item = Hat	
Material	Fabric Vinyl Polymer (rigid)	Padded fabric	Head protection
Style	Round sides Flat sides	Flat sides	Subjective
Visor	Long Short	Short	Compatibility with vision requirements
Color	Soft hues	Blue	Same as jacket

Table 3-9. Wardrobe Item - Leisure Garment (Page 1 of 2)

Design Detail	Candidates	Selection	Basis
	Garment Item = Trousers		
Material	Cotton Cotton blend PBI X400	Cotton blend	Comfort Absorbency Appearance
Construction	Woven Knit	Woven	Wear Appearance
Entry	Front entry	Front entry	Standard
Cuff	Snap Hook and pile Ribbed Slide	Ribbed	Comfort Warmth Appearance
Entry fastener	Slide Snaps Hook and pile	Slide	Strength Ease of operation
Waist provisions	Elasticized Belt Combination	Combination	Size adaptation Style
Pockets	Slash External	Slash	Adequate storage capacity Style
Style	Universal Tapered	Tapered	Subjective Appearance
Color	Soft hues	Soft hue compatible with shorts	Subjective
	Garment Item = Shirt		
Style	Knit polo shirt Woven shirt	Both (2 of each)	Variety
Color	Soft pastels	By choice	Variety

Table 3-9. Wardrobe Item - Leisure Garment (Page 2 of 2)

Design Detail	Candidates	Selection	Basis
	Garment Item = Shirt (Continued)		
Fasteners	Slide Snap Hook and pile	Snap (woven only)	Current fashion
Entry	Pullover Front entry	Knit pullover, woven front entry	Current fashion
Material	Cotton blend Synthetics (or nonflammable synthetic with properties of cotton)	Cotton blend or cotton substitute	Absorbency Appearance
	Garment Item = Shoes or Slippers		
Construction	Vinyl Leather	Fabric with reinforced heel, sole and toe	Porosity Softeners Extreme wear resistance not required
Material	Knit Woven	Knit - shoe sock with sole	Comfort Warmth Storage capability
Color	Any	Compatible with leisure garment and sleep wear	Universal function

Table 3-10. Wardrobe Item - Exercise Garments (Page 1 of 2)

Design Detail	Candidates	Selection	Basis
		Garment Item = Shorts	
Material	Cotton Cotton blend PBI X400	Cotton or cotton blend	Comfort Absorbency
Construction	Woven Knit	Woven	Ventilation endurance Cleaning
Style	Briefs Jockey	Briefs	Compatible with woven construction
Entry	Pull over Front	Pull over	Sizing Storage
Waist provisions	Belt Elasticized Draw string	Elasticized	Compatibility with entry Simplification
Color	Any	White	Subjective
		Garment Item = T-Shirt	
Material	Cotton Cotton blend PBI X400	Cotton or Cotton blend	Absorption Porosity Comfort
Construction	Knit Woven	Knit (loose)	Porosity Conformity
Entry	Frontal Pull over Other	Pull over	Weight Storage Conformal Compatibility with construction
Collar	Rib knit Standard Combination	Rib knit	Compatibility with knit construction Comfort Light weight Sizing

Table 3-10. Wardrobe Item - Exercise Garments (Page 2 of 2)

Design Detail	Candidates	Selection	Basis
	Garment Item = T-Shirt (Continued)		
Sleeve	Long Short	Short	Ventilation during exercise Minimum encumbrance
Cuff	Rib knit Loose Fastened	Rib knit	Compatibility with knit construction Storage Conformity
Waist	Ribbed Loose	Ribbed	Conformal Thermal comfort
Color	Any	White	Subjective
	Garment Item = Socks		
Material	Cotton Cotton blend Synthetic	Cotton Cotton blend	Absorbency Porosity
Construction	Knit Woven	Knit	Sizing Conformity
Color	Any	White	Subjective
	Garment Item = Sneakers		
Material	Vinyl Fabric Hide	Fabric	Porosity
Construction	Reinforced heel and toe	Reinforced heel and toe	Protection
Entry	Slide String Hook and pile Snap Buckle	Slide	Subjective (as long as sufficiently strong) Ease of entry
Color	Any	White	Subjective

Table 3-11. Wardrobe Item - Specialized Duty Garment

Design Detail	Candidates	Selection	Basis
		Garment Item = Clean Room Coverall	
Configuration	Two piece One piece	One piece (includes hat and booties)	Body encapsulation
Entry	Side Front	Front	Ease of donning
Material	Cotton Cotton blend Dacron	Dacron (continuous filament)	No lint or pilling
Construction	Woven Knit	Woven	Less lint or pilling
Collar	Rib Standard	Modified Standard	Compatible with woven material Interface with hat
Sleeve	Long Short	Long	Coverage of body
Cuffs	Ribbed Fastened Loose Elasticized	Fastened (snaps)	Interface with gloves and booties Conformal
Color	Any	White	Subjective Visual indication of cleanliness

Table 3-12. Wardrobe Item - Sleep Wear (Page 1 of 2)

Design Detail	Candidates	Selection	Basis
		Garment Item = Shirt	
Construction	Knit Weave	Knit	Warmth Conformity Storage
Entry	Pull over Front entry	Pull over	Storage Compatibility with knit construction
Material	Cotton Synthetic substitute	Cotton	Warmth Absorbency
Collar Cuff	Rib Standard Fastened	Rib	Compatibility with knit construction Loose fitting
Sleeve	Long Short	Long	Basic need for sleeping garment is added thermal protection
Color	Any	Pastel	Can be used alternately with leisure wardrobe Compatible with leisure trousers
		Garment Item = Pants	
Construction	Knit Weave	Knit	Warmth Storage
Configuration	Loose Tapered	Loose	Nonconfining
Material	Cotton Synthetic substitute	Cotton or cotton blend	Warmth Absorbency
Cuff	Standard Fastened Rib	Rib	Best thermal design Comfort

Table 3-12. Wardrobe Item - Sleep Wear (Page 2 of 2)

Design Detail	Candidates	Selection	Basis
	Garment Item = Pants (Continued)		
Waist	Belt Draw string Elasticized	Elasticized	Size adaptable Comfort
Color	Any	Pastel	Subjective
Fasteners	Slide Snap Hook and pile	None	None needed
	Garment Item - Robe		
Construction	Knit Weave	Knit	Warmth
Entry	Front entry Pullover	Front entry	Ease of entry
Material	Any absorbent material	Coarse weave, cotton or flannel	Warmth
Fasteners	Slide Snap Hook and pile	Snap	Strength not required Simple Lightweight
Color	Any	Soft hue	Subjective

4.0 ANCILLARY EQUIPMENT

4.1 DEFINITION

Ancillary equipment are those items which allow for retention of garment appearance during storage, and the additional fabric items considered necessary to satisfy the needs of crew members.

4.2 HANGER CONCEPTS (See Figure 4-1)

Garment hanger concepts must be compatible with the wardrobe selected and the garment transfer and storage areas. The types and amounts of hangers are a function of the crew total wardrobe, and as such, their complete definition must be determined with the wardrobe.

4.3 FABRIC USAGE (OTHER THAN WARDROBE)

In addition to the fabric used for the garments, there is a requirement for other fabric items such as compartment separators, chair covers, and lavatory separators. Table 4-1 presents a matrix that defines a typical fabric requirement. The fabric items listed on the matrix represent single unit quantities. Therefore, multiples will have to be considered to determine the requirements of a particular spacecraft/mission.

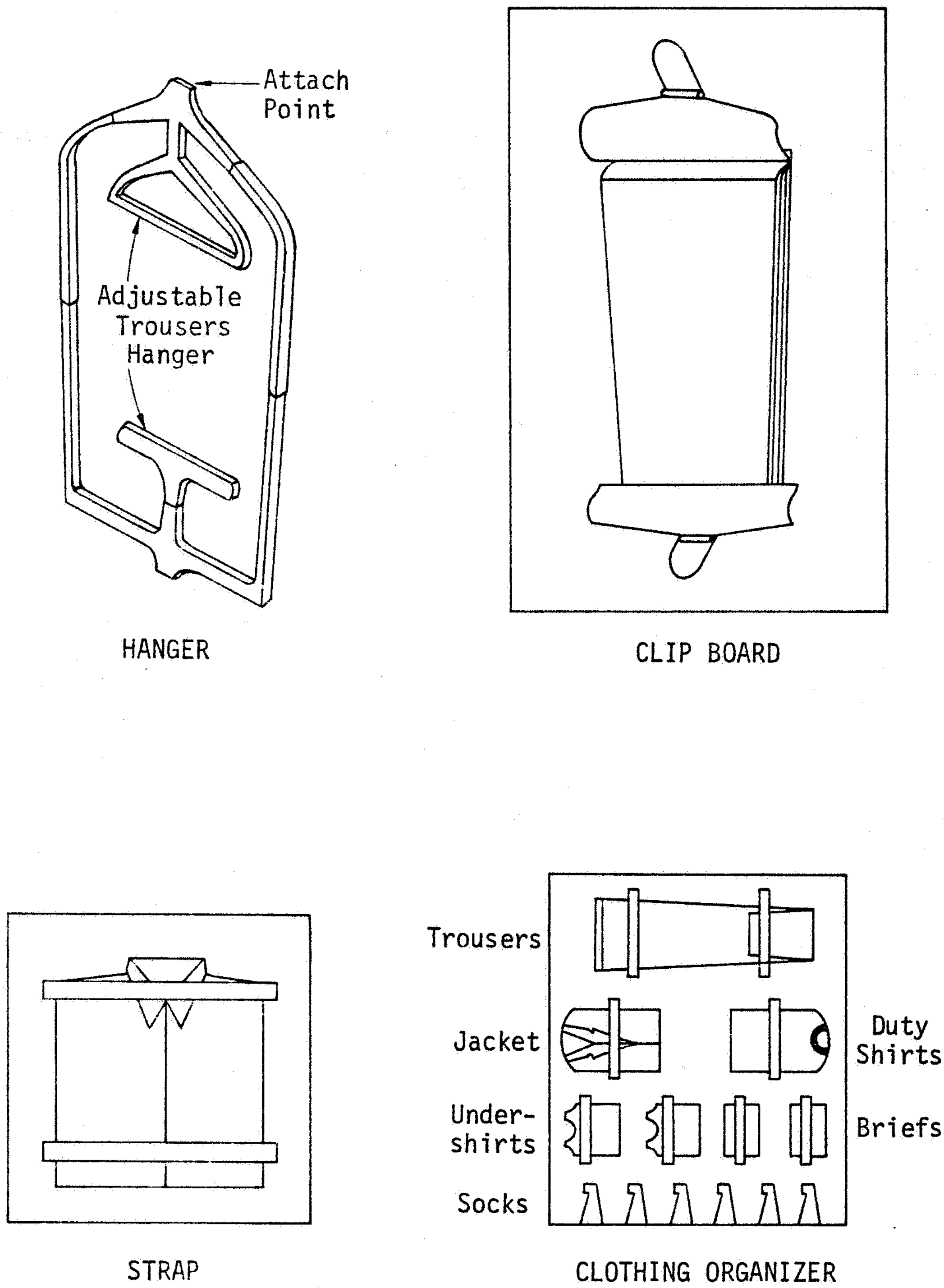


Figure 4-1. Garment Hanger Concepts

Table 4-1. Additional Fabric Usage

Description	Material Weight (oz/yd^2)	Unit Area (yd^2)	Unit Weight (lb)
Compartment separator	6.0	2.2	0.8
Chair cover	6.0	0.6	0.2
Couch cover	6.0	2.3	0.9
Napkins/wipes	2.5	0.1	0.02
Bedding	5.0	2.2	0.7
Waste container	6.0	0.5	0.2
Soiled garment container	6.0	0.6	0.2
Toiletry kit	6.0	0.2	0.3
Handkerchief	3.0	0.05	0.02

5.0 GARMENT DESIGN CRITERIA

This section of the handbook presents basic data concerning thermal aspects of clothing, garment construction, and the results of material evaluations. An illustrative example of the use of this section is presented in Appendix B. Various materials have been evaluated and the results of the testing efforts are presented in Appendix C, Fabrics Characteristics Summary.

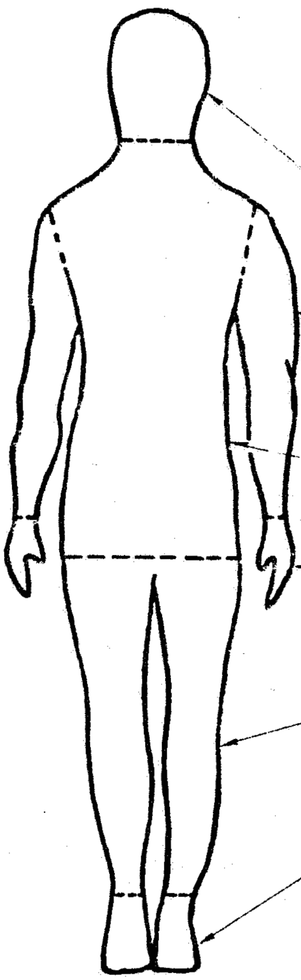
5.1 THERMAL DESIGN

One of the primary functions of clothing is to provide thermal comfort to the wearer by a layer (or layers) of insulation (both due to fabric and the entrapped gas) around the wearer's body. This section presents an analytical approach to the selection of clothing on a thermal basis. This analysis can also be applied to bedding materials or other fabric items that require thermal design.

Although the choice of clothing for temperate environments tends to be made on the basis of style, materials and appearance, this analysis forms a check upon the limits of thermal performance of the less common materials. With the use of the following figures, a garment may be defined knowing only the crew metabolic activity and environmental conditions of the spacecraft. An illustrative example of the use of the figures is presented in Appendix B.

5.1.1 Body Heat Rejection. The body produces heat in proportion to metabolic activity. Depending upon the environmental conditions surrounding the body, this heat is rejected to the atmosphere. The two paths of heat transfer from the body are by sensible means (conduction, convection and radiation) and latent means (evaporation of perspiration).

Figure 5-1 shows a representative distribution of the quantity of heat rejected by the body. The local sensible heat contribution is proportional to the local skin temperature and the area fraction of that portion of the body. The latent heat distribution is a function of the location of sweat glands in the body and is determined empirically. Not included in the figure is the amount of latent heat evaporation due to moisture yielded by the lungs during breathing. This value, of the order of 60-100 Btu per hour, is a function of metabolic rate and ambient dew point.



AREA	SENSIBLE	LATENT
Head	7%	2%
Arms	12%	3.6%
Torso	40%	50%
Hands	4%	0.5%
Legs	31%	43.4%
Feet	6%	0.5%
	100%	100%

For Low Metabolic Rates -
500 to 800 Btu/hr

Figure 5-1. Body Heat Rejection Distribution

Although the absolute values presented in the figure may vary due to environmental conditions and metabolic rates, the primary use of the chart is a reference point for evaluation of the mechanics of body heat rejection and distribution.

5.1.2 Body Latent Heat Rejection. The relationship between the sensible and latent heat rejection by the body is presented in Figure 5-2. It can be seen that for a given metabolic rate, the amount of sweating that occurs is a function of the dry bulb temperature. Below a certain temperature, the amount of latent heat rejection is approximately constant. This is comprised of water vapor released from the lungs and diffused through the skin. As the temperature is increased, the "threshold" of sweating is reached. This occurs when the surrounding air can no longer remove the metabolic heat by sensible means and the skin secretes perspiration for evaporative cooling.

In Figure 5-2, the assumption is made that the surrounding environment may receive all the water vapor from the body, thereby requiring no heat storage in the body. For the values presented in the figure, a dew point of 45°F is assumed. The effect of dew point upon evaporation is shown later in Figure 5-12.

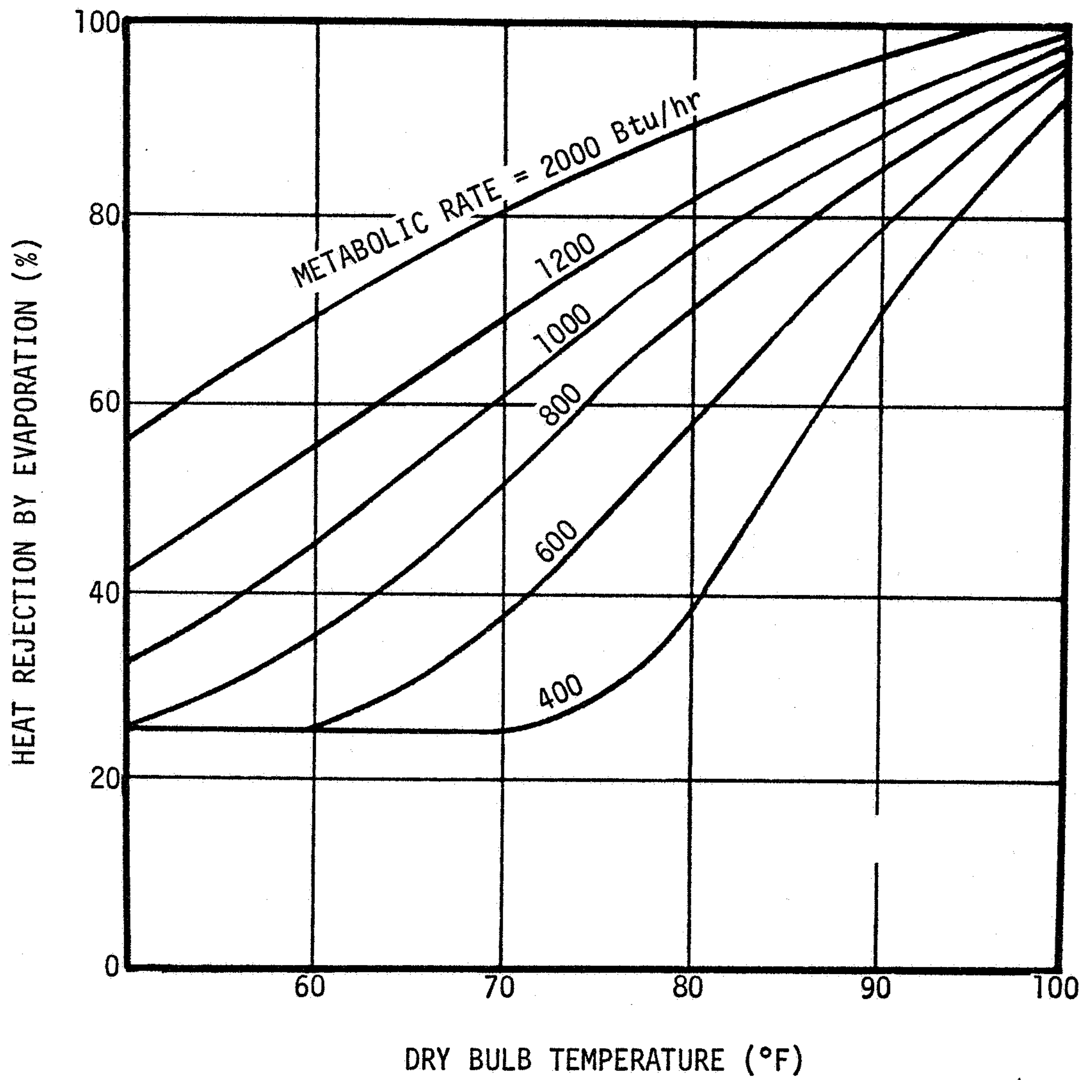


Figure 5-2. Body Latent Heat Rejection

5.1.3 Insulation Required for Comfort. The thermal comfort of a man may be related to his skin temperature, and the skin temperature is affected by the surrounding environmental conditions. The criteria for total body insulation required for comfort is presented in Figure 5-3. Heat is rejected from the body according to the following relationship:

$$Q_{sensible} = UA\,(T_{skin} - T_{ambient})$$

where:

Q - Heat load (Btu/hr)
U - Overall heat transfer coefficient (BTU/ft^2-°F-hr)
A - Body surface area (ft^2)
T - Temperature (°F)

The heat load involved in this calculation is the sensible heat load which is assumed to be 75 percent of the total metabolic heat load at a condition of no perspiration. The body area used in the calculation is estimated to be 20 square feet and the overall heat transfer coefficient includes both heat rejection by convection and radiation. The value of average skin temperature used is 92°F for a condition of comfort.

A new variable, the insulation value, is obtained by transposing the equation as follows:

$$I = \frac{1}{U} = \frac{A(T_{skin} - T_{ambient})}{Q_{sensible}}$$

and using the established unit of insulation, the Clo*, the equation is:

$$I = \frac{0.88\,A\,(T_{skin} - T_{ambient})}{Q_{sensible}}$$

*Clo is a unit of insulation and is defined as the amount of insulation necessary to maintain comfort at a mean skin temperature of 92°F in a room at 70°F with air movement not over 10 feet per minute, humidity not over 50 percent, with a metabolism of 50 calories per square meter per hour. Typical insulation values (Clo):

Nude	0.5 (due to air insulation)
Flight coveralls with cotton underwear	1.0
Flight coveralls with woolen underwear	2.0

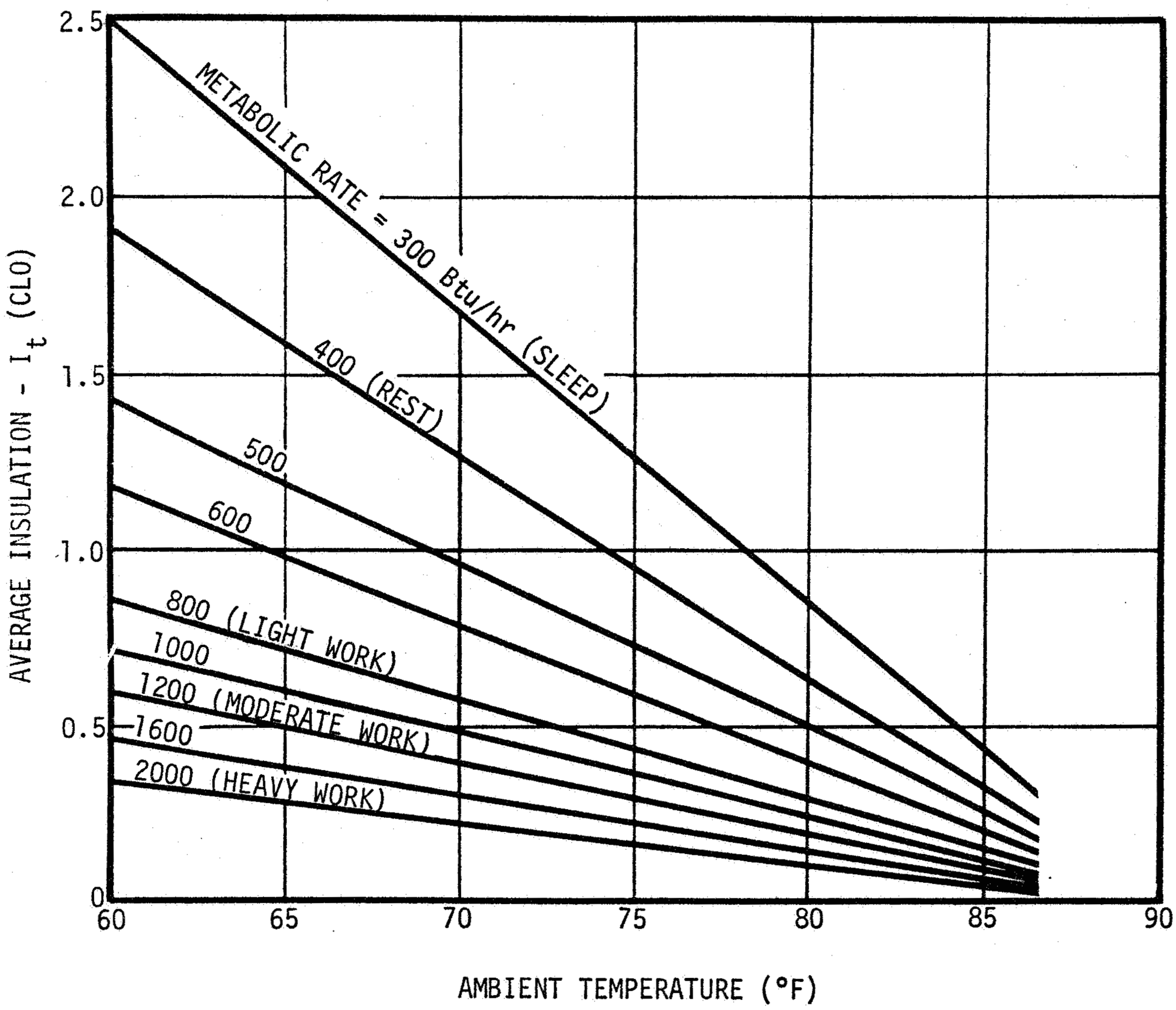


Figure 5-3. Total Body Insulation Required for Comfort

5.1.4 Allowable Variation in Insulation. The previous curve (Figure 5-3) is based upon equilibrium conditions in which there is no heat stored or lost from the body. It has been established, however, that heat may be lost from the body with no discomfort resulting from lowering the body temperature. This quantity, the maximum allowable heat debt, is dependent upon the weight of the individual and the activity level. For periods of normal activities, the maximum allowable heat debt is 600 Btu for a 50th percentile man. For sleeping periods, this value is 300 Btu.

Since the insulation surrounding the body influences the rate of body heat rejection, the rejection rate may be greater than the metabolic rate. This condition will exist if a lesser amount of insulation than the amount determined in Figure 5-4 is used. The higher heat rejection rate may be tolerated and the individual will remain comfortable until the maximum debt is reached. For a rate difference of 75 Btu/hr, the length of time to a sensation of coldness is 600 ÷ 75 = 8 hours.

The variation in insulation allowable for a given temperature for the tolerance periods of 4 and 8 hours (considered representative of a typical crewman duty cycle) is shown in Figure 5-4. The values of 68° to 80°F are representative of spacecraft limits. The comfort zone defined by these boundaries establishes the temperature and time limitations of a given insulation value.

5.1.5 Local Insulation Requirements. The average value of insulation (from Figure 5-3) is useful in the determination of an overall criteria for comfort. Figure 5-5 is presented to relate this average value to the local insulation required for a given body area. The distribution of insulation over the body is based upon the assumption that the total average insulation is composed of the sum of the products of the local insulation and the applicable body area.

$$I_{total} = \sum (I_{torso} \times \frac{A_{torso}}{A_{total}}) + (I_{legs} \times \frac{A_{legs}}{A_{total}}) + \ldots\ldots$$

The contribution of insulation is also expressed as follows:

$$I_{local} \times \frac{A_{local}}{A_{total}} = I_{total} \times \text{percent contribution}$$

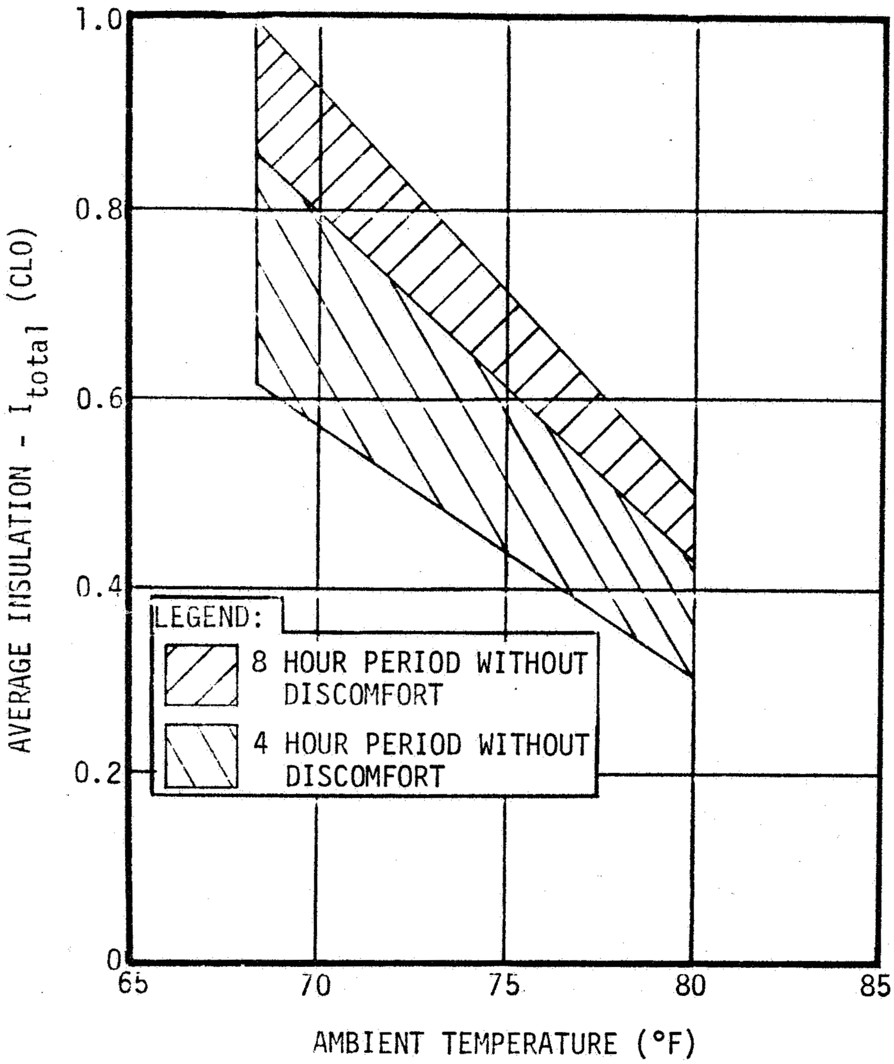


Figure 5-4. Comfort Zone

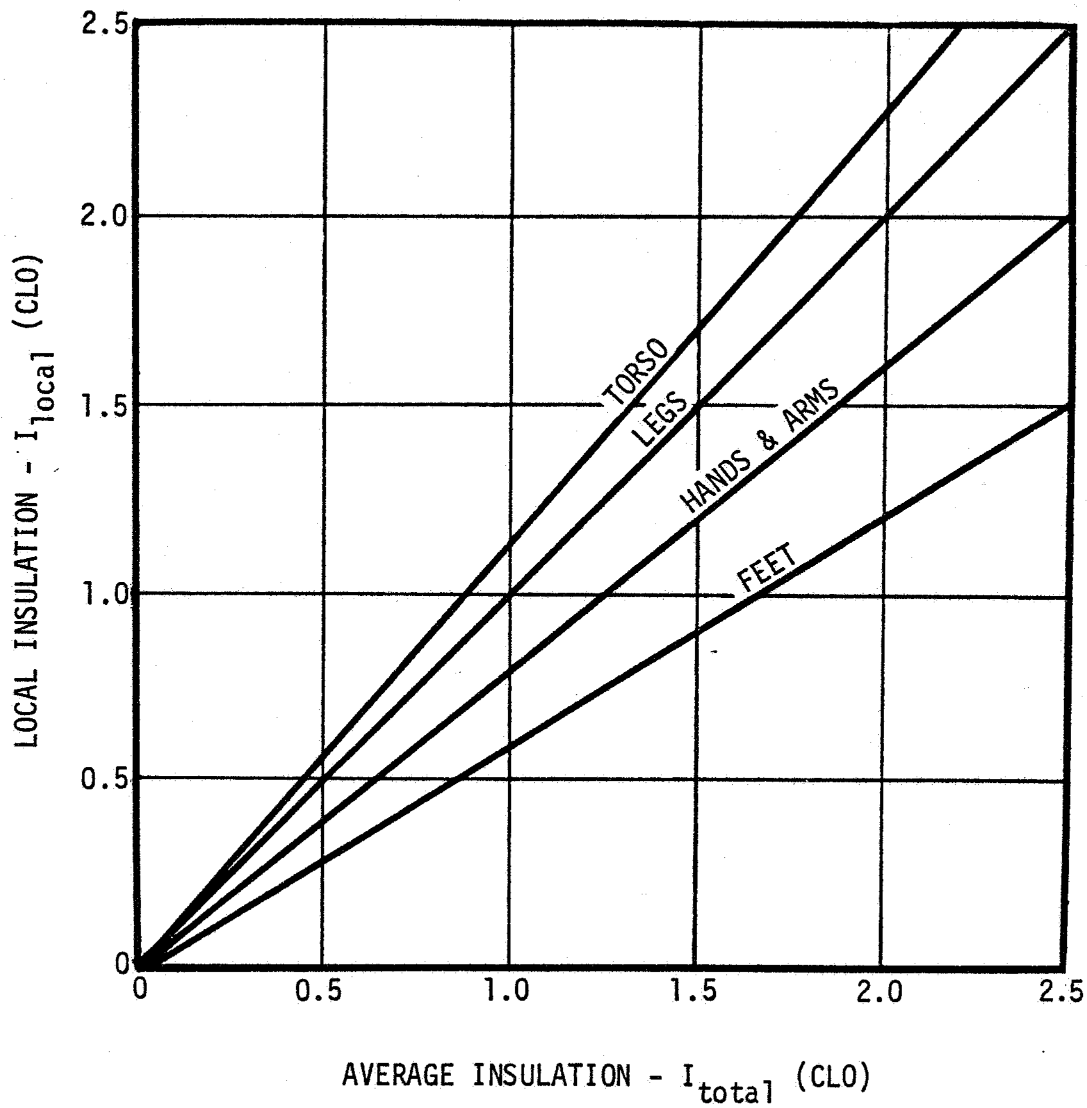


Figure 5-5. Local Insulation Requirements

Assuming that the percent contribution of insulation of a local area must be equal to the percent heat production (% Q) of that area, the final form of the equation is:

$$I_{local} = \frac{I_{total\ (average)} \times \%\ Q}{\frac{A_{local}}{A_{total}}}$$

Example Calculation (Torso)

The torso area contribution is 36 percent of the total body area (A_{local}/A_{total}). From Figure 5-1, it may be seen that the heat produced by the torso is 40 percent of the body sensible heat. The relationship between the total average insulation and the local insulation required for the torso is:

$$\frac{I_{local}}{I_{total}} = \frac{0.40}{0.36} = 1.1$$

5.1.6 Effective Temperature (T_{eff}). The effective temperature is an empirically derived index which relates the conditions of humidity, temperature and air velocity. This temperature is a sensory scale which is based upon the sensation of warmth or cold by subjects under various conditions. The theoretical basis for its use is found in the heat rejection balance of the body:

$$Q_{rejected} = Q_{sensible} + Q_{latent}$$

If the total rejected heat is assumed to be simply convection heat transfer, an effective ambient temperature results as the heat transfer coefficients and evaporative capability change.

