NASA CR 102051

HANDBOOK OF GARMENT SELECTION CRITERIA FOR A SPACE STATION

prepared for the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

by

Austin C. Morris

B. WELSON & CO., INC.

Hartford, Conn.

FOREWARD

The Handbook of Garment Selection Criteria is a collection of the data obtained in the six month study contract NAS 9-9563, HABITABILITY: GARMENT CONCEPTS AND ENGINEERING DATA. Although the study program ground rules were based upon a space station mission, the data presented herein is applicable for a variety of mission constraints. This handbook plus the study final report and prototype garment for a space station constitute the completion of this study activity. At present, further study in the area of habitability is planned that will expand upon the areas presented in this book. Data for such areas such as complete crew wardrobe definition, space station fabrics usage, cleaning systems and properties of new materials is to be compiled in a fashion similar to this handbook.

The appendix to this handbook provides an illustrated example in the use of the data presented herein.

PREFACE

With the flights of Mercury, Gemini and Apollo, the clothing of the flight crew members was selected on the basis of the immediate needs of the particular mission. Since the crews and mission lengths involved were relatively small, there was little impact in the selection of the garments of the crews.

As the mission lengths increase and crew sizes grow in number, it is apparent that the penalty of the clothing and related systems of the crew members will no longer be negligible and will require investigation. The purpose of this handbook is to present the criteria by which a garment may be evaluated for use in a space station. It is not intended for use as the absolute criteria for design, rather, it is to familiarize persons of engineering discipline with the steps and rationale involved.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF TABLES

SECTION 1.0 THERMAL CONSIDERATIONS

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.

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 charts, 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 charts is presented in Appendix A.

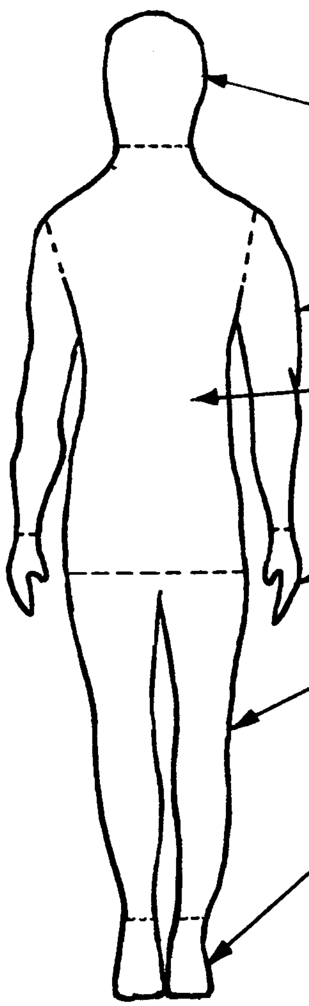
BODY HEAT REJECTION

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 be sensible means (conduction, convection and radiation) and latent means (evaporation of perspiration).

Figure 1-1 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 chart is the amount of latent heat of evaporation due to moisture yielded by the lungs during breathing. This value, of the order of 60-100 BTU/hr, is a function of metabolic rate and ambient dew point.

Although the absolute values presented in the chart 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.

FIGURE 1-1 BODY HEAT REJECTION DISTRIBUTION



AREA	SENSIBLE	LATENT
Head	7%	2%
Arms	12%	3.6%
Torso	40%	50%
Hands	4%	.5%
Legs	31%	43.4%
Feet	6%	.5%
	100%	100%

For low metabolic rates
(500 - 800 BTU/hr)

References; 2,3,5

BODY LATENT HEAT REJECTION

The relationship between the sensible and latent heat rejection by the body is presented in Figure 1-2. 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 1-2, 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 the section in Figure 1-10.

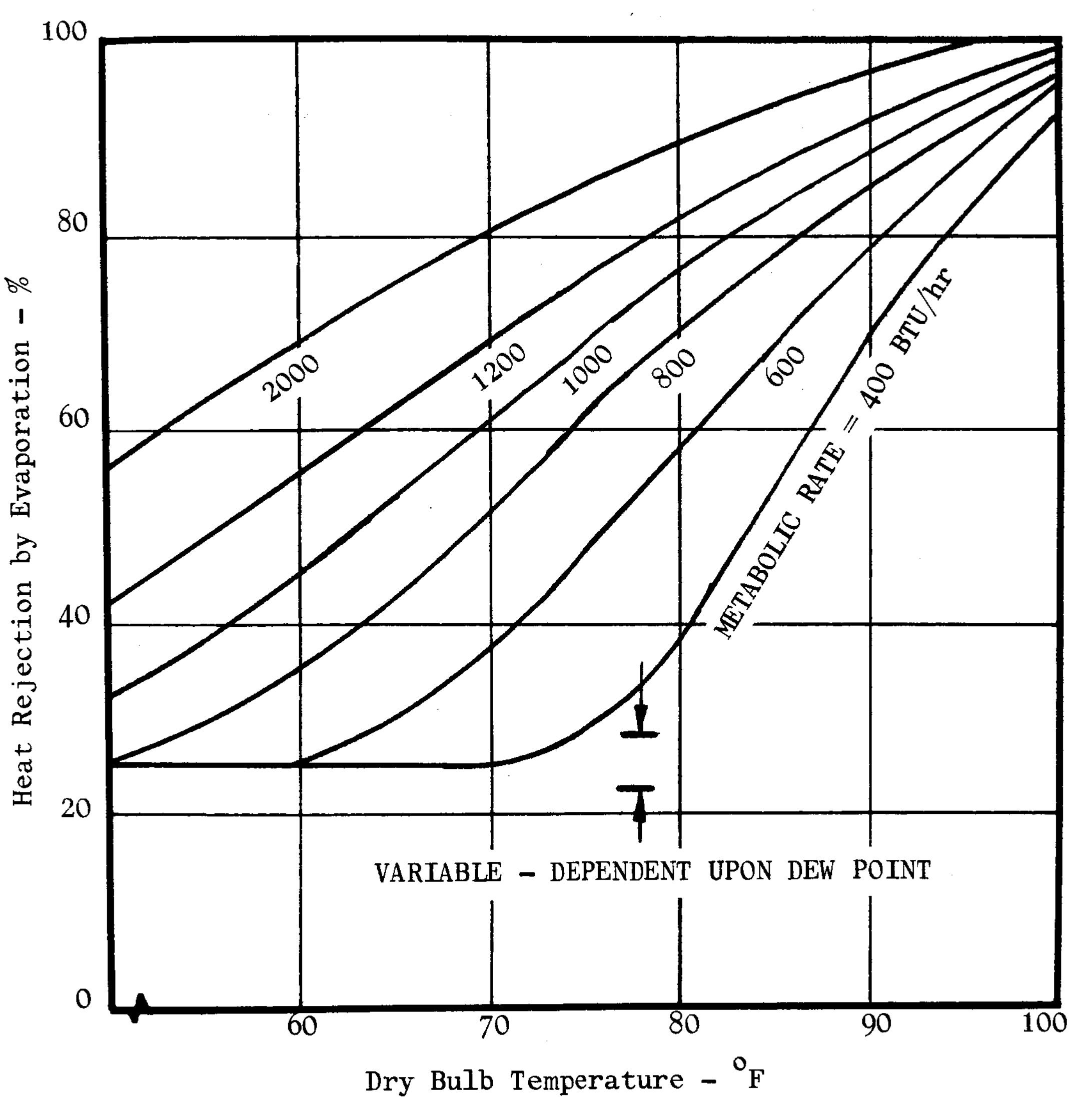


FIGURE 1-2 BODY LATENT HEAT REJECTION

References; 3,6

INSULATION REQUIRED FOR COMFORT

The thermal comfort of a man may be related to his skin temperature. As the skin temperature is affected by the surrounding environmental conditions, a criteria for comfort is established in Figure 1-3.

Heat is rejected from the body according to the following relationship:

$$Q \text{ sensible} = UA\ (T \text{ skin} - T \text{ ambient})$$

where:

Q - Heat load - BTU/hr
U - Overall heat transfer coefficient-BTU/ft^2-^{o}F-hr
A - Body surface area - ft^2
T - Temperature - ^{o}F

The heat load involved in this calculation is the sensible heat load which is assumed to be 75% 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^{o}F for a condition of comfort.

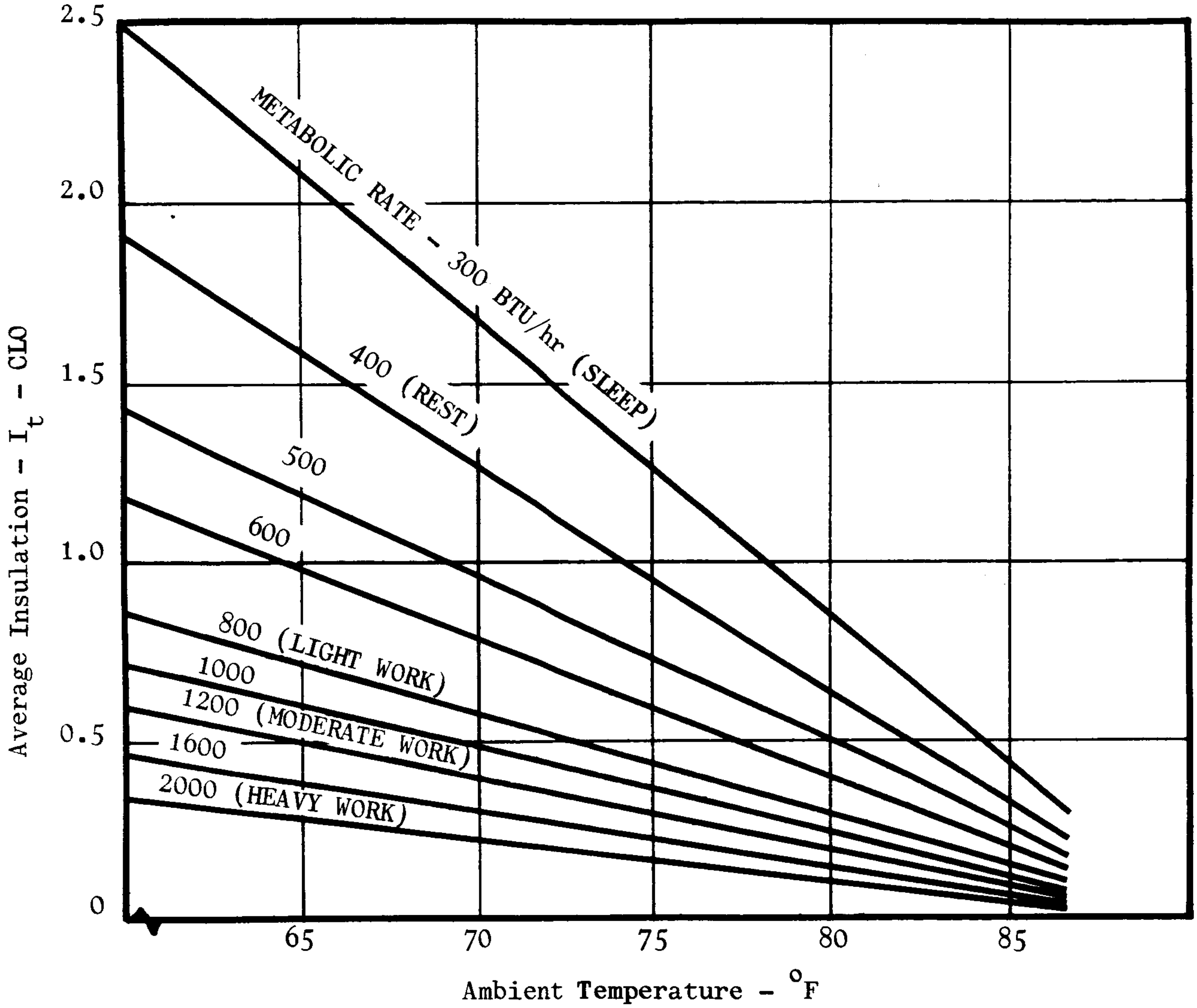
A new variable, the insulation value, is obtained by transposing the equation thusly:

$$I = \frac{1}{U} = \frac{A(T \text{ skin} - T \text{ ambient})}{Q \text{ sens.}}$$

and using the established unit of insulation, the clo, the equation is:

$$I = \frac{.88\ A\ (T \text{ skin} - T \text{ ambient})}{Q \text{ sens.}}$$

FIGURE 1-3 TOTAL BODY INSULATION REQUIRED FOR COMFORT



Typical Insulation Values

Article	Insulation
Nude	0.5 (due to air insulation)
Flight Coveralls with cotton underwear	1.0
Flight Coveralls with woolen underwear	2.0

Reference; 5

LOCAL INSULATION REQUIREMENTS

The average value of insulation (from Figure 1-3) is useful in the determination of an overall criteria for comfort. Figure 1-4 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.

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

The contribution of insulation is also expressed thusly:

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

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:

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

An example of this calculation is shown for the torso.

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

$$\frac{I_{local}}{I_{total}} = \frac{.40}{.36} = 1.1$$

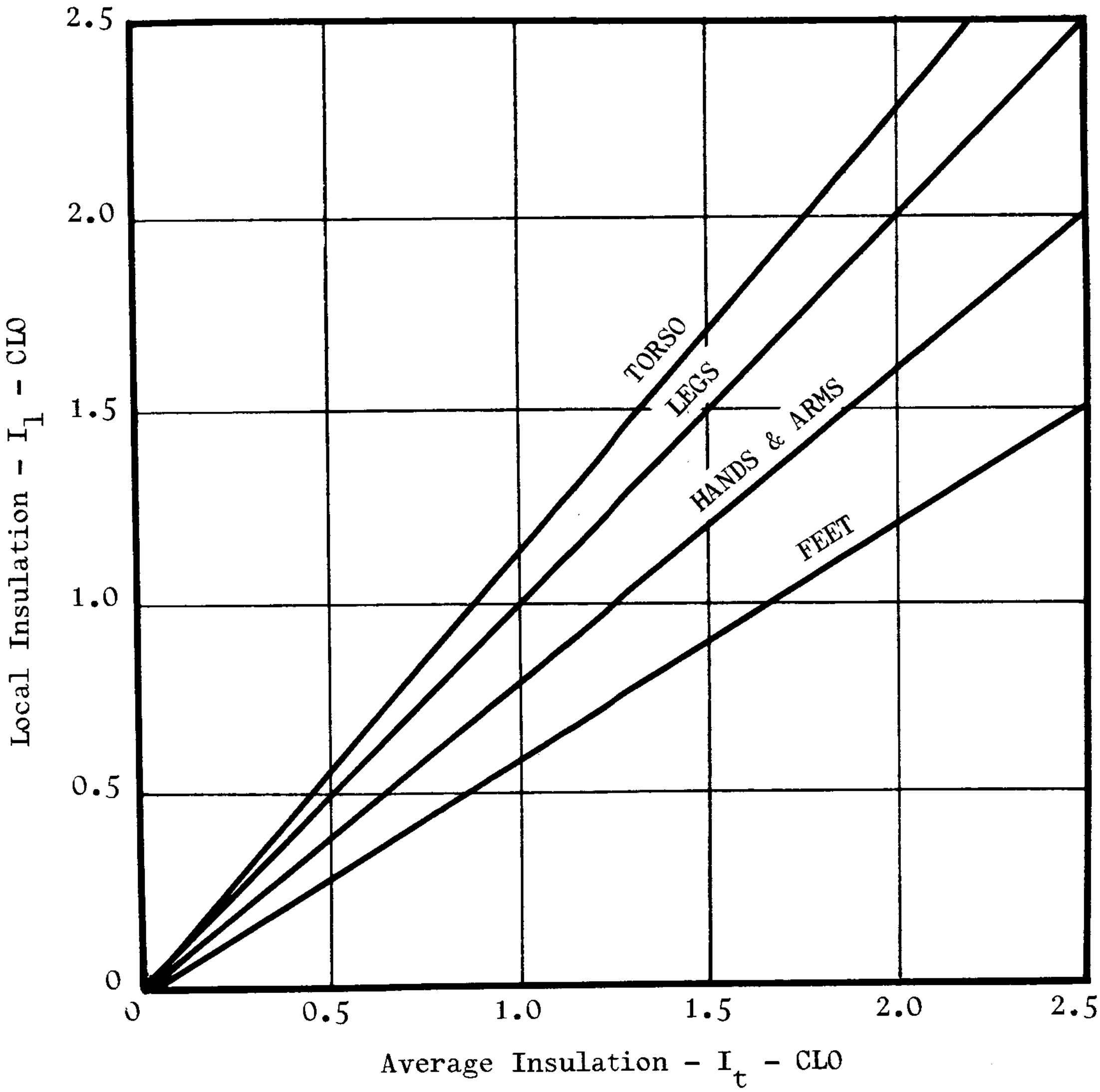


FIGURE 1-4 LOCAL INSULATION REQUIREMENTS

Metabolic Range - 500 - 800 BTU/hr

Reference; 5

ATMOSPHERE INSULATION PROPERTIES

Once the local insulation requirement has been determined from Figure 1-4 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 1-4

The atmosphere insulation value is related to the radiant and convective heat transfer coefficient. The radiant value is approximated as a constant (0.5 BTU/ft^2 - ^{o}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-hr-^{o}F
k = Gas Conductivity - BTU/ft^2-hr-^{o}F
d = Major Diameter- ft
Re = Reynold's Number ($\rho DV/\mu$)
Pr = Prandtl Number ($Cp\mu/k$)

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

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

These values are plotted for an oxygen/nitrogen atmosphere in Figure 1-5 A and an oxygen/helium atmosphere in Figure 1-5 B.

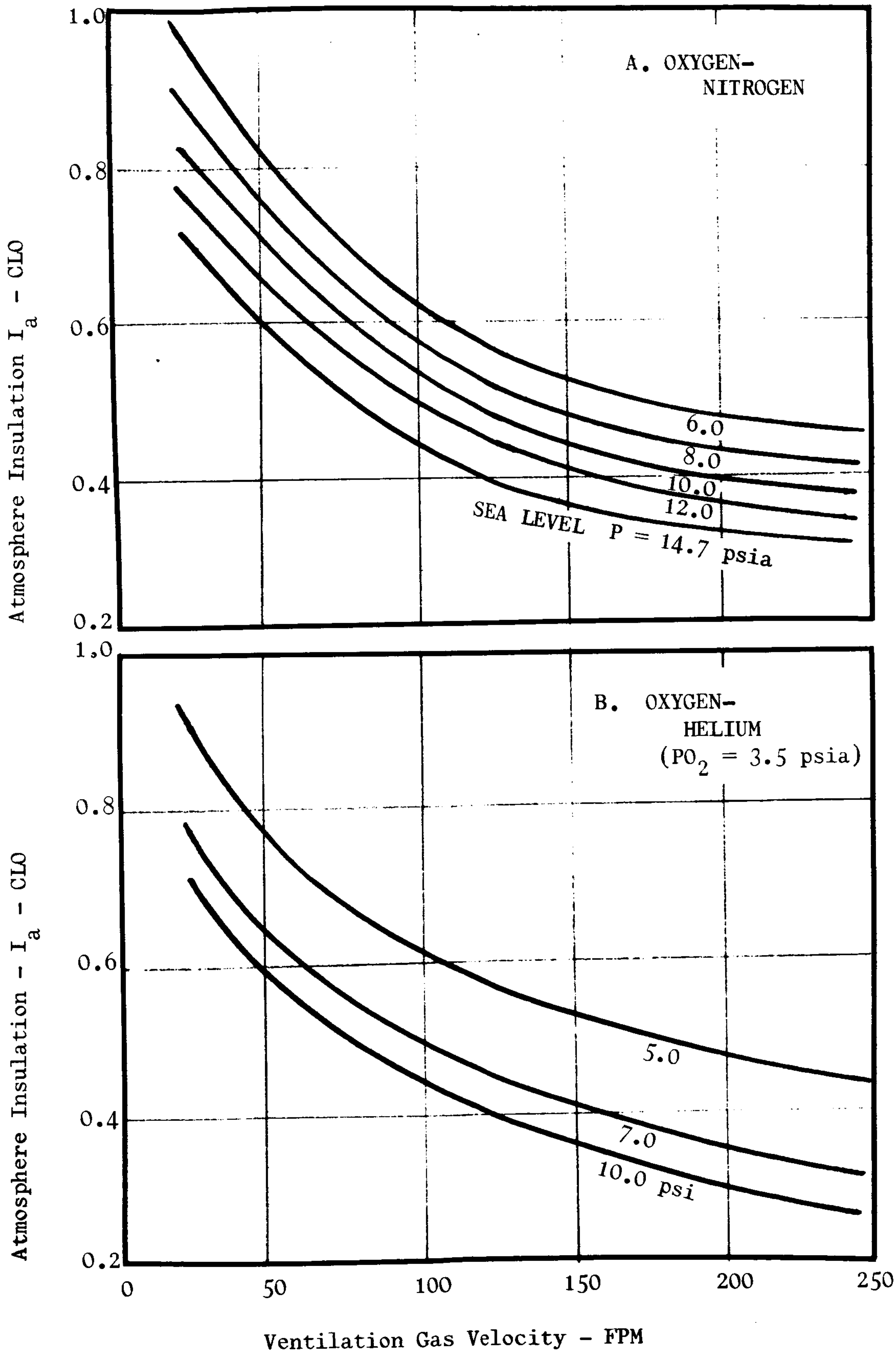
Since the thermodynamic and physical properties of oxygen and nitrogen are close, only the total pressure is indicated. In the case of oxygen helium, in which the properties are not approximately the same, an oxygen partial pressure of 3.5 psia is used for all conditions.