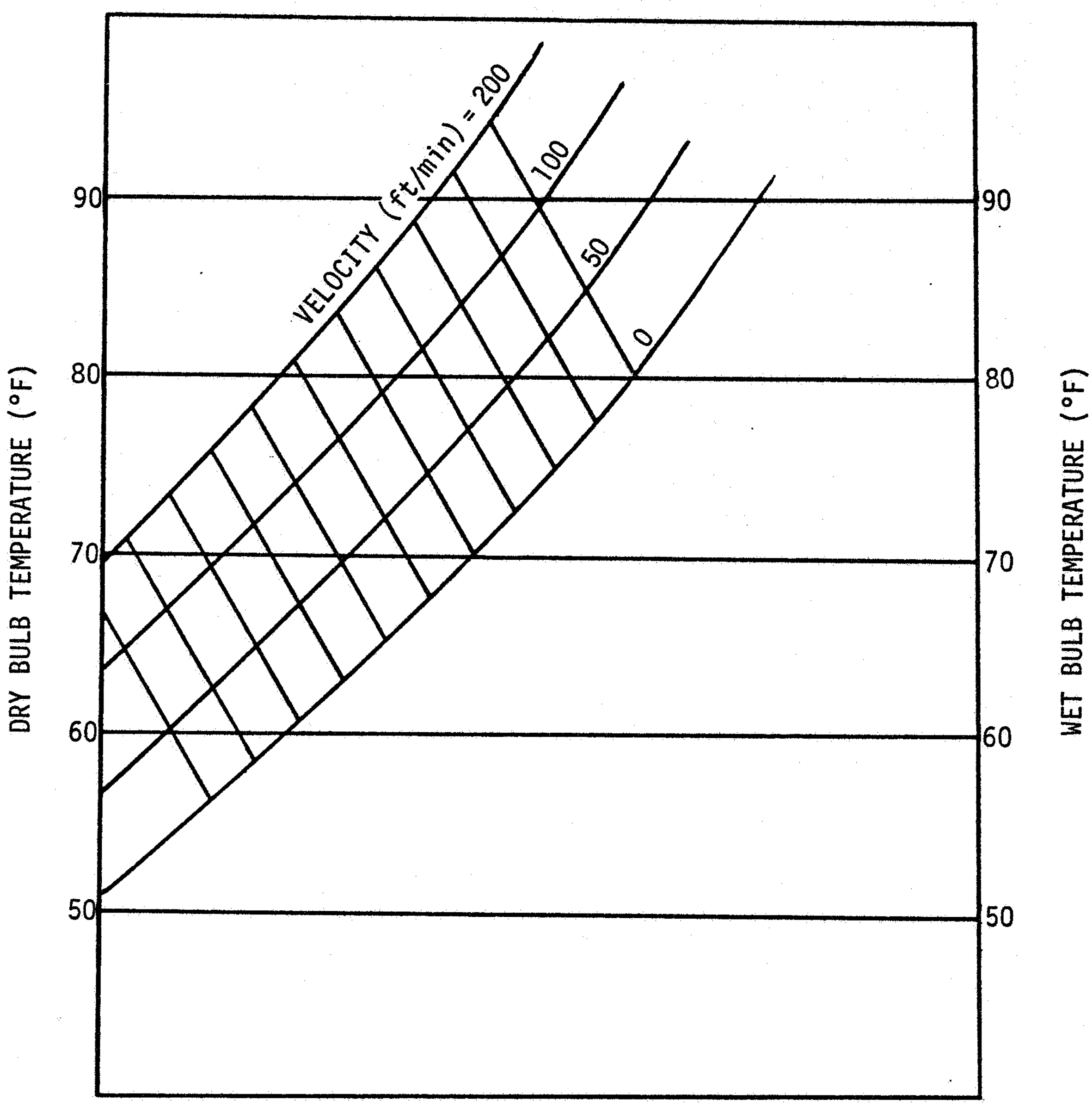
$$Q_{rejected} = UA\,(T_{skin} - T_{eff}) = UA\,(T_{skin} - T_{\substack{ambient \\ drybulb}}) + M_{H_2O}\,{}_2h_{fg}$$

where:

M_{H_2O} = Mass H_2O (lb)

h_{fg} = Latent heat of vaporization of water (Btu/lb)

If Q_{latent} approaches zero, $T_{eff} = T_{drybulb}$. This occurs when the humidity reaches 100 percent. Figure 5-6 shows the nomograph for establishing an effective temperature for a normally clothed person.



Example: Given Dry Bulb 80°, Wet Bulb 65°, and Velocity of Air 50 ft/min: Draw line from dry bulb 80° to wet bulb 65°. At the intersection with the 50 ft/min velocity line, read horizontally to determine the effecitve temperature on the given conditions. In this case the value is approximately 74°F.

Figure 5-6. Effective Temperature

5.1.7 Atmosphere Insulation Properties. Once the local insulation requirement has been determined from Figure 5-5 for the extreme environmental and metabolic conditions, the atmosphere insulation must be computed prior to determination of garment properties. The relationship is presented below:

$$I_{local} = I_a + I_c$$

where:

I_a = Atmosphere insulation

I_c = Required insulation of clothing

I_{local} = Local insulation required from Figure 5-5

The atmosphere insulation value is related to the radiant and convective heat transfer coefficients. The radiation value (h_{rad}) is approximated as a constant (0.5 Btu/ft^2-°F-hr) within the temperature range of a space vehicle. The convective coefficient is a function of the density and velocity of ventilating gas according to the following relationships:

$$h_{conv} = 0.56\ k/d\ (Re)^{0.5}(Pr)^{0.33}$$

where:

h = Convective film coefficient (Btu/ft^2-°F-hr)

k = Gas conductivity (Btu/ft^2-°F-hr)

d = Major diameter (ft)

Re = Reynold's number ($\rho DV/\mu$)

Pr = Prandtl number ($C p\mu/k$)

Then the insulation value is the reciprocal of the sum of the two coefficients:

$$I_a = \frac{1}{h_{conv} + h_{rad}} \quad \text{expressed in Clo} \quad = \frac{0.88}{h_{conv} + h_{rad}}$$

These values are plotted for an oxygen/nitrogen atmosphere and an oxygen/helium atmosphere in Figure 5-7. Since the thermodynamic and physical properties of oxygen and nitrogen are close, only the total pressure is indicated. In the case of oxygen/helium, in which the properties are not approximately the same, an oxygen partial pressure of 3.5 psia is used for all conditions.

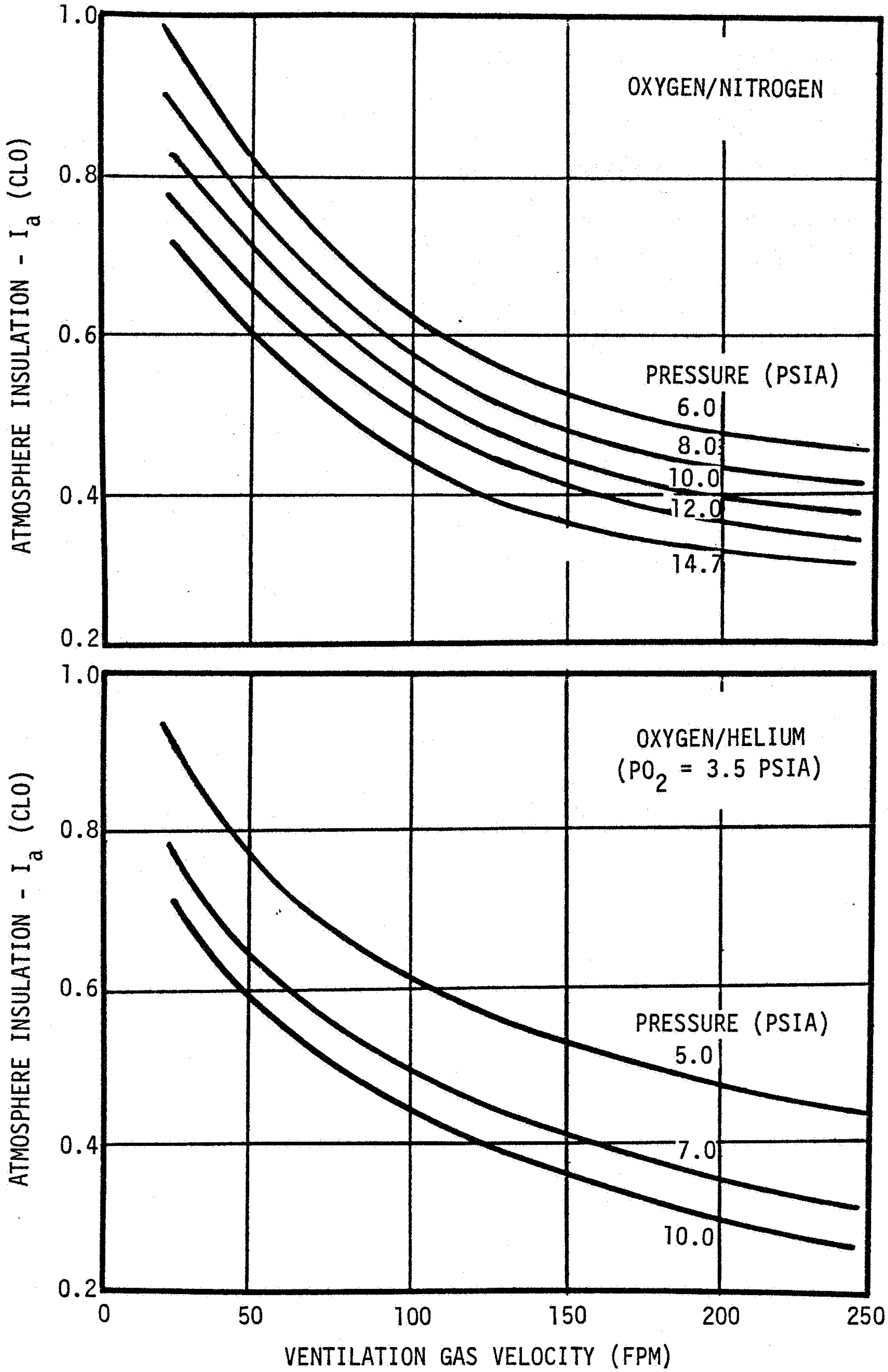


Figure 5-7. Atmosphere Insulation

Once the atmosphere insulation property has been obtained for a given condition, its value is subtracted from the local insulation value:

$$I_{clothing} = I_{local} - I_{atmosphere}$$

If the resultant is zero or negative, no covering is required on that portion of the body due to thermal considerations.

5.1.8 Effect of Drape upon Clothing Insulation. Once it has been determined that clothing is required for an area of the body, that value of insulation is attributed to both the clothing fabric and the air layer between the body and the cloth. Figure 5-8 presents the effect of the air layer between the cloth and the body. In this figure, it is assumed that there is no free convection (zero-g condition) in that space. Several fabric insulation values (I_{fabric}) are presented. These values are a function of the weave, thickness, and yarn conductivity as shown in Figures 5-9 and 5-10. To use the curves in Figure 5-8 in conjunction with the previous computations, the effective insulation must be equal to the local clothing insulation required. Knowing the portion of the body to be covered, the overall clothing distance, and the effective insulation necessary, a value of I_{fabric} is obtained for subsequent use in Figure 5-9.

Example

A loose fitting dacron shirt ($I_{fabric} = 0.01$) has an effective insulation value of 1.25 Clo at an average distance from the body of 0.25 inch. If the shirt is taken in to an average distance of 0.15 inch to make it more conformal, a reduction of effective insulation will occur. The new insulation will be 0.75 Clo.

Typical values of clothing distance from the body in inches are as follows:

Garment	Distance
Tights	0.05
Trousers	0.10-0.20
Dress shirt	0.15-0.30
Sweat shirt	0.30-0.50

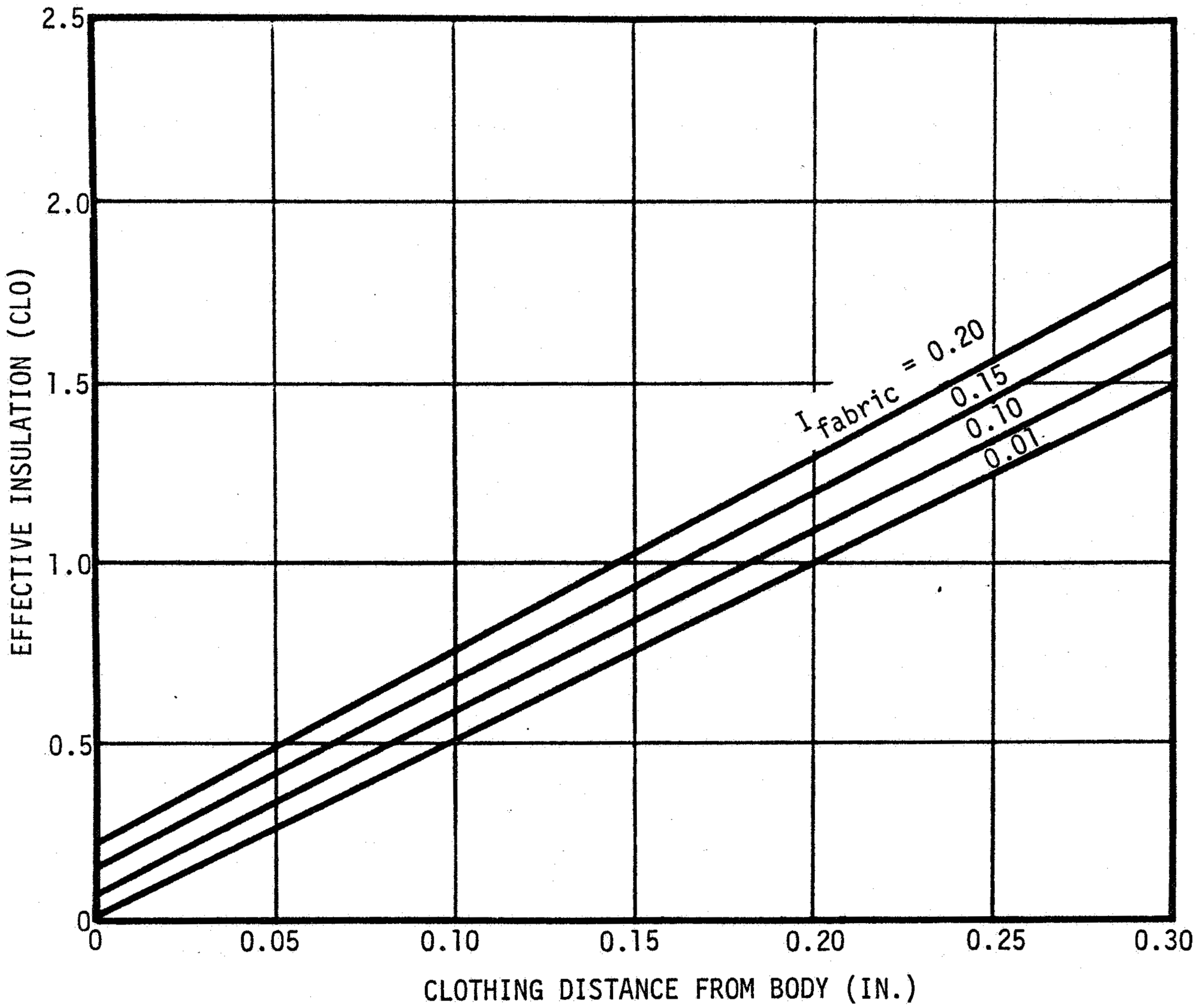


Figure 5-8. Effect of Drape upon Clothing Insulation

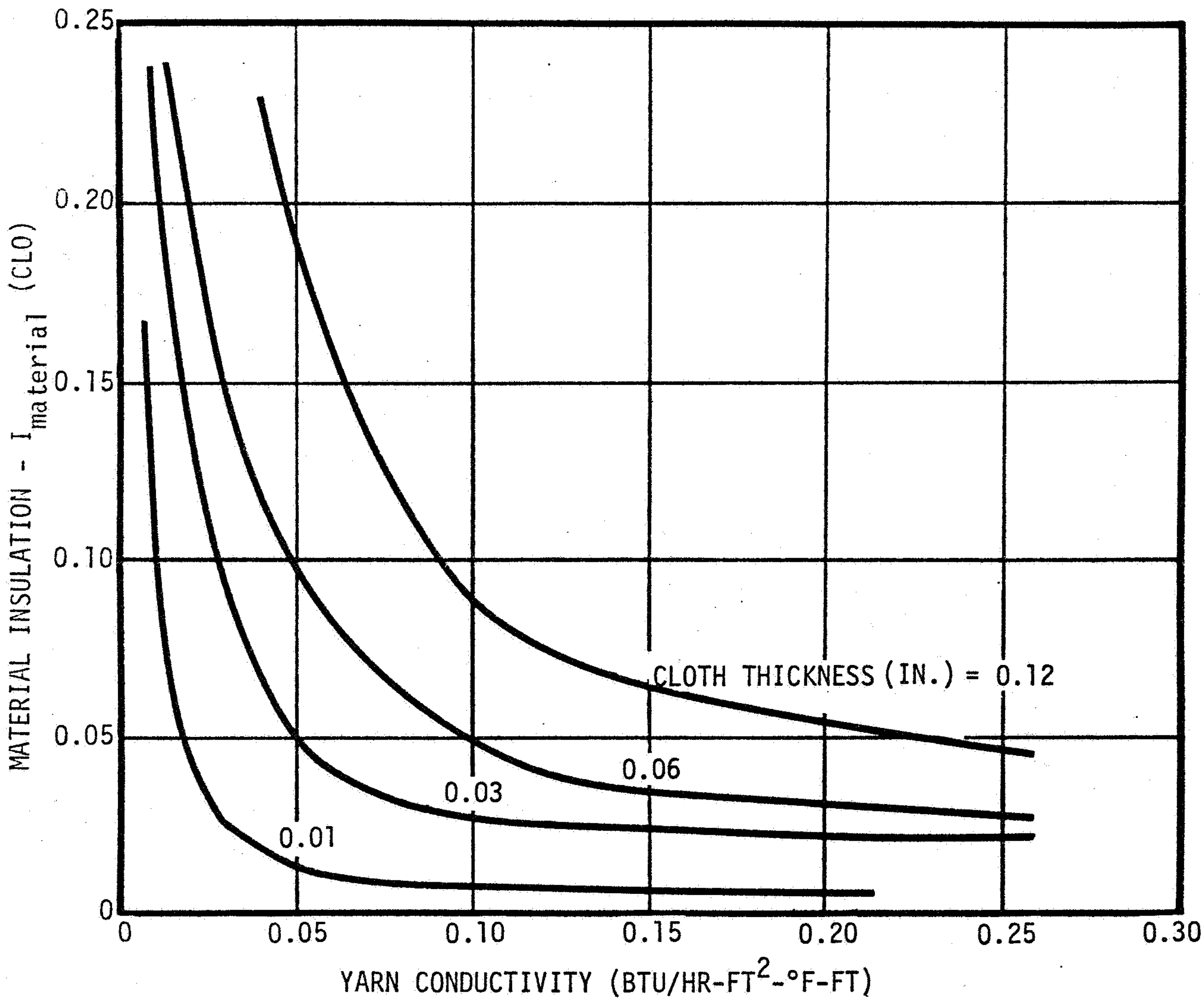
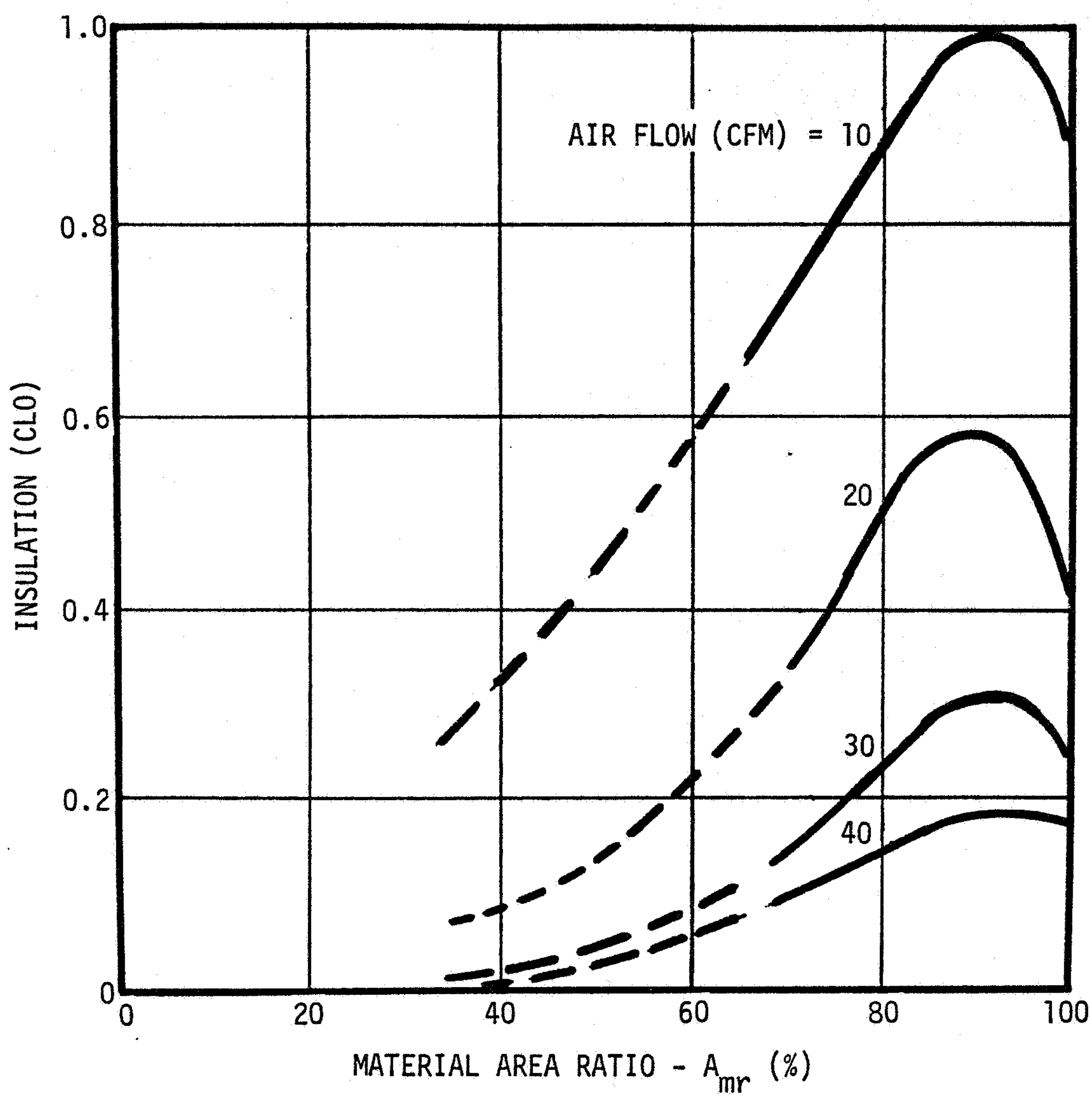


Figure 5-9. Material Insulation Properties



$$A_{mr} = \frac{A_{material}}{A_{total\ body\ area\ to\ be\ covered}}$$

Figure 5-10. Weave Effect upon Material Insulation

5.1.9 Fabric Insulation Properties. The fabric insulation property is a function of material insulation properties and the material weave. Expressed in equation form:

$$I_{fabric} = I_{material} \times \text{Weave Factor}$$

These variables are shown in Figures 5-9 and 5-10.

The material insulation value, $I_{material}$, is a function of yarn conductivity and cloth thickness. It is assumed that the fabric is a homogeneous layer of material and is governed by the equation:

$$I_{material} = 0.88\ t/k$$

where:

t - is the thickness in inches

k - is the thermal conductivity in Btu/hr-ft^2-°F-ft

Examples of selected yarn conductivity are as follows:

Cotton	0.038
Nylon	0.125
Teflon	0.130
Dacron	0.150
Beta	0.300

5.1.10 Weave Effect upon Material Insulation. The effect of the weave upon the insulation property of a fabric is shown in Figure 5-10. These curves reflect the data obtained from testing of four swatch samples of varying porosity. The test series consisted of the measurement of conditions surrounding the swatches with a variation in air flow upon the item (reference Paragraph 5.1.3).

Since $I = \frac{0.88 \Delta TA}{Q_{sensible}}$, insulation values were determined for each use.

5.1.11 Fabric Porosity and Material Area Ratio. The material area ratio is a variable in fabric construction which lends itself to convenient use in geometric calculations. Figure 5-11 shows the relationship betweem material area ratio and garment permeability.

5.1.12 Effect of Dew Point and Fabric Porosity on Evaporative Heat Rejection. The effectiveness of body cooling by evaporative means is governed by the capacity of the surrounding air to receive the water vapor and the insulating properties of the clothing worn. Figure 5-12 presents the relationship between the ambient dew point, the porosity factor of the fabric, and the capability for vapor to transfer through the clothing by diffusion through the openings between the fabric yarns. The equation used is:

$$Q = \delta \frac{(\rho_2 - \rho_1) A h_{fg}}{x}$$

where:

Q = Evaporative heat flux (Btu/hr)
δ = Diffusion coefficient of water vapor (ft^2/hr)
ρ = Partial density of water vapor (lb/ft^3)
A = Area through which vapor passes (ft^2)
h_{fg} = Latent heat of vaporization of water (Btu/lb)
x = Distance between skin and fabric (in.)