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

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

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

FIGURE 1-5 ATMOSPHERE INSULATION



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 1-6 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.

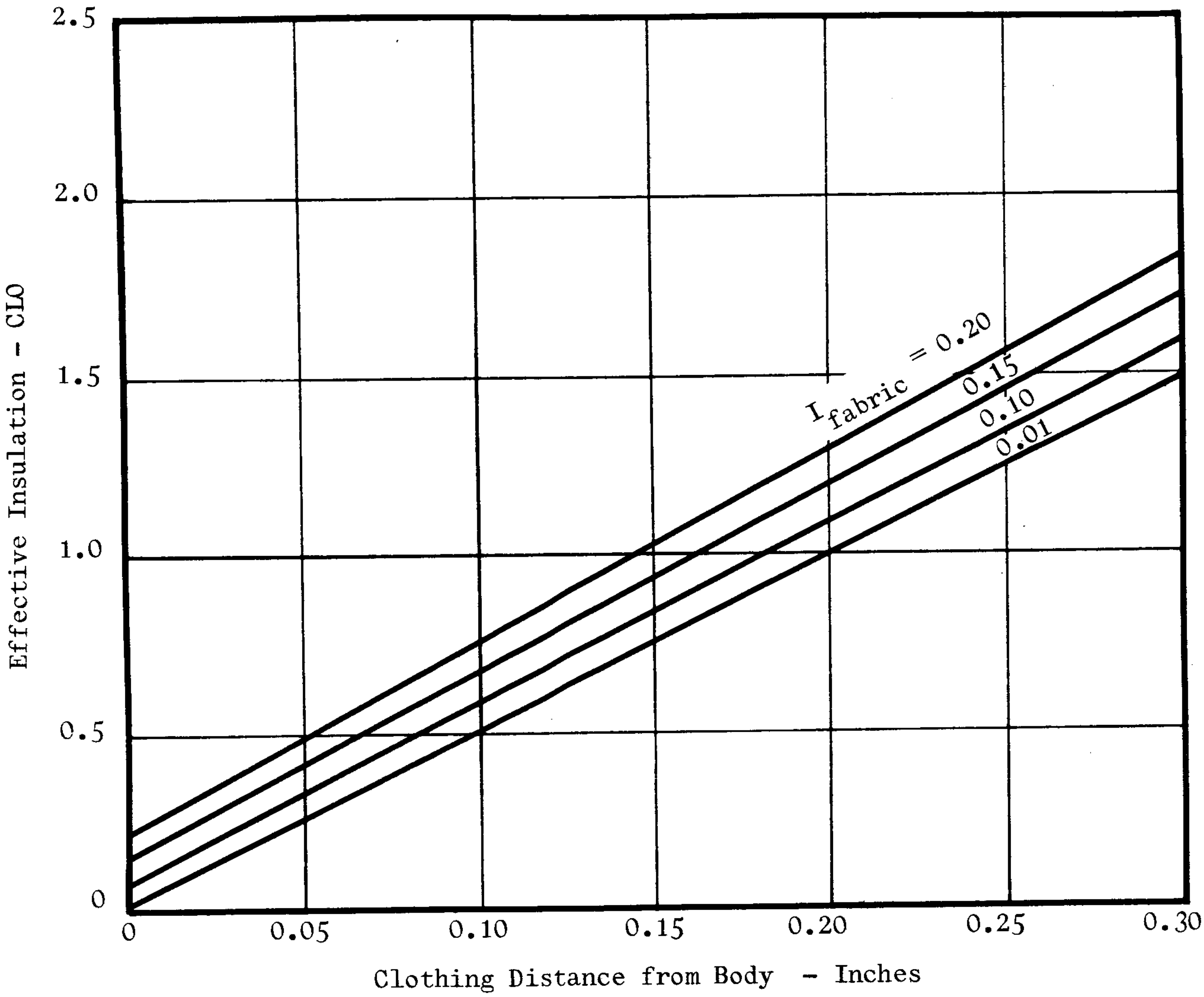
Several fabric insulation values (I_{fabric}) are presented. These values are a function of the weave, thickness and yarn conductivity as shown in Figures 1-7 and 1-8.

To use this curve in conjunction with the previous computations, the effective insulation is equal to the local clothing insulation required. Knowing the portion of the body to be covered, an overall clothing distance, and the effective insulation necessary a value of I_{fabric} is obtained for subsequent use in Figure 1-7.

An example of the use of the curves is presented below:

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

FIGURE 1-6 EFFECT OF DRAPE UPON CLOTHING INSULATION



Typical Values

Item	Distance (in.)
Tights	0.05
Pants	0.10 - 0.20
Dress Shirt	0.15 - 0.30
Sweat Shirt	0.30 - 0.50

FABRIC INSULATION PROPERTIES

The fabric insulation property is a function of the yarn conductivity, thickness and weave. Expressed in equation form:

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

Treating both of these variables separately, Figures 1-7 and 1-8 are presented.

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

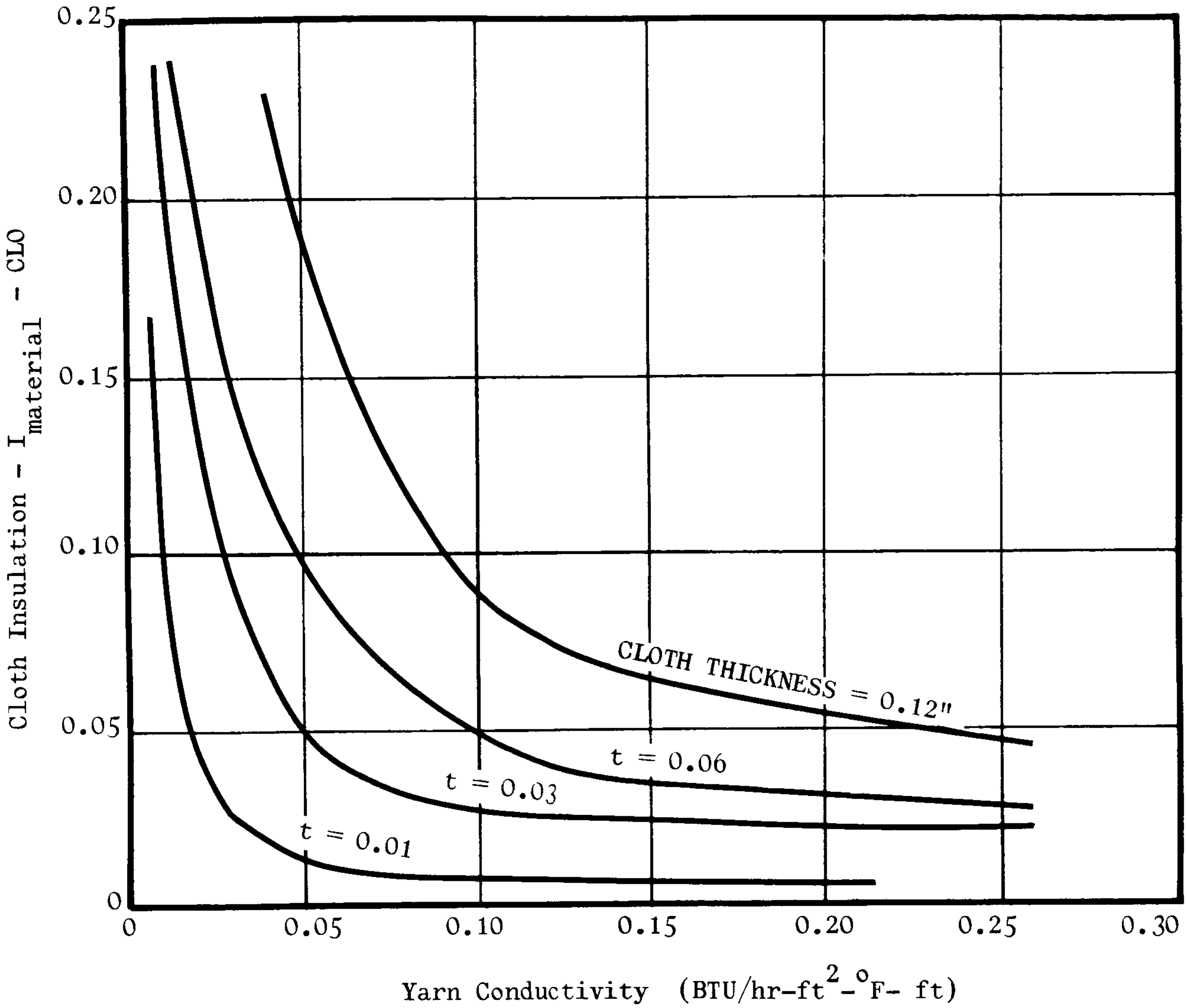
$$I = .88\ t/k$$

where:

t - is the thickness in feet
k - is the thermal conductivity in BTU/hr-ft^2-$^\circ$F-ft

Since the selection of materials is somewhat limited, the thickness of each of the materials may be determined for a given material insulation. Assuming a weave factor of 1.0, the material insulation is equal to the required fabric insulation (determined from Figure 1-6). Depending upon materials allowed (Section 3), a thickness may be determined.

FIGURE 1-7 MATERIAL INSULATION PROPERTIES



Yarn Conductivities	
Cotton	0.038
Nylon	0.125
Teflon	0.130
Dacron	0.150
Beta	0.30

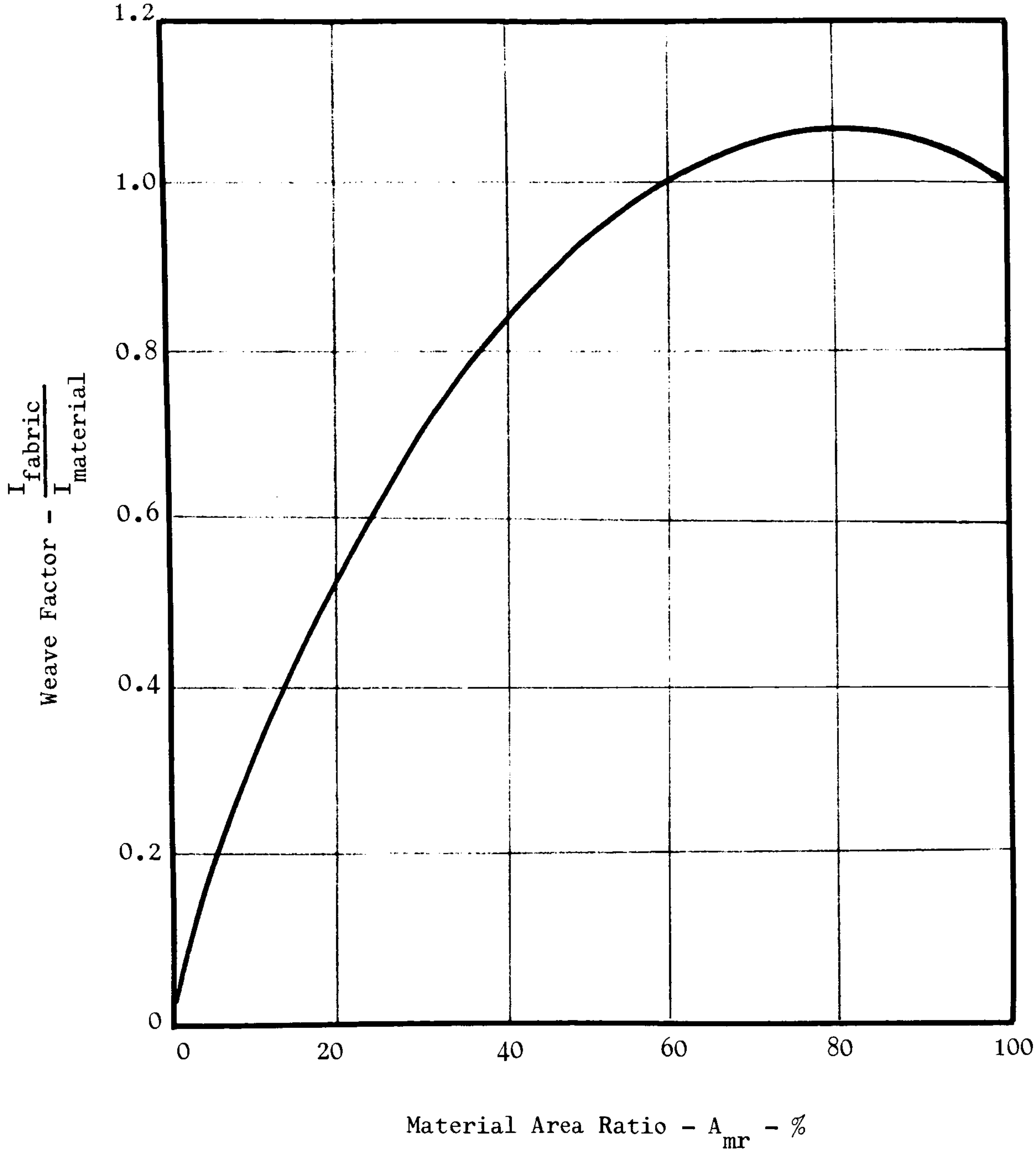
WEAVE EFFECT UPON MATERIAL INSULATION

The effect of the weave upon the insulation properties of the fabric is shown in Figure 1-8. The material area ratio, A_{mr}, is defined as the total material area per square inch of fabric. For most clothing the material area ratio is 90% or greater.

With low gas ventilation velocities, it is assumed that the addition of air spaces between the fibers increases the insulation properties, (i.e. decreasing area ratio increases weave factor). Offsetting this phenomena is the reduction of material, resulting in zero material insulation at zero area ratio.

For most clothing applications a weave factor value of 1.0 is suggested due to the characteristics of the cloth used in garments and the wide range of its application.

FIGURE 1-8 WEAVE EFFECT UPON MATERIAL INSULATION



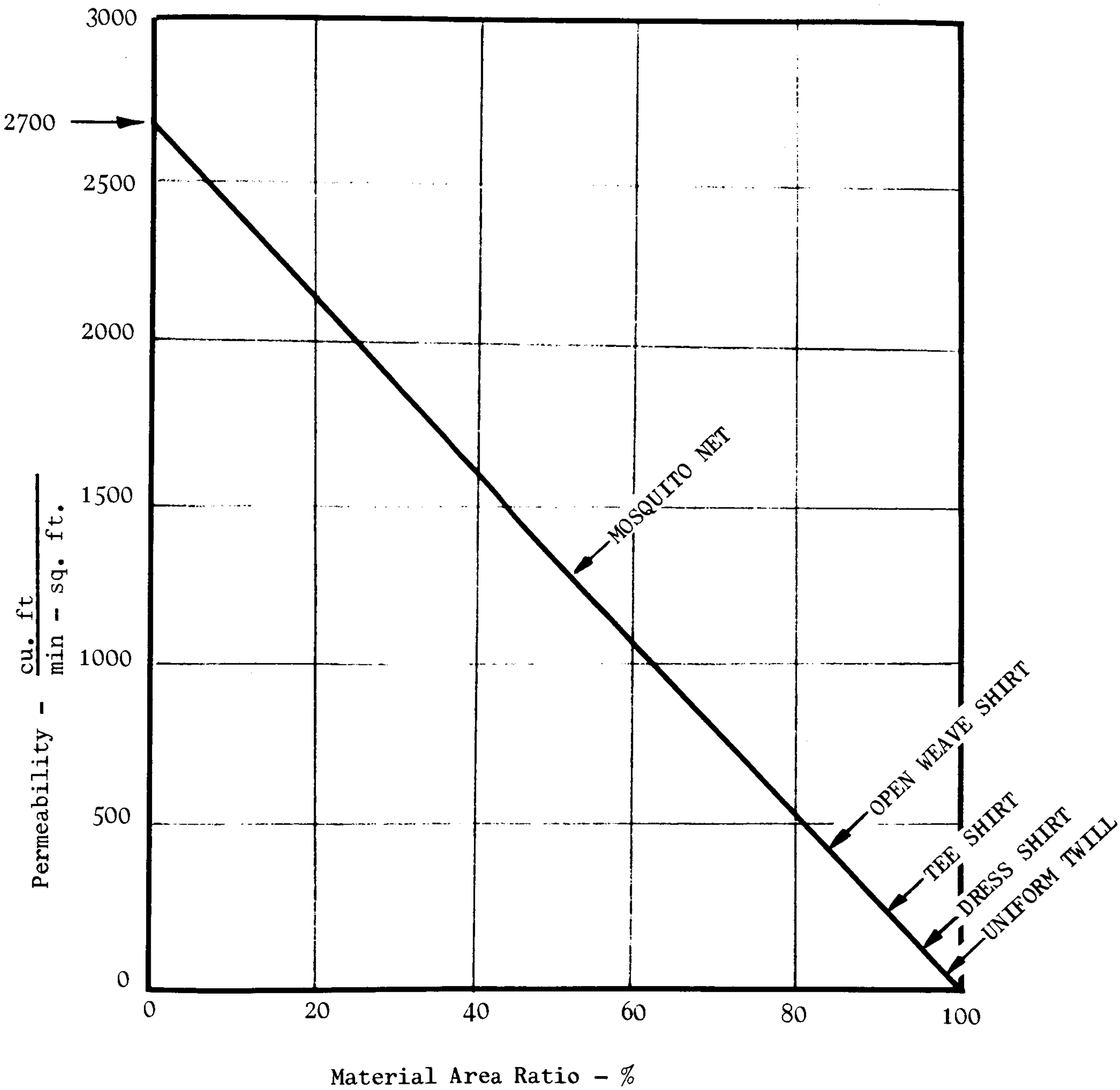
$$A_{mr} = \frac{A_{material}}{A_{total}}$$

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 1-9 shows the relationships between this variable and the commonly used garment term of permeability.

Permeability is measured in terms of cubic feet per minute of atmospheric gas per square foot of fabric with a 0.5 inch of water pressure difference.

FIGURE 1-9 FABRIC POROSITY AND MATERIAL AREA RATIO



Reference; 5

EFFECT OF DEW POINT AND FABRIC POROSITY UPON 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 1-10 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 equations 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 stations 1 and 2 - ft (skin to fabric)

Assuming saturated conditions at the skin and:

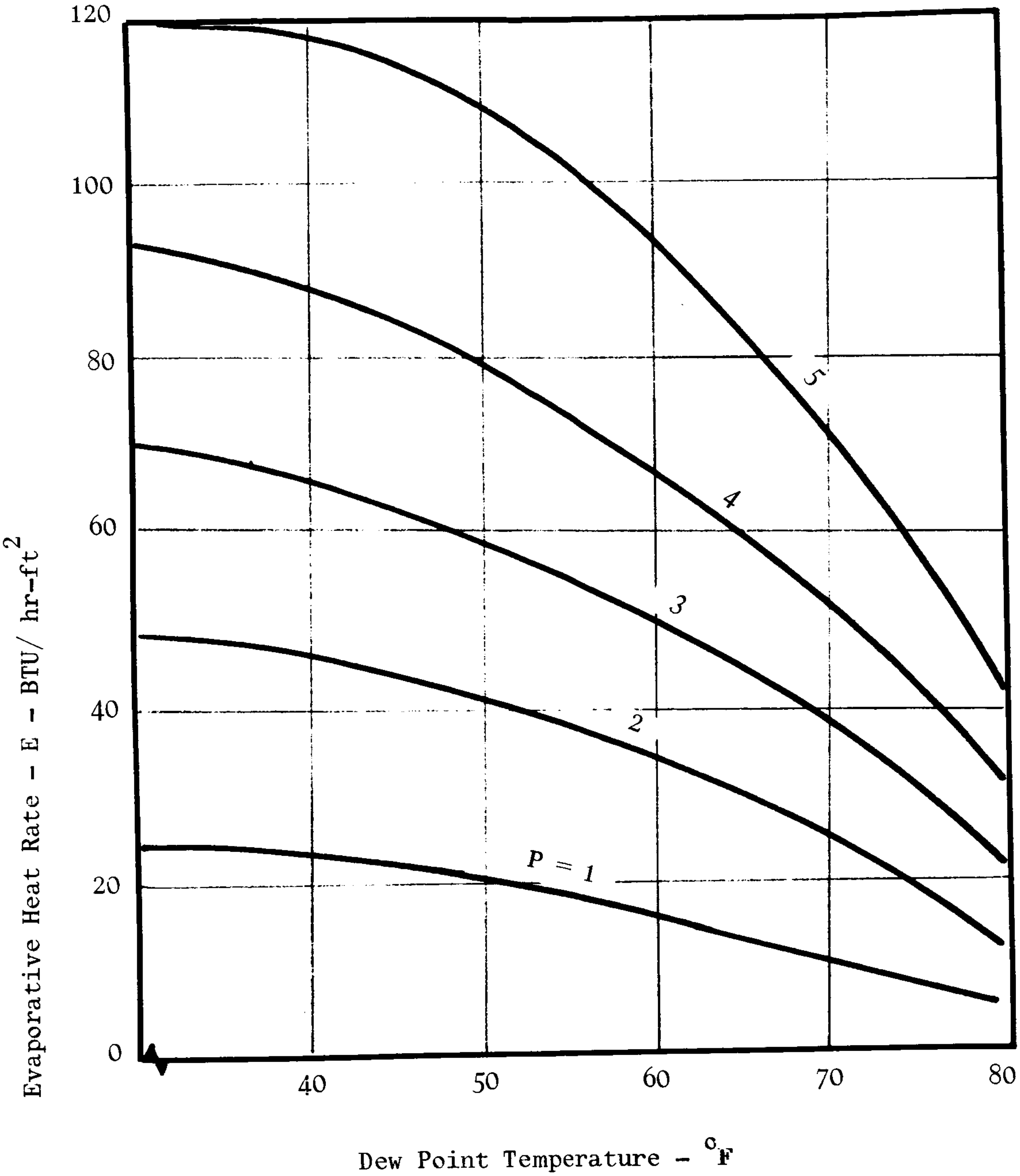
$$A = A_{fabric} \text{ (1 - material area ratio)}$$

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

The term $\left[\frac{1 - A_{mr}}{x}\right]$ is designated as a porosity factor in which drape employs an extremely important role.Typical values of this factor are presented in Figure 1-10.

FIGURE 1-10 EFFECT OF DEW POINT AND

FABRIC POROSITY UPON EVAPORATIVE HEAT REJECTION



P = Porosity Factor

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

A_{mr} = Material Area Ratio

x = Average Distance from Skin

Article	P
Tee Shirt	2.0
Knit Shirt	1.5
Pants	0.5
Dress Shirt	0.33

SUMMARY

The thermal data presented in Section 1.0 is based upon the heat transfer and thermodynamic interactions between a man and his clothing. To apply this data in the selection of a garment, Appendix A is attached to this handbook showing one illustrative example.

SECTION 1.0 REFERENCES

1. Ference, M.; Lemon, H.; and Stephenson, R.; Analytical Experimental Physics, University of Chicago Press, Chicago Illinois, 1956.

2. Full Pressure Suit Heat Balance Studies, Technical Report LS-140, Contract NAS 9-2886, February 1965.

3. Hardy, J. D. and Du Bois, E. F., Basal Metabolism, Radiation, Convection at Temperatures of 22 to 35°C. Journal of Nutrition, 15:477, 1938.

4. Modern Plastics Encyclopedia - 1968, McGraw Hill, Inc. Vol 45, No 14A, New York, N. Y., October 1968.

5. Newburgh, L.N., Physiology of Heat Regulation and the Science of Clothing, W. B. Saunders Company, Philadelphia, Pa. 1949.

6. Webb, Paul, Ed. Bioastronautics Data Book NASA SP 3006, Washington, D. C. 1964.

SECTION 2 - CONSTRUCTION

With the general garment body distribution requirements determined by thermal or other criteria, the elements of garment construction are presented in this section. The section is divided into the following areas and the uses of the applicable areas are discussed in Appendix A.

2.1 Fabric Data

This portion deals with fabric geometry and determination of fabric weight with given yarn properties.

2.2 Design Detail

This section presents the rationale for selection of fasteners, stitching, seams, cuffs, pocket location, and entry provisions.

2.3 Style

Single and two piece garment styles are presented with typical uniforms and functional garments. Concepts of headgear and footwear are shown for reference.

2.4 Weight Determination

This section presents the consideration made when computing the weight of a garment. Included is the amount of fabric required for a given article.

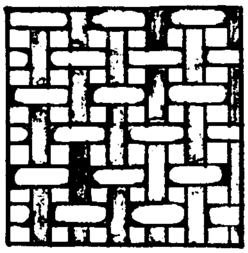
SECTION 2.1 - FABRIC DATA

In the construction of garments and cloth, there are three fabric categories: woven, nonwoven and knitted construction. The category of nonwoven materials include synthetic materials which are characterized by lofty webs of fibrous materials of mechanical or adhesive type bond. Nonwoven materials, however, 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 in this section. Discussion and uses of the remaining two types of fabric construction are presented in Figure 2-1.

FIGURE 2-1 CONSTRUCTION OF COMMON FABRICS BASIC WEAVES AND KNITS

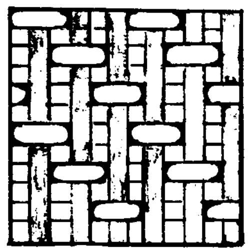
WEAVES: Provide rigidity, endurance, high strength, mendability.

PLAIN WEAVE:



.MAXIMUM ENDURANCE
.MAXIMUM STRENGTH
.MOST WIDELY USED FOR CLOTHING

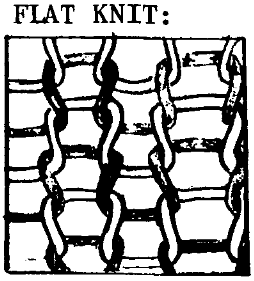
TWILL WEAVE:



.MOST RESILIENT
.BEST MEMORY
.USED IN HEAVY WEAR

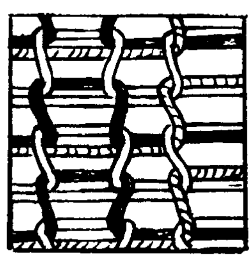
KNITS: Provide softness, warmth, conformity, porosity.

FLAT KNIT:



.BASIC KNIT

INTERLOCKING KNIT:



.TEAR RESISTANT

WEAVE CHARACTERISTICS

The material area ratio (amount of material face area per unit area of fabric) 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 a value of A_{mr} of 75% 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.

Since the major portion of clothing possesses a material area ration of 80% or greater, the applicable yarn configuration is compressed.

The equation for the material area ratio are:

<u>Circular</u>

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

<u>Compressed</u>

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

N = Pick Density

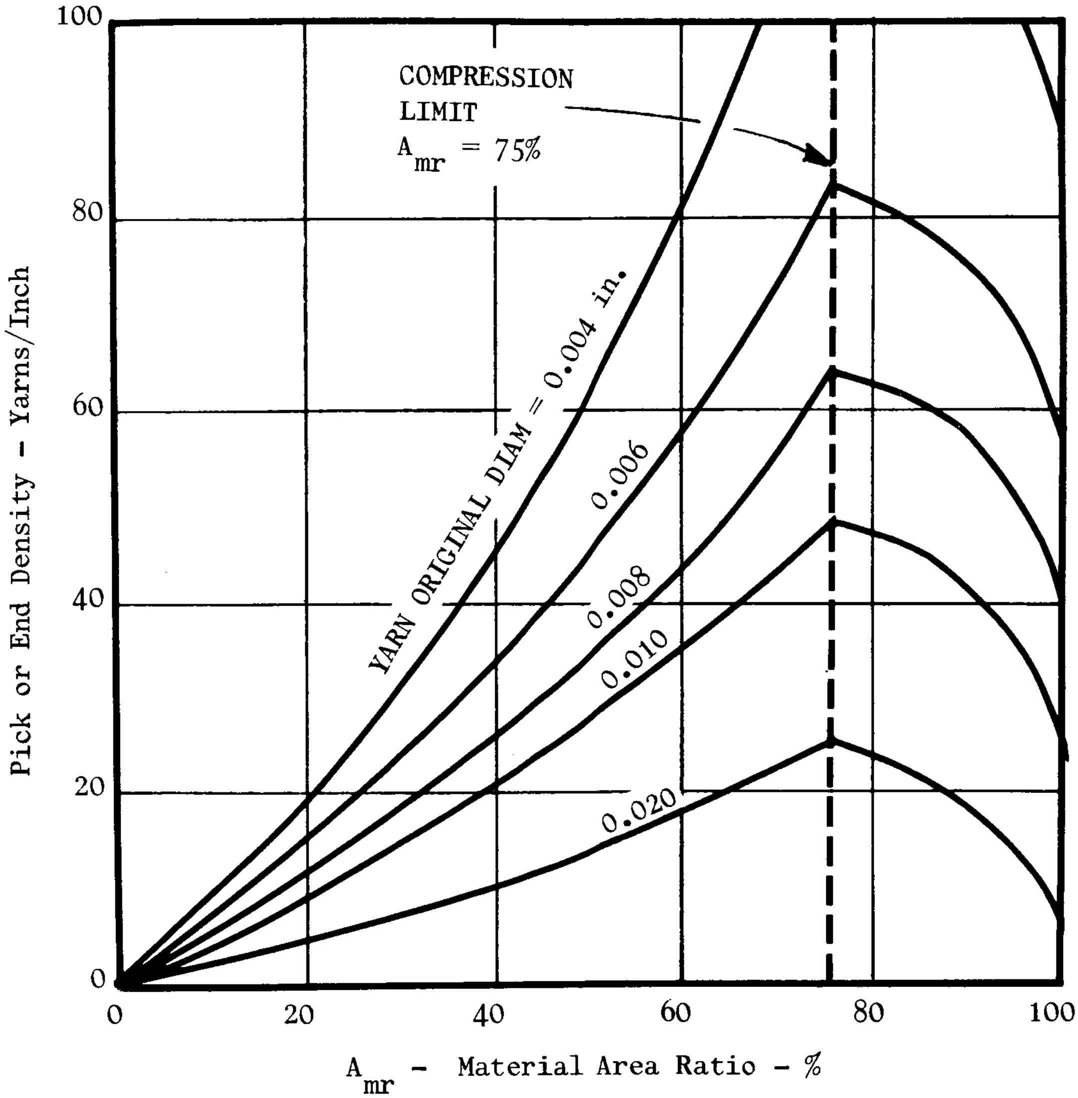
M = End Density

D_o = Yarn Circular Diameter

D = Compressed Yarn Major Diameter

FIGURE 2-2 WEAVE CHARACTERISTICS:

MATERIAL AREA RATIO AS A FUNCTION OF TEXTURE AND YARN SIZE



Plain Weave

Pick Density = End Density

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

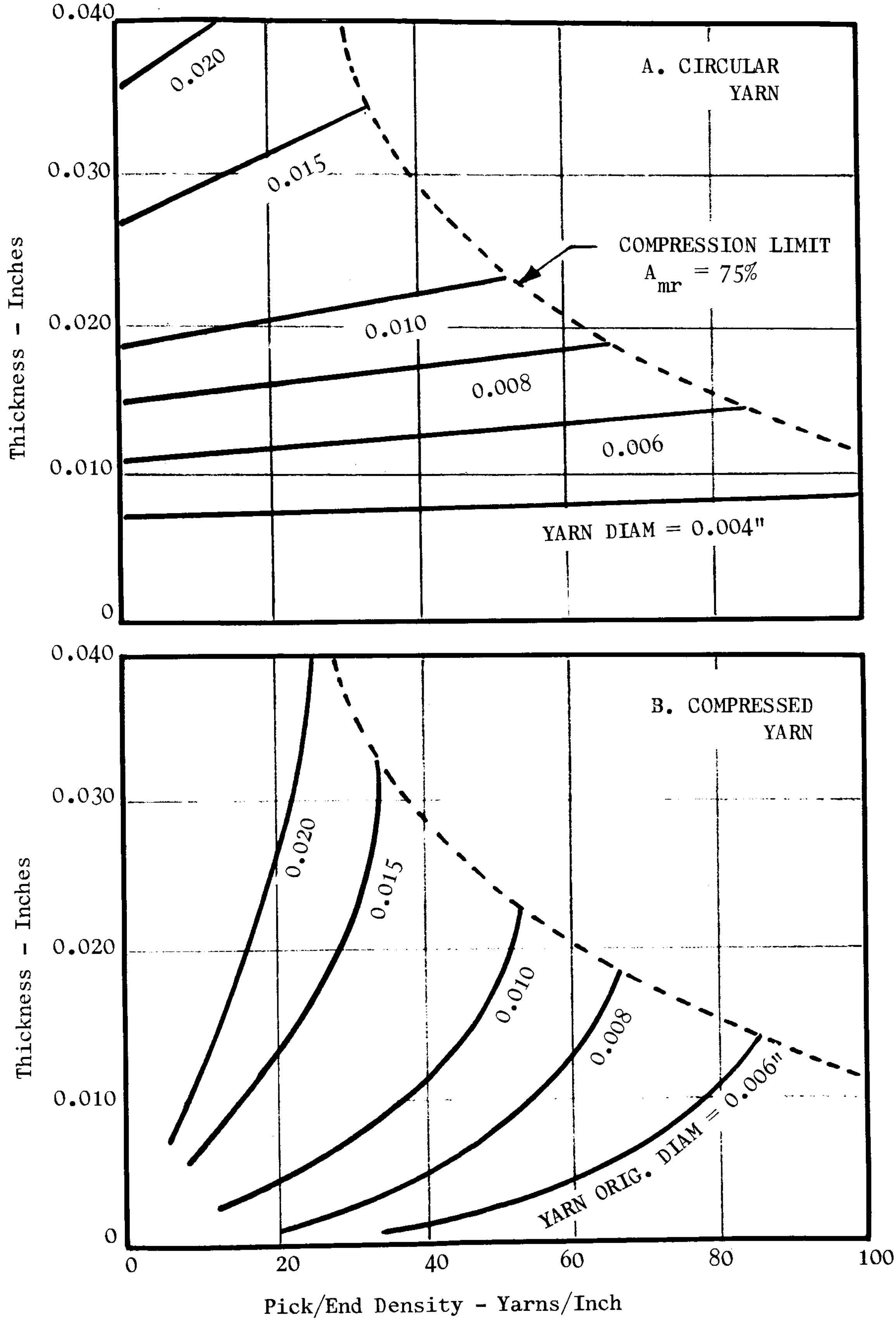
$A_{mr} > 75\%$ - Yarn Cross Section is Elliptical

FABRIC THICKNESS

The average thickness of a fabric is governed by the yarn geometry as shown in Figure 2-3. In curve A, thickness data is presented for circular yarn 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%. The data presented in the curves is applicable for a balanced (equal diameter and equal density in the warp and filler direction) fabric. The thickness value is computed by averaging the maximum and minimum thickness.

In curve B, the data for compressed yarn is presented. This curve includes the flattening effect of the yarn as the material area ratio is increased.

FIGURE 2-3 FABRIC THICKNESS



FABRIC WEIGHT

The fabric weight is a function of the yarn size, material density and the number of yarns per inch. Figure 2-4 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 presented in Figure 2-4 also. It is assumed that the fiber strands (filaments) comprise 90% of the yarn cross sectional area which is typical of a twisted yarn.

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/Inch

De_f = Filler Yarn Denier

ϕ_{cf} = Crimp Factor - Filler Yarn

M = End Density - Yarn/Inch

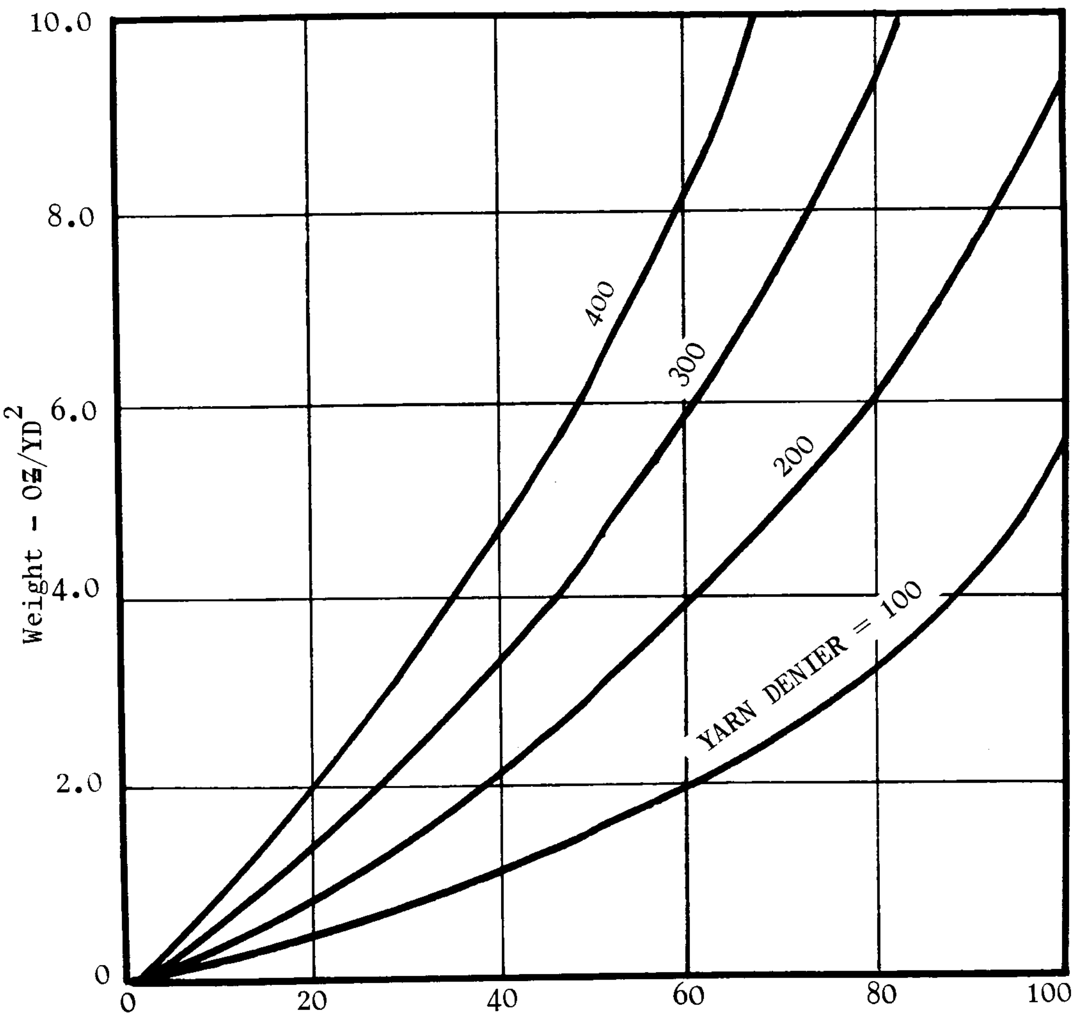
De_w = Warp Yarn Denier

ϕ_{cw} = Crimp Factor - Warp Yarn

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

D = Yarn Diameter

FIGURE 2-4 FABRIC WEIGHT FOR WOVEN CONSTRUCTION



$$\text{Yarn Diameter} = 3.9 \times 10^{-3} \sqrt{\frac{\text{Denier}}{\text{Density (lb/ft}^3)}}$$

For N = M, Enter Graph at Value

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

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 2-1.

Staple Yarn

Yarn which is formed by spinning fibers of descrete lengths.

Continuous Filament Yarn

Yarn formed by twisting two or more continuous fibers of material with no descrete length.

Monofilament Yarn

Yarn with a single continuous filament comprising the yarn strand.

TABLE 2-1 YARN COMPARISON

	STAPLE YARN	CONTINUOUS FILAMENT	MONOFILAMENT
Advantages	Soft hand adsorbent 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

SECTION 2.2 DESIGN DETAILS

The type and amount of fabric for a garment has been presented in the previous sections. This section of the handbook is concerned with the detail design aspects of clothing from an engineering sense. Included in this section are a familiarization with the following:

- Selection of stitches
- Seam selection
- Stitch number
- Seam location
- Selection of fasteners
- Pocket location
- Entry provisions

Since the details of the design of 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.

SELECTION OF STITCHES AND SEAMS

The selection of the proper seams and stitching techniques is 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

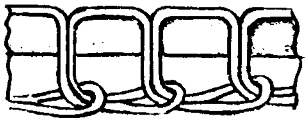
Seam type

The following illustrations and curves present the criteria for the determination of stitching and seam geometry.

The types of seams and their uses is presented in Figure 2-5. There are seven basic types of stitches, defined in MIL-STD-751, withe the class 300 being the most commonly available in machines due to its simplicity.

FIGURE 2-5 TYPES OF STITCHES

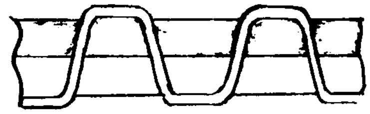
Class 100 - Chain Stitch



Description: Single Interlooping Thread

Uses: Basting

Class 200 - Hand Stitch



Description: Single Line Thread

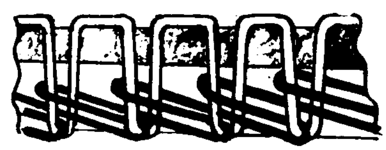
Uses: Ornamental, Basting

Class 300 - Lock Stitch

Description: Interlacing Multiple Threads

Uses: Seams, Attachments, Facing Joining, Hemming

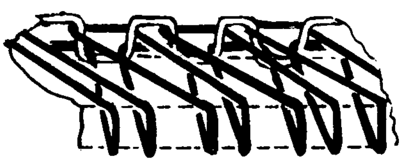
Class 400 - Double Lock Stitch



Description: Multithread Interlacing and Interlooping

Uses: Same as 300 Series

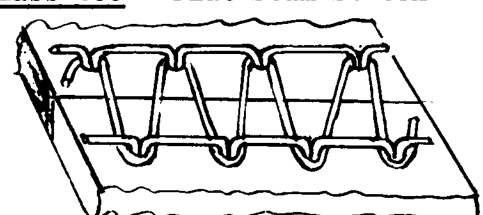
Class 500 - Overedge Stitch



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

Use: Same as Class 300

MINIMUM STITCH DETERMINATION

The number of stitches for proper strength in joining two fabric pieces together is a function of the properties of the fabric and the thread. For a proper seam, the strength of the stitches should be equal to or greater than the fabric joined. Presented in Figure 2-6 is a stitch number selection curve relating the important variables.