Assuming saturated conditions at the skin and:

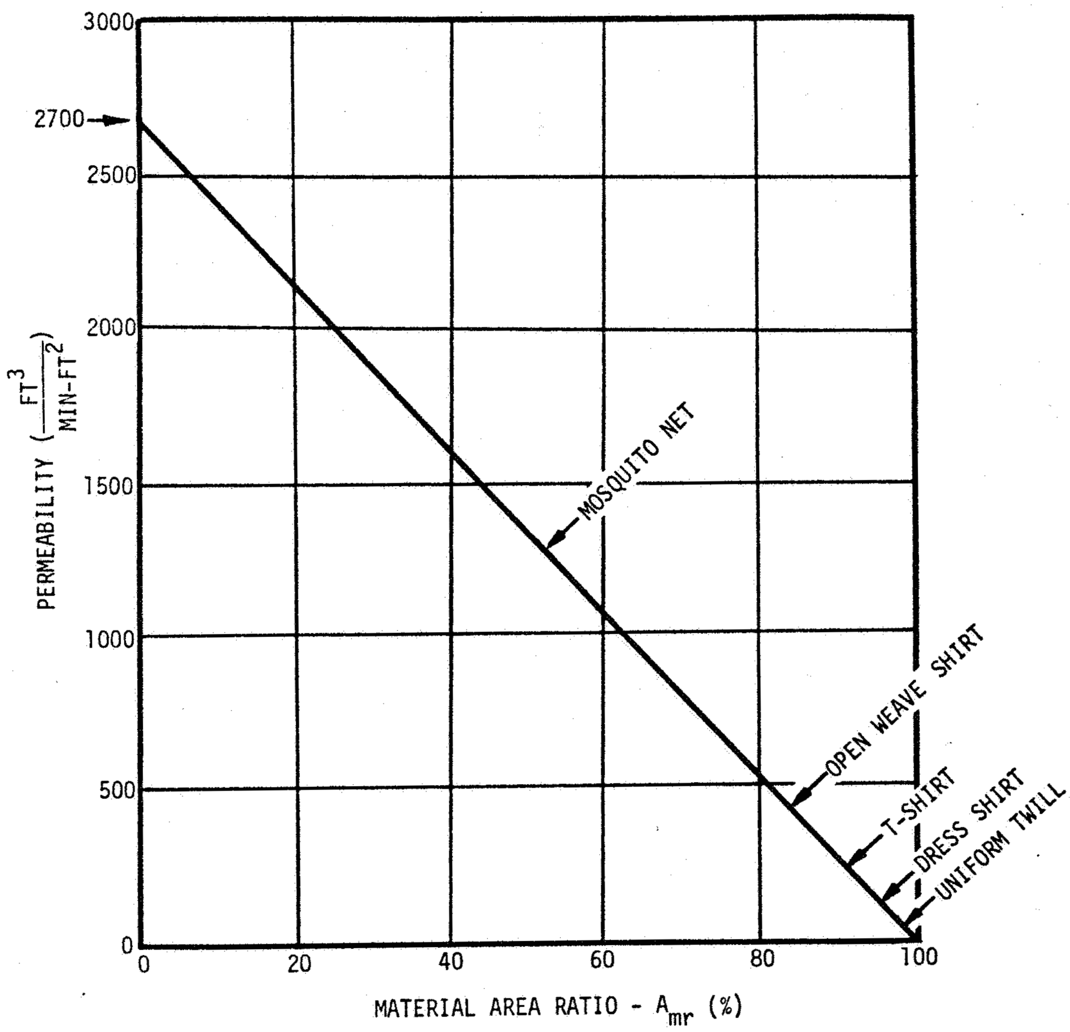
$$A = A_{fabric} (1 - A_{mr}),$$

the Evaporative Heat Rate (E) may be expressed as:

$$E = \frac{Q}{A_{fabric}} = (\delta h_{fg}) (\rho_{skin} - \rho_{amb}) \left[\frac{1 - A_{mr}}{x}\right]$$

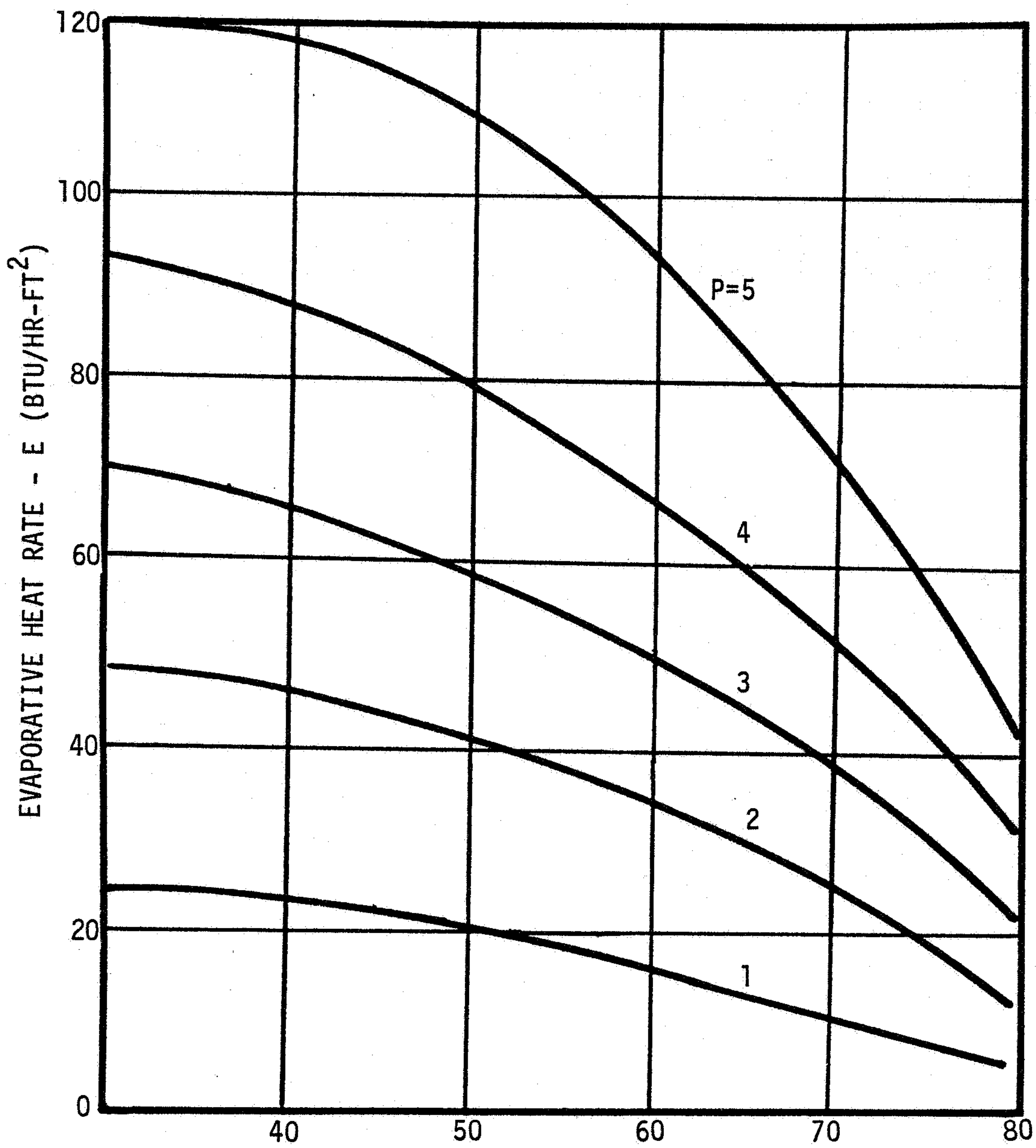
The term $[\frac{1 - A_{mr}}{x}]$ is designated as a porosity factor in which drape plays an extremely important role. Typical values of this factor are presented in Figure 5-12. Examples of fabric porosity for selected garments are as follows:

Garment	Porosity
T-shirt	2.0
Knit shirt	1.5
Trousers	0.5
Dress shirt	0.33



Permeability = Ft^3 per minute of atmospheric gas per ft^2 of fabric with 0.5 inch of water pressure difference

Figure 5-11. Fabric Porosity and Material Area Ratio



$$P = \frac{1-A_{mr}}{x}$$

where:

P = Porosity Factor

A_{mr} = Material Area Ratio (See Figure 5-10)

x = Average Distance From Skin (in.)

Figure 5-12. Effect of Dew Point and Fabric Porosity upon Evaporative Heat Rejection

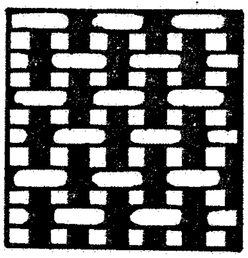
5.2 CONSTRUCTION

With the general garment body distribution requirements determined by thermal or other criteria, the elements of garment construction may be selected. The information presented in this paragraph consists of objective fabric and weight data, and subjective design detail. Appendix B presents the use of construction data in determining the weight of the garment/wardrobe.

5.2.1 Fabric Data. In the construction of garments and cloth, there are three fabric categories: woven, nonwoven, and knitted. The category of nonwoven materials includes synthetic materials which are characterized by lofty webs of fibrous materials of mechanical or adhesive type bond. Nonwoven materials exhibit substantial reduction in endurance strength, tensile strength, and cleaning endurance from woven fabrics. As a consequence, the major use of nonwovens is in disposable and specialized clothing. Nonwoven materials do not adhere to the fabric geometry relationships presented in this section, and therefore are not included. Knits provide softness, warmth, conformity, and porosity. Weaves provide rigidity, endurance, strength and mendability. Uses of the knit and weave fabric construction are presented in Figure 5-13.

5.2.1.1 Weave Characteristics. The material area ratio (A_{mr}) is determined by the number of yarns present in the given area. The resulting pick and end density (number of yarns per inch in the filling and warp direction) for a balanced plain weave is shown for several sizes of yarn. As the material area ratio, A_{mr}, is increased, the required yarn density must likewise increase. This is true until an A_{mr} value of 75 percent is reached. At this point, the distance between the opposing yarns is equal to the diameter of the yarn. If a further increase in material area ratio is required, the yarn is compressed into an elliptical cross section. As the yarn width increases, less space is available for additional yarns and the pick and end densities decrease. The material area ratio as a function of texture and yarn size is presented in Figure 5-14. Since the major portion of clothing possesses a material area ratio of 80 percent or greater, the applicable yarn configuration is compressed.

PLAIN WEAVE

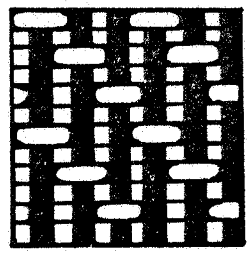


Maximum endurance

Maximum strength

Most widely used for clothing

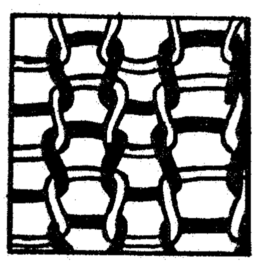
TWILL WEAVE



Most resilient

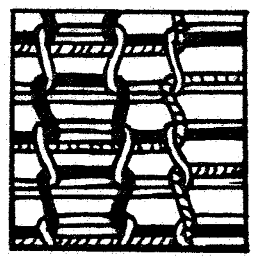
Used in heavy wear

FLAT KNIT



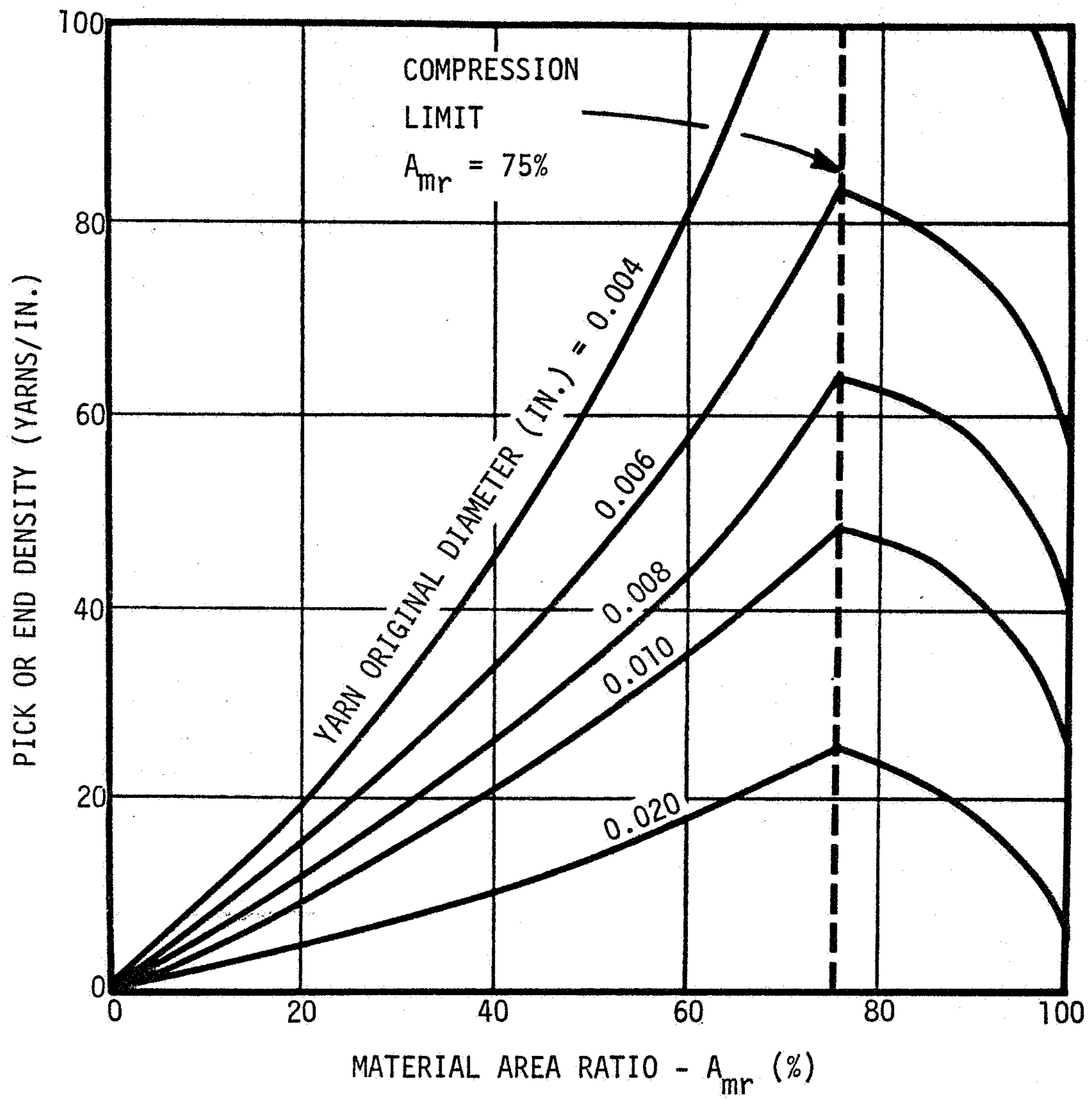
Basic knit

INTERLOCKING KNIT



Tear resistant

Figure 5-13. Basic Weaves and Knits



Plain Weave

Pick Density = End Density

$A_{mr} \leq 75\%$ - Yarn Cross Section is Circular

$A_{mr} > 75\%$ - Yarn Cross Section is Elliptical

Figure 5-14. Weave Characteristics - Material Area Ratio as a Function of Texture and Yarn Size

The equations for the material area ratio are:

Circular

$$A_{mr} = NMD \left(\frac{1}{N} + \frac{1}{M} - D_o\right)$$

Compressed

$$A_{mr} = NMD_o^{\,2} \left(2 + \frac{D_o^{\,2}}{\left(\frac{1}{N} - D\right)\left(\frac{1}{M} - D\right)}\right.$$

where:

N = Pick density

M = End density

D_o = Yarn circular diameter

D = Compressed yarn major diameter

5.2.1.2 Fabric Thickness. The average thickness of a fabric is governed by the yarn geometry as shown in Figure 5-15. In the circular yarn graph, thickness data are presented as a function of the yarn pick and end density. Crimp (the waviness of filler or warp yarn) is important as it will vary the thickness by 50 percent. The data presented in the curves are applicable for a balanced fabric (equal diameter and equal density in the warp and filler direction). The thickness value is computed by averaging the maximum and minimum thicknesses.

In the compressed yarn graph, the curve includes the flattening effect of the yarn as the material area ratio is increased.

5.2.1.3 Fabric Weight. The fabric weight is a function of the yarn size, material density, and the number of yarns per inch. Figure 5-16 shows the fabric weight as a function of the pick and end density and yarn denier. The denier is a unit which is based upon the weight of a given length of yarn (a piece of yarn 9000 meters long weighing 1 gram). The advantage in its use is that it incorporates both the density and diameter of the yarn material in a single unit. The same denier yarn for two different materials may have different diameters; however, the fabric weight is constant. The conversion from yarn denier to diameter is:

$$\text{Yarn Diameter} = 3.9 \times 10^{-3} \sqrt{\frac{\text{Denier}}{\text{Density}}}$$,where density is in lb/ft^3.

It is assumed that the fiber strands (filaments) comprise 90 percent of the yarn cross sectional area, which is typical of a twisted yarn.

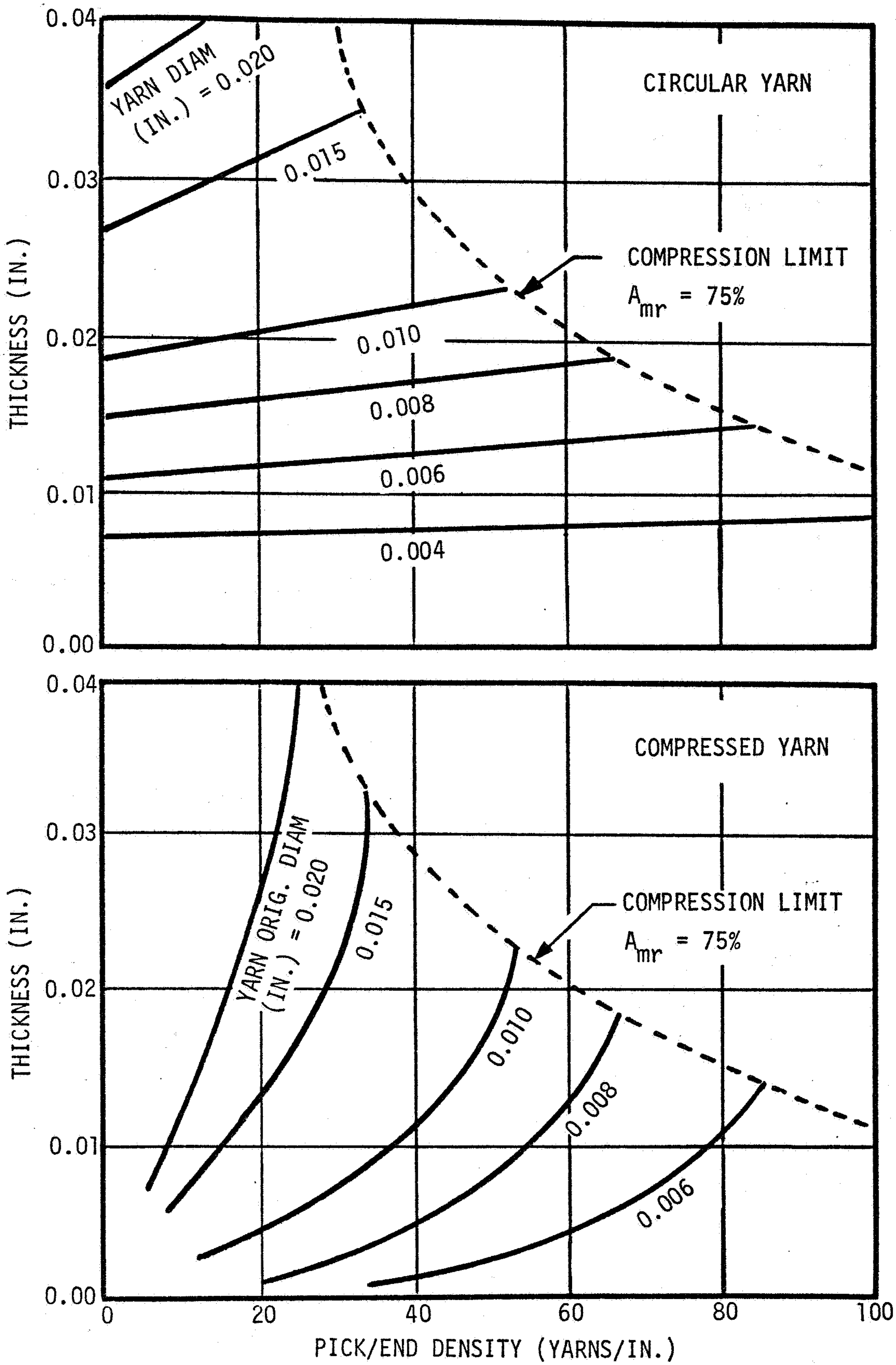
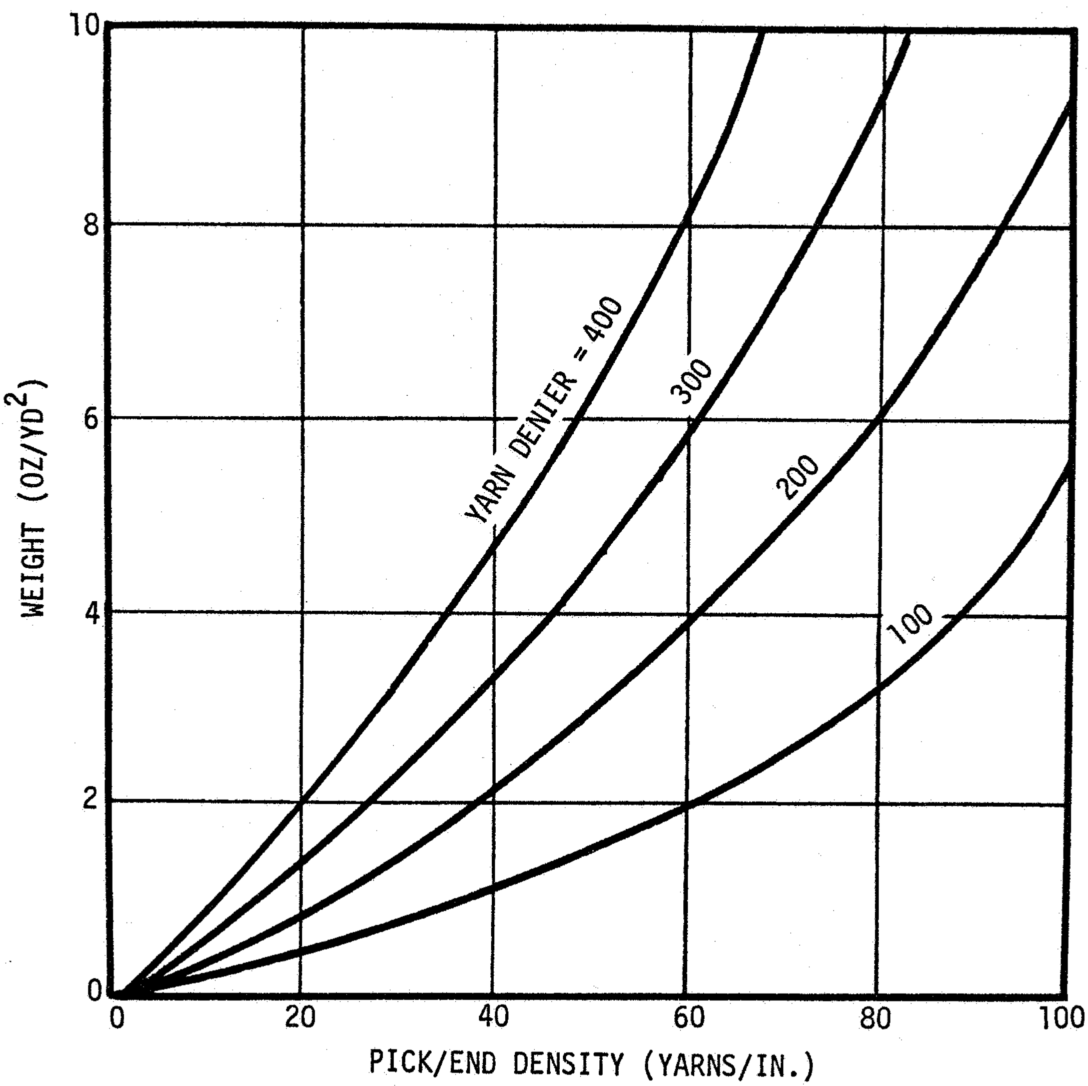


Figure 5-15. Fabric Thickness



For N = M, Enter Graph at Value

For N ≠ M, Enter Graph at Value $\frac{N+M}{2}$

where:

N = Pick Density (Yarn/In.)

M = End Density (Yarn/In.)

Figure 5-16. Fabric Weight for Woven Construction

The equation for the weight of the fabric is:

$$W = N(De_f)\ \phi_{cf} + M(De_w)\ \phi_{cw}$$

where:

N = Pick density (yarn/in.)

De_f = Filler yarn denier

ϕ_{cf} = Crimp factor (filler yarn)

M = End density (yarn/in.)

De_w = Warp yarn denier

ϕ_{cw} = Crimp factor (warp yarn)

and:

ϕ_{cw} is determined by the following equation

$$\phi_{cw} = \frac{1}{M}\left[\frac{1}{M} \cos\ (\sin^{-1}\ 2MD) + 2D\ (\sin^{-1} ND\right]$$

D = Yarn diameter (in.)

For a given material, the fabric weight will be in direct proportion to the linear yarn density, weave construction, and material density. The bulk density of each of the fibers considered for clothing is as follows:

Material Bulk Density (lb/ft^3)

Nylon	- 72	Cotton	- 95
PBI	- 82	Teflon	- 144
Dacron	- 86	Fiberglas	- 156
Nomex	- 86		

In computing the weight of a yarn, the yarn linear density or packing factor must be known. In the case of a monofilament, the linear density is equal to the bulk density with a packing factor of 1.0. For a loose yarn strand with no twist, the packing factor can be as low as 60 percent, yielding a much lower density than the bulk density value. For a twisted yarn, a conservative figure of 90 percent is used.

The denier is used to relate the linear density and bulk density of a yarn strand. The diameter value for a given denier yarn is computed as follows:

$$\text{Yarn Diameter} = 3.9 \times 10^{-3} \sqrt{\frac{\text{Denier}}{(\text{Packing Factor})\ (\text{Bulk Density})}}$$

5.2.1.4 Yarn Selection. Depending upon the type of material to be used in the garment fabrication, several yarn configurations are available. Presented below is a description of each type with the pertinent considerations shown in Table 5-1.

- Staple Yarn - Yarn which is formed by spinning fibers into a single continuous strand of yarn
- Continuous Filament Yarn - Yarn formed by twisting two or more continuous fibers into a single continuous strand of yarn
- Monofilament Yarn - Yarn with a single continuous filament comprising the yarn strand

Table 5-1. Yarn Comparison

	Staple Yarn	Continuous Filament	Monofilament
Advantages	Soft Absorbent Dull finish	Strong soil resistant	Fast drying
Disadvantages	Produces lint	Slippery Shiny	Stiff Shiny, Cold
Materials	Natural and synthetic	Synthetic and silk	Synthetic only
Applications	All types of clothing	Clothing outerwear	Hosiery

5.2.2 Design Details. Since the details of designing a garment are a matter of style and somewhat subjective, the data of this section contains the reference point from which the subjective decisions may be made. The following subjects are discussed in the following paragraphs:

- Selection of stitches
- Selection of seams
- Stitch number
- Seam location
- Selection of fasteners

5.2.2.1 Selection of Stitches and Seams. The selection of the proper seams and stitching techniques are based on the premise that the strength of a seam between two pieces of fabric is a function of stitch type, thread strength, number of stitches, and seam type. The types of seams and their uses are presented in Figure 5-17. There are seven basic types of stitches defined in MIL-STD-751, with the class 300 being the most commonly available in machines due to its simplicity.

5.2.2.2 Minimum Stitch Determination. The number of stitches for proper strength in joining two fabric pieces is a function of the properties of the fabric and thread. For a proper seam, the strength of the stitches should be equal to or greater than the fabric joined. A stitch number selection curve relating the important variables is shown in Figure 5-18.

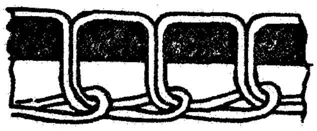
The theory of the analysis is based upon a plain, superimposed seam (see Figure 5-19) with an interlacing stitch. The rupture strength of the thread is equated to the rupture strength of the fabric yarns.

5.2.2.3 Selection of Seams. There are over 180 types of seams available for garment fabrication listed in Federal Standard No. 751. Although each seam is somewhat different and varies in complexity, the types are variations of four basic categories.

- Superimposed Seams (SS) - This type of seam is analogous to a butt joint in which at least one pass of the joining threads are in tension when a force is applied to each of the joined fabrics.
- Lapped Seams (LS) - This type of seam is analogous to a lap joint in which at least one pass of joining thread is initially in shear when a force is applied to the joined fabrics.
- Bound Seams (BS) - This seam is used at the edge of a single piece of fabric to build up and contain the material.
- Flat Seam (FS) - This seam is similar to a superimposed seam; however, the stitching operation is performed with the final seam configuration. This stitch involves a "zig-zag" stitch alternating between the two fabric pieces.

The commonly used seams and their applications are discussed in Table 5-2.

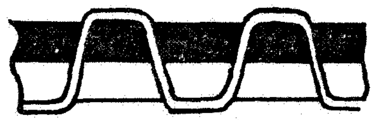
Class 100 - Chain stitch



Description: Single interlooping thread

Uses: Basting

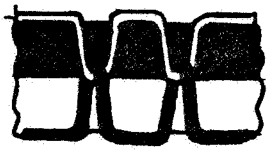
Class 200 - Hand stitch



Description: Single line thread

Uses: Ornamental, Basting

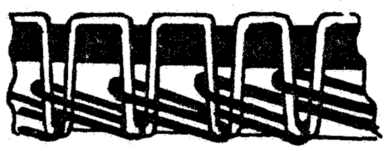
Class 300 - Lock stitch



Description: Interlacing multiple threads

Uses: Seams, Attachments, Facing Joining, Hemming

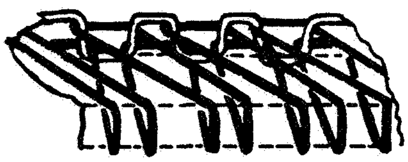
Class 400 - Double lock stitch



Description: Multithread interlacing and interlooping

Uses: Same as class 300

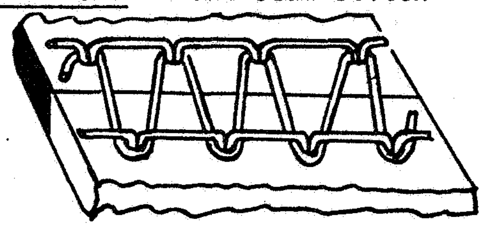
Class 500 - Overedge stitch



Description: Interlacing single thread over material edge

Uses: Edging

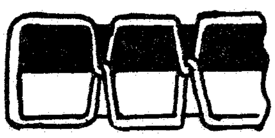
Class 600 - Flat seam stitch



Description: Multithread

Uses: Joining flat seams (type FS)

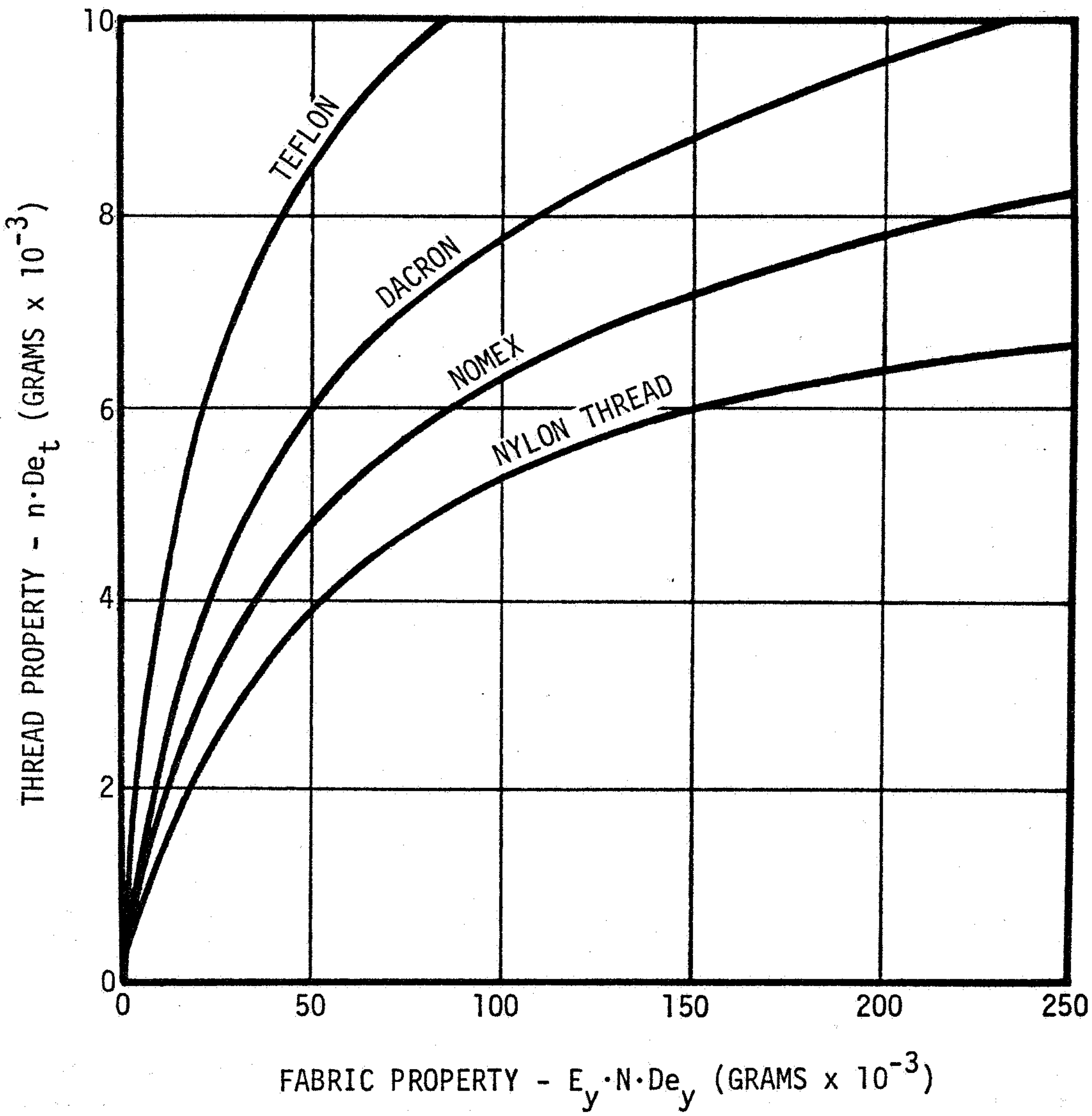
Class 700 - Single thread lockstitch



Description: Interlacing single thread

Uses: Same as class 300

Figure 5-17. Types of Stitches



where:

N = Pick or End Density (yarns/in.)