The theory of the analysis is based upon a plain, superimposed seam (see Figure 2-7) with an interlacing stitch. The rupture strength of the thread is equated to the rupture strength of the fabric yarns.

$$F_{rupture(thread)} = n\ (De_t)\ Et$$

where:

n = Number of Stitches/Inch
De_t = Thread Denier
Et = Thread Ultimate Loop Strength - g/Denier

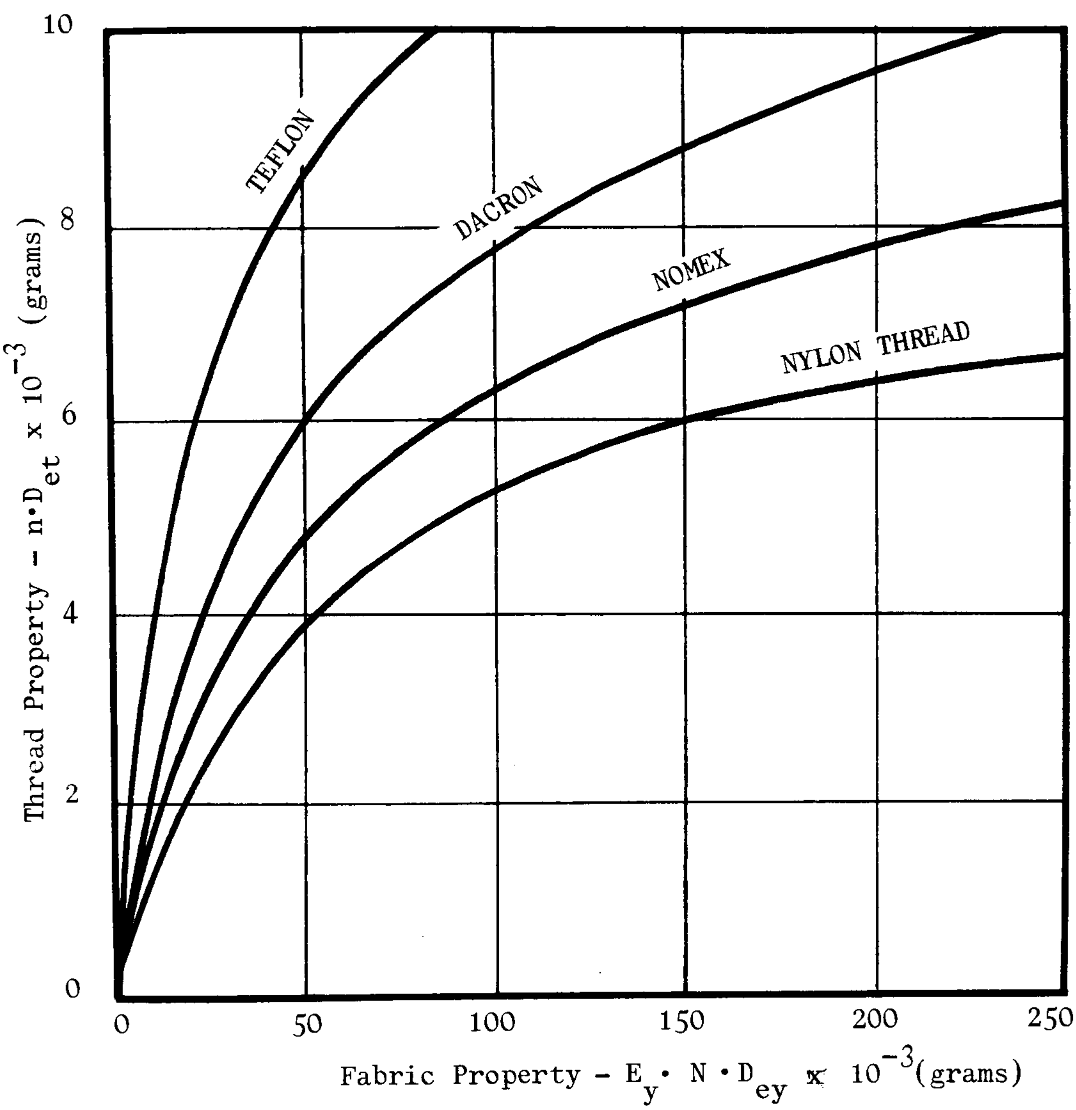
$$F_{rupture(fabric)} = f\ (N, De_y, Ey)$$

where:

N = Number of Yarns/Inch Perpendicular to Seam
De_y = Yarn Denier
Ey = Yarn Ultimate Strength - g/Denier

Equating both of these variables, the resultant are the curves in Figure 2-6.

FIGURE 2-6 STITCH NUMBER SELECTION



where:

N = Pick or end density - yarns/inch
E_y = Fabric yarn ultimate strength - grams/denier
D_{ey} = Fabric yarn denier
D_{et} = Thread denier
n = Minimum number of stitches/inch

Reference Data; 2

SEAM SELECTION

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

1. Superimposed Seams

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.

2. Lapped Seams

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.

3. Bound Seams

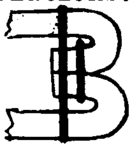
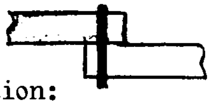
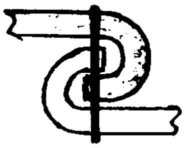
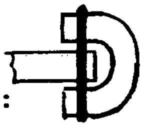
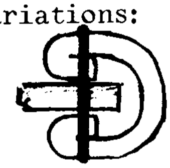
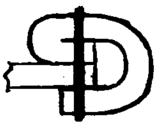
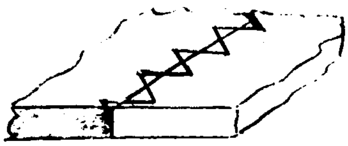
This seam is used at the edge of a single piece of fabric to build up and contain the material.

4. Flat Seam

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.

Figure 2-7 presents the commonly used seams and their application.

FIGURE 2-7 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 Necks

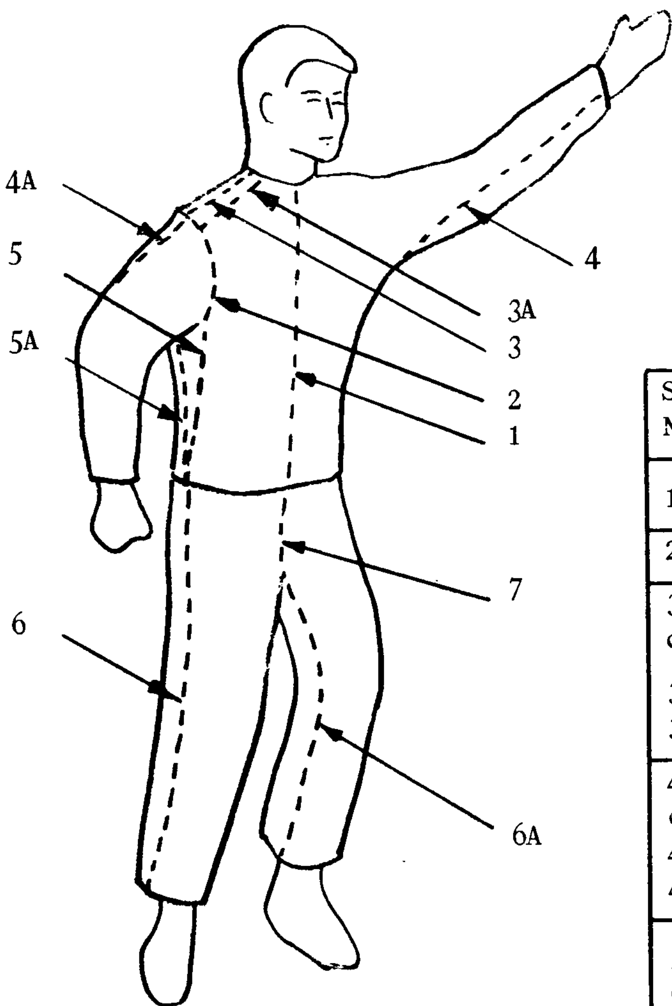
* Per Fed- Std- 751

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 fabricated. Comfort, drape, and the minimization of migration on the body is afforded by the proper use of seams in shaping a garment. Figure 2-8 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 location of seams are at the points of junctions of the limbs and places of maximum curvature.

In the construction of garments, the more conformal the garment, the more seams present. Sportswear, due both to relative expense and appearance, contains single seam construction throughout. Tailored garments and more formal attire contains double seams in the limbs and torso.

FIGURE 2-8 SEAM LOCATION



Seam No.	Seam Description	Applications
1	Entrance	All Woven Garments
2	Scye	All Woven Garments
3 only or	Upper Shoulder	Sports Shirts Tee 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 Pants non-Conformal
6 and 6 A	Outseam and Inseam	Tapered Pants
7	Entrance	All Woven Garments

SELECTION OF FASTENERS

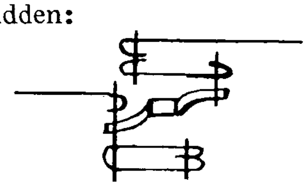
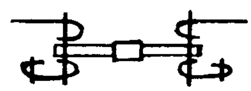
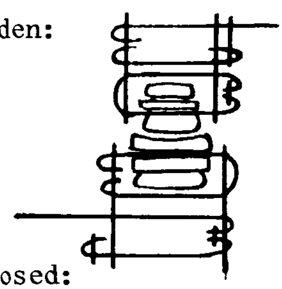
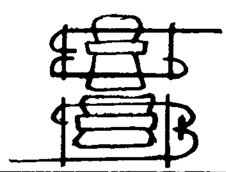
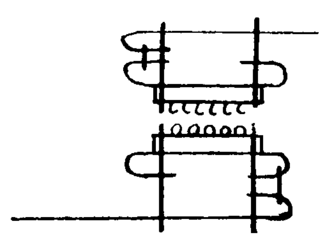
The fasteners used in garment design range from the use of buttons, as normal street clothes, to the use of hook and pile tapes. The general requirements for fasteners are to temporarily secure two pieces of fabric together with a reasonable amount of strength within the dexterity limits of the hands.

The requirements for fasteners are divided into four areas as defined by their use on the garment:

1. Garment entrance closures
2. Cuffs
3. Pockets
4. Garment adjustments

Each of these applications is presented in Figure 2-9.

FIGURE 2-9 FASTENER COMPARISON

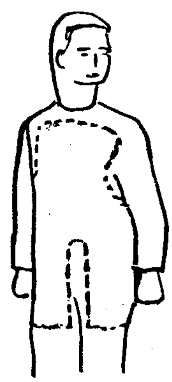
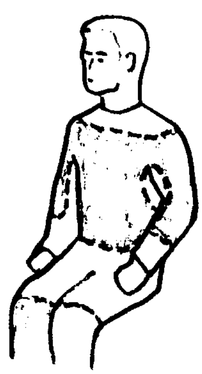
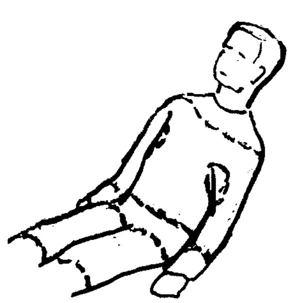
TYPE	WEIGHT	STRENGTH	SEAM REQUIREMENT	REMARKS
Slide	0.025 to 0.07 oz/in.	Equal to or Greater than Fabric	Hidden:  Exposed: 	.Strongest and Heaviest Fastener. .Configuration Controlled per Fed-Spec-V-F-106C. .Ease of Operation.
Snap	0.1 to 0.2 oz	Reinforced Fabric to Avoid Tearing	Hidden:  Exposed: 	.Used on Apollo ICG. .Possible Spart transmission with hydrophoic materials. .Lightest
Hook and Pile	0.04 to 0.06 oz/in.	Shear: >4 lbs per inch Pull: 0.5 to 2 lbs.	Hidden: 	.Poor Drape with Continuous Closure. .Ease of Fastening. Reference; 6

POCKET LOCATION

The location of pockets in a garment is a function of the items contained and the working position of the crewmen. With the availability of increased workspace in space stations, the task oriented items such as checklists, manuals and such amy be contained at the work station. The use of pockets in a space station garment shall be concerned with the items presented in Figure 2-10.

Two styles of pockets are available, the internal and external type. The internal, or slash pocket, conceals the material within the harment and is hidden from sight. The capacity of the pocket is limited due to the drape requirements of the garment. In the external pocket, increased space is available with the use of folded sides, however, a utilitarian style results.

FIGURE 2-10 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	

ENTRY PROVISIONS

Figure 2-11 shows the common garment entry methods for both single and two piece coverall garments. For the two piece coverall garments, the entry provision to the pants is the same as shown in Concept 1. In all cases, a front entry is desirable if a space station crew member is to don the garment unaided.

Concept 1 - Front Entry (two piece)

This method of entry requires the least fastener penalty by having the least mating surface length. It is symmetrical, allowing equal pocket distribution and the most common of entrance methods.

Concept 2 - Side Entry

The side entry method is advantageous for specialized duties that involve contamination 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 relatively stiff fastener seam is at an area of least length change during body bending.

Concept 3 Partial Front Entry

The technique is used primarily with stretchable materials such as knits and requires overhead donning.

Concept 4 - Front Entry (single piece)

This approach is the combination of Concept 1 (pants and jacket) for a single piece suit. Its primary disadvantage is the interface with the waste management sub-system.

Concept 5 - Extended Front Entry

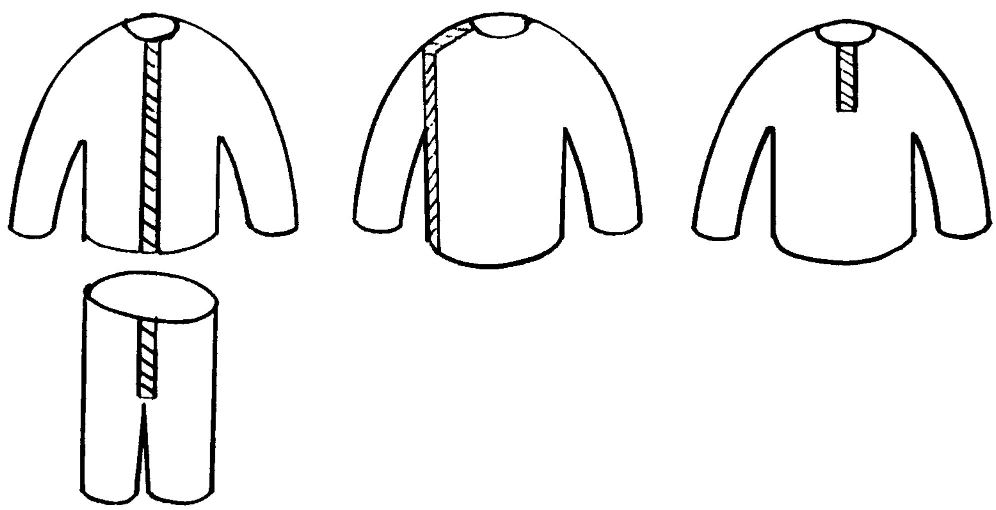
This technique is advantageous for extremely cramped donning areas. It allows a fixed position of the body on the garment while putting limbs into sleeves and legs.

Concept 6 - Front Entry (single piece - alternate)

In this method, the entry seam is extended to the rear waist. This approach allows crew elimination without removing the unit.

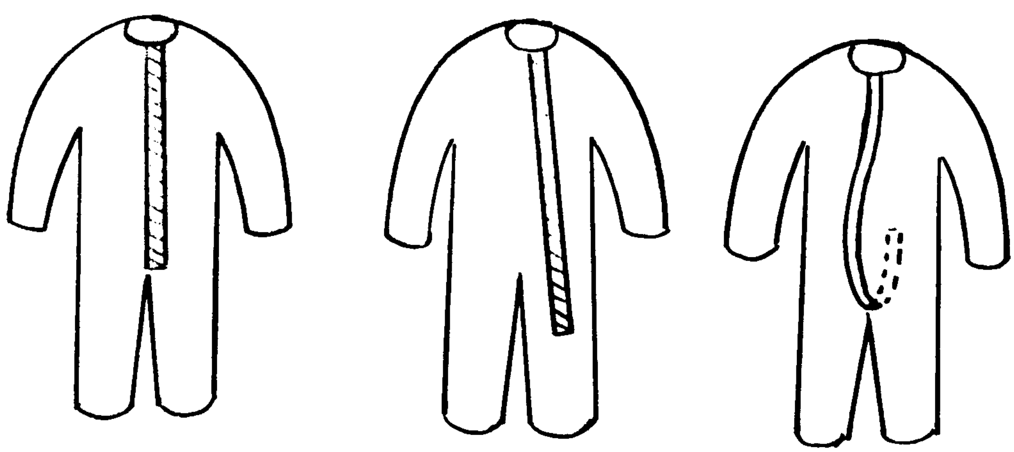
FIGURE 2-11 GARMENT ENTRY PROVISIONS

Two Piece



1 2 3

Single Piece



4 5 6

GARMENT OPENINGS

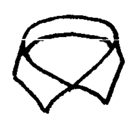
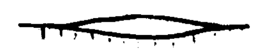
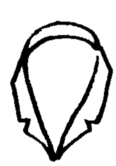
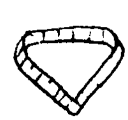
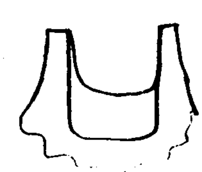
The appearance of a garment is governed by the external treatment of its openings located at the neck,wrists, waist and ankles. The next several pages show several styles for each area and the relative merits of each.

Collar Design

One of the functions of a collar is to prevent chafing of woven materials against the neck. The formality of a garment can be established by the collar design, by its intended use with a necktie and its basic style. Since neckties are an undue burden in zero gravity, this item should not be required. The type of collar should be selected on the basis of comfort, style and materials involved.

The basic types of collars and their derivatives are presented in Figure 2-12 for comparison.

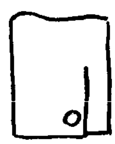
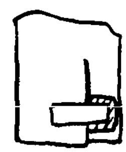
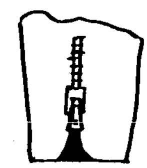
<u>FIGURE 2-12 COLLAR CONFIGURATIONS</u>

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 - No separate 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

CUFF DESIGN

The purpose of a cuff is to strengthen the portion of the fabric of a garment around the ends of a sleeve or pant leg. A desirable quality for a cuff is for it to be conformal with the ankle or wrist to avoid encumberance and to increase 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.Figure 2-13 shows several commonly used cuff configuration and the applicable comments.

<u>FIGURE 2-13 CUFF DESIGN</u>

TYPES	SNAP	HOOK AND PILE	RIBBED	SLIDE
Configuration				
Application	Street Clothes	Apollo ICG	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	Lighweight	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, Awak-ward, Requires Fitting

SECTION 2.3 GARMENT STYLE

The style of a garment for use in a space station must have the combined elements of proper function, least weight and interface penalty and aesthetic appeal. In the previous sections, the elements of the construction and design details of a garment were treated. This section deals with the functional/aesthetic aspects of garment design.

The crew of a space station will require a uniform style during duty hours as in the case of outlying military installations such as nuclear submarines and arctic bases. Although variations in the uniform are desirable according to a single crew members task assignment and work station limitations, at least one single standard uniform should be designed.

This section presents a cross section of military and specialized uniforms for consideration in establishing a style for a space station crew.

BASIC GARMENT CONFIGURATION

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.

The matrix presented in Table 2-2 presents the criteria by which to assess the need for a single or two piece coverall garment.

TABLE 2-2 COMPARISON OF SINGLE AND TWO PIECE COVERALL GARMENTS

CRITERIA / ITEM	SINGLE PIECE	TWO PIECE
Advantages	Total Enclosure of Body Antisnag	Adaptability to Temperature Waste Management Compatability
Disadvantages	Requires Tailoring for Proper Drape	Some Migration
Weight	1.5 - 2.0 lbs. Slightly Less than 2 Piece	1.6 - 2.1 lbs
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

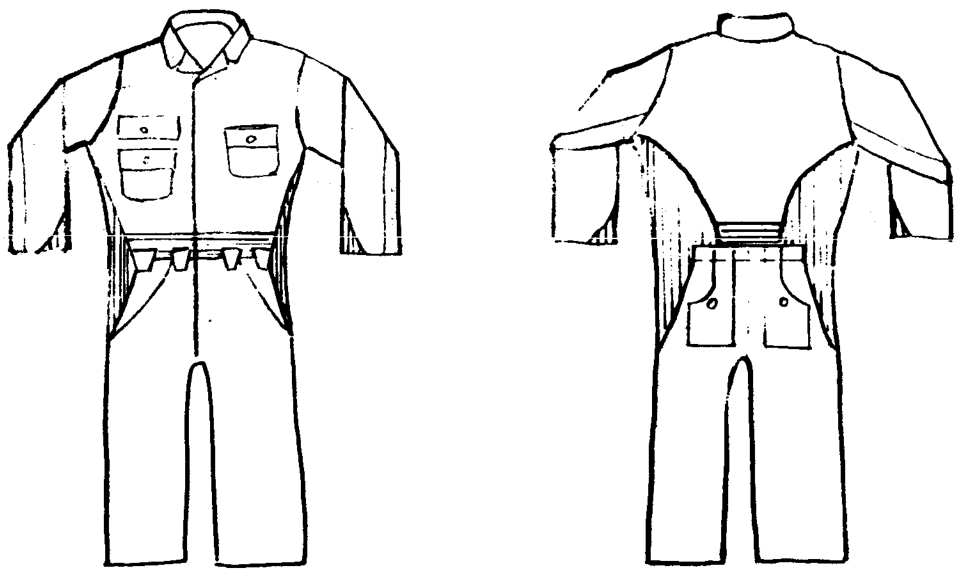
SINGLE PIECE COVERALLS

Figure 2-14 shows several of the present single piece coveralls in use in the military. The users of these coveralls range from a pilot to a crew member of an atomic submarine. The primary differences between the configurations are due to the type and location of the pockets, the adjustment provisions, and the type of fasteners used.

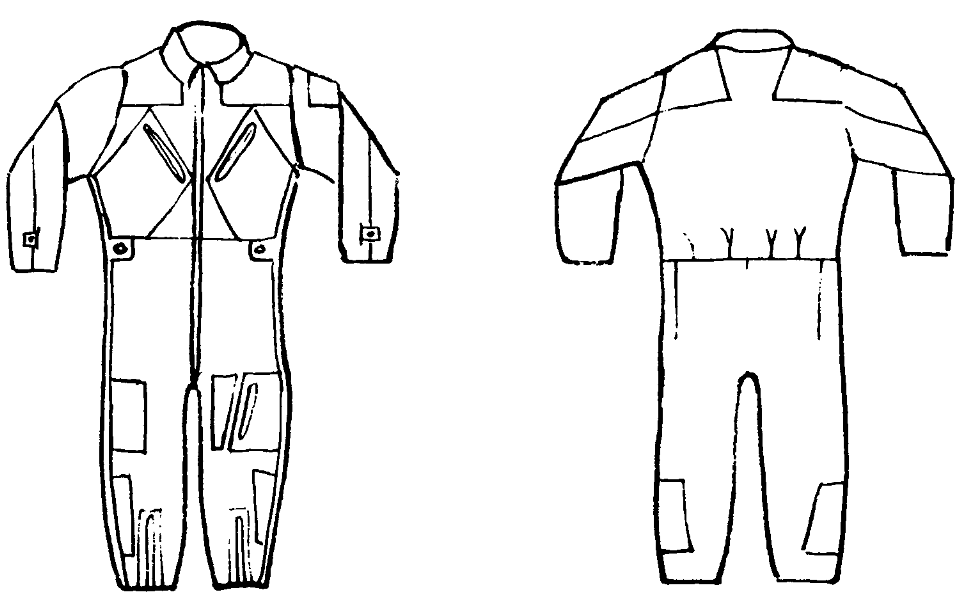
In one case, size interchangeability has been introduced to a certain extent with the addition of expandable material at the waist and side panels of the submarine coverall garment. In this manner the drape is also improved as the garment is more conformal in this area.

The uses of present single piece garments are generally limited to personnel performing specific tasks requiring environmental or contaminant protection.

FIGURE 2-14 COVERALL CONCEPTS



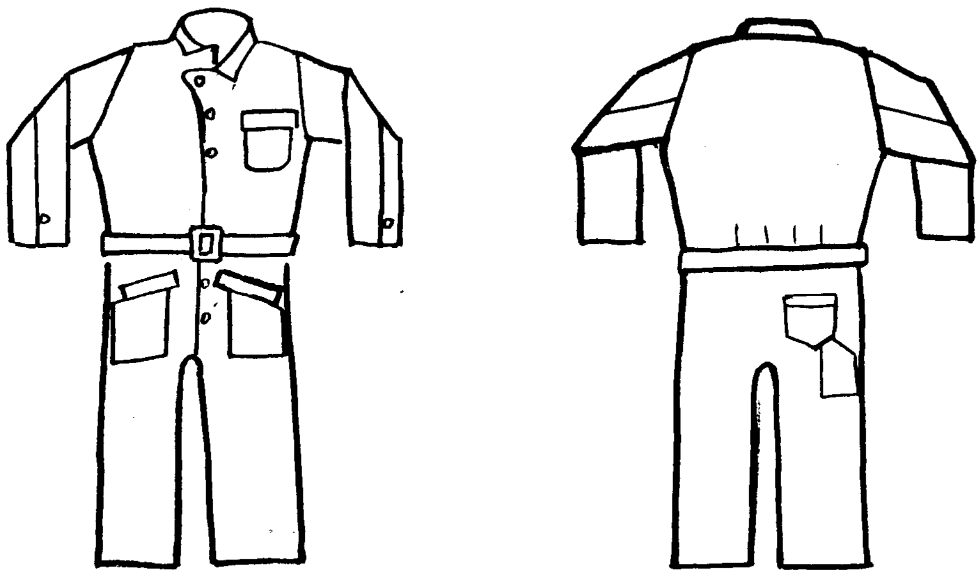
Utility Coveralls
(Nuclear Submarine)
MIL-C-21897 (S & A)



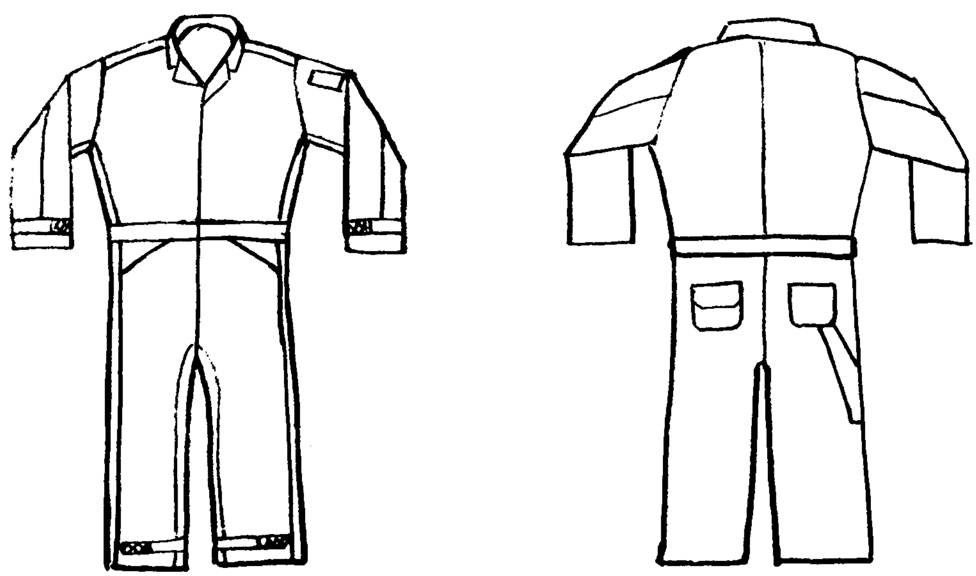
K2B SUIT

MIL-C- 6265E (USAF)

FIGURE 2-24 (CONTINUED) COVERALL CONCEPTS



MIL-C-2202D (Navy)

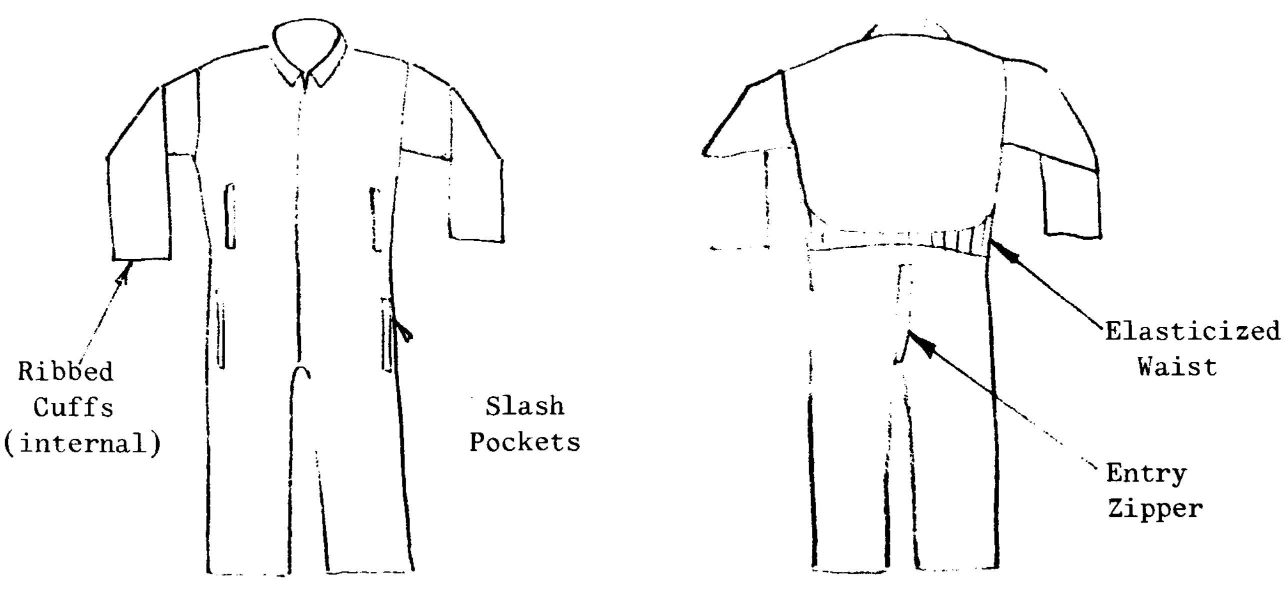


CMU - 3/P
MIL-C-27845A

TYPICAL COVERALL CONCEPT FOR A SPACE STATION

Figure 2-15 shows a typical coverall design that may be applicable to the crew of a space station. Internal pockets and hid-seams are used to avoid the "work garment" connotation of the single piece item. Space vehicles envisioned beyond the Apollo program will contain more on-board usable space. Items that have been customarily stored in pockets such as check lists and manuals will be permanently situated at the work station and will not require special pockets in the garment.

FIGURE 2-15 TYPICAL SPACE STATION GARMENT



TWO PIECE COVERALLS

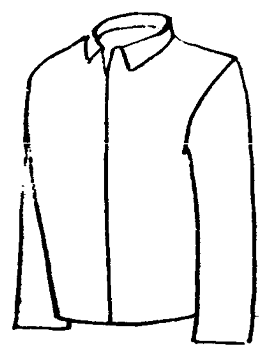
Two piece coveralls and uniforms have been employed in all branches of the service for both general and heavy duty operations. The advantages of a two piece garment are in the area of launderability and flexibility. The two piece garment does not require laundering the pants and jacket at the same time thereby not requiring as much laundering system volume. The flexibility afforded by a two piece garment is the adaptation to temperature variations by removal of the jacket.

The major drawback to a two piece garment is encountered with the crew in a closely confined work station. Migration of the jacket will occur with extreme body motion. Depending upon the degree of confinement, the jacket may not return to the original position. With space availability in space stations, this appears to be of lesser importance. Figure 2-16 shows several typical designs.

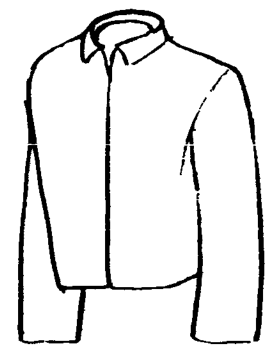
FIGURE 2-16 TWO PIECE COVERALL GARMENTS

JACKET STYLES

Conformal

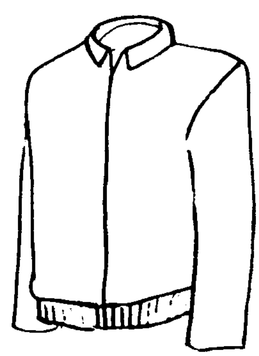


Full Length Tapered

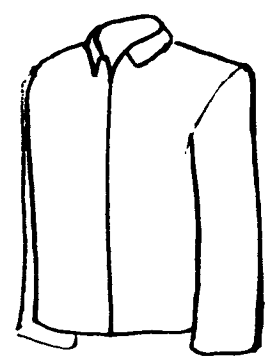


Waist Length Tapered

Non Conformal



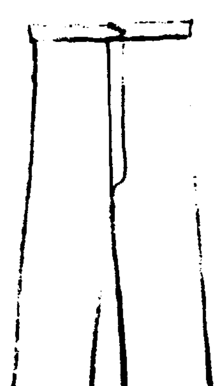
Ribbed



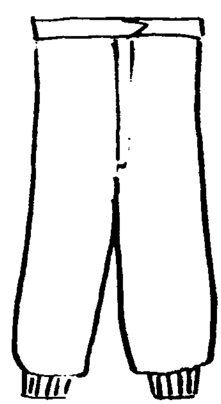
Non Tapered

PANTS

Tapered



Nontapered



Ribbed

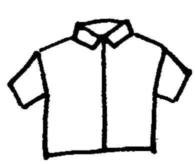
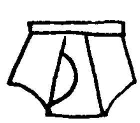
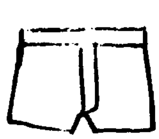
SHIRTS AND BRIEFS

The clothing worn underneath the coverall garment consists of shirts, socks, briefs and, if mission constraints permit, a tee shirt. Figure 2-17 presents the types of shirts applicable to a space station crew.

Knit shirts are considered to be most applicable to missions of this kind due to the storage and thermal requirements. A knit shirt is soft, thereby being comfortable. It can be easily folded and stored while offering the highest insulation qualities per unit weight. The disadvantage of a knit shirt is its lack of rigidity in storing items in pockets and abrasion wear resistance. If, however, the shirt is customarily covered by the jacket, neither of these considerations are as important as the advantages afforded.

The same relative merits apply to a lesser extent to the briefs. An individual's choice is according to personal preference and fit, however, weight and thermal considerations favor the knit type. Endurance and launderability are the assets of the woven type.

FIGURE 2-17 SHIRT AND BRIEF STYLES

STYLE	USES	ADVANTAGES	DISADVANTAGES
Knit Shirts  longer short sleeve	Conformal Shirts T-Shirts	Soft, Comfortable, Easily Stored, Absorbent, Weight	Cleaning Endurance
Woven Shirts 	Dress Shirts Sports Shirts	Rigid, Favorable for Pockets, Endurance, Loose Fitting	Requires Collar Entry Fasteners, Storage Volume
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, Tear Resistance, Migration Donning Pants

FOOTWEAR

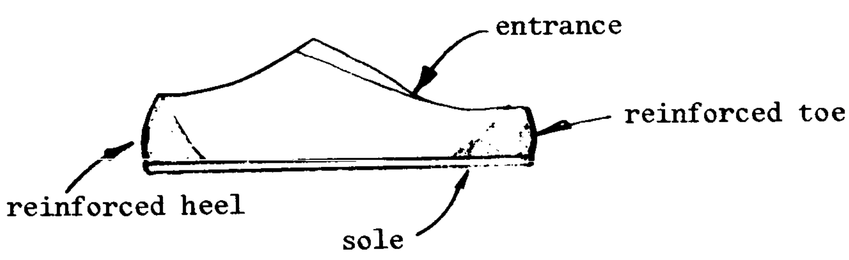
The footwear of a crew of a zero gravity space station has a somewhat different function than street shoes fulfil. The feet are used like the hands in restraining the body in a given location. The combination of the station restraints and the shoe design must be considered for proper function.

Presented in Figure 2-18 are several shoe concepts which are compatible with the vehicle restraints of Section 5. The primary function of the shoe is to protect the toe and heel area and to provide a mating surface for a toe hold restraint.Other considerations in shoe design are proper foot coverage and entry provisions.

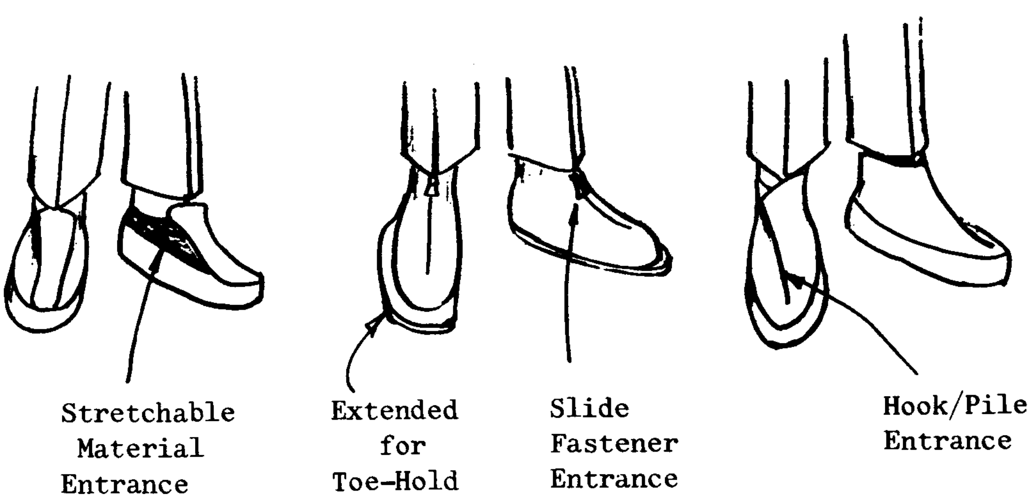
The shoe must be fabricated from a porous material due to the tendency of the feet to sweat. Depending upon the porosity of the material, stockings or socks may be required. The function of a sock is to transfer water from the foot and evaporate it at its surface. In this manner, the insulating qualities of the sock keep the foot warm while water is evaporated through the shoe.

FIGURE 2-18 FOOTWEAR CONCEPTS

General Features



Styles



HEADWEAR

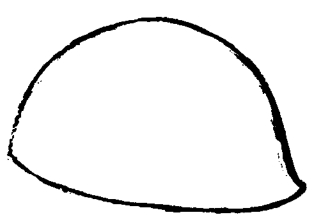
The use of headwear in a space station is to avoid injury to a crew member during an uncontrolled transit in a zero gravity environment. The head may withstand a load resulting from an impact against a wall with a maximum velocity of 12 feet per second. Since velocities of 10 feet per second may be attained by the crew in a weightless condition, protection against injury is necessary.

The area requiring greatest protection is the area least likely to be covered, the face. The second most critical area are 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 region, less emphasis is placed on this area than facial protection. Table 2-3 shows several bump hat concepts which are based upon facial protection as one of the primary considerations by the use of a visor or other provision.

An alternative to the use of "bump hats" is the employment of padding in the space station walls and very large radii of curvature in the design of accomodations.

TABLE 2-3

PROTECTIVE HEADGEAR

TYPE	PROTECTION	WEIGHT	REMARKS
Fabric:  	Foam or Inflatable Pads. Polyvinyl, Polyurethane Foams.	2-4 oz	Foldable, Comparable to Military Style Headgear. Requires Suspension System
Rigid Hats  	Rigid Shell Covering Head of Fiberglas Plastic Metal	4-8 oz	Requires Suspension System. Provides best Protection. Communication Gear may be Incorporated Reference; 5

SECTION 2.4 GARMENT WEIGHT DETERMINATION

The weight determination of a garment is done by computing the following relationship:

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

where:

W_{fabric} = Fabric Weight Per Unit Area

A_{fabric} = The Area of Material in a Garment

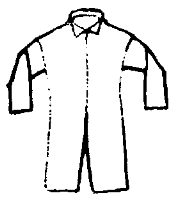
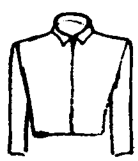
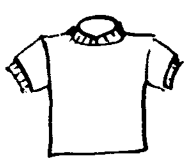
W_{fixed} = The Weight of Fixed Articles on the Garment

The fabric weight is a function of material and weave and may be found in Section 2.1. The remaining items to be determined are the fabric area in a garment and the accompanying fixed weights. Figure 2-19 shows the material area requirements for several garments. As there is a difference in area according to size, the data is presented in the small, medium, large and extra large categories. For a description of the determination of size and the size distribution is a given crew, see Section 4.0.

Included in the area requirements is a factor of 10% which applies to facings, reinforcements and seams.

FIGURE 2-19 - GARMENT MATERIAL REQUIREMENTS

(Area in Square Yards)

Item \ Size	Small	Medium	Large	X-Large
One Piece Coverall 	2.75	3.2	3.5	3.8
Jacket 	1.25	1.7	1.85	2.0
Pants 	1.7	1.9	2.05	2.15
Shirt 	0.75	0.85	0.95	1.05
Tee Shirt 	0.70	0.80	0.90	0.97
Briefs 	0.30	0.35	0.40	0.45
Socks 	← 0.1 →			

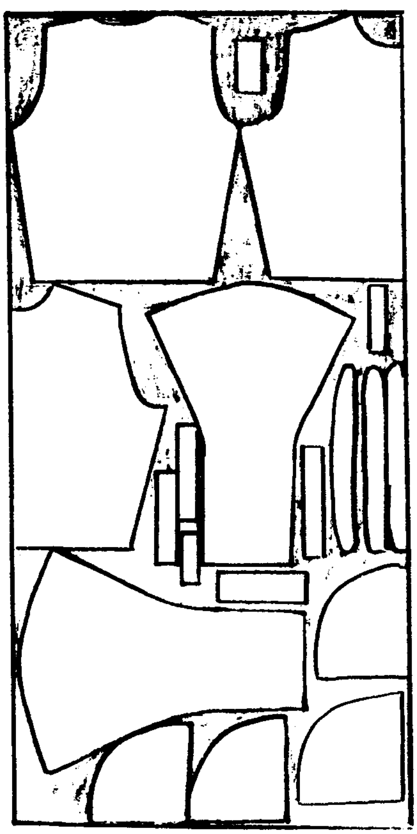
FABRIC QUANTITY

The amount of fabric required to make a typical flight garment is shown in Figure 2-20. It is assumed that the material is a balance plain weave so that the orientation of the weave(straight of the goods) may be parallel or perpendicular to the fabric warp (lengthwise direction).