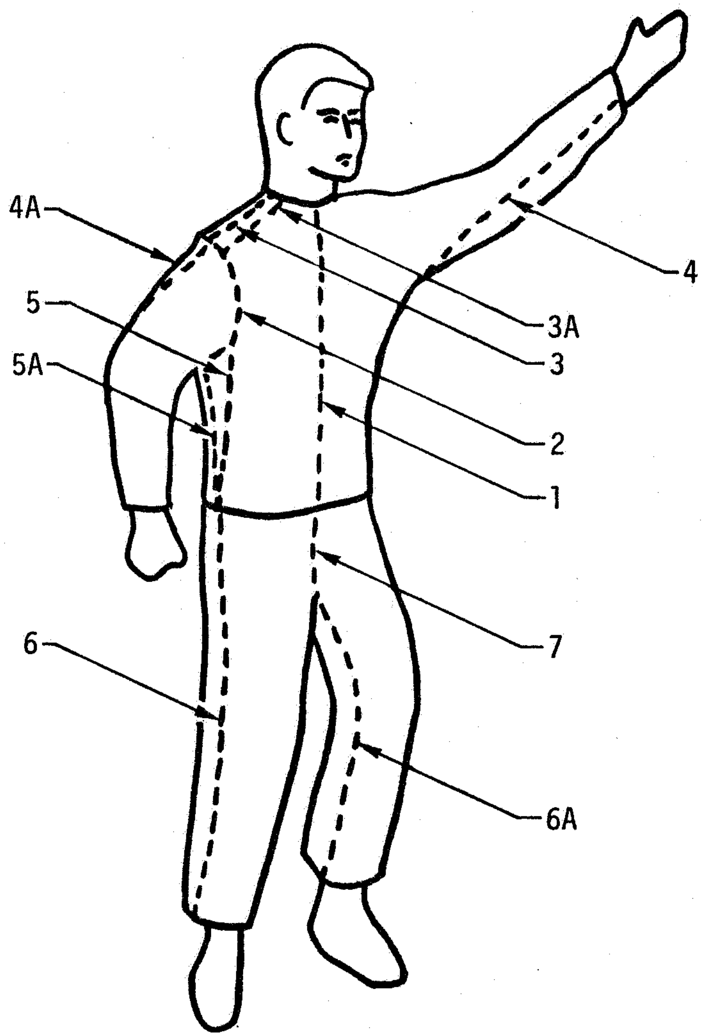
E_y = Fabric Yarn Ultimate Strength (grams/denier)

De_y = Fabric Yarn Denier

De_t = Thread Denier

n = Minimum Number of Stitches/In.

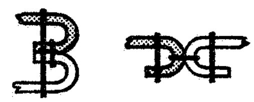
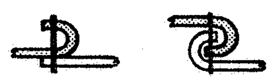
Figure 5-18. Stitch Number Selection



Seam No.	Seam Description	Applications
1	Entrance	All woven garments
2	Scye	All woven garments
3 only or	Upper shoulder	Sports shirts T-shirts
3 and 3 A	Yoke panel	Dress shirts Knit shirts
4 only or	Arm inseam	Sports jackets
4 and 4 A	Arm inseam and outseam	Tailored jackets
5 or	Torso	All woven garments
5 and 5 A	Torso panel	Tapered, conformal jackets
6 only or	Outseam	Work trousers, non-conformal
6 and 6 A	Outseam and inseam	Tapered trousers
7	Entrance	All woven garments

Figure 5-19. Seam Locations

Table 5-2. Common Seams

Class*	Type	Common Configurations	Uses
SS	Superimposed seam	Basic configuration:  Variations: 	Hidden seams Edges Pockets Zippers
LS	Lapped seam	Basic configuration  Variations: 	High strength seams
BS	Bound seam	Basic configuration:  Variations: 	Edges
FS	Face seam	Basic configuration: 	Joining fabrics: Knits to woven fabrics in cuffs and necks

*Per Federal Standard 751

5.2.2.4 Seam Location. The function of seams, in addition to the joining of two pieces of fabric, is to provide shape and stiffness to the garment. Comfort, drape, and the minimization of migration on the body are afforded by the proper use of seams in shaping a garment. Figure 5-19 presents the basic location of seams in men's garments and the variations available. As the function of seams is to provide shape to a garment, the general locations of seams are at the points of junctions of the limbs and places of maximum curvature. The more conformal the construction of a garment, the more seams are present. Sportswear, due both to relative expense and appearance, contains single seam construction throughout. Tailored garments contain double seams in the limbs and torso.

5.2.2.5 Selection of Fasteners. A comparison of fasteners is presented in Table 5-3.

5.2.3 Garment Weight Determination. The weight determination of a garment is accomplished by computing the following relationship:

$$W_{garment} = W_{fabric} \times A_{fabric} + W_{fixed}$$

where:

W_{fabric} = Fabric weight per unit area

A_{fabric} = Area of material in a garment

W_{fixed} = Weight of fixed articles on the garment

The fabric weight is a function of weave and material and may be found in Paragraphs 5.2.1.1 and 5.2.1.3. Table 5-4 shows the material area requirements for several garments according to size. The data are presented for small, medium, large and extra large categories. See Paragraph 3.1.2 for a description of size and size distribution.

The area requirements in Table 5-4 include a factor of 10 percent which applies to facings, reinforcements and seams.

Table 5-3. Fastener Comparison

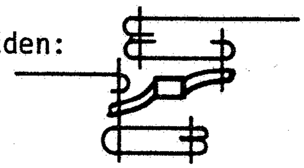
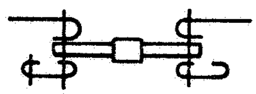
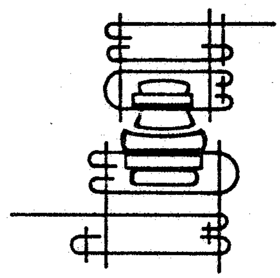
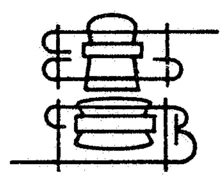
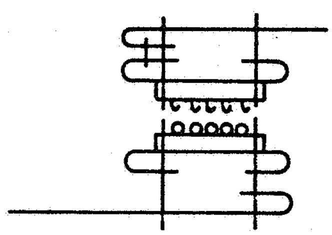
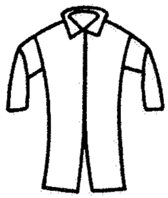
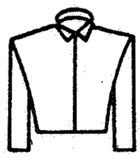
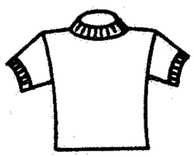
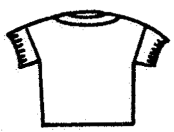
Type	Weight	Strength	Seam Requirement	Remarks
Slide	0.025 to 0.07 oz/in.	Equal to or greater than fabric	Hidden:  Exposed: 	Strongest and heaviest fastener Configuration controlled per Fed-Spec-V-F-106C Easy to operate
Snap	0.1 to 0.2 oz	Reinforced fabric to avoid tearing	Hidden:  Exposed: 	Used on Apollo coveralls Possible spark transmission with hydrophobic materials Lightest
Hook and Pile	0.04 to 0.06 oz/in.	Shear: >4 lb per in. Pull: 0.5 to 2 lb	Hidden: 	Poor drape with continuous closure Easy to fasten

Table 5-4. Garment Material Requirements (Area in Square Yards)

Item \ Size		Small	Medium	Large	X-Large
One piece coverall		2.75	3.20	3.50	3.80
Jacket		1.25	1.70	1.85	2.00
Pants		1.70	1.90	2.05	2.15
Shirt		0.75	0.85	0.95	1.05
T-Shirt		0.70	0.80	0.90	0.97
Briefs		0.30	0.35	0.40	0.45
Socks		0.10	0.10	0.10	0.10

5.2.3.1 Garment Fixed Weight Articles. The articles associated with a garment that contribute to its weight are the fasteners, cuffs, pockets and stiffeners. Table 5-5 presents a typical weight estimate of the fixed weight articles found on a garment.

Table 5-5. Fixed Weight Articles

Item	Article	Weight (oz)
Jacket	Cuffs (ribbed) Zipper Collar stiffener	4.0
Trousers	Zipper Ribbing	2.5
Shirt (knit)	Ribbing Zipper	0.5
Briefs	Ribbing	1.0
T-Shirt	Ribbing	0.3

5.2.3.2 Material Weight Comparison. Typical flight garments fabricated from various materials were weighed and are presented in Table 5-6. The garments are representative of the large-regular size as defined in Section 3.

Table 5-6. Flight Garment Weight Data (Weight in Pounds)

Garment Description	Teflon (Brown)	Teflon (White)	Polybenzimidazole (PBI)	Durette (Woven)	Cotton (Blend)
Trousers	1.014	1.404	1.186	1.011	0.856
Jacket	1.008	1.431	1.272	0.988	1.010
Shirt	-	0.985	-	-	0.331

5.3 MATERIALS EVALUATION

5.3.1 Natural and Synthetic Materials. The materials used in garment fabrication for specialized earth and space missions are:

Cotton	Nylon
Wood	Polyester
Fiber glass	Nomex
Teflon	Polybenzimidazole (PBI)

The two types of materials used in fabrics are synthetic and natural. In the case of natural materials whose fibers are obtained directly from animals or plants, only staple yarn is available. In the case of synthetic materials which are produced from polymers, both staple and continuous filament yarns are available.

Some properties of pure synthetic substances are generally undesirable on the basis of comfort or appearance. For this reason, blends of synthetic with other synthetic or natural materials and geometric variations are made. The performance of a blend (strength, shrinkage, endurance) is not a straight line function between the two end points. A blend will possess the characteristics of the lower valued material until at least a 50-percent mix is reached.

5.3.2 Guide to Man-Made Fibers. Man-made fibers, or synthetics, can be combined to obtain various blends of fabrics to satisfy particular end use requirements. A brief description of the man-made fibers that could be considered for spacecraft use follows.

- ACRYLIC - A manufactured fiber in which the fiber forming substance is any long-chain synthetic polymer composed of at least 85 percent (by weight) of acrylonitrile units $(-CH_2 - \underset{CN}{\underset{|}{C}}H-)$.

  Uses - Blankets, carpets, upholstery, industrial clothing.
  Popular trade name - Acrilan

- MODACRYLIC - A manufactured fiber in which the fiber forming substance is any long chain synthetic polymer composed of less than 85 percent but at least 35 percent by weight, of acrylonitrile units $(-CH_2 - \underset{CN}{\underset{|}{C}}H-)$.

  Uses - Pile fabrics, draperies, carpet, industrial fabrics.
  Popular trade name - Dynel

- POLYESTER - A manufactured fiber in which the fiber forming substance is any long chain synthetic polymer composed of at least 85 percent (by weight) of an ester of dihydric alcohol and terephthalic acid (P-HOOC-C_6H_4-COOH).

  Uses - Curtains, dress goods, floor coverings, blend for wash and wear suitings, rainwear.
  Popular trade name - Dacron

- RAYON - A manufactured fiber composed of regenerated cellulose as well as manufactured fibers composed of regenerated cellulose in which substituents have replaced not more than 15 percent of the hydrogens of the hydroxyl groups.

  Uses - Blankets, carpets, dress goods, industrial products, clothing, in blends with other fibers to enhance functional and aesthetic features.
  Popular trade name - Avril

- ACETATE - A manufactured fiber in which the fiber forming substance is cellulose acetate, where not less than 92 percent of the hydroxyl groups are acetylated, the term "triacetate" may be used as a generic description of the fiber.

  Uses - Swimwear, bonded fabrics, carpets, upholstery, clothing
  Popular trade name - Arnel

- NYLON - A manufactured fiber in which the fiber forming substance is any long chain synthetic polyamide having recurring amide groups as an integral part of the polymer chain (-C-NH-) with O attached to the C.

  Uses - Swimwear, clothing, upholstery, industrial goods, wash and wear fabrics.
  Popular trade name - Nomex, Nylon 6, Nylon 66

- GLASS - A manufactured fiber in which the fiber forming substance is glass.

  Uses - Curtains, draperies, fillings, reinforcing materials.
  Popular trade name - Beta, Fiberglas

- FLUOROCARBON - A manufactured fiber formed of long chain carbon molecules - available bonds saturated with fluorine.

  Uses - Clothing, coverings, upholstery, draperies.
  Popular trade name - Teflon

- POLYBENZIMIDAZOLE (PBI) - A manufactured fiber composed of a long chain polymer having nitrogen as a major constituent.

  Uses - Clothing, coverings, upholstery
  Popular trade name - PBI

Two treated fabrics, Fypro and Durette, are being considered for spacecraft use. These treated fabrics are obtained through a chemical process which changes the molecular structure of an existing textile product to enhance the flammability characteristics of a particular fabric. Currently, treated Nomex is used as the base fiber in this process. Test results involving Fypro and Durette are contained in Appendix C, Fabric Characteristics Summary.

5.3.3 Flammability. One of the most important criteria in the selection of a fabric is the degree of flammability of the material. The flame propagation rate and/or autoignition temperature are indices by which an evaluation of flammability is made. A great deal of testing and evaluation of these properties has been made by the National Aeronautics and Space Administration and presented in the report, "Nonmetallic Materials Design Guidelines and Test Data Handbook".

From this book and other studies, a limiting oxygen index has been created which is defined as the minimal volume fraction of oxygen in a slowly moving gaseous atmosphere that will sustain combustion.

$$n = \frac{PO_2}{PO_2 + PN_2}$$

where:

n = Limiting oxygen index percent

PO_2 = Oxygen partial pressure

PN_2 = Nitrogen partial pressure

Using this index to assess the relative flammability of materials, Figure 5-20 shows the comparison of limiting oxygen indices. The data are presented for two oxygen partial pressures and indicate the total pressure at which the flammability characteristics of different materials are the same. For a given PO_2, a material has a greater tendency to burn as the total pressure decreases.

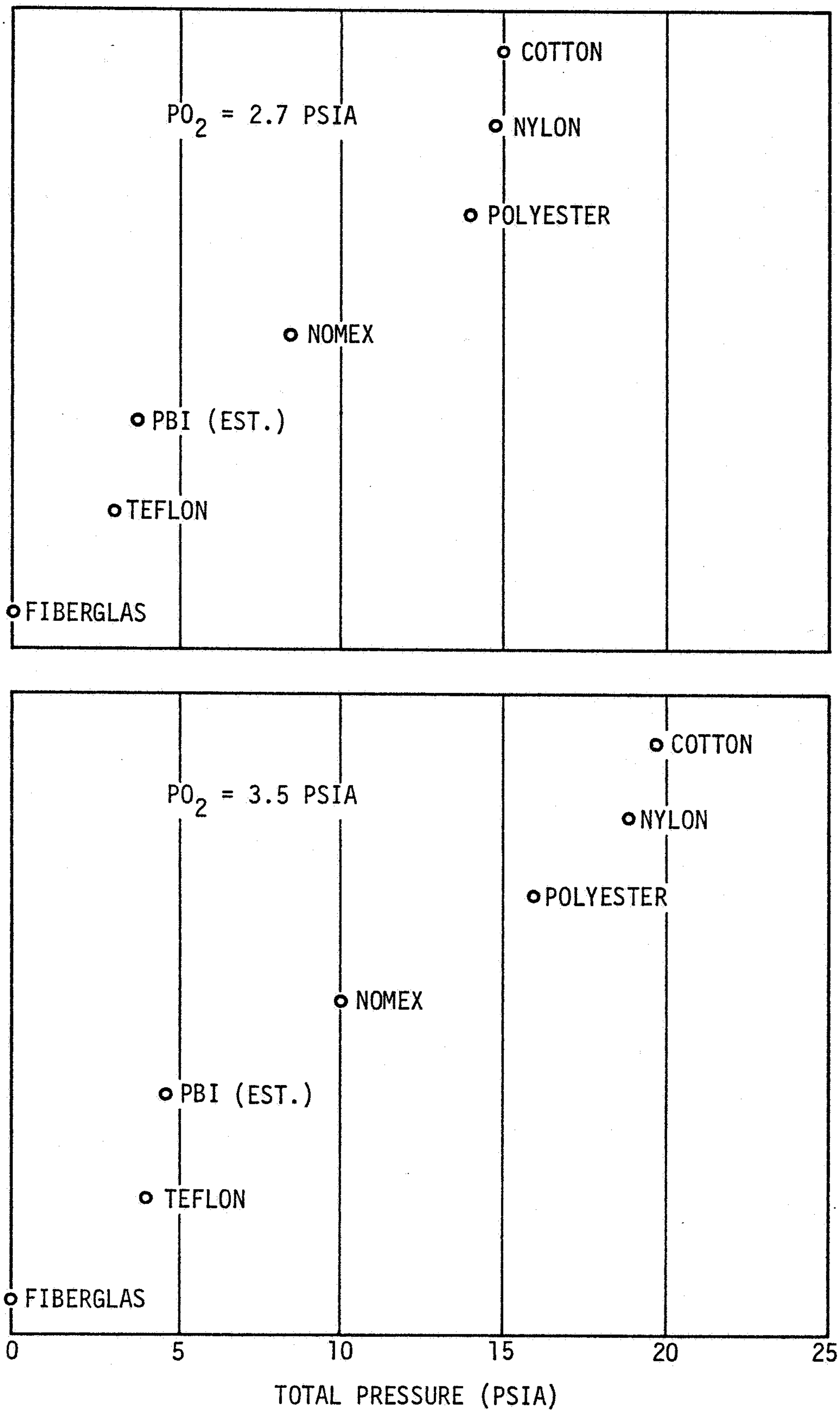


Figure 5-20. Material Flammability Comparison
(Points of Equal Flammability)

5.3.4 Material Temperature Limits. The temperature compatibility of a fabric is important from a flammability standpoint; however, damage may occur to a garment at temperatures below the autoignition or flash point temperatures. The data presented in Table 5-7 show the relative maximum temperatures for various materials and the type of damage that occurs.

Table 5-7. Material Temperature Limits

Material	Maximum Service Temperature (°F)	Effect
Cotton	250-300	Yellows at 250°, decomposes at 300°F
Nylon	300	Discolors, flows at 400°F, melts at 480°F
Polyester	275 (spun) 300 (monofilament)	Flows
Glass	1300	Softens
Nomex	Rapid degradation above 700	Loss of strength at elevated temperatures
PBI	700 - 800 (estimated)	Shrinks
Teflon	400	Flows, fibers shrink

5.3.5 Chemical Resistance of Materials. Table 5-8 presents the chemical resistance properties of several materials. Chemical stability is a consideration in the removal of stains, bleaching, laundering, and the intended use of a garment.

Table 5-8. Chemical Stability of Materials

Material \ Effect of:	Acids	Alkalies	Other
Cotton	Disintegrated by hot dilute or cold concentrated acids	Swelling (as in mercerization) in caustic-no damage	Bleached by hypochlorites and peroxides Dissolves in cupramonium hydroxide
Nylon	Hydrochloric, sulfuric and nitric acid attack	Substantially inert	Good resistance Soluble in phenolic compounds and formic acid
Nomex	Same as nylon	Sodium hydroxide attacks	Good resistance, moderate strength loss with sodium chlorite
Polyester	Partial decomposition with concentrated sulfuric acid	Disintegrated by strong alkalies at boiling temperatures	Good resistance to bleaches, generally insoluble
Glass	Resistant	Resistant	Resistant
Teflon	Inert	Inert	Only reactants are alkali metals, fluorine gas at high temperature, and chlorine trifluoride

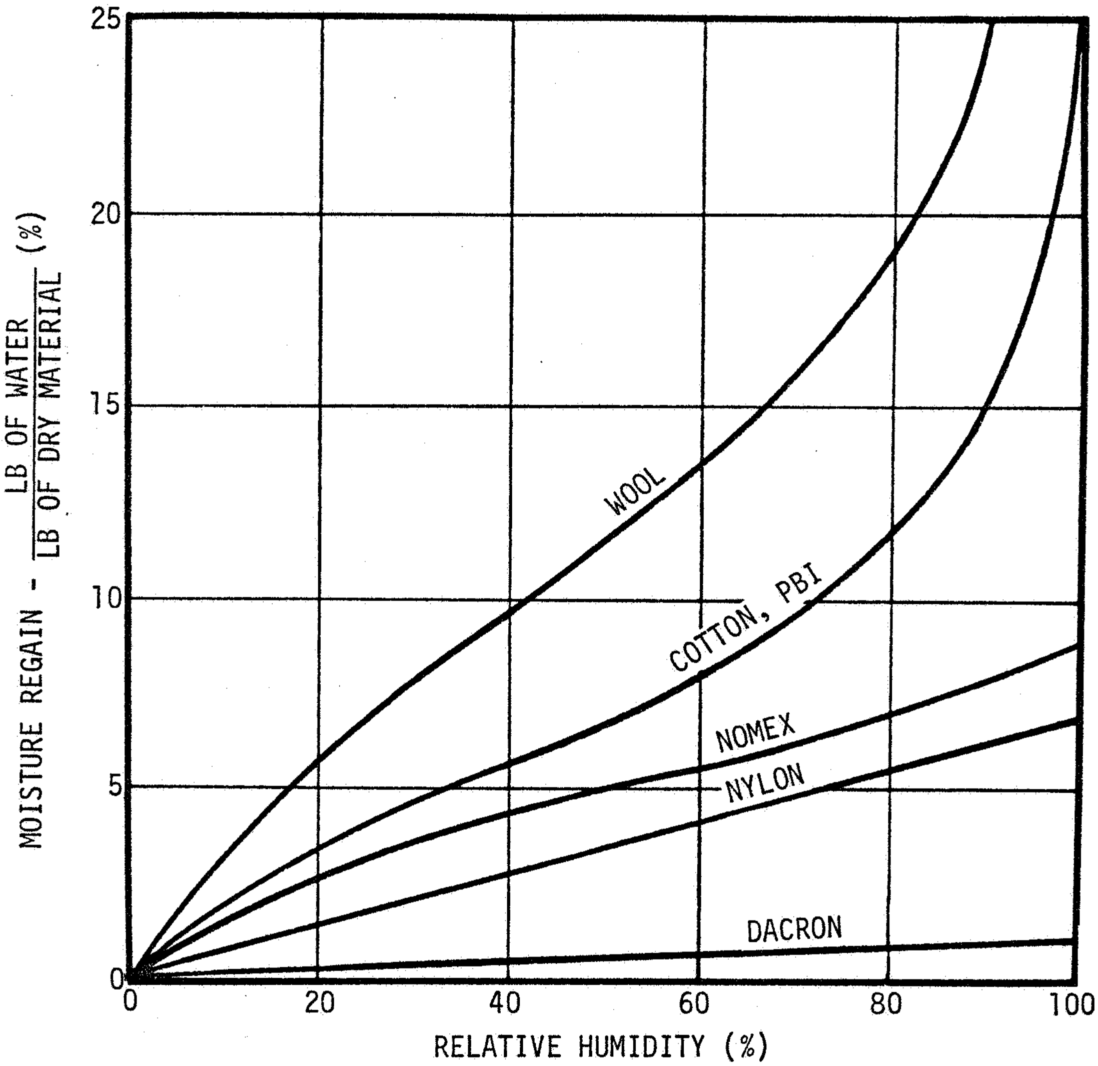
5.3.6 Moisture Regain. One of the most important factors in the comfort of a garment is the amount of moisture absorbed in the fabric. This is due to the ability of a fabric to hold perspiration without a "wet" sensation. The term "moisture regain" refers to the percent weight of water that a fabric may hold by absorption per unit fabric weight. Figure 5-21 shows the relative performance of various materials with respect to water absorption. Synthetic materials tend to be non-absorbent while natural materials are highly hygroscopic. The variable of relative humidity is based upon a standard dry bulb temperature of 77°F.

The water regain characteristic is also an important consideration with respect to garment static electricity. Since absorbed water in a garment provides conduction, the lesser water regain a fabric exhibits, the more likely local static charges may be induced when rubbed in a dry atmosphere.

5.3.7 Water Compatibility. One of the considerations in the selection of a fabric is its compatibility with water (resistance to shrinkage). Shrinkage is a function of several variables, two of which, the material and weave, are described below.

For a hygroscopic material, shrinkage occurs as the cross sectional area of a fiber increases due to absorption. This requires that the opposing yarn pass through a greater arc length due to the increased radius.

Since the fiber will not stretch appreciably, this results in shortening of the fabric. Table 5-9 shows the relative swelling properties of fibers when exposed to water (low to moderate temperatures). Although the mechanics of shrinkage are complex and numerous, a major criterion in the aspect of shrinking is the fabric construction. In general, the tighter the weave (higher material area ratios), the lesser the amount of shrinking that takes place. This is due to the initial configuration (large arc segments) and tension on a fiber. A typical example of the shrinkage characteristic for wool is presented in Figure 5-22.



Note: Moisture Regain for Teflon and Fiberglas = 0, Temperature = 77°

Figure 5-21. Moisture Regain Characteristics

Table 5-9. Fiber Swelling Due to Low Temperature Water Exposure

Material	Type	Length Change (%)	Diameter Change (%)
Cotton, raw	Hygroscopic	1.2	14.0 - 30.0
Cotton, mercerized	Hygroscopic	0.1	20.0
Glass	Hydrophobic	0.0	0.0
Nylon	Partially hygroscopic	1.2	1.9 - 2.6
Nomex	Partially hygroscopic	1.2+	3.0
Dacron	Partially hygroscopic	0.0 - 0.1	0.0 - 0.3
Teflon	Hydrophobic	0.0	0.0

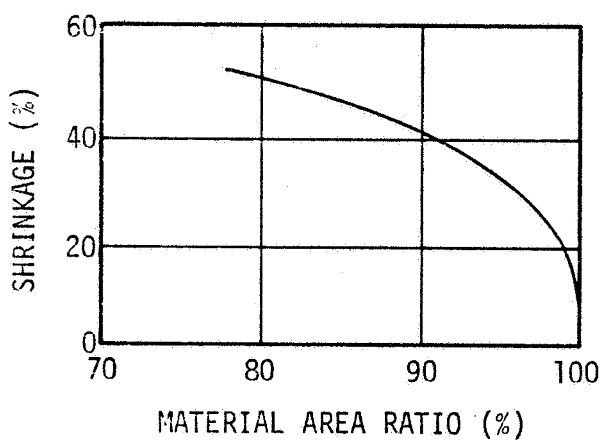


Figure 5-22. Typical Shrinkage Characteristics for Wool

Shrinkage of certain hydrophobic materials occurs in a different fashion and is somewhat equivalent to annealing steel. Stresses formed in the fibers during initial manufacture or weaving are relieved, thus causing the length of a yarn to contract. This type of shrinking is caused chiefly by exposure to higher temperature rather than exposure to water.

5.3.8 Material Structural Properties. The selection of a material for a particular garment may depend upon its structural properties with respect to life and strength. Although the weave characteristics influence the structural properties greatly, the selection of material is the major consideration. Table 5-10 lists a few of the variables in the consideration of weave effect upon the properties of materials. By changing fabric geometry, several changes in properties may be produced.

Table 5-10. Fabric Texture Considerations

With an Increase In:	Uniaxial tensile strength	Stiffness	Air permeability	Abrasion resistance	Shear resistance	Flex endurance	Thickness	Tear strength
Fiber linear density		+	+	+		-	+	
Yarn linear density	+	+	-	+	+	→+-	+	+
Yarn twist	→+-	+	+	→+-	+	→+-	+	
Yarn/Inch	→+-	+	-	+	+	-	+	-
Weave pattern interlacings	-	+	-	+	+	-		-

KEY

\+ Increases

\- Decreases

→+- First Increases, then Decreases

Blank - No Change

5.3.8.1 Tensile Strength. The strength of a material can be directly related to the fabric yarn and the weave construction. Assuming the weave is constant, a fabric will possess the relative yarn properties presented in Figure 5-23. This chart relates the tenacity (stress expressed in grams/denier) and elongation (strain) of a yarn sample. The elastic modulus of a yarn (expressed in grams per denier) is comparable to Young's Modulus for a metal and is expressed as follows:

$$\text{Tensile Strength} = \text{Tenacity} \times 12{,}000 \times \text{Specific Gravity}$$

5.3.8.2 Abrasion - Flexural Endurance. The aspect of wearing endurance of a fabric cannot be rated by a single test or analytical approach. The wearing of clothes results in a combination of tensile stresses, flexural loads, and abrasion in a garment. For this reason, the two criteria discussed below and the tensile strength data of Figure 5-23 have been established as the measuring stick of endurance. Figure 5-24 presents the relative ratings of the typical materials in each category.

Abrasion endurance of a fabric is tested by rubbing a sample with a material of given roughness. The abrasion resistance of a material is expressed in cycles of a turntable or wheel before failure (breakdown of fabric). Flexural endurance is determined by bending a fabric sample over a small radius of curvature until failure.

In both cases, the flexural and abrasion characteristics are a function of the weave as shown in Table 5-10. The data of Figure 5-24 is based upon a uniform weave and yarn thickness.