A standard fabric width of 38 inches is assumed for the comparison of the area of cloth used in a garment to the total of fabric area. The example used is a two piece garment of medium regualr size.

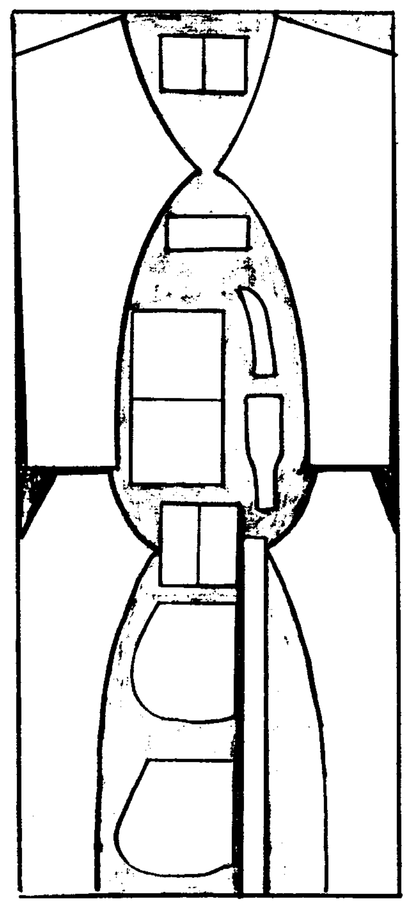
FIGURE 2-20 FABRIC REQUIREMENTS

Jacket Pattern Layout



$$\frac{\text{Total yds.}}{\text{Jacket yds.}} = \frac{2.5}{1.7} = 1.46$$

Trousers Pattern Layout



$$\frac{\text{Total yds}}{\text{Trouser yds.}} = \frac{2.8}{1.9} = 1.48$$

GARMENT FIXED WEIGHT

The articles associated with a garment that contributes to its weight are the fasteners, cuffs, pockets, stiffness and emblems. The table below presents a typical weight estimate of the articles found on a garment.

TABLE 2-4 FIXED WEIGHT ARTICLES

ITEM	ARTICLE	Weight
Jacket	Cuffs (ribbed) Zipper Collar Stiffener	4 oz
Pants	Zipper Ribbing	2.5 oz
Shirt (knit)	Ribbing Zipper	0.5 oz
Briefs	Ribbing	1.0 oz
Tee Shirt	Ribbing	0.3 oz
Hat		4.0-8.0 oz
Shoes		4.0-8.0 oz

SUMMARY

The data presented in Section 2.0 consists of objective fabric and weight data and subjective design detail and style data. Appendix A shows the use of the construction data in determining the weight impact of the garments considered.

SECTION 2.0 REFERENCES

1. Doblin, Frank C., The Modern Mitchell System of Men's Designing American Mitchell Fashion Publishers, Chicago, Ill.

2. Fact Book of Synthetic Fabrics for use in Clean Rooms, Angelica Uniform Company, June 1, 1965.

3. Federal Standards: Fed-Spec-V-F-106C, Fasteners, Slide, Interlocking.

4. Freeston, W. D.; Skelton, J.; Gardella, J. W.; Temin, S. C.;Mechanical Properties of High Temperature Fibrous Structural Materials, AFML-TR-68-279, July 1, 1968.

5. Gurjian, E. S. Md. Phd. etal, The Evaluation of Protective Helmets in Sports, Journal of Trauma, Volume 4, 1964.

6. In-Flight Coverall Garment - (Apollo), B. Welson Drawing B W-1043, September 17, 1968.

SECTION 3.0 MATERIALS SELECTION

This section contains the criteria by which materials are evaluated for use in a space mission. As the mission environments approach an earth equivalent, less emphasis will be placed upon the rigorous selection of materials for compatibility.

The section is divided into the following four areas for the assessment of a proper material.

3.1 Natural and Synthetic Materials

This section deals with the general properties of pure materials and blends.

3.2 Environmental Criteria

The relative compatibility of selected materials is presented with respect to flammability, temperature, moisture regain and water compatibility.

3.3 Structural Properties

The properties of various materials such as weight, strength, friction and endurance are compared.

3.4 Performance

The aspects of static electricity, color fastness, luster and cleaning compatibility are presented.

SECTION 3.1 NATURAL AND SYNTHETIC MATERIALS

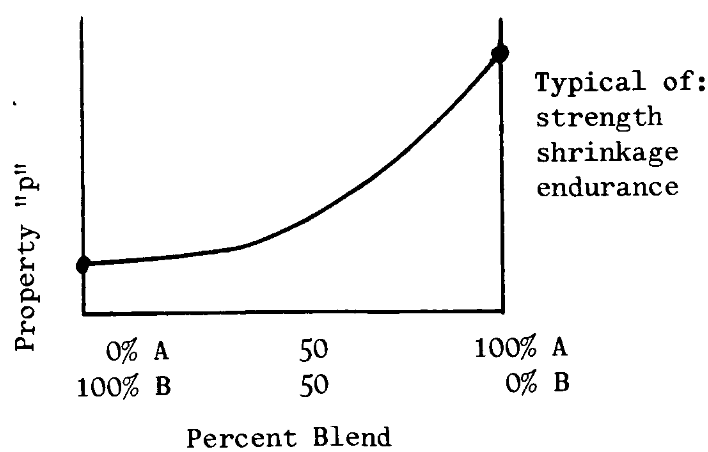
The materials used in garment fabrication for specialized earth and space missions are listed below.

cotton	nylon
wool	polyester
fiberglas	nomex
teflon	polybenzimidazole (PBI)

Each of these materials possess their own respective properties which are compared in this section. Two types of materials are used in fabrics, 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, staple and continuous filament yarns are available (the properties of each type are compared in Table 2-1).

Some properties of pure synthetic substances are generally undesirable on the basis of comfort or appearance. For this reason blends of synthetic with synthetic or natural materials and geometric variations are made. Figure 3-1 presents typical performance characteristics as a function of a blend of materials A and B.

Figure 3-1 Typical Blend Effect Upon Yarn Properties[7]



The performance of a blend is not a straight line function between the two end points. A blend will possess the characteristics of the lower valued material until at a least 50% mix is reached.

SECTION 3.2 ENVIRONMENTAL DATA

The environment to which a material will be subjected is a function of the intended mission. The space mission prior to the Apollo time period contained such extremes as vacuum exposure and a pure oxygen atmosphere. For the missions envisioned for a space station or base, the most extreme temperature may be encountered while ironing or drying, and the highest oxygen concentration will be equivalent to an earth atmosphere. During the interim, however, a wide variety of atmosphere conditions may be present. For that reason, the following parametric data is presented to assess the performance of several candidate materials.

FLAMMABILITY

One of the most important criteria in the selection of a fabric is the relative 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.

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

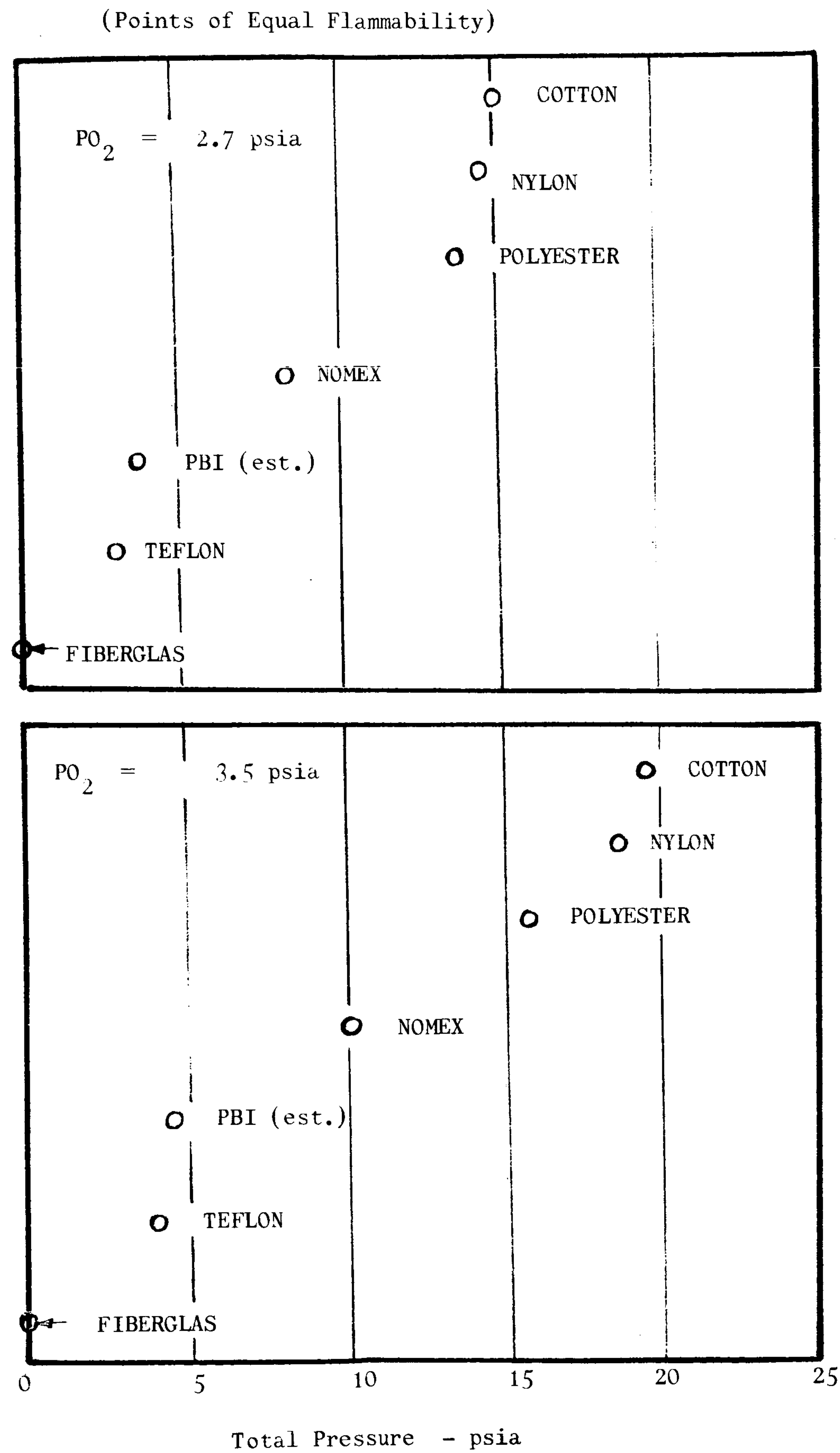
n = Limiting Oxygen Index %

PO_2 = Oxygen Partial Pressure

PN_2 = Nitrogen Partial Pressure

Using this index to assess the relative flammability of materials, Figure 3-2 shows the comparison of limiting oxygen indices. The data is presented for two oxygen partial pressures and indicates the total pressure at which the flammability characteristics of different materials are the same. For total pressures less than the index value, the greater the tendency for a material to burn. For increasing total pressures (to the right of the index point) the less tendency to burn.

FIGURE 3-2 MATERIAL FLAMMABILITY COMPARISON



References; 2,9

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 3-1 shows the relative maximum temperatures for various materials and the type of damage that occurs.

TABLE 3-1

MATERIAL TEMPERATURE LIMITS [1,7]

MATERIAL	MAXIMUM SERVICE TEMPERATURE- °F	EFFECT
Cotton	250 - 300	Yellows at 250°, Decomposes at 300°F
Nylon	300	Discolors, Flows at 400 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 (est.)	Shrinks
Teflon	400	Flows, Fibers shrink

CHEMICAL RESISTANCE OF MATERIALS

Table 3-2 presents the chemical resistance properties of several materials. Chemical stability is a consideration in the removal of stains, bleaching or laundering and the intended use of a garment.

TABLE 3-2 CHEMICAL STABILITY OF MATERIALS[7]

EFFECT OF MATERIAL	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 alkali metals fluorine gas at high temperature and chlorine trifluoride

MOISTURE REGAIN

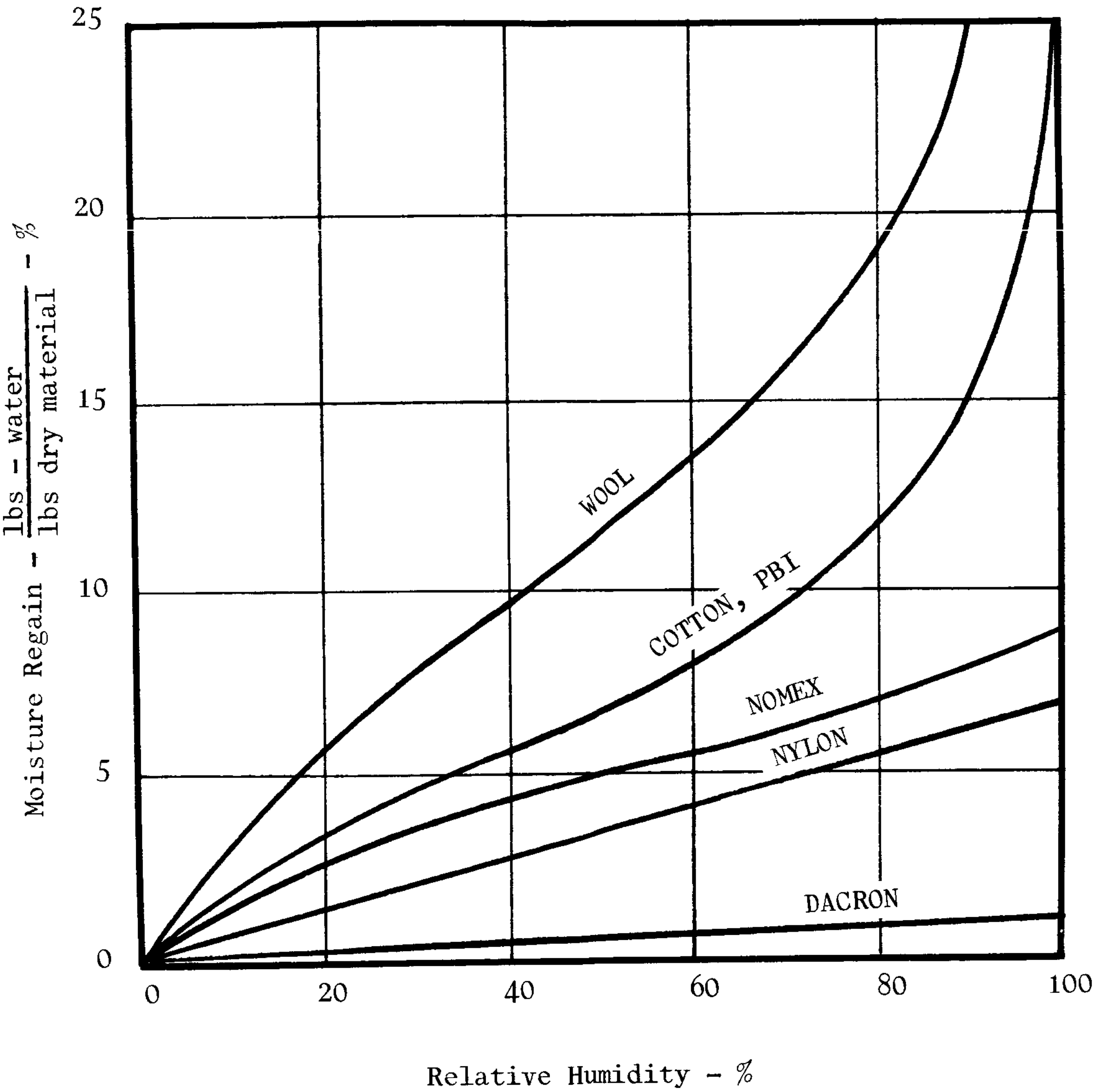
One of the most important factors in the comfort of a garment is the amount of moisture absorbed in the fabric. This is due to the ability of a fabric to hold perspiration without a"wet" sensation.

The term"moisture regain" refers to the percent weight of water that a fabric may hold by absorption per unit fabric weight. Figure 3-3 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 varible 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. Table 3-7 presents the relative static charge producing ability for common fabrics.

A knowledge of a fabric water regain is also necessary when evaluating the drying heat load and duration. Application of this data may be seen in Figure 3-7.

FIGURE 3-3 MOISTURE REGAIN CHARACTERISITCS



TEFLON, FIBERGLAS = 0

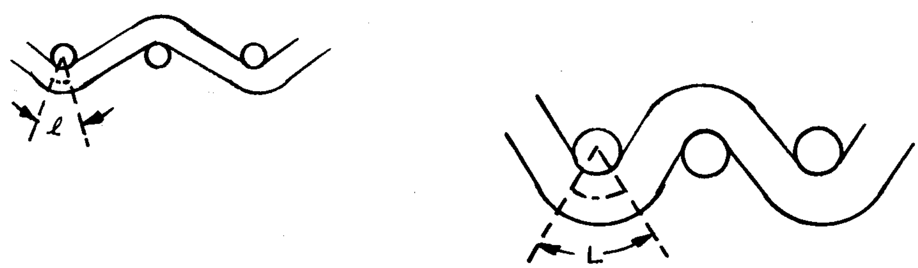
Temperature - $77^{o}F$

References;1,7,8

WATER COMPATIBILITY

One of the considerations in the selection of a fabric is its compatibility with water and its 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.



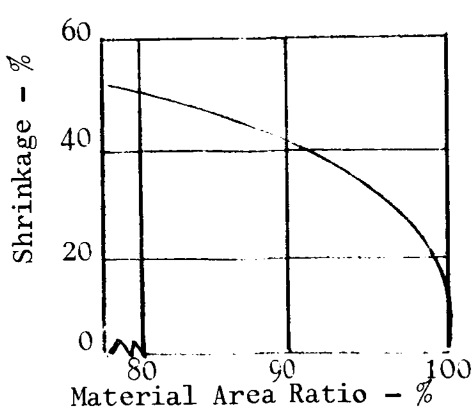
Since the fiber will not stretch appreciably, this results is shortening of the fabric.Table 3-3 shows the relative swelling properties of fibers when exposed to water. (low to moderate temperatures)
Although the mechanics of shrinkage are complex and numerous, a major criterion in the aspect of shrinking is the fabric construction. In general,the tighter the weave(higher area ratios) the lesser amount of shrinking will take place. This is due to the initial configuration (large arc segments) and tension on a fiber.A typical example of the shrinkage characterisitic is presented for wool in Figure 3-4.

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.

TABLE 3-3 FIBER SWELLING DUE TO LOW TEMPERATURE WATER EXPOSURE [7]

MATERIAL	TYPE	LENGTH CHANGE %	DIAMETER CHANGE %
Cotton, Raw	Hygroscopic	1.2	14 - 30
Cotton, Mercerized	"	0.1	20
Glass	Hydrophobic	0	0
Nylon	Partially Hygroscopic	1.2	1.9 - 2.6
Nomex	"	1.2+	3.0
Dacron	"	0 - 0.1	0 - 0.3
Teflon	Hydrophobic	0	0

FIGURE 3-4 TYPICAL SHRINKAGE CHARACTERISTIC FOR WOOL [6]



SECTION 3.3 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 3-4 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 3-4 FABRIC TEXTURE CONSIDERATIONS[4]

With an Increase In:	*Uniaxial Tensile Strength*	*Stiffness*	*Air Permeability*	*Abrasion Resistance*	*Shear Resistance*	*Flex Endurance*	*Thickness*	*Tear Strength*
Fiber Linear Density		+	+	+		–	+	
Yarn Liner Density	+	+	–	+	+	$\overset{\rightarrow}{+\,-}$	+	+
Yarn Twist	$\overset{\rightarrow}{+\,-}$	+	+	$\overset{\rightarrow}{+\,-}$	+	$\overset{\rightarrow}{+\,-}$	+	
Yarns/Inch	$\overset{\rightarrow}{+\,-}$	+	–	+	+	–	+	–
Weave Pattern Interlacings	–	+	–	+	+	–		–

KEY

+ Increases

– Decreases

$\overset{\rightarrow}{+\,-}$ First Increases, then Decreases

MATERIAL WEIGHT

For a given material, the fabric weight will be in direct proportion to the linear yarn density, weave construction and material density. In a previous section, the function of weave geometry has been presented (Figure 2-4). Table 3-5 below presents the bulk density of each of the fibers considered for clothing.

TABLE 3-5 MATERIAL BULK DENSITY (lb/ft^3)

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

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% yielding a much lower density than the bulk density value. For a twisted yarn, a conservative figure of 90% is used.