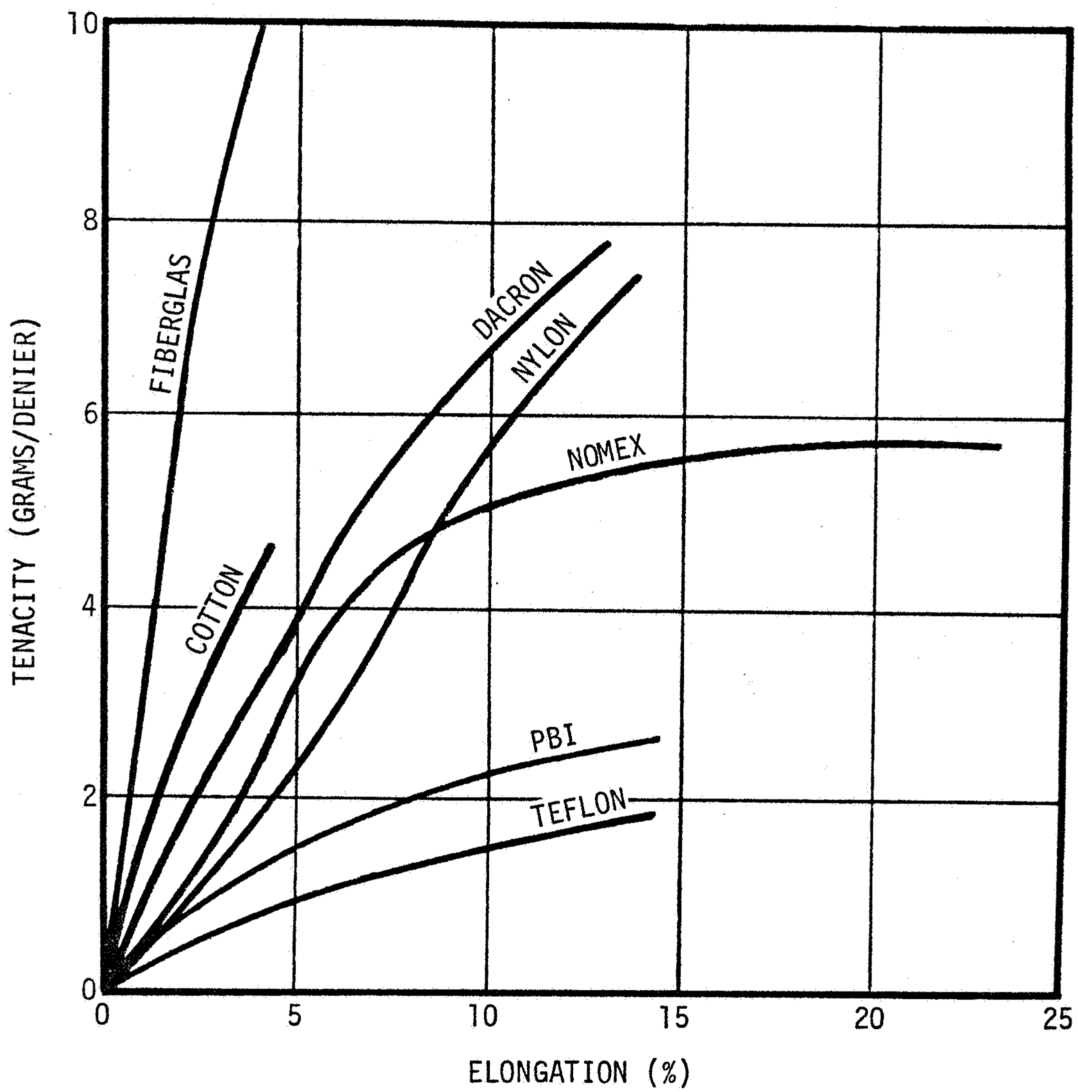


Figure 5-23. Yarn Tensile Strength

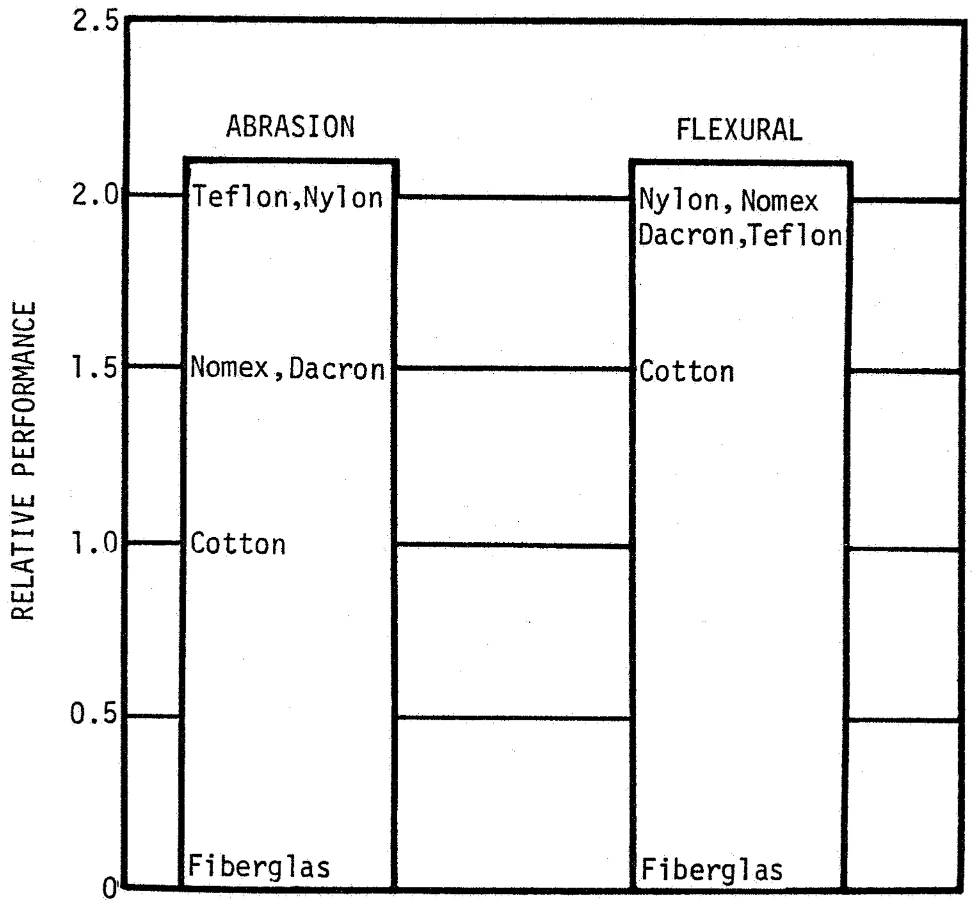


Figure 5-24. Relative Material Endurance Characteristics

5.3.9 Material Performance.

5.3.9.1 Wrinkle/Shape Recovery. The neatness of a garment is judged by the number of wrinkles induced by wearing. This criteria is most important from an appearance standpoint. The recovery of a material from folding or stretching is indicative of wrinkle resistance. Such tests were performed upon simple materials and the results are presented in Figure 5-25. The fiber elastic recovery data for several fibers are shown in this figure. It is apparent that cotton is the most prone to permanent distortion with a given strain.

5.3.9.2 Color. Three aspects are important in the selection of garment color:

- Identification - By the establishment of a separate color for a crew or particular individuals of a crew, instant recognition may be achieved.
- Attention - By the use of an intense color, recognition may be made from greater distances.
- Compatibility - The garment color must be compatible with the vehicle color scheme and light intensity for eye comfort.

The following list presents the colors that are commercially available for several materials.

Material	Available Colors
Cotton	All
Nylon	All
Dacron	All
Nomex	International Orange, Natural, Olive
Fiberglas	All
Teflon	Natural (Brown) to White
PBI	Brown

5.3.9.3 Cleaning Compatibility. The relative penalty of cleaning a garment in space is an important assessment with respect to weight and power. First, certain materials are inherently less susceptible to soiling and require less cleaning provisions. Secondly, the power required for drying is a function of the fabric material and construction.

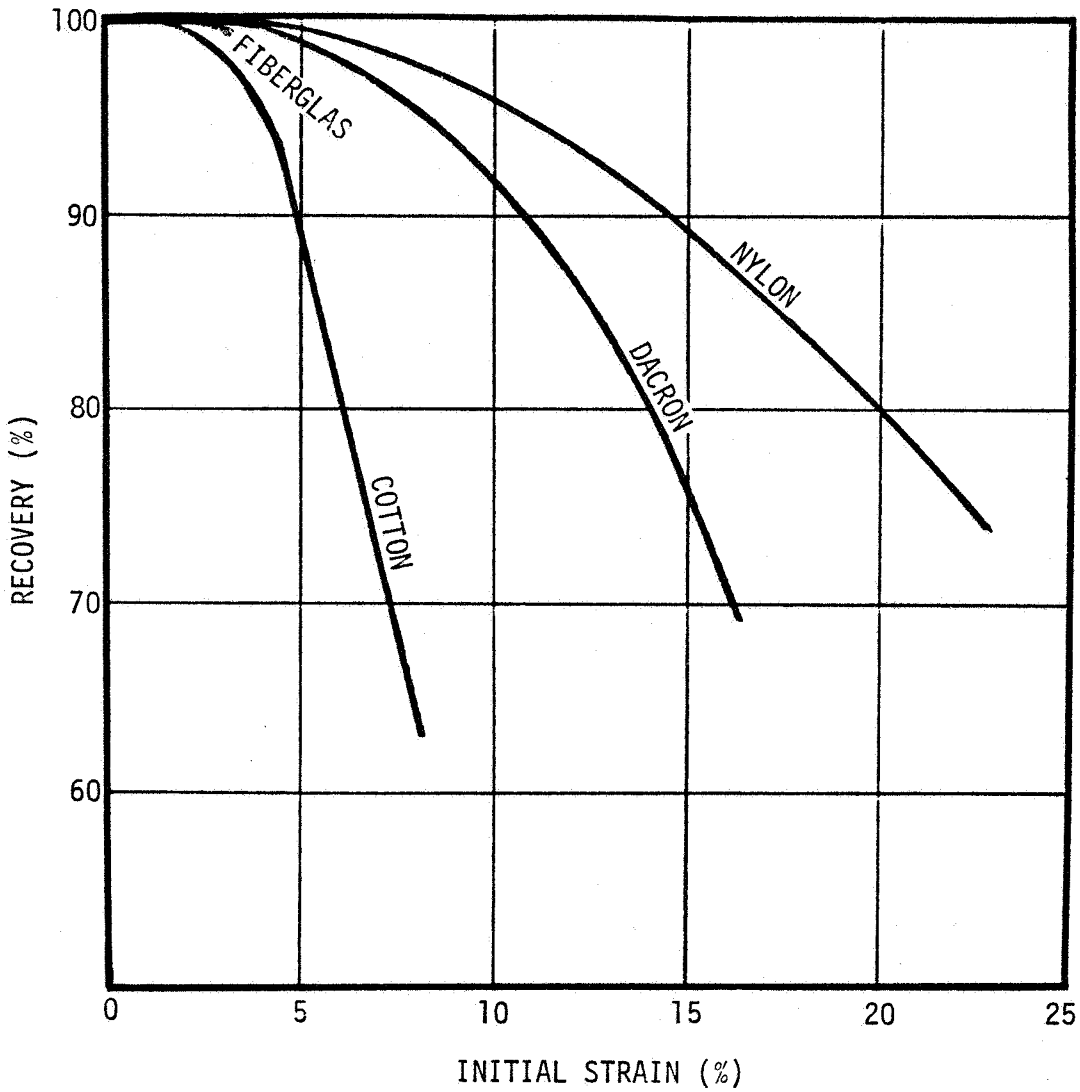


Figure 5-25. Fiber Elastic Recovery

The amount of soiling may be somewhat controlled by the selection of the yarn configuration. In general, continuous filaments provide less area in which soil may build up and the quantity of water and detergent required for cleaning is not as great. The amount of water absorbed by the materials has an effect upon the drying load of each garment. The relative energy to dry a given material is shown in Figure 5-26.

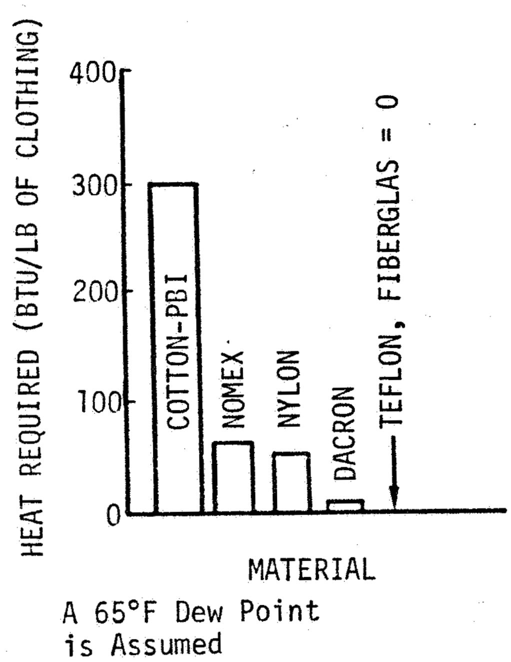


Figure 5-26. Relative Drying Penalty

5.3.9.4 Electrostatic Performance. Rubbing may cause an electrostatic charge to build up in a garment due to the nature of the material and insulating properties of the fabric. Dry fabrics are good insulators, and thereby allow potential differences between charged areas. However, with hygroscopic materials, water is entrained in the fibers due to the humidity and acts as a conductor. The entrained water does not permit charge differences in a single garment due to its conductivity. By this feature, it is apparent that the charge affinity of a fabric due to rubbing is a function of its water regain and the atmosphere dew point. With a low dew point, spark generation is a safety consideration in the presence of combustible materials and high oxygen partial pressures.

Certain materials will assume a charge more readily than others due to their molecular structure. The Triboelectric* Series for materials is shown below. This list is composed of fabrics that will become positively charged if rubbed with a fabric below it on the list (40 percent relative humidity).

Triboelectric Series for Typical Fabrics

Glass
Wool
Nylon
Cotton
Dacron
Teflon

5.3.10 Laundering Test Results. Certain select materials were tested to evaluate the effect of repeated laundry cycles upon the clothing/fabric properties. The testing effort consisted of subjecting sample swatches of various materials to a washing at a maximum temperature of 160°F for a wash cycle time of 40 minutes, and tumble drying with a hot air setting that allowed the temperature to reach approximately 250°F when the load was completely dry. After 10, 25, 50, 100, 150 and 200 washing cycles, the test items were subjected to mechanical properties tests to determine the effect of continued washing on material flex and flat abrasion resistance, and material strength, shrinkage, and reflectance characteristics. New fabric swatches were then subjected to soiling tests by laundering clean swatches in a tub containing soiled swatches (soiled with a mixture of vegetable oil, mineral oil and carbon) to measure the tendency for any of the fabrics to pick up soil from the wash solution.

Jackets manufactured from the selected materials were subjected to a wool fabric washing procedure where: the maximum wash water temperature was 95°F, the wash cycle time was 26 minutes, and the garments were tumble dried at 160°F. Shrinkage measurements were made repeatedly throughout the garment testing. Results of this testing effort are contained in the following figures and tables. All testing was conducted at the American Institute of Laundering in Joliet, Illinois.

*Triboelectricity is defined as a charge of electricity generated by rubbing two materials together.

5.3.10.1 Crease Resistance Test. Swatches of ten sample fabrics were subjected to a crease resistance test. The test was accomplished by folding a sample swatch, placing a 1.5 pound weight on the fold for five minutes, removing the test specimen and placing it on a crease recovery tester (identical to the one shown in Federal Standard CCC-T-191b - Method 5212.1), and measuring the percent crease recovery for the particular fabric. Figure 5-27 depicts the results of the crease resistance tests.

5.3.10.2 Shrinkage Test (Swatches). The results of shrinkage measurements made on test swatches are shown in Figure 5-28.

5.3.10.3 Shrinkage Test (Jackets). The results of shrinkage measurements made on jackets are shown in Figure 5-29.

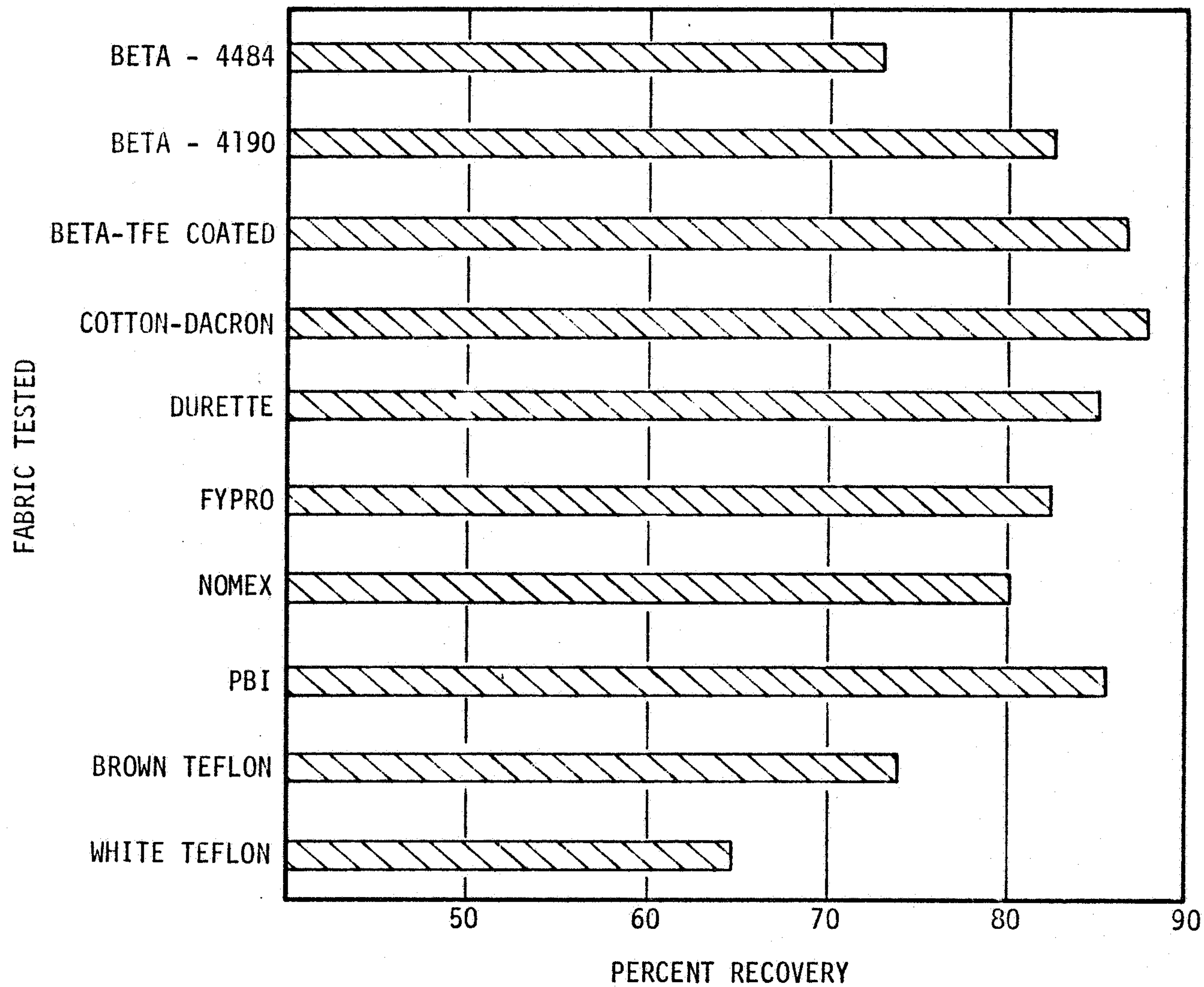
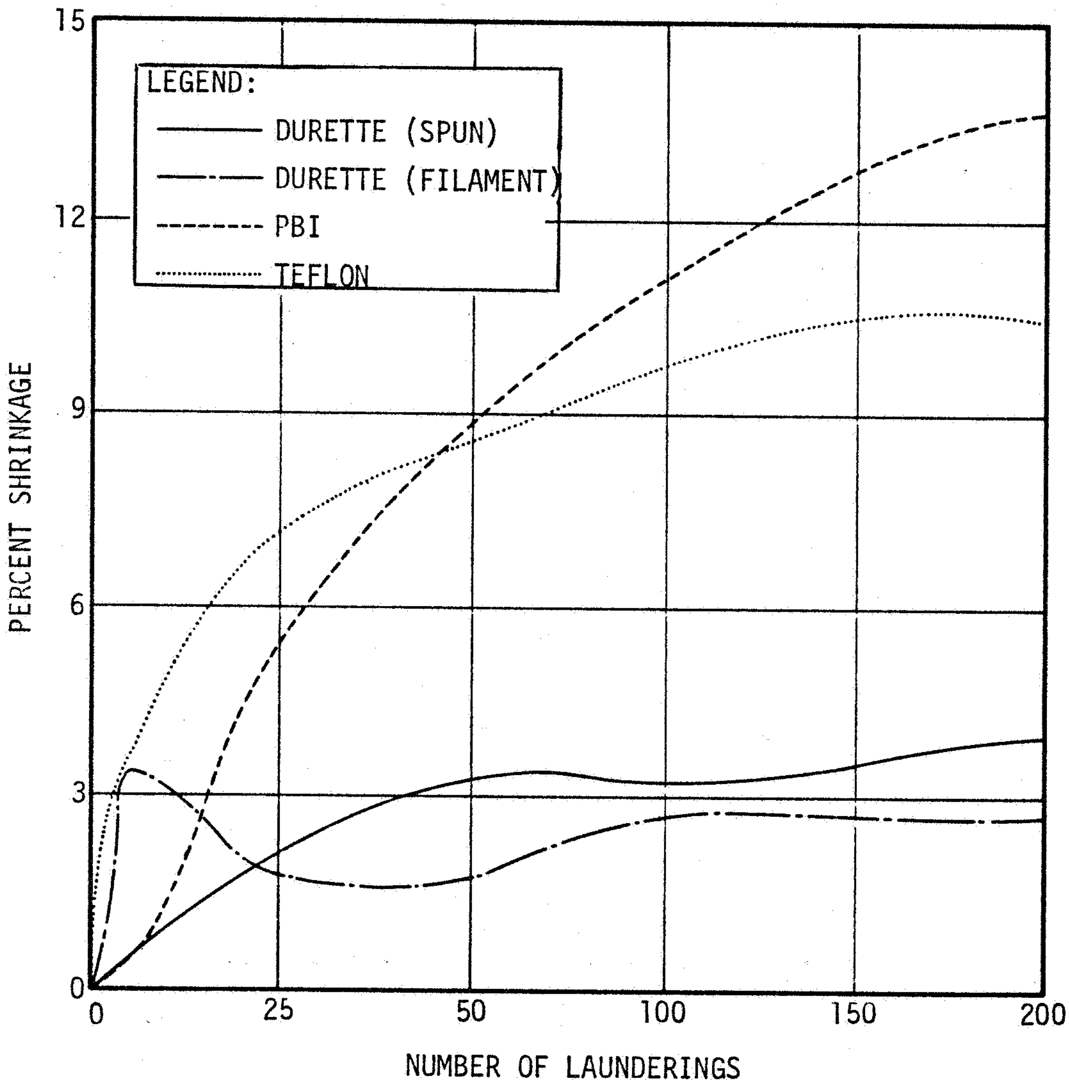
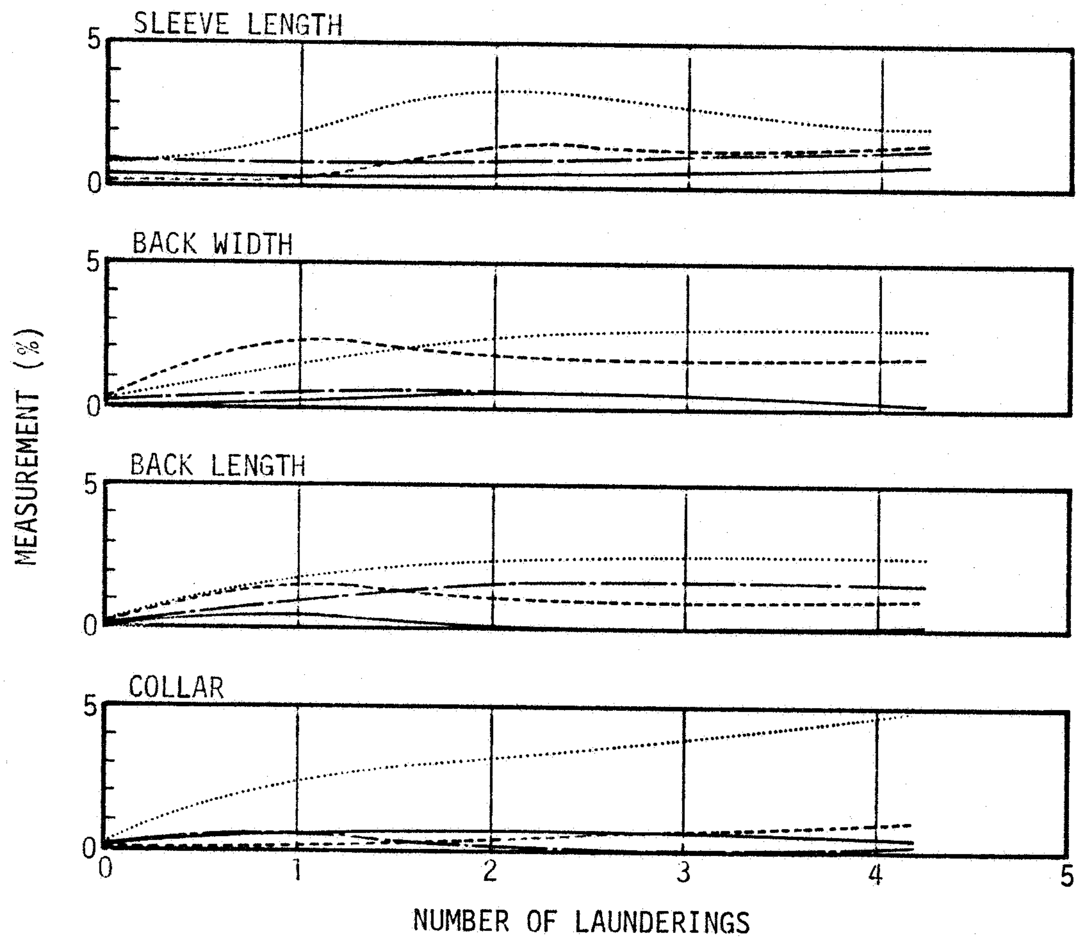


Figure 5-27. Crease Resistance Test



Test Conditions: Standard White Wash Procedure
Wash Cycle Temp. = 160°F
Tumble Dried at 250°F (MAX)

Figure 5-28. Shrinkage Test (Swatches)



LEGEND:

- DURETTE (SPUN) — solid line
- DURETTE (FILAMENT) — dash-dot line
- PBI — dashed line
- TEFLON — dotted line

Test Conditions:
Wool Wash Procedure
Wash Cycle Temp. = 95°F
Tumble Dried at 160°F

Figure 5-29. Material Shrinkage (Jackets)

6.0 WARDROBE LOGISTIC CONSIDERATIONS

Logistic considerations of a garment system include weight and volume. This section examines typical garment folding techniques, actual flight hardware folded volumes, vacuum packaging, and garment transfer envelopes. Weight data are presented in Section 3.

Garment packaging may be done by pressing folded garments together and evacuating the package. A simplified approach in calculating the volume requirements of a garment would be to multiply the number of folds by the fabric thickness for a given demension. Although this technique would be applicable for a piece of cloth, the addition of padding, cuffs, collars, fasteners, and ribbing do not allow this approximation for a garment. The major consideration in packing a garment is its interface with adjacent garments. However, by proper folding and packing, the local areas of relatively larger thickness can be minimized.

Figure 6-1 is a representation of a folding technique that can be used in preparing garments for packaging and transfer.

6.1 TYPICAL FLIGHT GARMENT FOLDED ENVELOPES

Flight garments, representative of articles of clothing to be used on the Skylab Program, were folded to determine the optimum packaging envelope. Two folded configurations were considered, namely, rolled and standard flat fold techniques. The items measured consisted of jackets and trousers made from Teflon, PBI, Durette, and cotton, and cotton shirts, briefs, and socks. The results of the measurements are shown in Figure 6-2.

6.2 VACUUM PACKAGED GARMENT VOLUMES

An investigation of vacuum packaging of a typical flight article (jacket and trouser combination) yielded the results depicted in Figure 6-3. Vacuum packaging of garments consists of evacuating the sealed package.

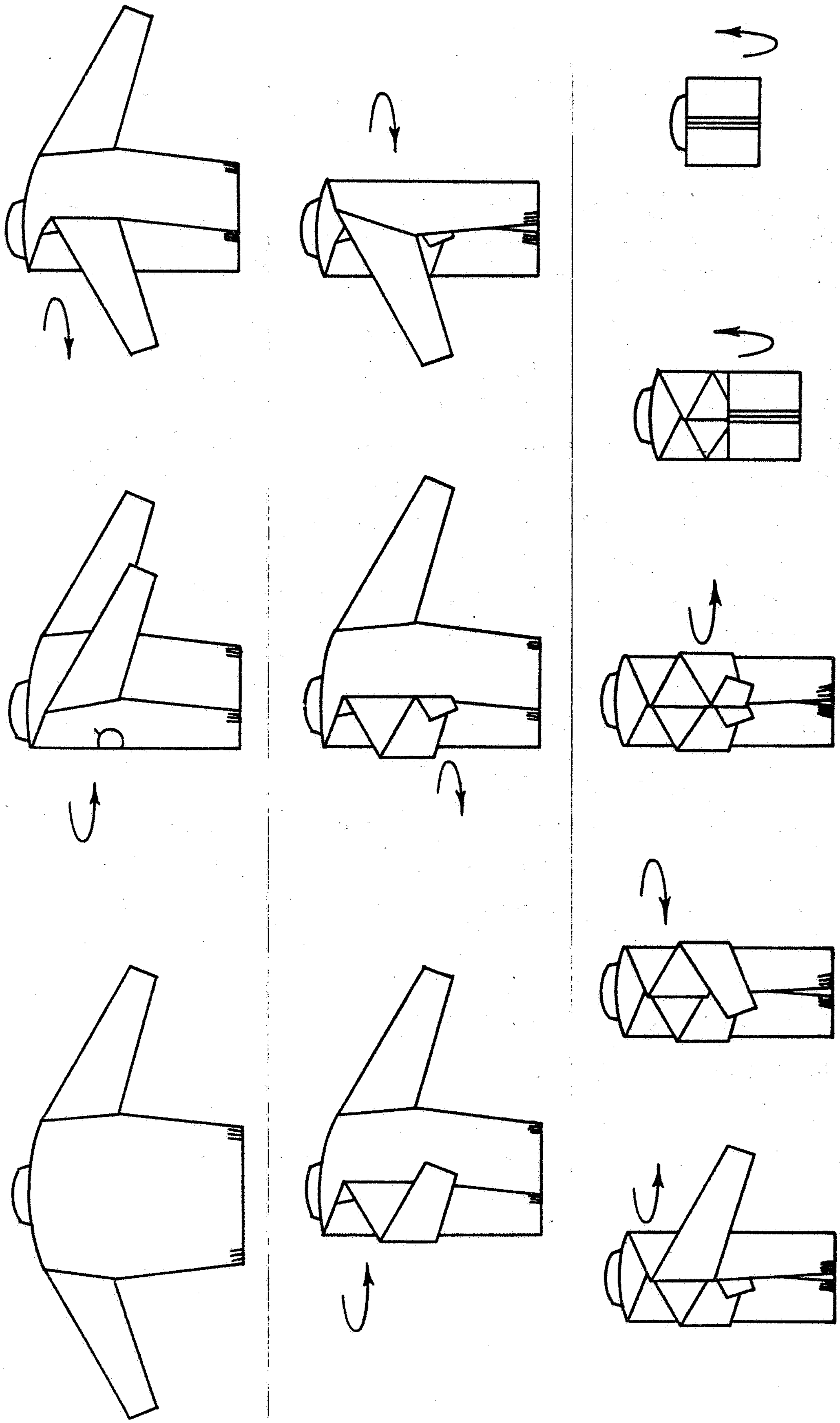


Figure 6-1. Sample Folding Technique

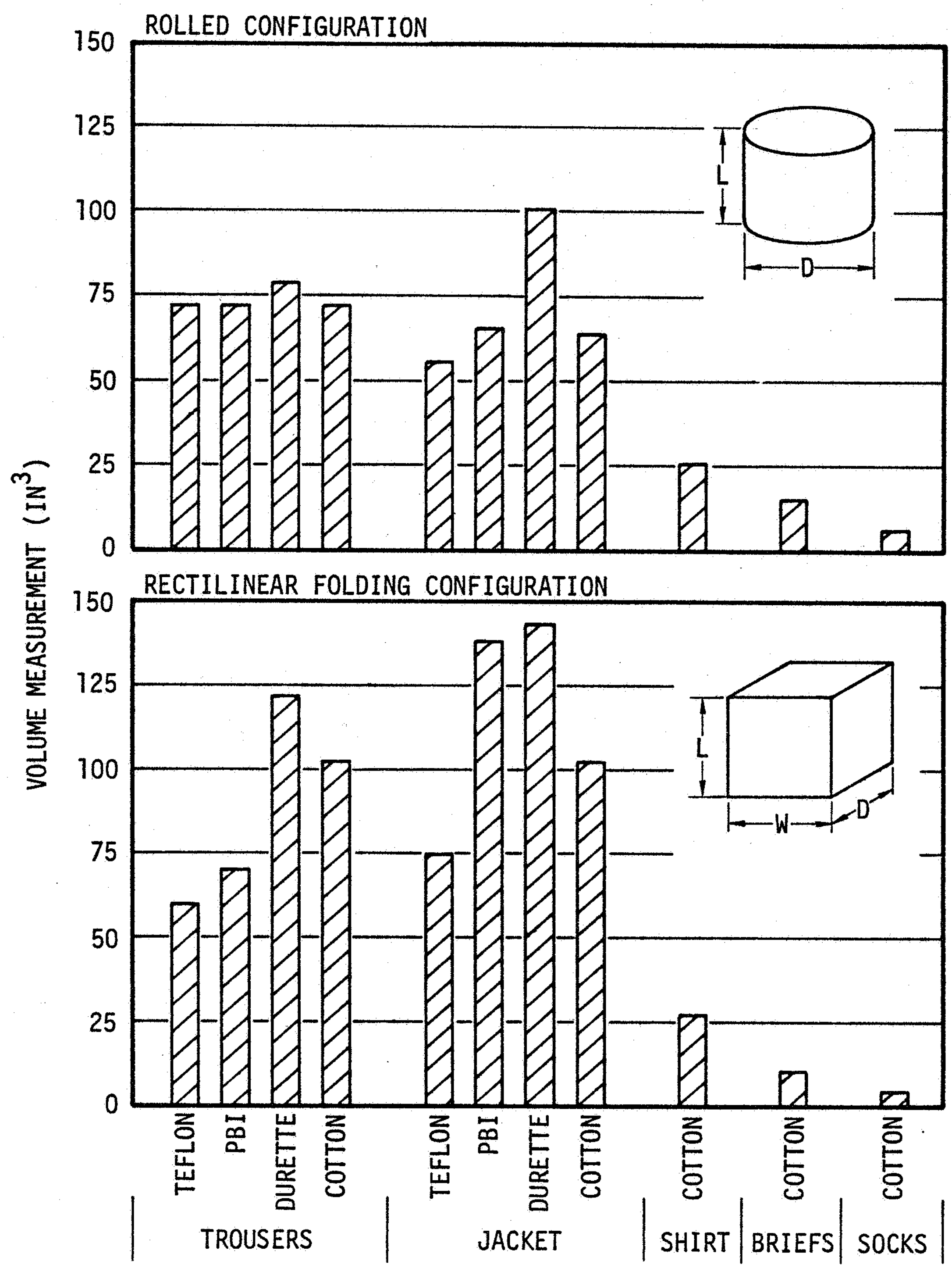


Figure 6-2. Flight Garment Folded Envelope

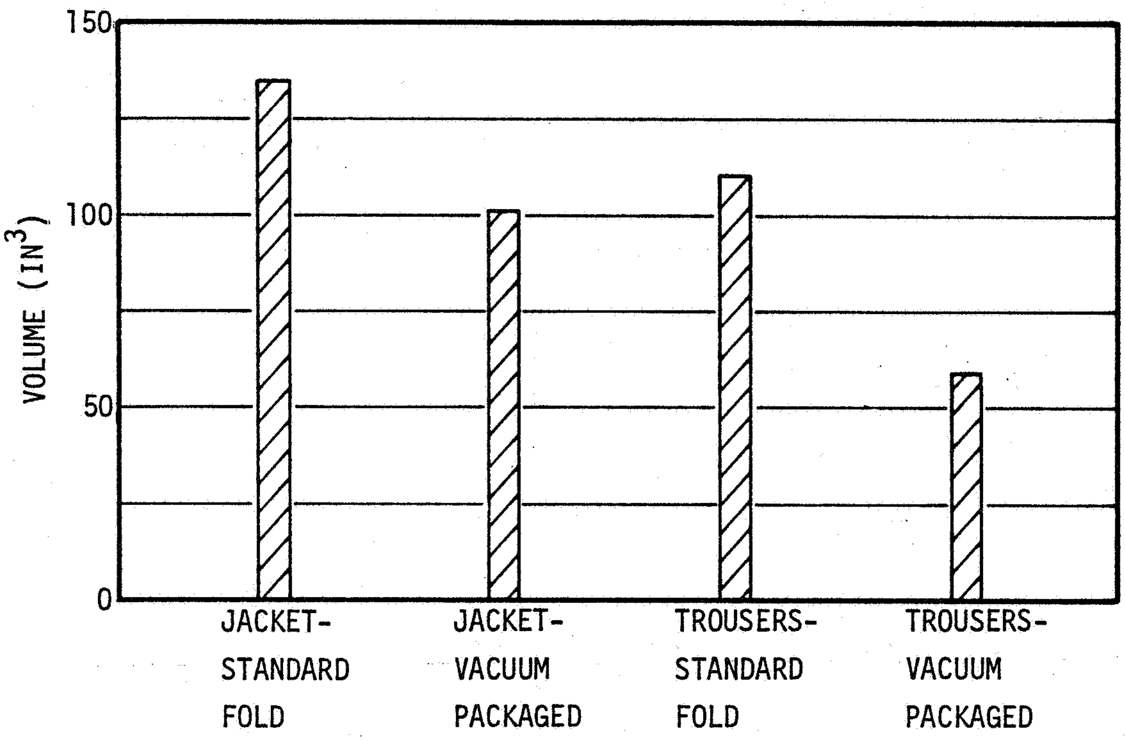


Figure 6-3. Sample Vacuum Packaging (Cotton Flight Garment)

6.3 TYPICAL FOLDED VOLUME EXAMPLES

Figure 6-4 shows the typical volume requirements as a function of wear cycle for a single crew member. These values are based upon vacuum packed garments with ribbed cuffs and reinforcements. Since there is more than one of each item of the wardrobe, proper folding and packaging is applied. An assumption is made that regardless of the wash interval, two briefs and T-shirts and two pairs of socks will be supplied for a crew member. Figure 6-4 shows that this quantity is the minimum number possible.

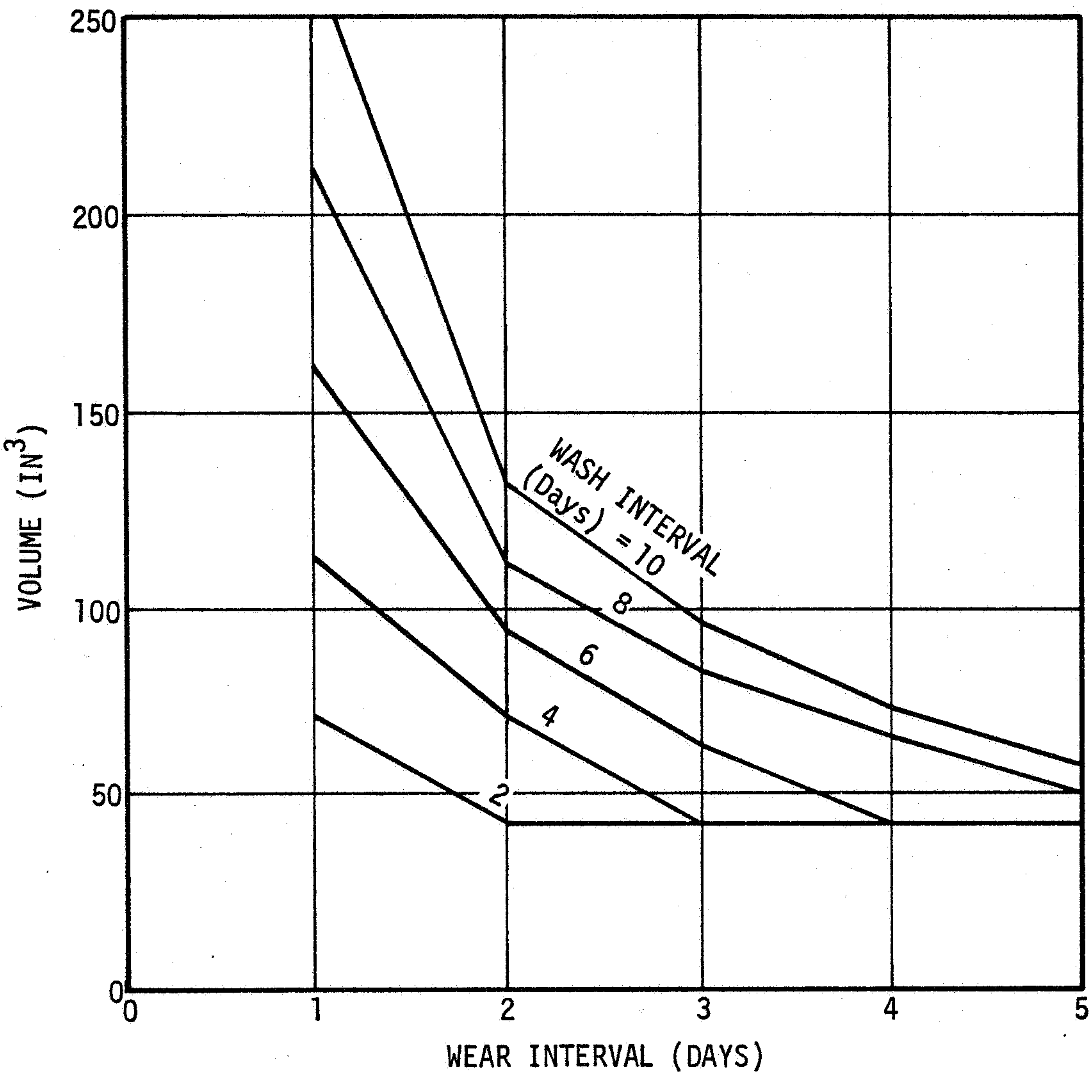


Figure 6-4. Packed Volume Requirements of Underwear for a Crew Member (Briefs, Socks, T-shirt)

6.4 GARMENT TRANSFER ENVELOPES

After a crewman's wardrobe has been packaged, it must be transferred to the space vehicle in orbit. This requires a definition of the garment transfer envelopes to enable interfacing the clothing system with the transfer vehicle. Examples of transfer envelopes associated with the Skylab disposable garment system are presented below:

SKYLAB Disposable Wardrobe and Quantities

Garment	Mission Duration 14 Day	28 Day	56 Day
Trousers	2	4	8
Shirts	5	4	8
Jackets	2	4	8
Briefs	7	14	28
Socks (pr.)	7	14	28
Shoes (pr.)	1	1	2
Gloves (pr.)	1	1	1
Total volume (in^3)	900	1000	3000

6.5 CLOTHING STORAGE (IN ORBIT)

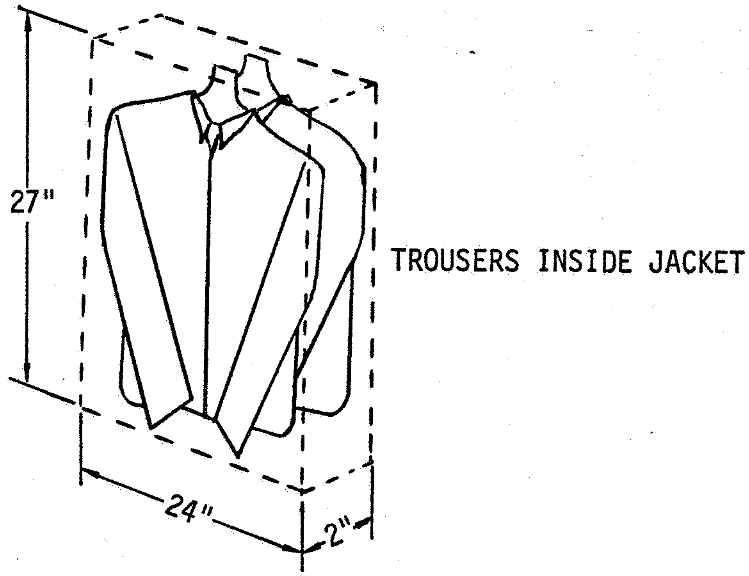
The two basic requirements for a storage area are:

1. Maximum use of space available
2. No degradation in garment appearance.

The compartment concepts contained herein are based upon garments alone. Figure 6-5A presents the typical volume and envelope requirements for a jacket and trousers combination. It is assumed that these are the only items which require hanging and that the remaining garments are stored in a folded condition.

To simplify the logistics problem, garments are packaged in functional groups, i.e., one module will contain a duty garment ensemble, another may contain the leisure garment ensemble. This method will allow selective resupply as individual items wear out rather than require the shipment of a complete wardrobe. An example of modular storage compartments incorporating combined transit/storage capability is shown in Figure 6-5B. The transit carrying case offers storage space for the folded and personal items while in orbit.

A) JACKET AND TROUSERS HANGING STORAGE VOLUME



B) MODULAR PACKAGING

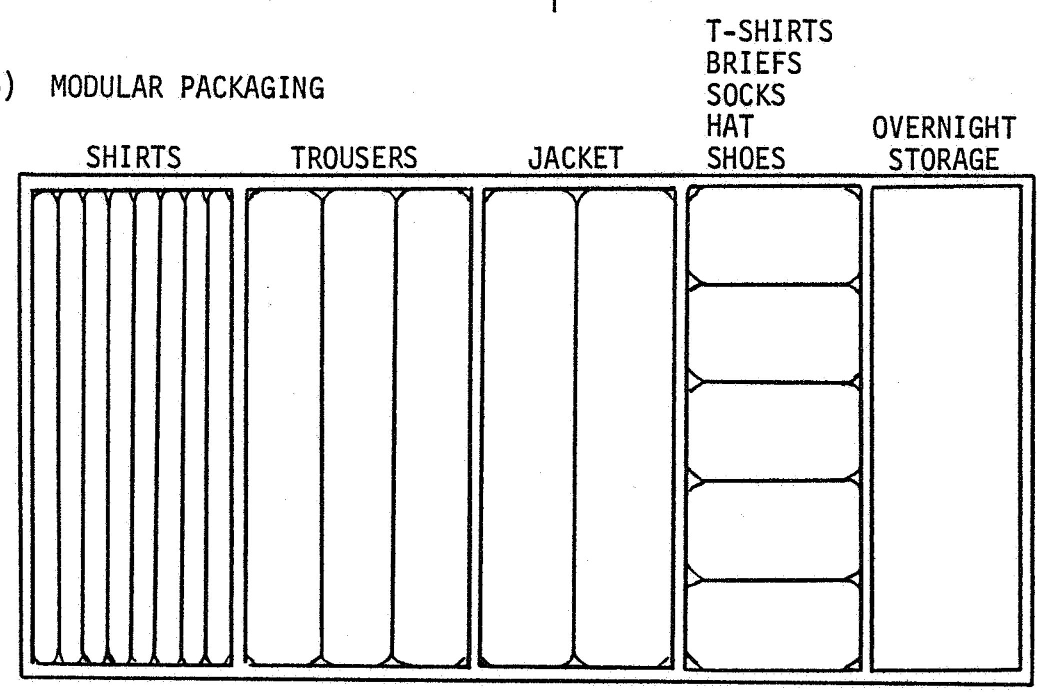


Figure 6-5. Clothing Storage

7.0 LAUNDRY SYSTEM CONCEPTS

The wardrobe of a crew will be disposable or reusable depending on the results of the computations and analyses to determine the appropriate wardrobe. This section presents an overview of laundry systems required to support a reusable wardrobe system. The following assumptions were made in selecting candidate laundry systems.

1) Laundry load size - 20 pounds
2) Crew size - 12 men per laundry system
3) Solvent - Water

7.1 AUTOMATIC LAUNDRY SYSTEMS

The following data presents candidate automatic laundry systems that are designed for relatively large laundry loads (20 pounds).

Diaphragm Actuated Washer/Dryer

The conventional method of cleaning fabrics is to apply agitation in conjunction with immersion in a washing solution. One essential factor is that the washing solution be forced into the fibers of the material. This unit provides washing action by alternately soaking and squeezing the clothing semi-dry. The washing solution is pumped from one chamber to the other.

Reciprocating Washer/Dryer* (Figure 7-1)

The washer/dryer unit utilizes an inner-compartmented perforated impeller that is oscillated to provide washing, rinsing and drying action, and spun to provide phase separation during the fill cycle and to provide centrifugal force to expel the water. An electrical heat source in the static outer housing provides drying heat. A multi-cam timer, in conjunction with solenoid valving, sequences the wash, rinse and dry cycles. Laboratory testing has indicated that spin drying with a centrifugal force of approximately 4.5 g will remove 89 percent of the saturated water content of a cotton sample.

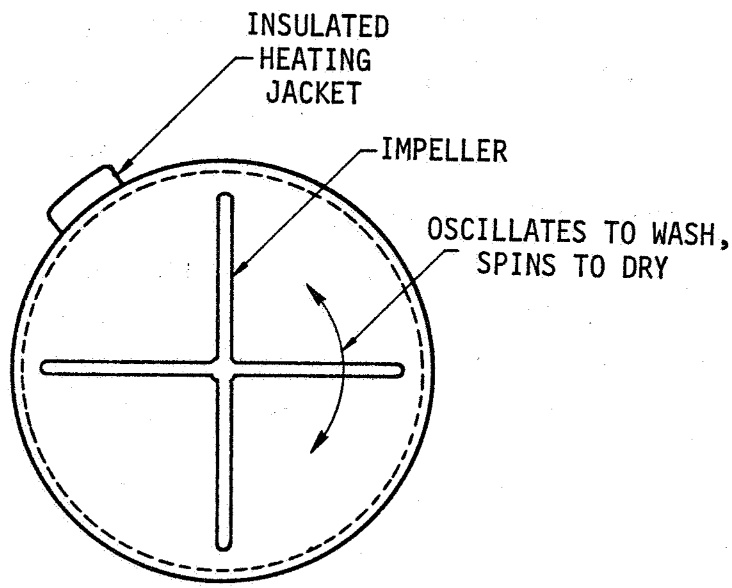


Figure 7-1. Reciprocating Washer/Dryer

*Data extracted from Reference 4.

Rotary System-Water Solvent (Figure 7-2)

A concept drawing and associated engineering data are provided below.

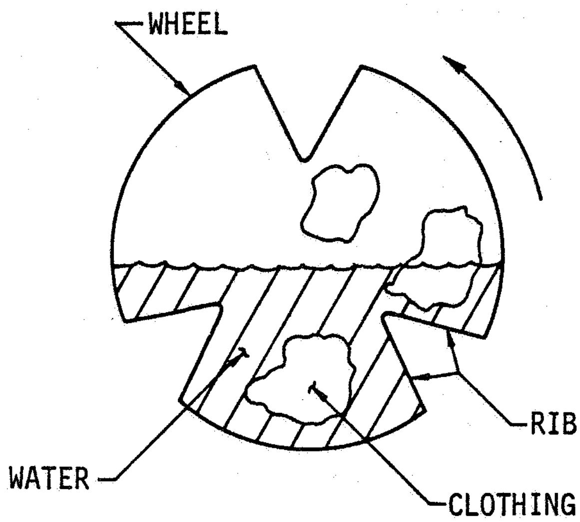


Figure 7-2. Rotary System-Water Solvent

Engineering Data

Load Factor	-	2.5 lb/ft^3
Weight	-	50 lb
Tub Volume	-	8 ft^3
Power	-	345 watts
Water		
Suds	-	190 lb
Rinse	-	140 lb/cycle

Requires Gravity

Oscillatory System-Water Solvent (Figure 7-3)

A concept drawing and associated engineering data are provided below.

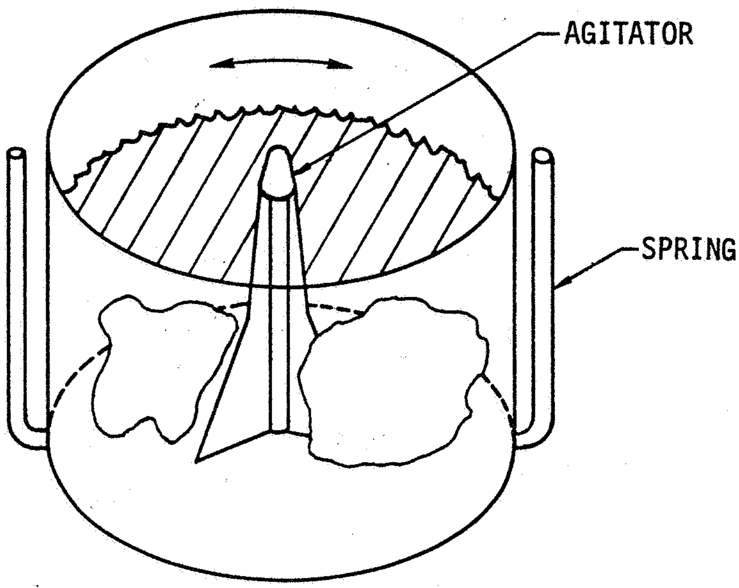


Figure 7-3. Oscillatory System-Water Solvent

Engineering Data

Load Factor	-	3.3 lb/ft^3
Weight	-	44 lb
Tub Volume	-	6 ft^3
Power	-	535 watts
Water	-	
Suds	-	300 lb
Rinse	-	250 lb

Does Not Require Gravity

Rotary System-Hydrocarbon Solvent (Figure 7-4)

A concept drawing and associated engineering data are provided below. The parameters of the rotary system (water and hydrocarbon solvents) and the oscillatory system are compared in Table 7-1, Figure 7-5 and Figure 7-6.

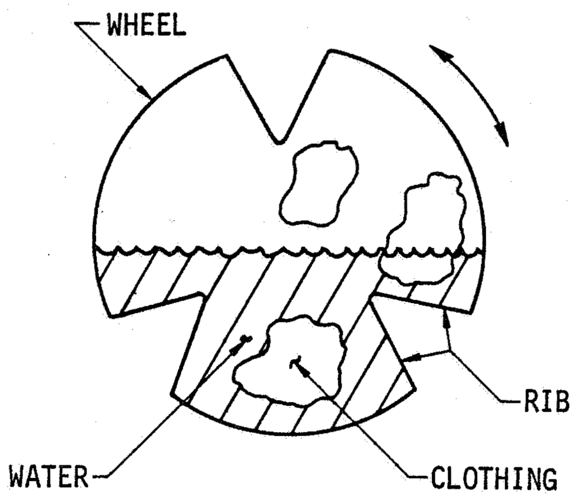


Figure 7-4. Rotary System-Hydrocarbon Solvent

<u>Engineering Data</u>

Load Factor	-	2 lb/ft^3
Weight	-	56 lb
Tub Volume	-	10 ft^3
Power	-	640 watts
Solvent		
Wash	-	445 lb
Rinse	-	345 lb
Requires Gravity		

Table 7-1. Automatic Laundry Concept Comparison

Criteria \ System	Rotary - Water	Oscillatory - Water	Rotary - Hydrocarbon Solvent
Weight (lb) (at payload of 20 lb)	50	44	56
Power (watts) (at payload of 20 lb)	345	535	640
Volume (ft^3)	8	6	10
Water/Solvent Per Cycle (lb)	330	550	790
Remarks	Requires gravity	Operable in zero g	Possible hazardous or toxic chemicals Requires gravity

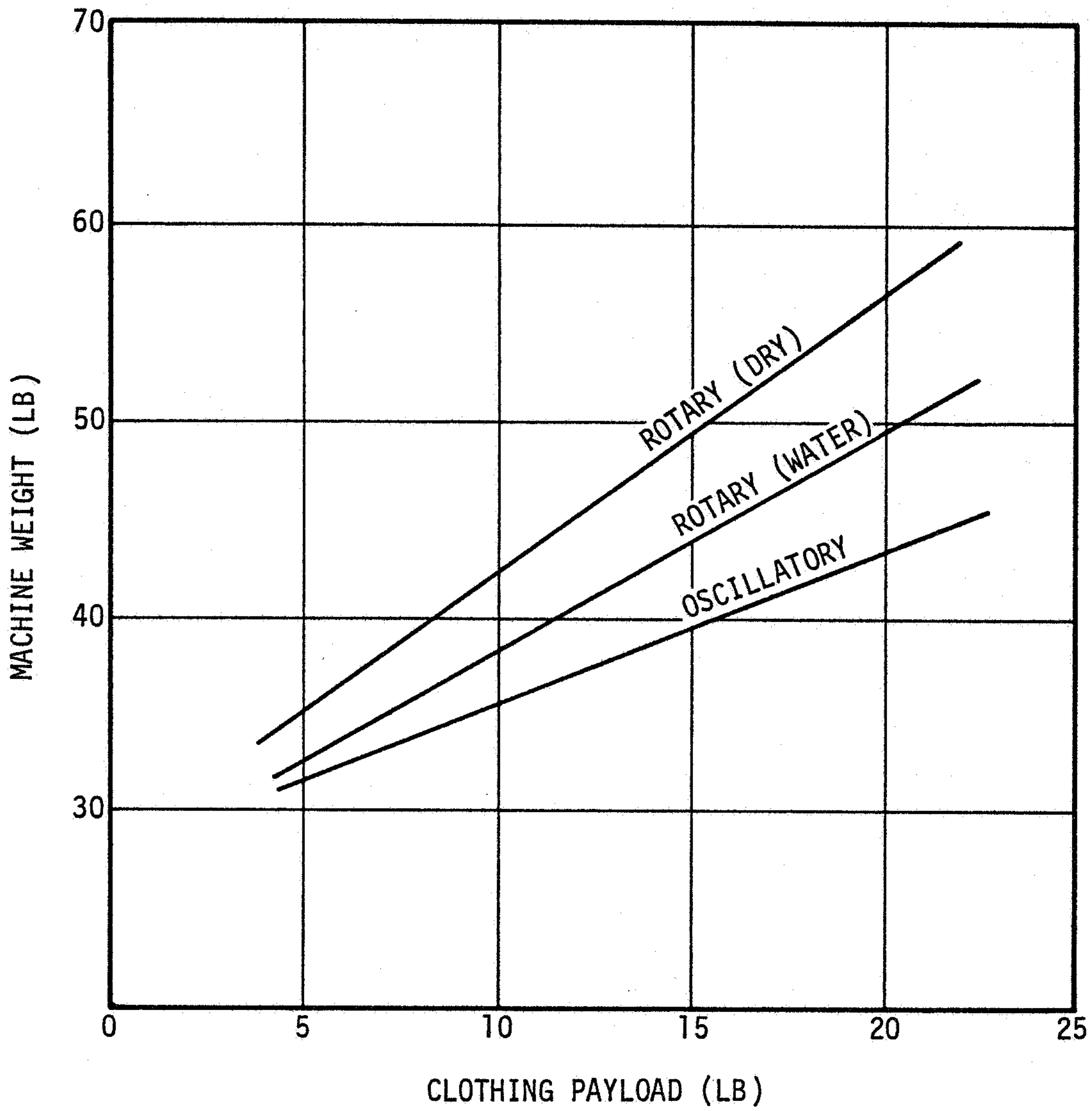


Figure 7-5. Automatic Laundry System Weight Comparison

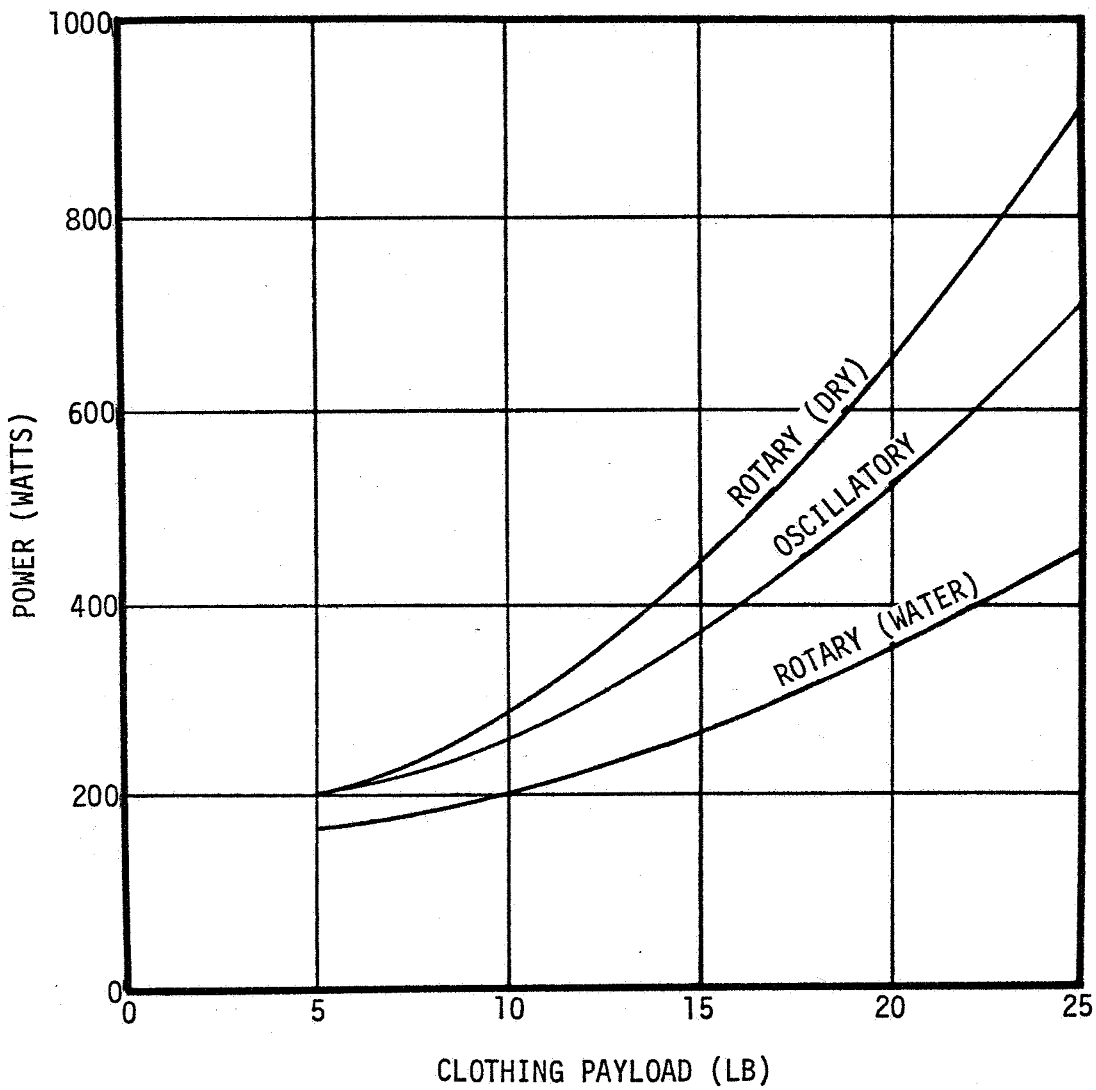


Figure 7-6. Automatic Laundry System Power Comparison

7.2 HAND LAUNDRY CONCEPTS

If small laundry loads of 5 pounds or less are considered, a hand laundry concept would be adequate to satisfy the washing requirements. The following pages provide several hand laundry concepts that would be adequate to accommodate a wash load composed of light articles such as shirts, socks, and briefs.