The denier (the weight in grams of 9000 meters of a yarn) is used to relate the linear density and bulk density of a yarn strand. If one were to compute the diameter value for a given denier yarn, it is:

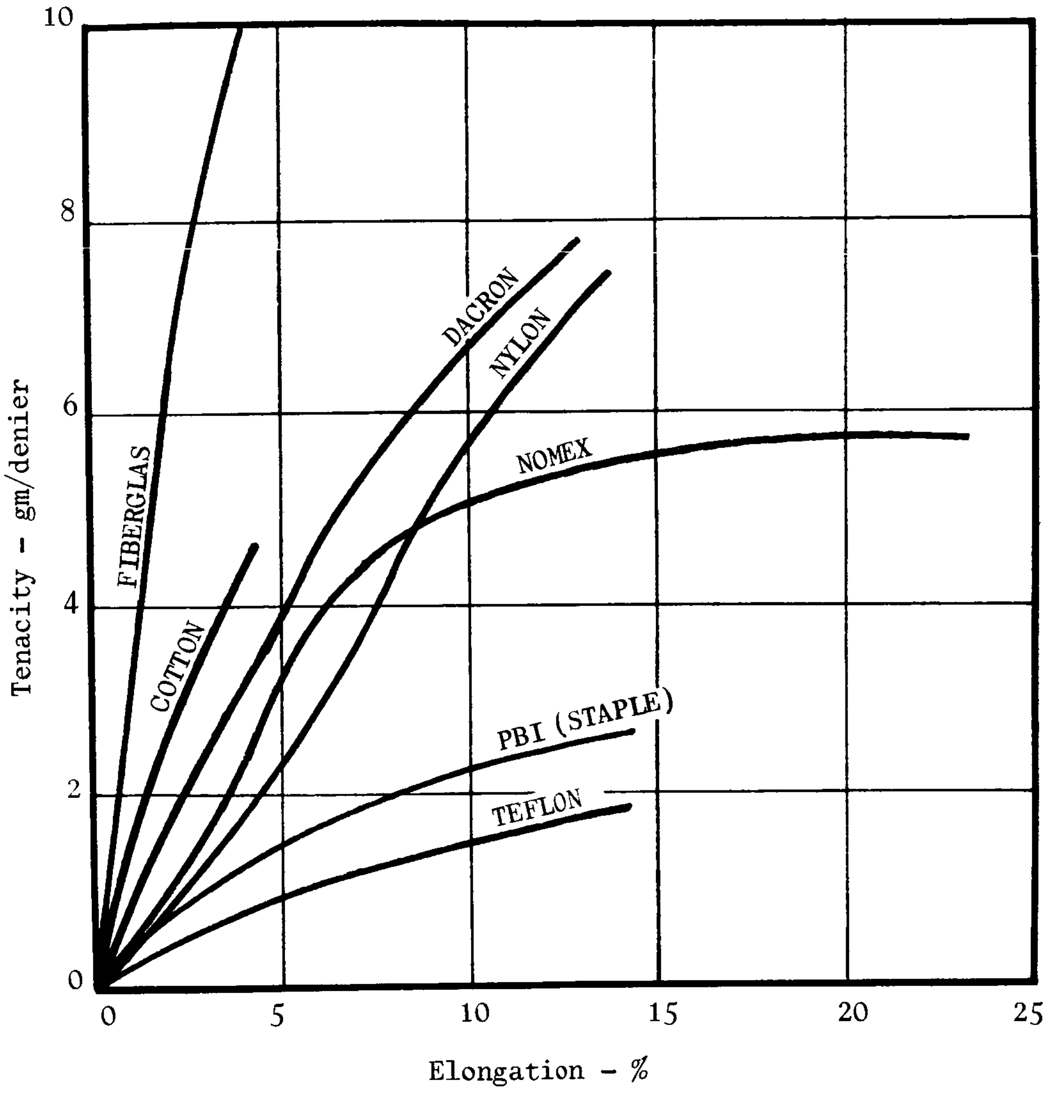
$$\text{Yarn Diameter} = 3.6 \times 10^{-3}\sqrt{\frac{\text{Denier}}{(\text{packing factor})(\text{bulk density})}}$$

MATERIAL STRENGTH

The strength of a material can be directly related to the fabric yarn and the weave construction. Assuming the weave constant, a fabric will possess the relative yarn properties presented in Figure 3-5. 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 g/den) is comparable to Young's Modulus for a metal. Conversion of the values are:

Tensile Strength = Tenacity x 12,000 Specific Gravity

FIGURE 3-5 YARN TENSILE STRENGTH



References; 1,5,6,7

ABRASION - FLEXURAL ENDURANCE

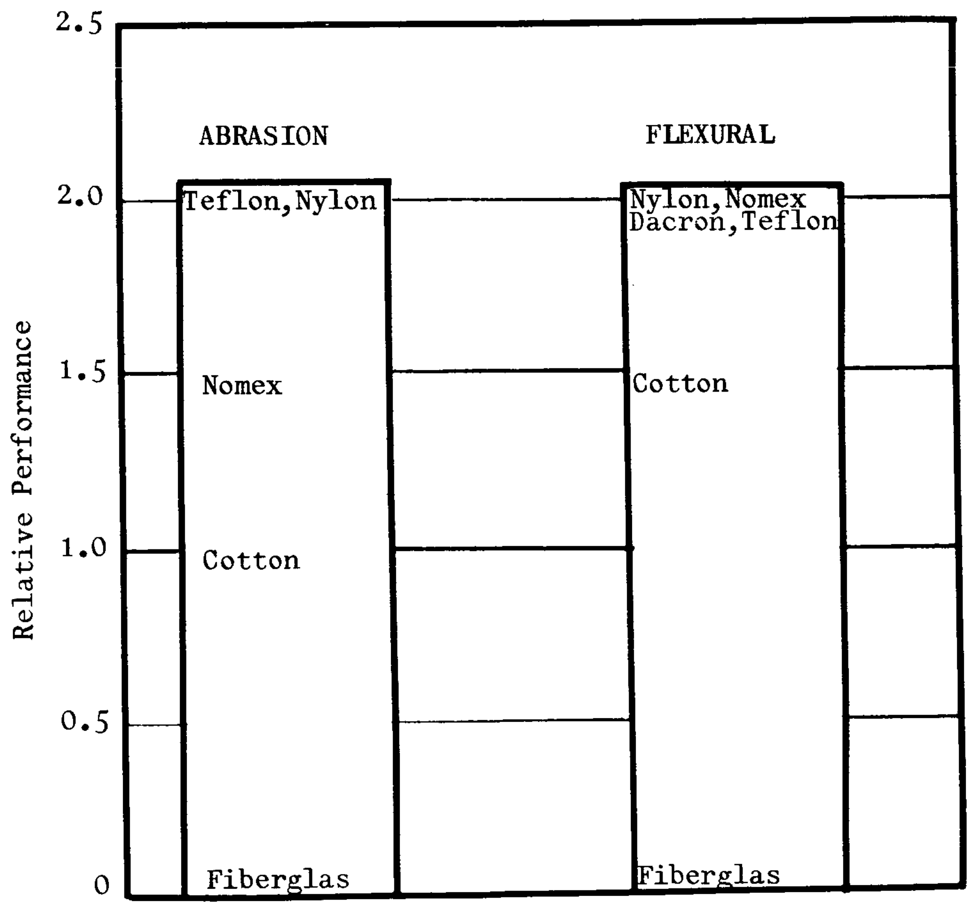
The aspect of wearing endurance of a fabric cannot be rated by a single test or analytical approach. The wearing of clothes results in a combination of tensile stresses, flexural loads and abrasion in a garment. For this reason, the following two criteria have been established with the tensile strength data of Figure 3-5 as the measuring stick of endurance. Table 3-6 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).

Flexual endurance is determined by bending a fabric sample over a small radius of curvature until failure.

In both cases, the flexual and abrasion characterisitics are a function of the weave as shown in Table 3-4. The data of Table 3-6 is based upon a uniform weave and yarn thickness.

TABLE 3-6 RELATIVE MATERIAL ENDURANCE CHARACTERISTICS



Reference; 4

SECTION 3.4 PERFORMANCE

The aspect of performance in the selection of materials deals with the ability of the material to provide a desired function. This function may be in areas of appearance or compatibility with required work tasks.

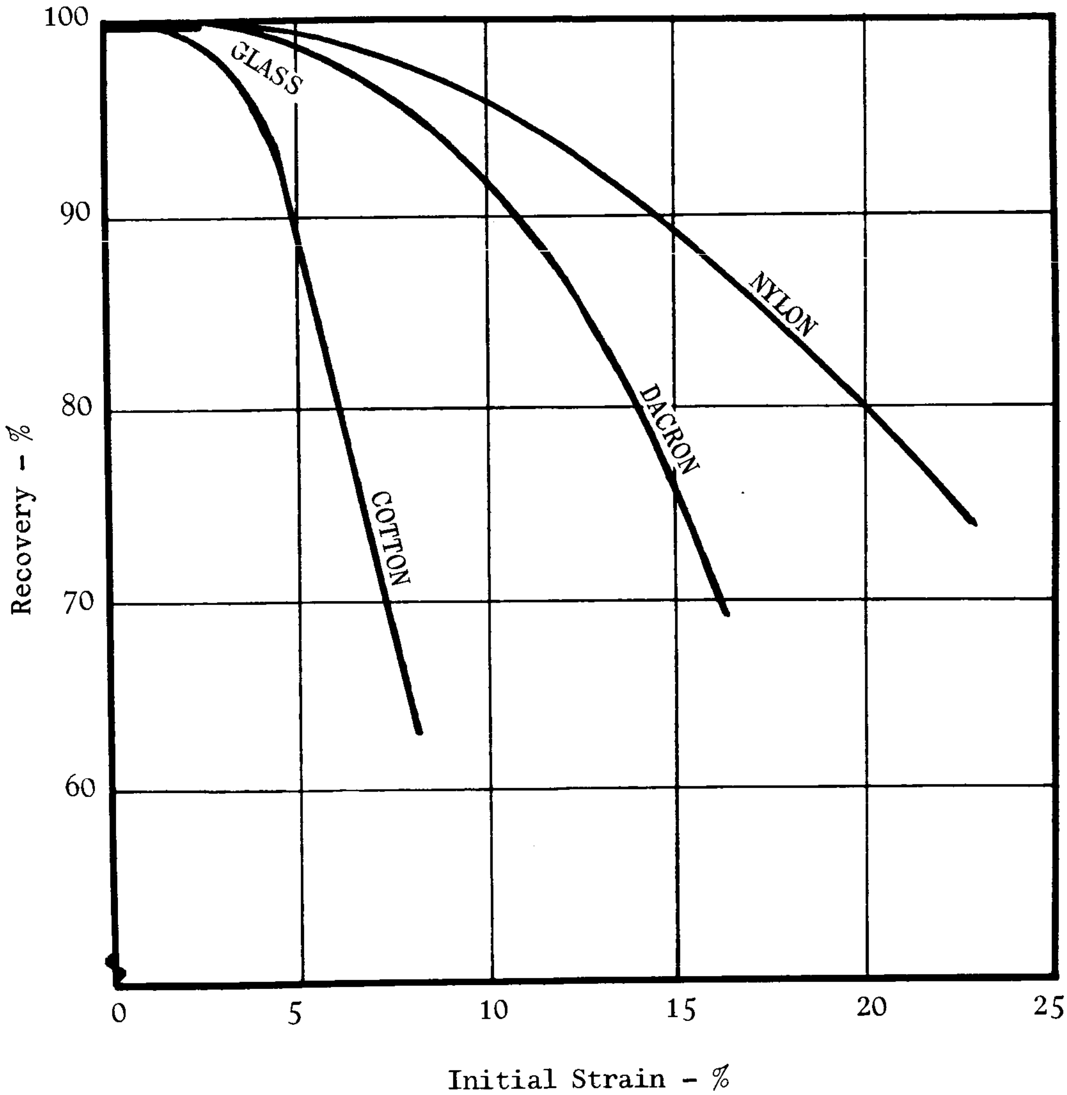
The appearance of a garment is one of the most important aspects of garment selection in that the image of the wearer is established by his clothing. Features such as fabric wrinkle resistance and color are treated in this category.

The performance of a fabric with respect to cleaning compatibility and static electricity is presented in this section.

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 are performed upon simple materials resulting in the relative ranking of Figure 3-6. The fiber elastic recovery data for several fibers is shown in this figure. It is apparent that cotton is the most prone to permanent distortion with a given strain.

FIGURE 3-6 FIBER ELASTIC RECOVERY



Reference; 6,7

COLOR

The choice of color in a garment is a subjective decision based upon previous missions and similar circumstances. Three aspects are important, however, in the selection of garment color.

1. Identification

   By the establishment of a separate color for a crew or particular individuals of a crew, instant recognition may be achieved. If critical tasks require such time limitations, this may be an important parameter.

2. Attention

   By the use of an intense color, recognition may be made at large distances. This criteria is not so important inside a vehicle as on the outside during extravehicular activity.

3. Compatibility

   Inside a space station, the garment color must be compatible with the vehicle color scheme and light intensity for eye comfort.

In the selection of a color for a garment, the basic hues customarily used for military duty have been variations of white, blue, green, brown and black. The actual hue has been determined by tradition or by the required field use. One of the influencing factors in the color selection space station garments is whether choice is commercially available.

The following list presents the colors presently available for several materials.

MATERIAL	AVAILABLE COLORS
Cotton	All
Nylon	All
Dacron	All
Nomex	Int'l Orange, Natural, Olive
Fiberglas	All
Teflon	Natural (Brown) to White
PBI	Brown

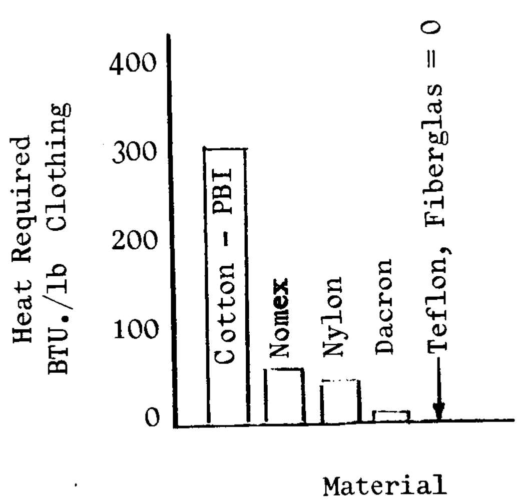
CLEANING COMPATIBILITY

The relative penalty of cleaning a garment in a space station 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. Presented below are the factors involved in the cleaning conderations of a material.

The amount of soiling of a garment may be somewhat controlled by the selection of the yarn configuration. In general, continuous filaments provide less area in which soil may build up. This places an advantage with the synthetic materials. Likewise, the quantity of water and detergent is not as great for these materials for the same reason.

The amount of water absorbed by the materials have an effect upon the drying load of each garment. Shown in Figure 3-7 is the relative energy to dry a given material.(a 65^{o}F dew point is assumed)

FIGURE 3-7 RELATIVE DRYING PENALTY



ELECTROSTATIC PERFORMANCE

An electrostatic charge may build up in a garment that has been rubbed by another surface or by itself. This is due to the nature of the material and the insulating properties of the fabric. Dry fabrics, by themselves, are good insulators, thereby allowing potential differences between charged areas. With hygroscopic materials, however, water is entrained in the fibers due to the humidity in the air 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. Presented in Table 3-7 is the Triboelectric Series for materials. This list is composed of fabrics that will become positively charged if rubbed with a fabric below it on the list. (40% relative humidity)

TABLE 3-7 TRIBOELECTRIC SERIES FOR TYPICAL FABRICS [3]

Glass
Wool
Nylon
Cotton
Dacron
Teflon

SECTION 3.0 REFERENCES

1. Bulletins

   - The A.I.L. Member (Service Bulletin to the members of the American Institute of Laundering) Number 400, Joliet, Illinois, May 26, 1950.
   - Fiberglas as a Textile Material, Owens Corning Bulletin, 15-GT-3586.
   - Properties of Nomex, Textile Fibers, DuPont Bulletin NP-33, October 1963.
   - Properties and Processing of Teflon Fiber, DuPont Bulletin T-10, April, 1965.
   - Service Bulletin,American Institute of Laundering, Laundering, Laundering White Polyester/Cotton Shirts, Bulletin No. 571, Feb. 1965.

2. Dorr, Victor A.; and Schreiner, Heinz R.; Region of Non Combustion, Flammability Limits of Hydrogen/Oxygen Mixture, Full Scale Combustion and Extinguishing Tests and Screenign of Flame Resistant Materials Ocean Systems Incorporated, Contract Number - N00014-66-C0149, U. S. Navy, 1 May 1969.

3. Fact Book of Synthetic Fabrics for use in Clean Rooms, Angelica Uniform Company, June 1, 1965.

4. Ford, Renee, Assoc. Ed. "Technology of Textiles" Science and Technology, Sept. 1968.

5. Freeston, W. D.;Skelton, J.; Gardella, J. W.; Temin, S. C.; Mechanical Properties of High Temperatures Fibrous Structural Materials. AFML-TR-68-270, July 1968.

6. Kaswell, Ernest R.; Textile Fiber Yarns and Fabrics, Reinhold Publishing Corporation, 1953.

7. Kaswell, Ernest R. Wellington Sears Handbook of Industrial Textiles. Wellington Sears Company. Inc. New York, 1963.

8. Modern Plastics Encyclopedia - 1968, McGraw Hill, Inc. Vol. 45 No 14A, New York, N. Y. October 1968.

9. Non-Metallic Materials Design Guidelines and Test Data Handbook. NASA MSC-NA D-68-1 Rev. C. February 28, 1969.

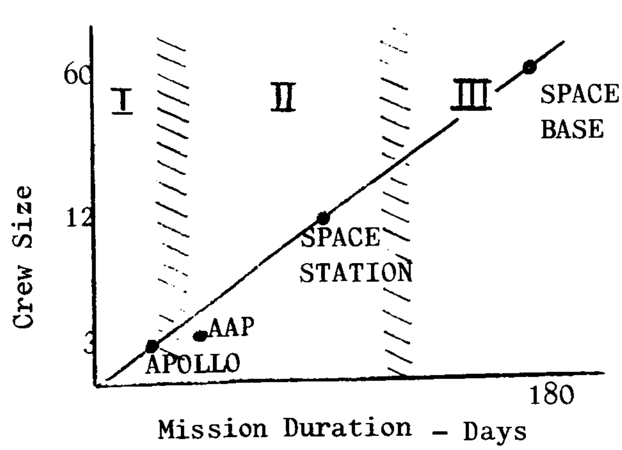
SECTION 4.0 CREW CONSIDERATIONS

One of the most important aspects in the design of a garment system is the make-up and function of the crew and the character of the mission. The space mission is to be performed in the future would appear to be categorized in the following manner with respect to habitability.

HABITABILITY PHASE	CHARACTERISTICS	APPLICATION
I	Crew systems are primarily utilitarian and functionally oriented. Highly specialized and trained for particular missions.	Mercury Gemini Apollo Early AAP
II	Crew systems and vehicle layout more spacious and comfortable. Crews having more general skills, and mission goals more general.	(MOL) AAP, Early space station
III	Earth equivalent environment for an outpost. Permanant facility with little dependence on earth other than resupply. Emhasis on crew comfort and leisure time activities.	Late space station Space base and beyond

These habitability phases are a convenient reference when discussing the applicability of certain ground rules to a particular mission. One would not expect to see a shower bath in the present Apollo command module, nor, on the other hand, be as vitally concerned with an item's weight for a space base. The habitability phases are also a function of crew size and mission time. A graphic representation is shown in Figure 4-1.

FIGURE 4-1 HABITABILITY PHASES



CREW ORGANIZATION

Although it is intended that the garment selection criteria presented in this handbook be applicable for all three of these phases, this section dealing with the makeup of the crew is applible primarily for phases II and III.

Included in this section is a discussion of the organization and function of a crew, the sizes and size distribution of the men and the factors involved in the selection of a wardrobe.

The organization of a crew of a space base will affect the selection of garments due to status and function of a crew member. The allocation of clothing on this basis requires study beyond the data presented herein.

Figure 4-2 presents a typical breakdown of a crew of a station or base and gives a typical garment allocation for each. The basic wardrobe consists of the normal changes clothing required on a scheduled basis which includes:

Jackets

Shirts

Pants

Socks

Shoes

Headgear

FIGURE 4-2 WARDROBE REQUIREMENTS AS DETERMINED BY CREW STATUS AND FUNCTION

FUNCTION - TITLE	PERCENT OF CREW	TYPICAL ASSIGNED WARDROBE			
EXECUTIVE -Commander -Dep. Commander -Managers	10%	Basic Wardrobe	Extra Change	Dress Uniform*	Clean Room Spec. Gear
MEDICAL -Doctors -Biomed & Physio.	10%	Basic Wardrobe	Extra Change	Medical Gear	
SCIENTIFIC PROFESSIONAL -Experimenters	15%	Basic Wardrobe	Partial Change	Protective & Functional Gear Clean Room Gear	
CREWMEN -Mess Attendants -Cook -Maintenance	20%	Basic Wardrobe	Protective Clothing		
SPECIALIST & TECHNICIANS -Navigators -Meteorol.,Oceanog. -Astron. Data Mgmt.	45%	Basic Wardrobe			

*Late Phase III

CREW WARDROBE SELECTION

The number of clothing articles in a basic wardrobe of a crew member will be a function of the following criteria in the order listed:

1. Allowable Weight
2. Allowable Volume
3. Personal Preference
4. Hygienic Standards

The amount of clothing accompanying a crew member will establish a relationship between a wear interval for a garment and a period between washings for laundered clothing.