Manual Clothes Washing Device* (Figure 7-7)

A small, self-contained, manually operated washing device can be provided for each crewman to avoid problems of cross-contamination. The unit consists of two flexible bags: one containing the items to be washed, and the other the germicidal cleansing solution. The two bags are interconnected with a central section containing two passageways. The washing solution will exit the washing bag through one passageway and return filtered through the other passageway. The manual washing action would include squeezing the cleansing solution back and forth between the bags with the solution being filtered each time it re-enters the washing bag. After 10 to 15 cycles, the solution can be wrung back into the solution bag where it will be available for reuse. The washing bag is then unzippered and the clothing removed for either vacuum drying or free evaporative drying. The filter and solution are replaced when required.

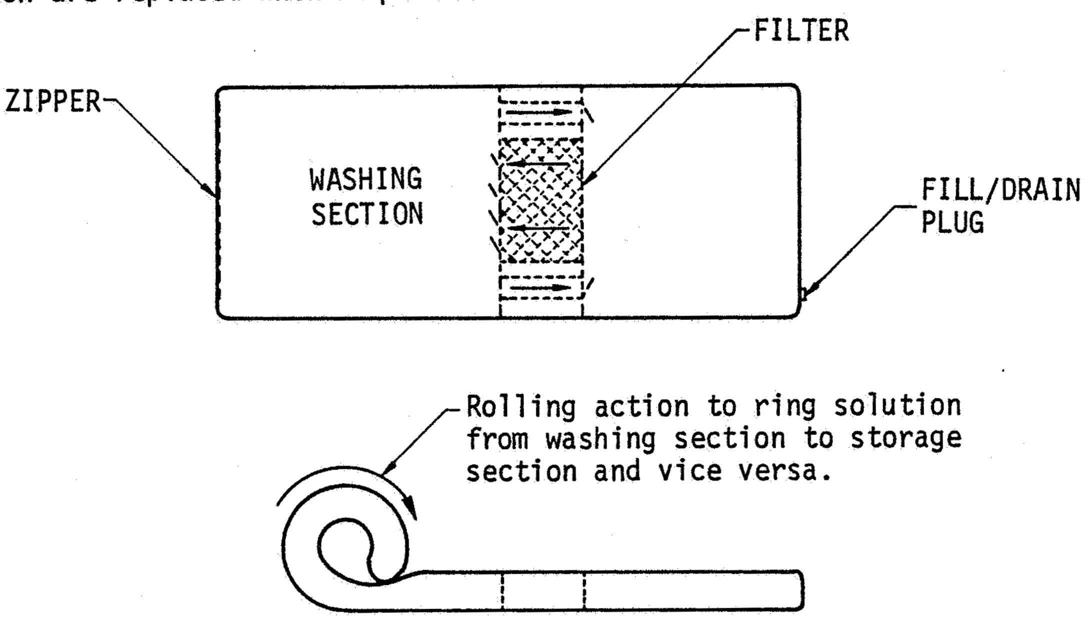


Figure 7-7. Manual Clothes Washing Device

*Data extracted from Reference 4.

Flexible Water Bag (Figure 7-8)

A small, manually-operated, flexible water bag has been developed for washing clothes. The manual washing and rinsing action is accomplished by agitating the solution back and forth in the bag by using the hand grips. The draining of the solution between washing and rinsing and after rinsing is accomplished by squeezing the solution from the clothes and bag after connection to the charge/discharge adapter.

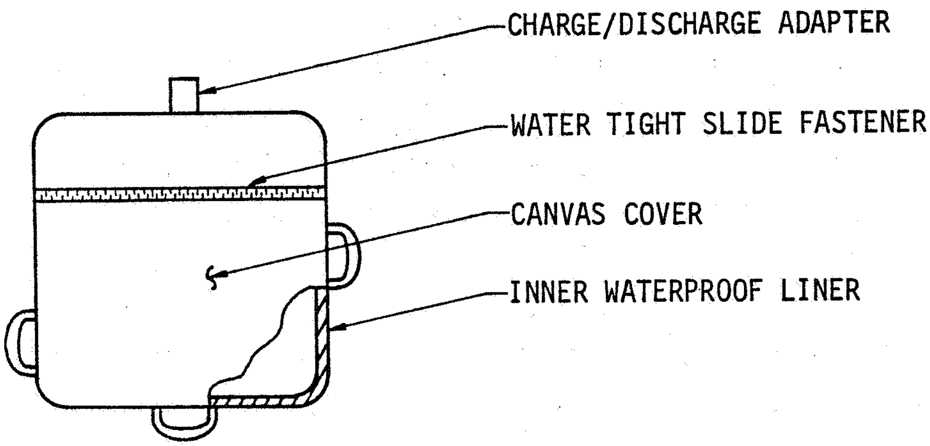


Figure 7-8. Flexible Water Bag

Water Bag and Tub Hand Manual Washing Devices

Concept drawings are provided in Figure 7-9.

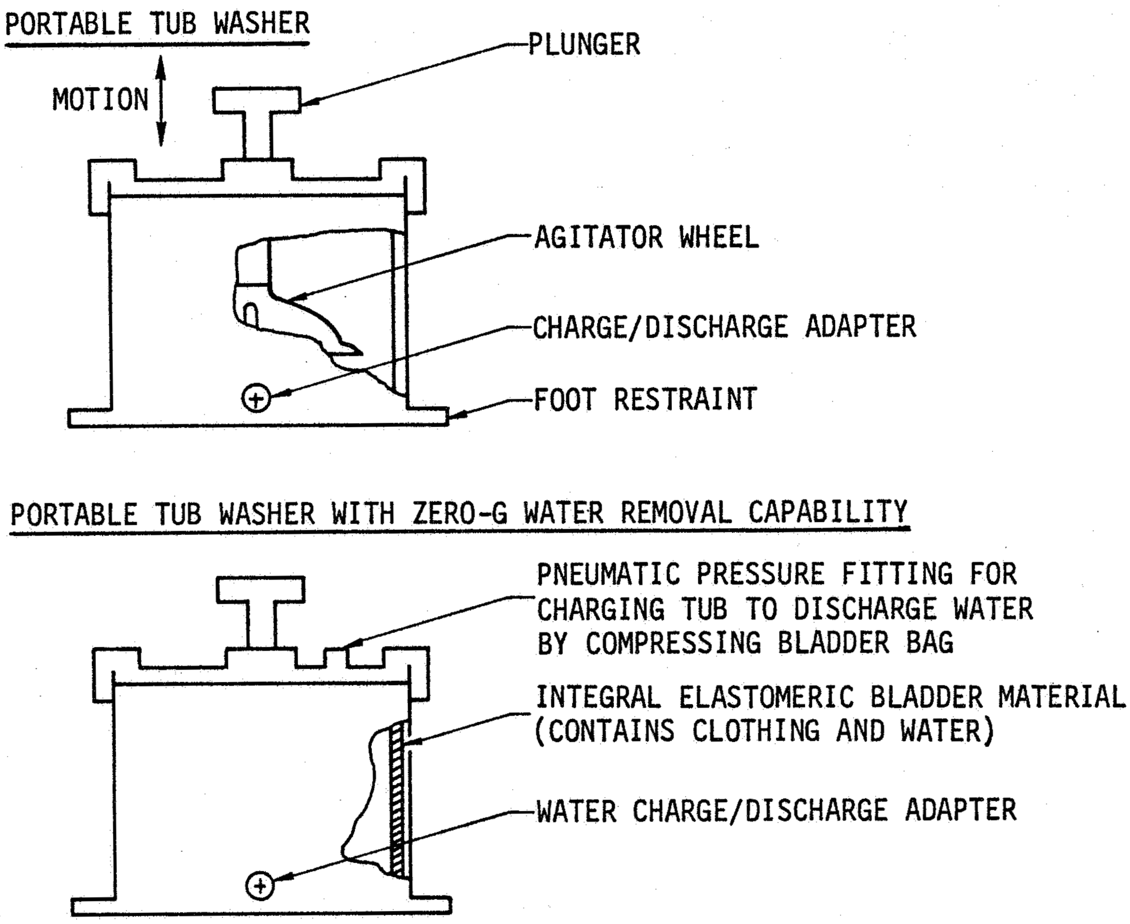


Figure 7-9. Water Bag and Tub Hand Manual Washing Devices

7.3 DETERGENTS

7.3.1 Soaps. Soaps are the salts of a carboxylic acid and an alkali. Only the salts of the higher molecular weight acids, (C_{10} and above), and the monovalent alkalies, are useful as cleaning agents. From a practical standpoint, soaps are limited to the sodium, potassium, ammonium, and amine salts of the fatty acid series from lauric (C_{12}) to stearic (C_{18}), or of rosin or napthenic acids.

Soaps of all types are inactivated in acid solutions and are rendered ineffective by water hardness and high concentrations of dissolved salts. Classification of soaps is provided in Table 7-2.

7.3.2 Synthetic Detergents. Synthetic detergents are surface-active agents capable of removing, dispersing, and suspending solid soils from the surface being cleaned. Detergents are surface-active agents which, in addition to lowering the surface tension of their solutions and promoting "wetting out" of soil particles, have the property of deflocculating (breaking down) soil aggregates and keeping them in suspension in the waste water. This allows the rinsing action to be carried out without redeposit of the soil on the fabric.

Detergents achieve their superior surface activity by an exacting ionic or colloidal balance between the water-soluble portion of the structure called the hydrophile and the water-insoluble portion called the hydrophobe. If the compound is too hydrophilic, a wetting agent without significant detergency is produced, if too hydrophobic, an emulsifier is produced.

Table 7-3 depicts the classification of detergents together with typical detergent compounds and their relative performance as a detergency agent.

Table 7-2. Classification of Soaps

Identification	Basic Constituents	Common Uses
Sodium Soaps		
Tallow soaps	Chip, flake, bar, and powder made from refined animal fats	Most common soaps for general use, good detergent for use at high temperatures
"Castile" vegetable oil soaps	Bars, pastes, and liquid made from olive oil (pure castile) or corn or cotton seed oils	Mild detergent for use involving hand work
Coconut oil soaps	Usually liquid soaps of high foaming power	General use, may irritate some skin
Tall oil soaps	From tall oil (a paper making by-product), contains about 50% fatty acid soaps the balance resin-acid soap	General use, low cost soap
Rosin soaps	Dark color, soft soap	Inexpensive for many uses, frequently used with tallow soap to form yellow soap
Potassium Soaps		
Liquid scrub soaps	Solutions of potash soaps from animal and vegetable fats	General use in hand work
Coconut hand soaps	Liquid skin soaps from palm and coconut fatty acids	Used in wash rooms and as coconut shampoo
Mixed base soaps	Soaps derived from mixed coconut and vegetable fats or from coconut fatty acids and oleic acid	Personal use - hands, shampoo
Amine Soaps	Made directly from the fatty acids	Used in degreasing and cleaning metal parts (Amine soaps)

Table 7-3. Classification of Synthetic Detergents

Identification	Performance As A Detergent*	Stability In Hard Water*
Anionic		
Soaps	Excellent	Poor
Sulfated alcohols	Excellent	Fair to Poor
Sulfated olefins	Good	Fair
Sulfated oils	Poor	Good
Sulfated monoglycerides	Good	Good
Sulfated amides	Good	Good
Alkylaryl polyether sulfates	Excellent	Good
Alkyl sulfonates:		
Petronates	Poor	Fair
Nytron	Excellent	Good
Sulfonated amides	Excellent	Excellent
Sulfosuccinate	Good	Excellent
Sulfonated ethers	Excellent	Good
Alkylaryl sulfonates	Excellent	Good
Heterocyclic sulfonates	Good	Good
Catinoic		
Tertiary amines	Fair	Poor
Aeterocyclic amine	Fair	Poor
Quaternary	Good	Poor
Nonionic		
Amine fatty acid condensate	Good	Good
Ethylene oxide fatty acid	Excellent	Excellent
Alkylaryl polyether alcohol	Excellent	Excellent
Ethylene oxide fatty alcohol condensate	Good	Excellent
Miscellaneous:		
Thioethers	Excellent	Excellent
Pluronics	Excellent	Excellent

*Criteria for ratings of excellent, good, fair and poor are presented in Reference 5.

7.3.3 Germicidal Detergent Formulations. Germicidal detergent formulations hold prominent positions as antimicrobial agents. These are surface tension depressants employed primarily for sanitizing surfaces. Aside from their germicidal activity, a real value lies in their ability to facilitate the mechanical removal of micro-organisms from the contaminated surface. The three categories of detergents - the nonionic, the anionic (-) and the cationic (+), are classified according to their ionizing properties. Of the three categories, the cationic detergents have assumed prominent positions as anti-microbial agents. One of the best known within this category is benzalkonium chloride (BAC), appearing under such registered trade names as Zephiran, Roccal and Ammonyx T. There are many patented detergent compositions. Numerous bacteriostats which provide a residual, nonirritating finish to the fabric have been proposed to the detergent industry for sanitizing fabrics. An evaluation of detergent formulations for a specific usage is, in itself, a broad and complex field. Detergent formulations incorporating the desirable features of material compatibility, nonirritation, penetration, spreading, residual antimicrobial finish, solubilization, emulsification, low suds formation and germicidal activity can be prepared, both for general and specific usage.

APPENDIX A

GLOSSARY OF TERMS

The following definitions are commonly used terms in the textile industry.

Abraded Yarns - Continuous filament rayon yarns in which filaments have been cut or abraded at intervals and given added twist to bring about a certain degree of hairiness. Abraded yarns are usually plied or twisted with other yarns before usage.

Abrasion Resistance - Degree to which a fabric is able to withstand surface wear and rubbing.

Absorption - The property to attract and hold gases or liquids within the pores of a fiber, yarn, or fabric.

Adsorption - The attraction of gases, liquids, or solids to surface areas of textile fibers, yarns, or fabrics.

Affinity - Chemical attraction. The tendency of two elements or substances to unite or combine as fiber and dyestuff.

Air Permeability - Warmth or coolness of a fabric is measured by its porosity, or the ease with which air passes through it. Air permeability determines the warmth of blankets, etc.

Anti-Crease Process - A treatment of a fabric which enables it to resist and recover from creasing.

Anti-Static - Ability of a fabric to disperse electrostatic charges and present build-up of surface potential of static electricity.

Average Stiffness - Average load in grams per denier that will stretch the fiber 1 percent.

Blend - A combination of two or more fibers spun into a yarn; or a fabric containing a mixture of two or more fibers or yarns.

Body - The compact, solid or firm feel of a fabric.

Bonding - A process of pressing fibers into thin sheets or webs that are held together by adhesive, plastic, or cohesion (self-bonding).

Breaking Strength - Ability of a fabric to resist rupture by evenly applied tension, usually expressed as pounds of force applied to one inch width in warpwise or in fillingwise direction.

Building Process - Any one of several procedures for crimping, curling, or looping the yarn so that it becomes bulked, and occupies a volume greater than that indicated by the specific gravity of the fibers.

Bursting Strength - Ability of a fabric to resist rupture by pressure, usually expressed as pounds of force required to push a spherical surface through a peripherally clamped disc of fabric.

Calendering - A finishing process for fabrics producing a flat, shiny, smooth surface by passing the cloth through hollow cylinder rolls or a friction and glazing calender.

Carding - Process of opening and cleaning textile fibers which separates fibers from each other; lays them parallel, makes them into a thin web and condenses them into a continuous, untwisted strand of fibers called a "sliver".

Cellophane - Transparent film made from regenerated cellulose.

Cellulose - A carbohydrate of complex molecular structure which forms the chief framework of plant cells and walls. Used as a basic raw material for making rayon.

Colorfast - Fabric's ability to retain sufficient color so that no noticeable change in shade takes place during the normal life of the garment. Those changes (fading) can be affected by one or more color-destroying influences: atmospheric fumes, laundering, dry cleaning, crocking, perspiration.

Continuous Filament Rayon Yarn - Yarn formed by twisting two or more continuous rayon filaments into a single, continuous strand.

Cord - 1. The product formed by twisting together two or more ply yarns.

2. A rib on the surface of the fabric, e.g., a ribbed fabric like corduroy, whipcord, etc.

Count - 1. (Cloth) - Number of warp and filling yarns per inch in woven cloth.

2. (Yarn) - Size or weight of yarn.

Course - A row of loops running across a knitted fabric.

Crease Resistance (Wrinkle Resistance) - Ability of a fabric to resist the formation of wrinkles and creases contributing to a mussed appearance and the ability to recover from wrinkles and creases.

Crease (Or Pleat) Retention - Ability of a fabric to retain in normal use pleats or creases intentionally produced (usually) by heat treatment.

Crimp - 1. (Fiber) - The waviness in fibers, e.g., certain wools and rayon staple fibers.

2. (Yarn) - Also curvature produced in warp or filling yarn by weaving.

Cut - A length of woven cloth.

Denier - The weight, in grams, of 9,000 meters of yarn is the denier. The lower the denier, the finer the yarn. For example, 50 denier rayon is twice as fine as 100 denier rayon.

Dimensional Restorability - The ability of a fabric to return to its original dimensions. It is usually followed by a percentage figure that specifies the dimensional change as shown by laboratory tests. After fabrics have been properly constructed and finished, they will stretch or shrink; however, after ordinary ironing, they will return to their original dimensions. Hence, a 2 percent dimensional restorability means that although a fabric may shrink more than this in washing, it is restored to within 2 percent of its original dimensions by ordinary home pressing methods.

Dimensional Stability - Tendency of a fabric to retain its shape and size after being subjected to wear, washing, dry cleaning; this stability may be brought about by the kinds of fiber used in the fabric, by chemical treatment or by mechanical means.

Double Weave - A cloth woven with two systems of warp or filling threads so combined that only one is visible on either side.

Durable Press - A precured or postcured process whereby a garment is produced having a durably set shape and/or designed creases, and requires no ironing after controlled laundering for its normal use-life.

Elasticity - The property of a fiber or yarn to elongate upon applying tension, and to recover its length upon releasing tension.

Elongation - The deformation caused by a tensile force. It is expressed as a percentage of the original length.

End - One warp yarn or thread.

Extensibility - The length gained by stretching to the breaking point. It is expressed in percentage of the original length.

Fabric - Cloth or textile material woven or knitted; or felting of any fiber or mixture of fibers.

Felt - 1. (Pressed) - A matted material made from wool, hair, fur or certain synthetic fibers by a suitable combination of pressure, heat and moisture (without spinning, weaving or knitting), e.g., felt hats.

2. (Woven) - A heavy woven fabric characterized by a nap which has been subjected to a felting operation.

Fiber - The fundamental unit used in the fabrication of textile yarns and fabrics. A.S.T.M. defines a fiber as a unit of matter characterized by having a length at least 100 times its width or diameter.

Filament - An individual strand of continuous length drawn from one hole in the spinneret. The strands are collected into one continuous yarn.

Filling - The yarn running from selvage to selvage at right angles to the warp. Each crosswise length is called a "pick". The filling is sometimes referred to as "weft" or "woof".

Finishing - A final and sometimes special process through which fabrics are put in order to give them certain characteristics or appearances such as bleaching, scouring, calendering, embossing, napping, mercerizing, water-proofing, moth-proofing, etc., in preparation for the market or use.

Flexibility - The property of bending without breaking.

Gage or Gauge - The gauge indicates fineness or texture in knit fabrics. It refers to the number of needles in a given width. For example, in full-fashioned hosiery the number of needles per 1.5 inches represents the needles per 1.0 inch. The higher the gauge-number, the finer the texture of the fabric.

Gas Fading - Also called atmospheric fading, it is the effect of certain acid gases from fuel combustion upon some types of dyestuffs used in the dyeing of fabrics.

Glace - (French "iced"; pr. gla-say). A glistening, lustrous effect imparted to fabrics in finishing.

Hand - Term used to describe the touch, handle, or feel of fabrics.

Heat-Set - Stabilization of synthetic fabrics to insure no change in size or shape.

High Tenacity - High strength yarn of rayon or other man-made yarn.

Hydrophilic (or Hydroscopic) - Property of absorbing moisture common to rayon, silk, wool, and other natural fibers.

Hydrophobic - Non-absorptive fiber such as nylon and other synthetics.

Hygroscopic - Attracting or absorbing moisture from the air.

Knitting - To produce fabric on more than one needle by a method of inter-looping yarn or yarns. The lengthwise rows of loops are known as "wales" - the crosswise, horizontal rows of loops are known as "courses".

1. Circular knitting - The fabric comes from the knitting machine in the form of a tube. The threads run continuously in one direction in loops around the fabric.
2. Flat knitting - Is similar in construction to circular knitting. The differences are: (a) the fabric comes from the knitting machine in a flat form just as woven fabrics do; (b) the threads run in loops, alternately back and forth across the fabric; and (c) flat knit fabrics are capable of being "fashioned" or shaped in the knitting.
3. Warp knitting - Here, the fabric usually comes from the knitting machine flat just as woven and flat knit fabrics do. The threads run in loops in a general lengthwise direction.

Laminated - Fabric composed of layers of cloth joined together with resin.

Leno - A weave in which the warp yarns are arranged in pairs so as to twist one around the other between picks of filling yarn as in marquisetts. This manner of weaving gives firmness and strength to an open weave cloth and prevents slipping and displacement of warp and filling yarns.

Linters - Short cotton fibers which adhere to the seed after the first ginning. These are cut from the seed and used as a source of cellulose for the manufacture of rayon.

Luster - Shine or sheen of yarns, fiber or finished fabrics.

Mil - A unit commonly used for measuring the diameter of wires and textile monofilaments, being 1/1000 inch.

Modulus of Elasticity - Ratio of the stress in a material to the strain (elongation) with the elastic limit of the material.

Monofilament - A single filament.

Multifilament - Yarns with many fine continuous filaments or strands.

Nap - The downy or fuzzy surface of cloth produced by brushing.

Nonwoven - A fabric made up of a web of fibers held together by suitable chemical or fibrous bonding agents.

Pebble - The irregular or rough surface texture of a fabric.

Photomicrograph: A magnified photograph of a fiber, yarn or fabric obtained by attaching a camera to a microscope.

Pick - A throw of the shuttle. One filling thread is termed a pick on the loom or in the fabric.

Pick Glass - Magnifying glass with gauged aperture used for making a count of cloth.

Picot - (French "splinter"; pr. pec-co). A small loop woven on the edge of ribbon or a purl on lace. A picot edge may also be produced by a hem-stitching machine. Also refers to the run-resist loops usually found in the top of hosiery.

Piece - A standard length of a woven cloth as 40, 60 or 80 yards.

Pilling - Formation of little balls of fibers called "pills" on the surface of a cloth; caused by abrasion and wear.

Plain Knit - Simplest knit structure as in hose.

Plain Weave - The simplest of the fundamental weaves. Each filling yarn passes alternately under and over each warp yarn. Example: Taffeta.

Plated - A fabric that is produced from two yarns of different colors, characteristics, or qualities, one of which appears on the face, and the other on the back. A yarn may be plated by being covered by another yarn.

Ply - Yarns twisted together are said to be plied. Each end or thread is a ply.

Polymer - Molecular chain-like structure from which synthetic fibers are derived; produced by linking together molecular units called monomers.

Pyroxylin - A cellulose product which is used to coat cotton and rayon fabrics to make a fabric water-proof and stain resistant.

Residual Shrinkage - Amount of shrinkage remaining in a fabric after the decrease in dimensions has been determined by pre-shrinking; decrease in dimensions of a fabric after washing or dry cleaning.

Resiliency - Property of fiber or fabric to spring back when crushed or wrinkled.

Rib - A corded effect in a woven fabric; can be either lengthwise, cross-wise, or diagonal.

Rib Knit - Knit fabric with lengthwise ribs formed by wales alternating on right and wrong sides. If every other wale alternates between right and wrong side, it is called 1 x 1 rib. If two wales alternate, it is called 2 x 2 rib. A rib knit fabric is more elastic than plain knit and therefore has formfitting characteristics.

Saponification - Reaction which causes acetate to be converted to regen-erated cellulose.

Scouring - Removing the sizing and tint used on the warp yarn in weaving and in general cleaning the fabric prior to dyeing.

Seamless - Describes a tubular knit fabric with seams. A typical example is seamless hosiery.

Selvage or Selvedge - Edge on a woven or knitted fabric.

Shrinkage - The contraction of width or length of fabrics usually after wetting and redrying.

Sizing - Operation consisting of applying onto yarn starch, gelatin, oil, wax, or any other suitable ingredient to aid the process of fabrication or to control fabric characteristics, e.g., crepe fabrics. Warp sizing is generally referred to as slashing.

Slippage - The sliding or slipping of the filling threads over the warp ends or vice versa due to loose weave or unevenly matched warp and filling, thus leaving open spaces.

Sliver - A loose, soft, untwisted strand or rope of fibers; one of the first steps in making spun rayon.

Specific Gravity - Simple ratio of the weight of a given volume of the fiber to an equal volume of water taken as standard at stated temperatures.

Stabilizing - Treating a fabric so that it will not shrink or stretch more than a certain percentage.

Staple - Textile fibers of spinnable length.

Stiffness - Property of a fiber or fabric to resist bending.

Stretch - The lengthening of a filament, yarn, or fabric upon application of stress.

S-Twist - Direction of twist in a yarn or cord similar to the spiral part of the letter S. Formerly called "right" or "reverse" twist.

Swatch - Small piece of cloth used as a representative sample of any goods.

Tenacity - Stress that has to be applied to produce a particular elongation in a fiber. The breaking tenacity is the stress required to elongate a fiber to the breaking point.

Tensile Strength - Breaking strain of yarns or fabrics. High tensile strength means strong yarns or fabrics.

Tex - The weight in grams of 1000 meters of yarn is the tex number. The lower the tex, the finer the yarn.

Texture - Structural quality of a fabric; the surface effect of cloth.

Thermal Conductivity - Measurement of heat flow through a material.

Thermoplastic - A plastic material which is permanently fusible; term applied to true synthetic fibers describing their tendency to soften at higher temperatures.

Thread - A special type of tightly twisted ply yarn used for sewing; characterized by a combination of twisting and finishing with solid or semi-solid, wax-like materials to secure a smooth, compact strand which is quite flexible but presents no loose fibers.

Thread - Strand of yarn.

Tow - A continuous, loose rope of rayon filaments drawn together without twist.

Tricot - Type of fabric knitted with run-resistant stitch.

Tufting - Process of stitching of fabric, leaving the stitches long so that they can be cut or left as loops.

Twist - Turns in a thread or yarn usually expressed in turns per one inch.

Vinylidene Chloride - A thermoplastic resin derived from petroleum and salt.

Viscose - 1. The solution obtained by dissolving cellulose xanthate in caustic soda.

2. The process for making rayon by converting cellulose into viscose solution, which is then spun into rayon fibers.

Viscose Solution - Solution from which viscose filaments are produced.

Wale - A ridge or row of loops running lengthwise in woven or knitted fabrics.

Warp - Set of yarns which run lengthwise in a piece of woven and warp knit fabric.

Warp Pile - An extra set of warp yarns woven into a fabric to form an upright pile.

Wash and Wear - Phrase denoting a textile item which satisfactorily retains its original neat appearance after repeated wear and suitable home laundering with little or no pressing or ironing; fabric that required little or no ironing but may be washed, dried, and worn.

Waste - Fiber and yarn by-products created in the manufacturing or processing of fibers or yarns.

Weaving - The method or system of interlacing of warp and filling yarns to produce a woven fabric.

Weft - Means same as filling or woof.

Weighting - Finishing materials applied to a fabric to give increased weight.

Width - Distance between the two selvages of a cloth.

Yarn - A continuous strand for weaving or knitting.

1. Continuous filament rayon yarn: Yarn formed by two or more continuous rayon filaments into a single continuous strand.

2. Spun rayon yarn: Yarn formed from rayon staple by spinning or twisting into a single continuous strand of yarn.

Z-Twist - Direction of twist in yarn or cord called Z twist as the spirals conform in slope to the middle part of the letter Z; also called "left" or "regular" twist.

Certain terms were used in the discussion on the thermal aspects of clothing systems and are defined herein.

Clo - The Clo is a unit of insulation and is the amount of insulation necessary to maintain comfort and a mean skin temperature of 92°F in a room at 70°F with air movement not over 10 feet per minute, humidity not over 50 percent, with a metabolism of 50 Calories per square meter per hour. On the assumption that 76 percent of the heat is lost through the clothing, a Clo may be defined in physical terms as the amount of insulation that will allow passage of 1 Calorie per square meter per hour with a temperature gradient of 0.18°C. between the two surfaces.

$$1 \text{ Clo} = \frac{0.18°C.}{Cal/m^2/hr}$$

(Gagge, A. P., Burton, A. C., and Bazett, H. C.: Science 94: 428, 1941.) The ordinary business clothing of men has an insulation value of about 1 Clo. The best clothing has in practice a value of about 4 Clo per inch of thickness. The theoretical value for absolutely still air has been estimated as 7 Clo per inch at 18°C.

Effective Temperature - An index of the warmth felt by the human body on exposure to various temperatures, humidities and air movements, with walls and air at the same temperature. The scale of effective temperature has been fixed by the temperature of still and saturated air which feels as warm as the given conditions. For example, any air condition has an effective temperature of 60°F when it feels as warm as still air at 60°F saturated with water vapor.

Insulation Value of Clothing - Usually the insulation (number of Clo) of the clothing as worn and not the insulation of the fabrics alone.

Light Activity - Activity requiring from 60 to 100 $Cal/m^2/hr$ (basal metabolism is included).

Mean Skin Temperature - The skin temperature as determined by measuring the temperature of the surface of the body in various places and weighting the measurements as follows: feet 7 percent, lower leg 13 percent, upper leg 19 percent, trunk 35 percent, arm 14 percent, hands 5 percent, head 7 percent. These proportions have not been universally followed.

Met - A metabolic rate of 50 $Cal/m^2/hr$ which is the ordinary metabolism of a man seated at a sedentary task.

Metabolic Rate - The sum of the heat and the external work produced by an organism in a given time. The fundamental measurement is by calorimetry, but in practice it is measured by oxygen consumption.

Net Metabolic Cost - Metabolism due to the activity alone, the basal metabolism (about 40 $Cal/m^2/hr$) being substracted from the total. For example, light activity has a net metabolic cost of 20 to 60 $Cal/m^2/hr$ and work, heavy has a net metabolic cost of 240 to 340 $Cal/m^2/hr$.

Sedentary Occupation - An occupation not requiring more than 65 $Cal/m^2/hr$.

Wind Chill - That part of the total cooling that is due to the action of wind. This term is used almost exclusively in connection with cool or cold climates.

Work, Light (for young men) - Work requiring 100 to 180 $Cal/m^2/hr$ (basal metabolism is included).

Work, Moderate (for young men) - Work requiring 180 to 280 $Cal/m^2/hr$ (basal metabolism is included).

Work, Heavy (for young men) - Work requiring 280 to 380 $Cal/m^2/hr$ (basal metabolism is included).

Work, Exhausting (for young men) - Work requiring over 380 $Cal/m^2/hr$ (basal metabolism is included).

APPENDIX B

ILLUSTRATIVE EXAMPLE

B.1 INTRODUCTION

Examples of how to use this handbook, along with a hypothetical mission and its pertinent requirements, are presented in this appendix. The illustrated steps in determining a garment design are those which are based upon mission requirements with the subjective decisions left to the discretion of the reader.

The aspects of garment selection are divided as follows:

- Disposable vs reusable garments (Paragraph B.2)
- Garment system weight and volume (Paragraph B.3)
- Garment thermal design (Paragraph B.4)
- Garment construction (Paragraph B.5)

Each of the above considerations is pertinent to a section of the handbook. The output of the evaluation may not be a complete garment definition due to the subjective choices to be made; however, the major features will be determined.

Sample Mission X:

In mission X, a three-man crew is to perform an earth-orbital mission of 60-day duration. The atmosphere is an oxygen-nitrogen mixture with total pressure of 7.0 psia. The temperature ranges from 60 to 85°F; the maximum dew point temperature is 60°F. The gas ventilation velocity is 45 fpm. The crew and interface data are presented below:

Crew Data

Metabolic Rates - 1800 Btu/hr (exercise)
800 Btu/hr (maximum normal duty)
450 Btu/hr (duty)
300 Btu/hr (sleep)

Size - 50th percentile

Interface Data

Garment Wardrobe Weight Limit - 10 pounds

B.2 DISPOSABLE vs REUSABLE GARMENT SYSTEM DETERMINATION

As the mission duration and crew size increase, the need for a cleaning system increases. In Paragraph 3.3 of Section 3, one may assess the desirability of a cleaning system and the impact of using one. Using the mission model established at the beginning of the appendix and the wardrobe allowed by the computation in Section 3, a trade-off study may be performed. Assuming that a cleaning system is available for use on board, the following procedure is used to determine its penalty.

Step 1 - Establish Wear Rate (Laundry Load)

From paragraph 3.3.1.1 of Section 3:

$$\text{Wear Rate} = C \times \left(\frac{W_{shirt}}{WI} + \frac{W_{jacket}}{WI} + \frac{W_{other}}{WI}\right)$$

where:

C = Crew size   W = Weight   WI = Wear interval

Allowing a change of shirt, underwear and socks each day, the wear interval is 1. Knowing that a wash period of 11 days is required (steps 3 and 4 of Paragraph B.3.1), the wear interval of the pants and jacket is 11 days. With 3 crew men and the weights from Steps 3 and 4 of paragraph B.3.1:

$$WR = C \times \left[\frac{0.25}{1} + \frac{0.144}{1} + \frac{0.025}{1} + \frac{1.010}{11} + \frac{0.856}{11}\right]$$

= 1.76 lb/day (Laundry Load)

or 0.587 lb per man-day

Step 2 - Determine Laundry System Internal Volume

The weight penalty for a cleaning system for the mission model of 3 men is determined below. The following information must first be established:

$$\beta = \frac{CT}{LF \cdot UF}$$

where:

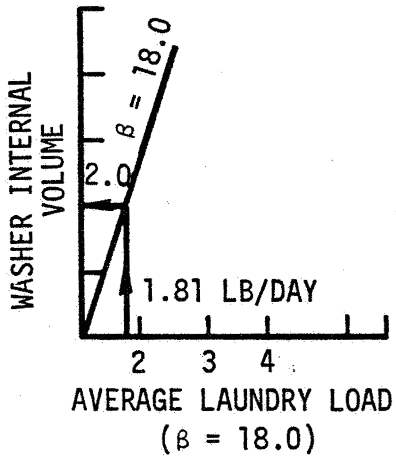
Cycle Time (CT) (total - washing and drying) = 1.5 hours

Loading Factor (LF) (determined by drying cycle) = 2.0 lb/ft^3

Usage Factor (UF) - 11 hours every 11 days = $\frac{11}{11 \times 24}$ = 0.0416

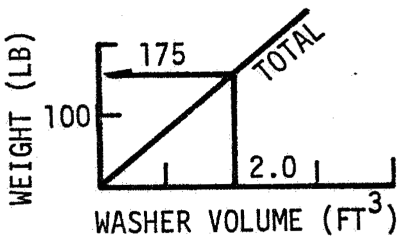
β = Laundry Factor

$$\therefore \beta = \frac{1.5}{2.0 \times 0.0416} = 18.0$$



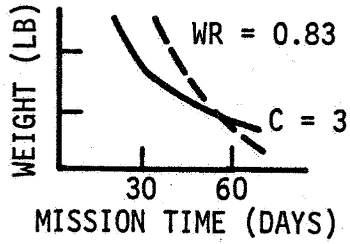
Step 3 - Weight Determination

Figure 3-8 of Section 3 presents the weight of a laundry system as a function of tub internal volume. This value includes washer, dryer, water reclamation system weights and weight of stored water. With a 2.0-cubic foot tub, the system weight is 175 pounds.



This value (175 pounds) may be altered greatly by changing the washing periods. If the wash time were increased from 1 hour per day to 2 hours per day, the weight penalty would be reduced to 100 pounds.

- Evaluation of Expendables - Since both of the laundry systems involve a relatively sizeable weight penalty with respect to garment weight, an assessment of a completely disposable garment system is made. This is accomplished by the use of Figure 3-9 which determines the breakeven weight point between a laundry system and a disposable garment system. At the 55-day mission point on the curve (for 4 men), a wear rate of 0.75 pound per day can be read for equal weight penalty.



This means that if all the garment changes were stored and thrown away, it would take a wear rate of 0.75 pound per day to equal the penalty of a laundry system. This is 30 percent more than the specified amount of 0.587 determined in Step 1.

In this mission example, the obvious solution is to increase the wear interval of each item until the weight constrained wardrobe accommodates the total mission, or an acceptable time allowance for hand washing is made.

B.3 GARMENT SYSTEM WEIGHT AND VOLUME DETERMINATION

Wardrobe selection is one of the prime considerations in the design of storage areas and baggage compartments in a shuttle vehicle. The selection of a garment system is a function of mission duration and crew number. For short missions, garment cleaning does not appear to be of great importance, and may be done by hand depending upon crew time available. The ground rule in garment selection is to allow as many garments as practicable within weight or volume limitations. If the volume or weight is unlimited, an earth-base cycle is the most desirable with certain clothes changed each day. The weight and volume techniques for wardrobe selection are presented below.

B.3.1 The Weight Approach. Given a weight allocation of 10 pounds of clothing per crew member, what is the best wardrobe, and what is its frequency of cleaning?

Step 1 - Determine Garments Required

The first step is to determine the basic articles of clothing (this has been accomplished partially in the thermal and construction sections).

Jacket	Briefs	Trousers
Shirt	Socks	Shoes
	Hat	

Step 2 - Determine Number of Wardrobe Articles

It is assumed that the shoes will be fabricated from a material that will not require cleaning during the orbital stay of a crew member. Where cleaning is required, the least number of any article is two. One is worn while one is washed, regardless of the wash cycle. Since the anticipated wear period for the jacket and pants is of the order of a period between washings, this leaves the number of underwear items, shirts and socks to be determined.

Step 3 - Select Fixed Weights from Total

The weights of the cotton blend jacket and trousers have been determined from Table 5-6 of Section 5. The weight of the shoes and hat are estimated.

Jacket	2 x 1.010 lb	=	2.02 lb
Trousers	2 x 0.856 lb	=	1.71 lb
Shoes		=	0.50 lb
Hat		=	0.50 lb
			4.73 lb

To find allowable weight of underwear, subtract 4.73 from 10.0 pounds which equals 5.27 pounds.

Step 4 - Find Garment Changes Permissible

From Garment Weight Calculations (paragraph 5.2.3)

Briefs	=	0.144 lb
Shirt	=	0.250 lb
Socks	=	0.025 lb
		0.419 lb

Then total changes permissible are $\frac{5.27}{.419}$ = 12.1 or 12 changes. Since one must be clothed while washing his clothing, the wash interval is every 11 days.

B.3.2 Volume Determination. The data of Tables B-1 and B-2 are concerned with the folded garments for vacuum packed conditions during transit, and non-vacuum packed conditions in orbit, respectively.

Table B-1. Transit Folded Volume (Vacuum Packed - Medium Size)

Item	Quantity	Item Volume (in.^{3})	Total Volume (in.^{3})	Envelope (in. x in. x in.)
Jacket	2	43	86	12 x 10.2 x .7
Trousers	2	57	114	12 x 8.6 x 1.1
Shirt	12	10	120	12 x 12 x 0.9
Briefs	12	10.8	130	12 x 9 x 1.3
Socks	12	5	60	10 x 3 x 2.16
Shoes	1	18	18	6 x 1 x 3.0
Hat	1	24	24	6 x 4 x 1.0
Total			552	

Table B-2. In Orbit Folded Volume (Medium Size)

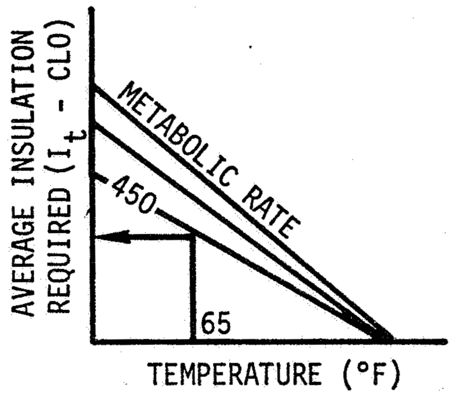
Item	Quantity	Item Volume (in.^{3})	Total Volume (in.^{3})	Envelope (in. x in. x in.)
Jacket	2	61	122	12 x 10.2 x 1
Trousers	2	77.4	155	12 x 8.6 x 1.5
Shirt	12	14.4	173	12 x 12 x 1.3
Briefs	12	16.2	194	12 x 9 x 1.95
Socks	12	5	60	10 x 3 x 2.16
Shoes	1	18	18	6 x 1 x 3
Hat	1	24	24	6 x 4 x 1
Total			746	

B.4 GARMENT THERMAL DESIGN

The following text explains the use of the figures and tables provided in Paragraph 5.1 of Section 5, and defines the distribution and porosity requirements for a garment.

Step 1 - Required Insulation for Comfort

The first step of the garment evaluation is the determination of the insulating requirements of the body for comfort. Knowing the crew metabolic rates and the mission environmental temperature extremes, the following information is obtained from Figure 5-3.



By entering the curve at the temperature extremes of 65 and 80°F, and metabolic rates of 450 and 2000 Btu/hr, the following data are obtained from the graph.

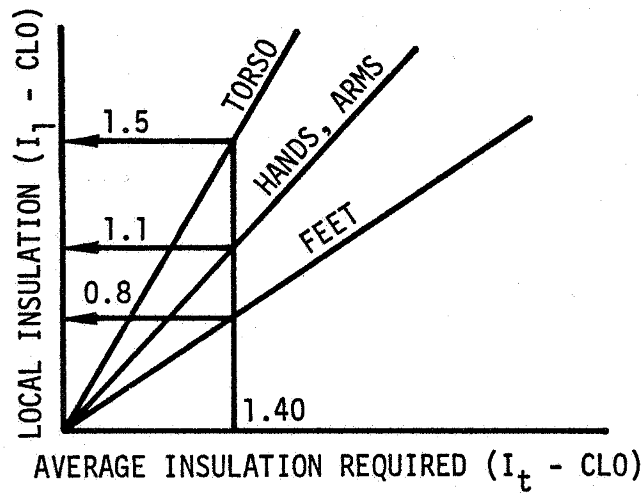
Average Insulation Requirements

Temperature (°F)	Metabolic Rate (Btu/hr)	Insulation (Clo)
65	450	1.40
	2000	0.25
80	450	0.60
	2000	0.15

Examining the extremes, the body must have an average insulation between 0.15 and 1.4 Clo.

Step 2 - Insulation Distribution

As the body produces heat at a rate according to body section, the insulation required is proportional to that distribution. This distribution may be obtained in Figure 5-5.



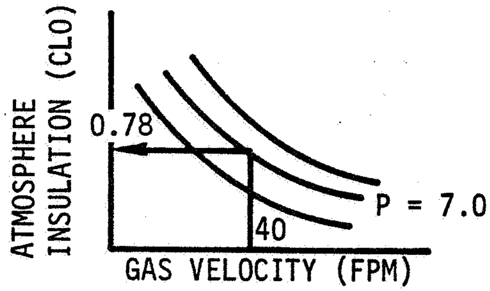
By entering the curve at each of the average insulation values determined in Step 1 above, the following data are derived.

Insulation Distribution - Clo

Local Insulation \ Average Insulation	1.40	0.60	0.25	0.15
Torso	1.5	0.65	0.25	0.15
Legs	1.4	0.60	0.20	0.11
Hands and Arms	1.1	0.50	0.17	0.10
Feet	0.8	0.35	0.15	0.10

Step 3 - Atmosphere Insulation

This step involves the determination of the atmosphere insulation (I_a) properties for a 7 psia, oxygen/nitrogen mixture. With a ventilation velocity of 40 fpm, the atmosphere insulation value is determined from Figure 5-7.



For a 7.0 psia, oxygen/nitrogen mixture, the atmosphere insulation value is 0.78 Clo.

Step 4 - Computation of Clothing Insulation

Remembering that the local insulation required is the sum of the atmosphere insulation and clothing insulation:

$$I_\ell = I_c + I_a$$

The clothing insulation is calculated by subtracting the atmosphere insulation (0.78 Clo) from the local insulation value determined in Step 2. When this is done, the following results are obtained.

Calculation of $I_c = I_\ell - I_a$

Clothing Insulation \ Average Insulation	1.40	0.60	0.25	0.15
Torso	0.72	-0.13	-0.53	-0.63
Legs	0.62	-0.18	-0.58	-0.67
Hands and Arms	0.32	-0.28	-0.61	-0.68
Feet	0.02	-0.43	-0.63	-0.68

Since all of the values are negative for the low average insulation cases, the only case to be considered from a thermal sense is the 65°F temperature low metabolic rate case (average insulation = 1.40). Clothing is required over the body, including long sleeves on the arms. (The temperature at which short sleeves are allowed is 73°F - found by determining the average insulation value for a local insulation of 0.78 Clo on the arms in Figure 5-5 and reading temperature in Figure 5-3 with a metabolic rate of 450 Btu/hr.)

Step 5 - Choice of Garment Design

The clothing insulation to be considered for each portion of the body (from Step 4) is presented below:

Arms - 0.32 Clo
Legs - 0.62 Clo
Torso - 0.72 Clo
Feet - 0.02 Clo

The thermal requirements of the feet can be easily met by footwear and will not be considered further. At this point a decision must be made for the construction of the garment. Since the design point of the garment is the lower temperature and metabolic limit, it is desirable to have a portion of the garment removable during the higher activity and temperature periods. This is accomplished by a removable jacket with shirt. (For nearly constant temperatures at the design point, a single-piece garment would be desirable.)

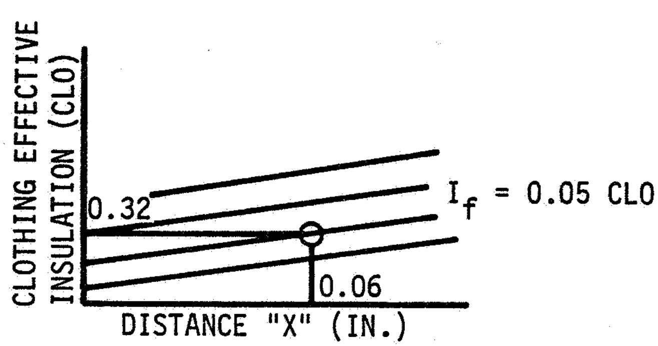
Step 6 - Drape Effect

The determination of the drape effect is found in Figure 5-8. Dressed in a jacket and shirt, the respective distances are 0.06 inch for a knit shirt and another 0.10 inch with the addition of a jacket. (The distance values at this time are estimates since no measurement data is available.)

Effective Insulation of Shirt + Effective Insulation of Jacket =

Torso Insulation

Knowing that the effective insulation requirement for an arm alone is 0.32 Clo, the chart is entered at 0.32. Assuming a conformal knit shirt (x = 0.06 inches), I_{fabric} is 0.05 Clo for the shirt.



The jacket effective insulation is then the difference, 0.72 Clo - 0.32 Clo = 0.40 Clo. Since entering the graph at 0.40 Clo and a clothing distance of 0.10 inch falls below the curve, a minimum value of 0.01 Clo is assumed for I_{fabric}. Neglecting the effect of briefs, the fabric insulation for the trousers is likewise 0.01 Clo, obtained by entering the graph at an effective insulation value of 0.62 Clo and a distance of 0.15 inch. The fabric insulation data are summarized below:

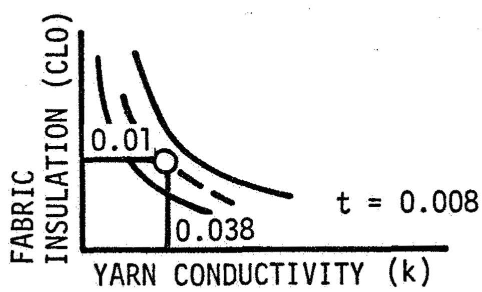
Fabric Insulation Requirements		
Shirt	-	0.05 Clo
Jacket	-	0.01 Clo
Trousers	-	0.01 Clo

Step 7 - Cloth Insulation Properties

The thickness of the material may be obtained from Figure 5-9 if the fabric insulation property is known. Before the final choice may be made, a limitation is placed on the allowable materials by the relative flammability. For a mission with atmosphere of 7 psia oxygen/nitrogen, a check of Figure 5-20 indicates that PBI, Teflon or Fiberglas may be used safely.

Since PBI is the lightest material, it is selected as the material for the garment for the purpose of this example mission. Since PBI is an experimental material with properties close to cotton, the properties of cotton (yarn conductivity 0.038 Btu/hr ft^2-°F-ft) are assumed.

Entering the curve of Figure 5-9 with the yarn conductivity and the required fabric insulation, the thicknesses are determined.



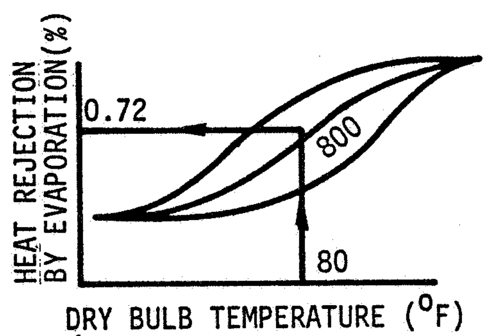
For k = 0.038, and the insulation requirements of Step 6, the following thicknesses are determined.

Cloth Thickness		
Jacket	-	0.008 inch
Pants	-	0.008 inch

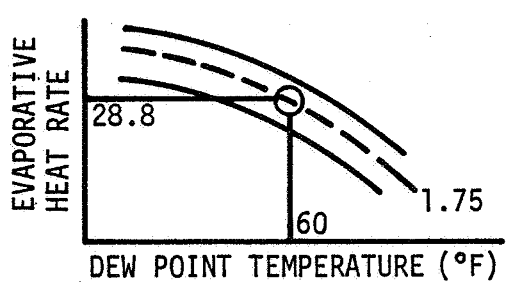
Since all of the items will contain high material area ratios, the weave factor of Figure 5-10 is assumed to be 1.0. Although these thicknesses are those calculated due to thermal considerations, they represent minimum values. In reality, the trousers and jacket may have equal or greater thickness due to endurance requirements.

Step 8 - Effect of Dew Point

With a metabolic rate of 800 Btu per hour normal maximum, it is important that sweat will not build up under the garments. This step determines the required fabric porosity. Using the worst case situation of a station temperature of 80°F, Figure 5-2 is used to determine the amount of latent heat rejection. With a temperature of 80°F and a metabolic rate of 800 Btu per hour, 72 percent of the body heat is rejected by evaporation of water.



Taking 72 percent of 800 Btu per hour, 576 Btu/hr evaporative heat load must be passed through the garment. Assuming the surface area of the body is 20 square feet, the average amount of heat passage is 576/20 = 28.8 Btu/hr-ft^2. With a maximum specified dew point temperature of 60°F, Figure 5-12 is entered at each of the respective values, and the porosity factor (P) of 1.75 is interpolated.



Assuming that a crew member will remove his jacket, the relationship $P = \frac{1 - A_{mr}}{x}$, is applicable for a shirt and trousers.

The values of x (from Step 6) are:

knit shirt = 0.06 inch

trousers = 0.15 inch

Then the maximum material area ratio for the shirt is:

$$A_{mr} = 1 - Px = 1 - 1.5(.06) = .91$$

and for the trousers = 1 - 1.5(.15) = .775

3.5 GARMENT CONSTRUCTION

The steps involved in determining the fabric geometry and weight of a garment are presented below.

Step 1 - Determine General Construction

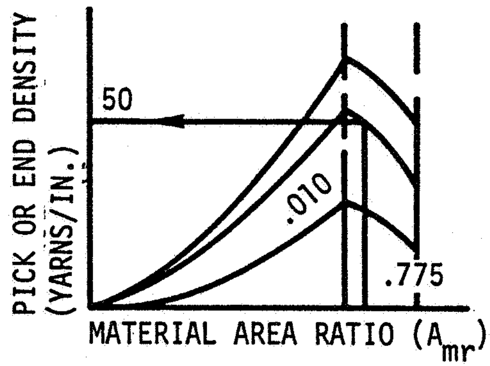
The first step is the determination of the construction techniques to be used. For the shirt and socks, a knit construction is advisable on the basis of porosity, warmth, and conformity. Trousers and jacket are woven due to rigidity and high strength.

Step 2 - Determination of Weave

Fabric requirements may be specified in several ways. It may be ordered in terms of weight per unit area or by yarn geometry. In the case of knits, the common technique is by the specification of weight. Knits for a T-shirt range in weight from 3 to 5 ounces per square yard and knits for sports clothes from 5 to 7 ounces per square yard.

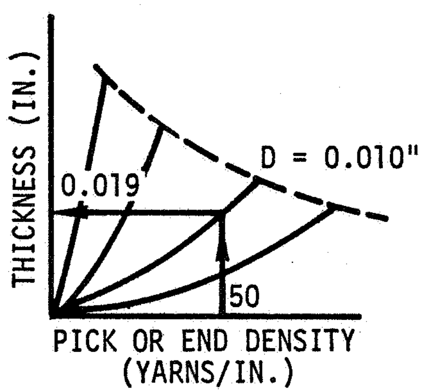
For weaves, however, the geometry and yarn properties may be needed. Recalling that the material area ratio of the pants is .775 (from B.4, Step 8), the geometry relationships may be established using Figures 5-14 and 5-15.

Knowing the required thickness or porosity, the geometry (pick and end density) may be determined with given yarn properties. Assuming that PBI yarn diameters of 0.010 and 0.005 inch are available, Figure 5-14 indicates that a pick/end density of 50 yarns per inch is required with a jacket of material area ratio of .775 (from B-4, Step 8).



Step 3 - Thickness

Remembering from B.4, Step 7 that the required minimum cloth thickness is 0.008 inch, and noting that A_{mr} = .75, Figure 5-15 is used to check the thickness. Entering at a pick/end density of 50 and a yarn original diameter of 0.010 inch, the thickness will be 0.019 inch.



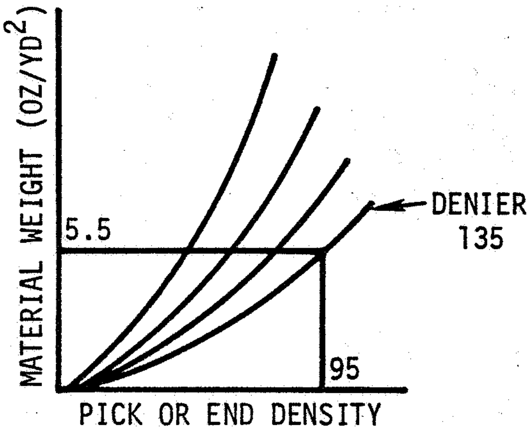
Since this thickness is twice the required value, the weight will be twice as heavy as required. The desirable choice at this point is to select the smaller diameter yarn. With half sized yarn, (0.005 inch), a pick/end density of 95 and thickness of 0.008 results with a material area ratio of .775.

Step 4 - Material Weight

If the fabric is to be purchased by specification of yarn geometry and material, Figure 5-16 is used to determine the weight of a square yard. Computing the denier value for PBI (density value found in Paragraph 5.2.1.3):

$$\text{Denier} = \frac{\text{Diam}^2}{3.9 \times 10^{-3}} \times \text{Density} = \frac{0.005}{(3.9 \times 10^{-3})^2} (82) = 135$$

Entering the curve with a pick/end density of 95, the resulting weight is 5.5 ounces per square yard.



Step 5 - Fabric Quantity

The above steps have been concerned with the weight of fabric. The next step is the determination of the fabric area included in the jacket, shirts, socks and trousers for determining weight penalty. Paragraph 5.2.3 contains the data to accomplish this. Table 5-4 presents the material area requirement for a crew member as a function of size. From the mission specification, the sizes of the crew will be fiftieth percentile. The data presented in Section 3.0 (crew data on Figure 3-1) reveals that a fiftieth-percentile crew member corresponds to medium-regular size. The following data may be determined directly from Table 5-4.

Area Requirements (yd^2)	
Jacket	1.70
Shirt	0.85
Trousers	1.90
Socks	0.10

Step 6 - Computation of Weight

Multiply the area by the fabric weight and add the fixed weight articles of Table 5-5:

Item	Area	x	Fabric Weight	+	Fixed Weight	=	Total Weight
Jacket	1.7		5.5		4.0 oz		13.4 oz
Trousers	1.9		5.5		2.5 oz		12.9 oz
Shirt	0.85		4.0*		0.5 oz		3.9 oz
Socks	0.1		4.0*		-		0.4 oz
Briefs	0.5		4.0*		1.0 oz		3.0 oz

*Estimate

The fixed weight may be altered by changes of fabric categories or any of the design details. The fixed weights above include ribbed cuffs, entry zipper fasteners and internal pockets.

APPENDIX C

FABRIC CHARACTERISTICS SUMMARY

Table C-1. Fabric Characteristics Summary

Physical Test Methods	(12)	Combustion Rates (in./sec)					Physical Characteristics (1)	(1)	(2)	(3)	(4)	(6)	(7)	(8)	(9)	(10)	(11)	(5)	Outgassing (13)			Availability	Supplier
	Weight (oz/yd^2)	Air	10 psia, 35% O_2/65% N_2	6.2 psia, O_2	16.5 psia, O_2	16.5 psia 60% O_2/40% N_2	Elongation (%)	Breaking Strength (Warp) (lb/in.)	Tear Strength (grams)	Wear Resistance (number of cycles)	Folding Endurance (number of cycles)	Stiffness (in./lb)	Abrasion (number of cycles)	Abrasion (number of cycles)	Air Permeability (ft^3/ft^2/min)	Electrostatic Charge (Nanocoulombs)	Thermal Conductivity (cal/sec/cm^2/(OC/cm))	Thickness (in.)	Odor (2.5 or lower is acceptable)	Carbon Monoxide (μgm/gm)	Total Organics (μgm/gm)		
Nylon	6.9			0.78			22	350	>6400	174	All Greater than 5,000	0.002	2468	870	7.98	8.0	1.49×10^{-4}	0.0145	12	1.2	0.0003	Commercial	Stern & Stern
Beta 4190B	6.5	0	0	0.0	0	0	8.1	106	2400	148		0.003	198	85	0.5	2.0	1.69×10^{-4}	0.008				Commercial	Owens/Corning
Beta 4484/Teflon	6.1	0	0	0.0	0	0	8.9	142	>6400	151		0.003	125	1200	22.7	18.0	1.2×10^{-4}	0.008 0.009				Available - special order	Owens/Corning
Teflon-Bleached T162-42	8.7		0.29	0.13	0.435		67	59	5100	93		0.0002	584	600	4.8	20.0	2.1×10^{-4}	0.009	0.9	0.7	34.0	Commercial	
Teflon-Natural	16.9			0.21	0.725		56	172	5400	343		0.002	1075	1952	11.2	32.0	1.8×10^{-4}	0.018	1.7	4.2	9.0	Commercial	E.I. DuPont
NOMEX (H.T. 90-40)	6.2		0.121	0.63	1.00		40	325	>6400	689		0.001	943	260	4.9	8.0	1.58×10^{-4}	0.013	7	0.4	1.0	Commercial	Stern & Stern
NOMEX - Treated - $POCl_3$ Br_2	7.3			0.42			10	128	3000	353		0.004	450	227	10.9	0.06	1.6×10^{-4}	0.014				Experimental	Dynatech
PBI - Untreated	5.0			0.003	0.009		20	149	4600	206		0.004	629	143	98.5	40.0	3.0×10^{-5}	0.0135	5	2.4	3.0	Government use only	Celanese
PBI - Treated - $POCl_3$	8.0	0		0.0			60	188	>6400	234		0.002	2481	1651	26.9	2.6	3.2×10^{-5}	0.017				Experimental	Dynatech
PBI - Treated - $POCl_3$ Br_2	5.9			0.14			20	184	5700	721		0.002	1200	1500	38.7	2.4	4.8×10^{-5}	0.014				Experimental	Monsanto
X-400	6.2		S.E.*	0.31	0.813		30	138	5900	126		0.0003	467	116	89.1	2.0	1.3×10^{-4}	0.012		3.7	0.0	Being evaluated	Monsanto
X-410	5.0		S.E.*	0.29			14	200	3000	96		0.001	145	65	28.9	18.0	1.8×10^{-4}	0.0118	11	2.8	1.0	Experimental	Monsanto
X-420	5.6			0.30			13.3	124	4100	93		0.002	100	350	43.4	0.01	2.0×10^{-4}	0.013				Experimental	Monsanto
Nickel Chromium (KARMA Cloth or Chromel-R)	18.0	0	0	0.0	0	0		176	5400	869		0.008	2034	977	68.8	0.0	N/A	0.010				Available - special order	Fabric Research Laboratory
FYPRO 5007/7	6.0	0	0.29	0.7		0.8	24	154	3800	836		0.003	217	41	49	12.0	2.0×10^{-4}	0.015	0.7	4.0	1.0	Commercial	Travis Mills
KYNOL Fiber			0.27*	0.71*		5.0*	20	1.7▲	-	-												Commercial	Carborundum Co.

Physical Test Methods

1. FED STD 191, Method 5104
2. FED STD 191, Method 5132
3. FED STD 191, Method 5302
4. ASTM-D 2176
5. FED STD 191, Method 5030
6. FED STD 191, Method 5202
7. FED STD 191, Method 5306 (C517 Wheel)
8. FED STD 191, Method 5304 (600 Grit Paper)
9. FED STD 191, Method 5450
10. Sweeney Test Method
11. Cenco-Fitch Test Method
12. FED STD 191, Method 5041
13. MSC-PA-D-67-13

*Self Extinguished
▲Breaking Tenacity, gm/denier

REFERENCES

NOTE

The primary source of data for this handbook was Reference 1. Data extracted from References 2 through 5 are noted in the text.

1. "Revised Handbook of Garment and Accessory Systems Selection Criteria for a Space Station," Welson and Company, Inc., November 1970.

2. "A Height, Weight Sizing System for Flight Clothing," WADC Technical Report 56-365, April 1965.

3. "Habitability: Garment Concepts and Engineering Data - Final Report," Welson and Company, Inc., 4 December 1970.

4. "Housekeeping Concepts for Manned Space Systems - Waste Control Tasks and System Concepts (Data Book)," Volume I, Fairchild-Hiller Report MS 124 Y0002, 30 October 1970.

5. "American Institute of Launderies," Chicago, Illinois.

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