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

1. Outer clothes, (jackets, pants) are worn 5 to 6 times longer than underclothes.
2. Underclothes must be changed on a regular basis at the same time, (i.e. briefs, socks, and shirt)
3. One pair of shoes, headgear or handwear will suffice for any given mission.
4. An earth-type cycle is desirable.

The methods for evaluating wardrobe requirements are as follows:

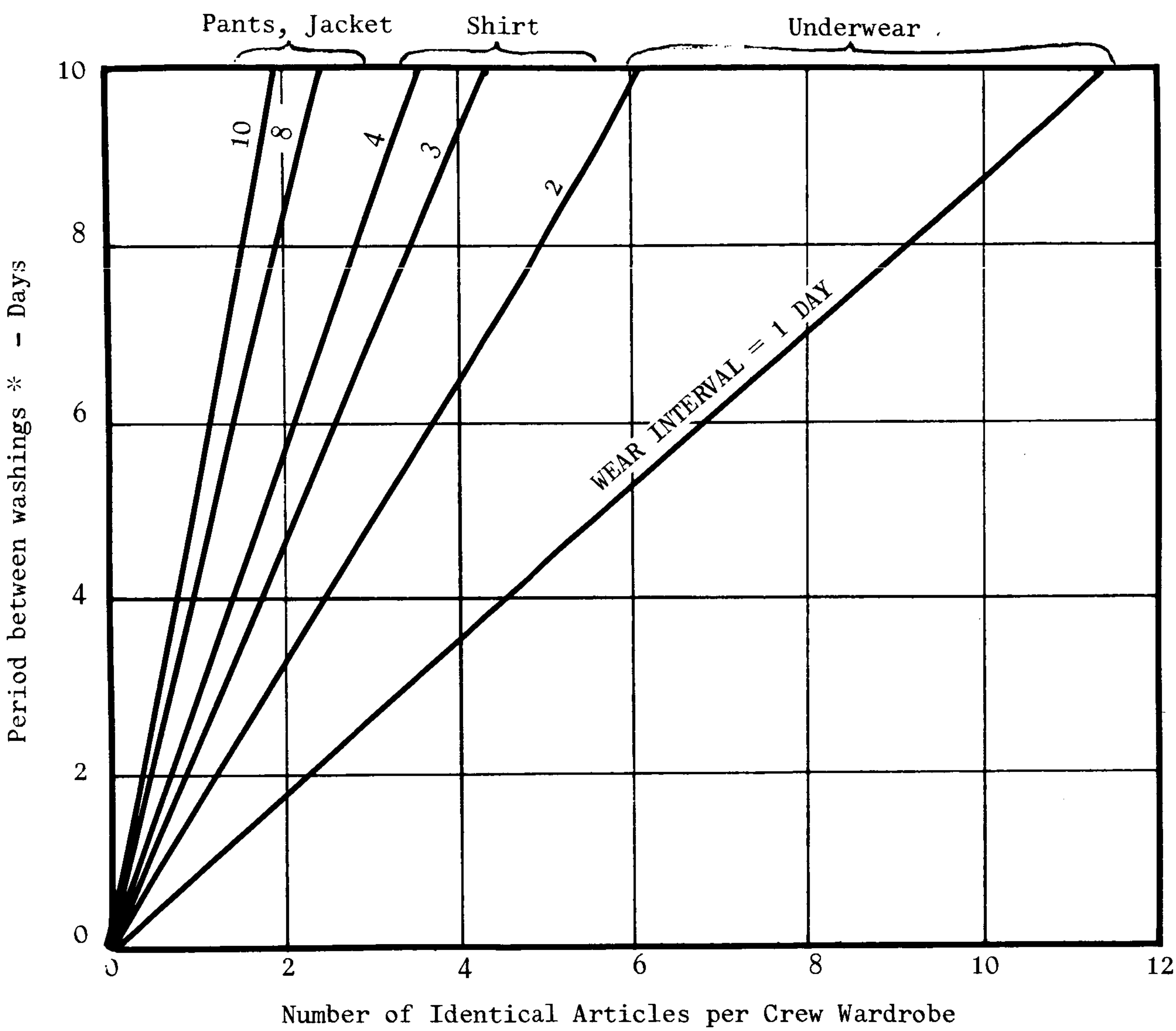
<u>Allowable Weight Approach</u>
Knowing the maximum weight allowed per member and the weight of the component garments, the wardrobe may be determined on a relative wear basis. The wear interval/clean period should then be assessed in Figure 4-3.

<u>Allowable Volume Approach</u>
This approach is the same as the weight approach, however, the transit volume in the shuttle vehicle is the important criteria. Knowing the volume values for each item, the breakdown may be estimated.

<u>Personal Preference</u>
This method of establishment of a wardrobe allows selection of this quantity of garments by judgment. It is used only when an excess amount of clothing is allowed by the above two methods. (long periods between cleaning) The crew duty cycle must be considered in the period between washings from Figure 4-3, and a reasonable wash period established.

<u>Hygienic Standards</u>
The soil that will be picked up by the clothing will be due primarily to body oils and contaminants. Although odors will build up, the crew perception will likewise be increased and no notice will be made of the level of odor. Dermatitis, however, may develop after a period three weeks wearing. If wear intervals beyond three weeks are contemplated, the use of bactericides should be considered.

FIGURE 4-3 CREW WARDROBE/WASH PERIOD REQUIREMENTS



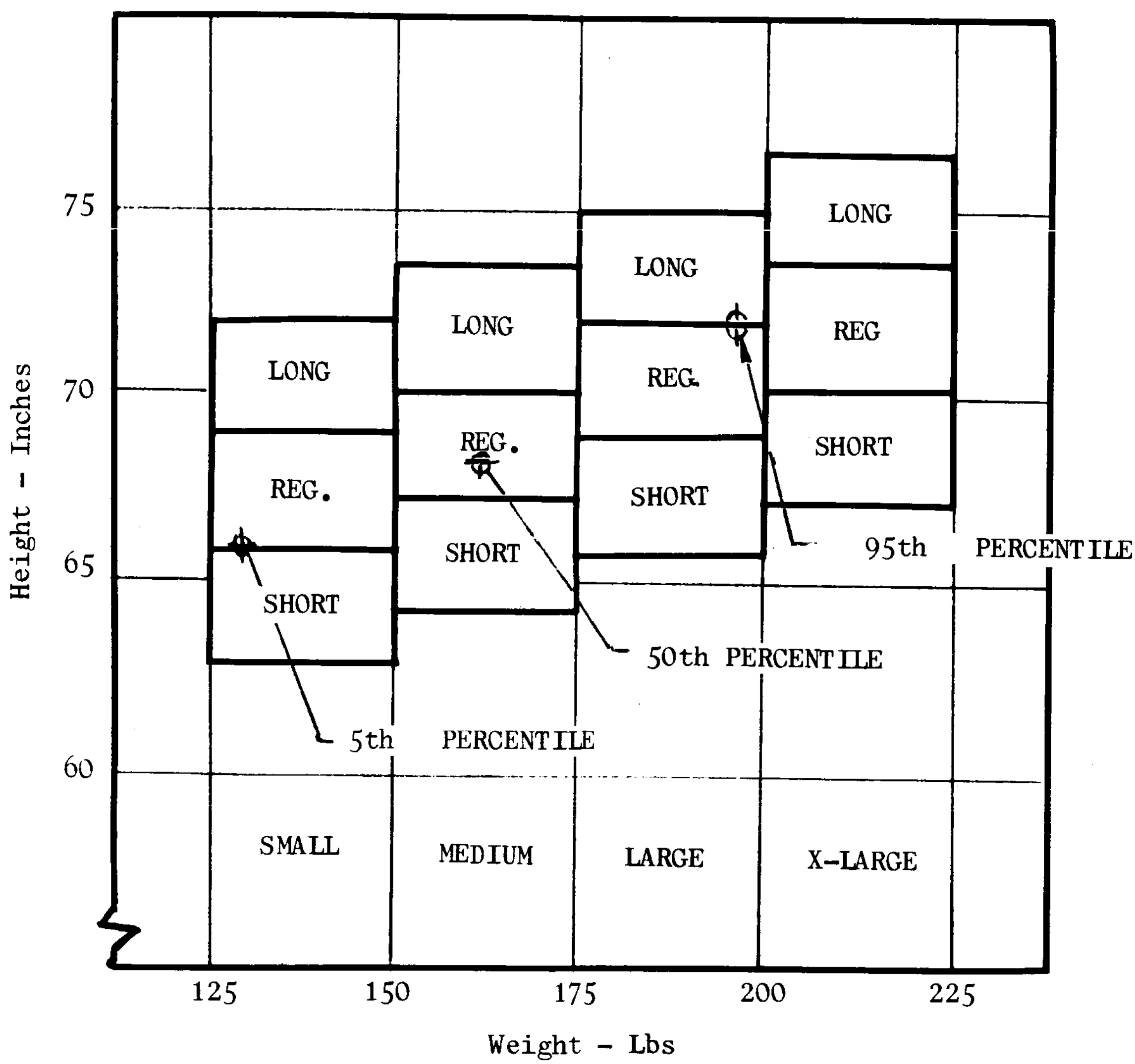
* (For fractions of a day, read the lower whole number value)

CREW SIZE CONSIDERATION

A sizing system has been developed for flight clothing which is based upon the measurements of height and weight of the crew members. In this sizing program four sizes have been established with three grades in each size category. These sizes have formed on the basis of measurements of four thousand Air Force personnel.

Figure 4-4 shows the relationships of each size and grade. Included in the graph are reference points for the fifth through ninety-fifth percentile crew members.

FIGURE 4-4 CREW SIZE CONSIDERATIONS - A 12 SIZE PROGRAM



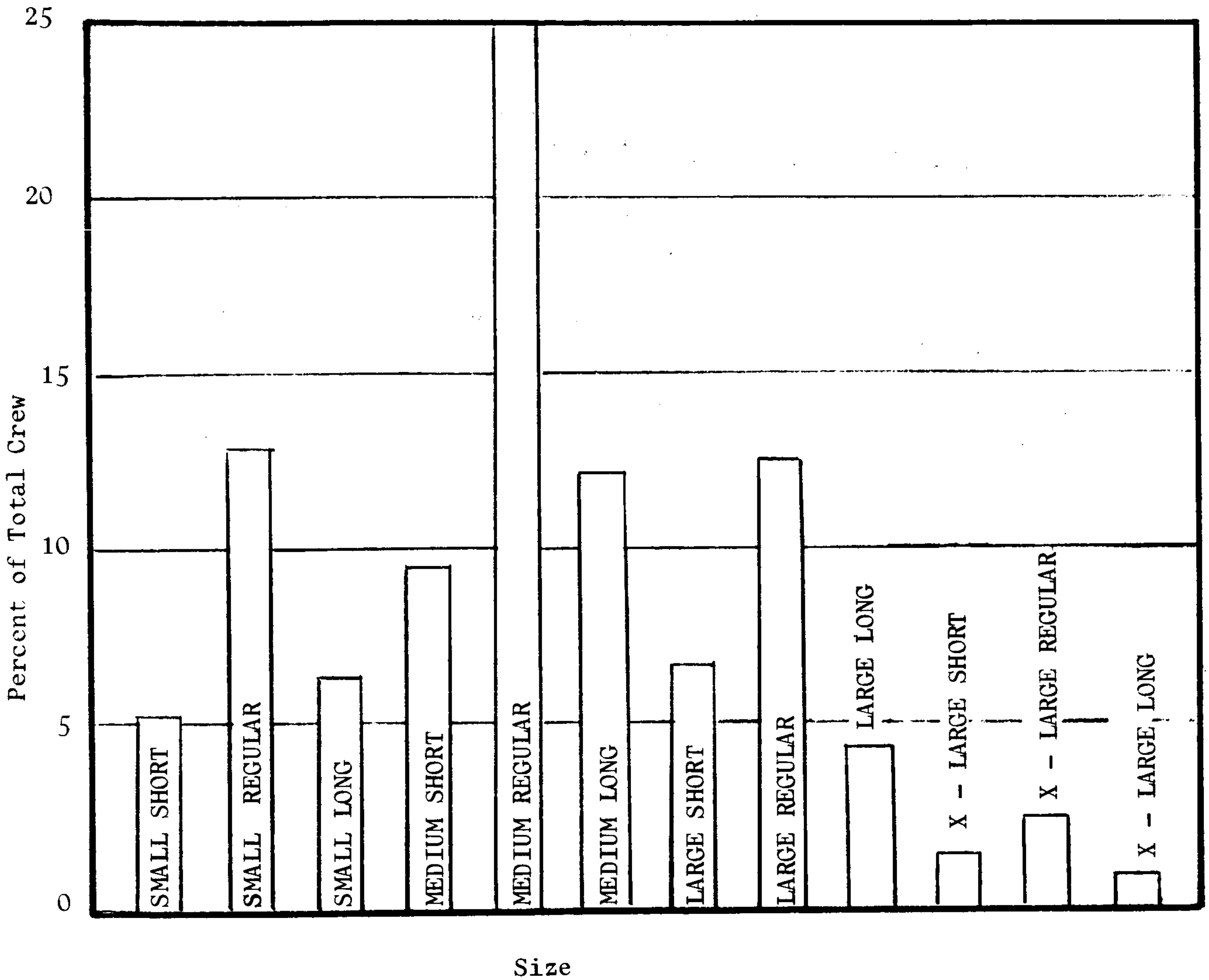
Reference; 1

CREW SIZE DISTRIBUTION

From a sample of 4000 men measured, a size distribution was obtained. This data indicates that at least 25% of the crew members of a space station will be of medium regular build. The data of Figure 4-5 together with the fabric weight and volume data of Section 2 and 5, allows an assessment of a total crew garment weight penalty.

This data is applicable to a population sample in the 1950's and may require modificaiton to reflect size changes of the prospective crews.

FIGURE 4-5 CREW SIZE DISTRIBUTION



N = 4000

Reference 1

SECTION 4.0 REFERENCES

1. Emanual, Irvin, and Alexander, Milton, A Height Weight Sizing System for Flight Clothing. WADC Technical Report 56 - 365, April 1965.

2. NASA Briefing: In-House Study of a Space Base - Guidelines/ Groundrules/Configuration MSC, May 20, 1969.

3. Space Station Program Definition (Phase B), Statement of Work NASA-MSC April 14, 1969.

4. Webb, Paul, Ed., Bioastronautics Data Book NASA SP 3006, Washington D. C. 1964.

5. Weybrew, B. B. Dr. Interview at Submarine Medical Research Laboratories, U. S. Navy Submarine Base, Groton, Conn. August 29, 1969.

SECTION 5.0 VEHICLE INTERFACE AND LOGISTICS

The design of space station accommodations will be governed by the makeup and duty requirements of the crew members. The workspace and personal areas for a crew member must be analyzed for compatibility with the man and his accessories for performance of a long term mission. This section presents the impact of a wardrobe of a crew member upon the design of a space station, the articles supporting a wardrobe, and the interfacing subsystems to the garment systems. Both the transit mode via a shuttle vehicle and the "in-orbit" period of crew operations are covered in the interface and logistics assessment of a wardrobe. The section is divided into the three areas summarized below.

5.1 Logistics Considerations

In this area, the storage and handling requirements are considered for each item of clothing during the crew transit stage from earth to the station.

5.2 Space Station Design Considerations

This section discusses the impact of storage, handling and donning of garments upon the design of the vehicle. Included in the section are typical design concepts.

5.3 Interfacing Systems

The interface of the garment system with the waste management, environmental control and cleaning systems are discussed.

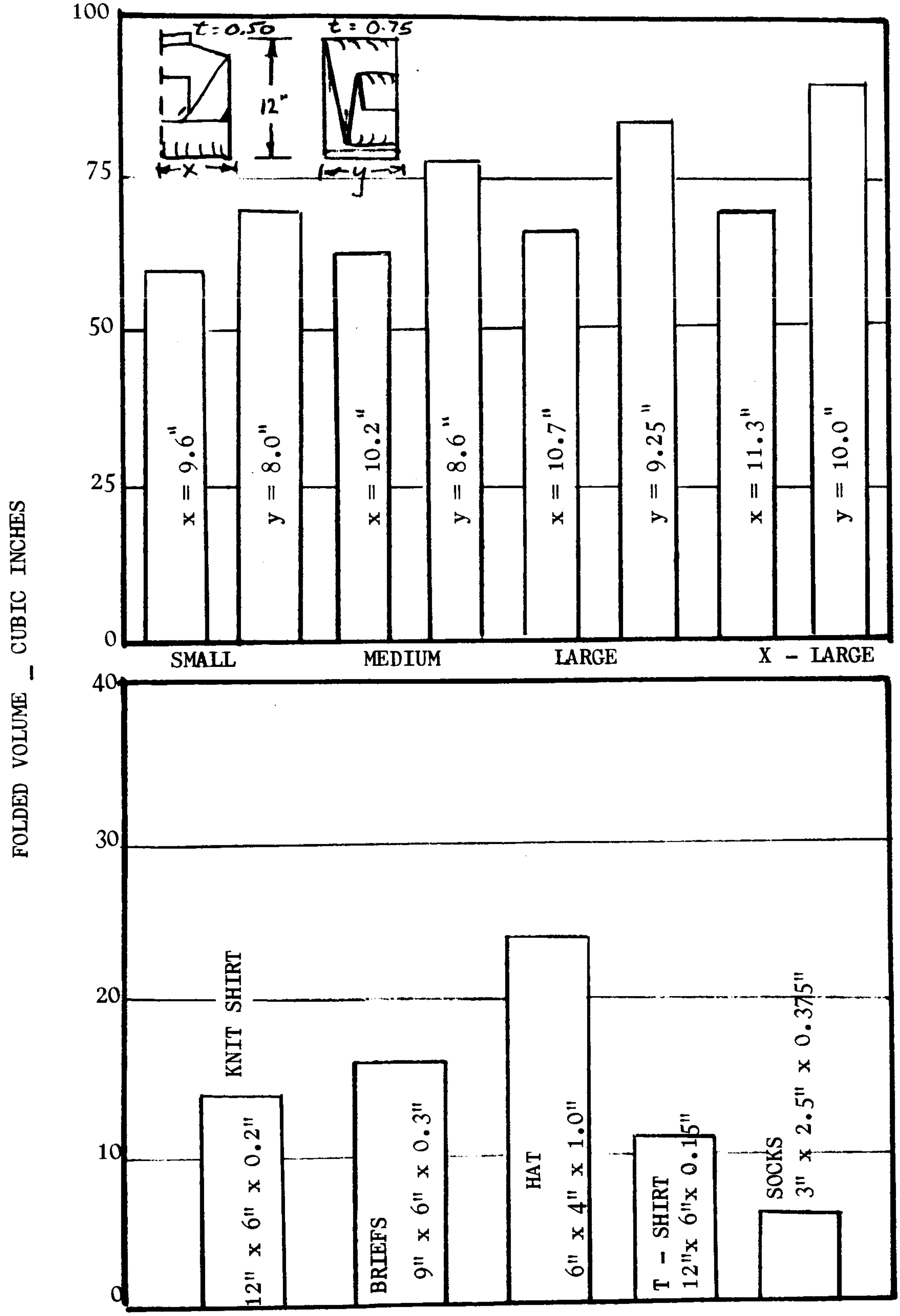
SECTION 5.1 LOGISTICS CONSIDERATIONS

The clothing required by a crew member for his tour of duty must be folded, packaged into a container and launched into orbit for his use. The logistics considerations of a garment are its weight (discussed in Section 2) and its bulk. This section presents data pertinent to the volume requirements of folded garments both during transit to the space station and in orbit.

Packaging garments for use in a space station may be done by pressing folded garments together (to minimize volume) and evacuating the container. This method will result in utilization of the major portion of the available volume. 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 dimension. Although this technique would be applicable for a piece of cloth, the addition of padding, cuffs, collars, fasteners, belts and ribbing do not allow this approximation for a garment. The major consideration in packing a garment is its interface with adjacent garments. By proper packing and folding, the local areas of relatively larger thickness may not occur at the same point and the effect minimized.

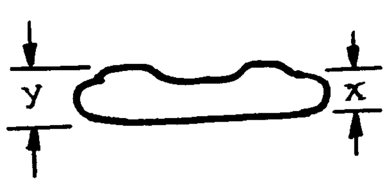
Figure 5-1 presents a non vacuum packaged volume of several garments based the maximum thickness of folding and a one square foot area allowed. These values would be used in estimating volume requirements in the space station.

FIGURE 5-1 GARMENT FOLDED VOLUMES



VACUUM PACKAGED GARMENT VOLUMES

The volume requirements for a garment that has been vacuum packaged is presented in Figure 5-2. Since the volume is a function of the garment design the presence of accessories, the pressed volume figures are applicable to a basic garment, without fasteners, ribbing or reinforcements. The effect of the additional items are also presented for inclusion in the calculation. Thus for a jacket, the basic folded volume is 40 cubic inches. If ribbed cuffs are used, the volume increases by 5 in^3. For minimum volume, proper superimposing or folding is necessary to avoid local spots of large thickness. An example is shown below.



Folded Garment

$t_{max} = y$

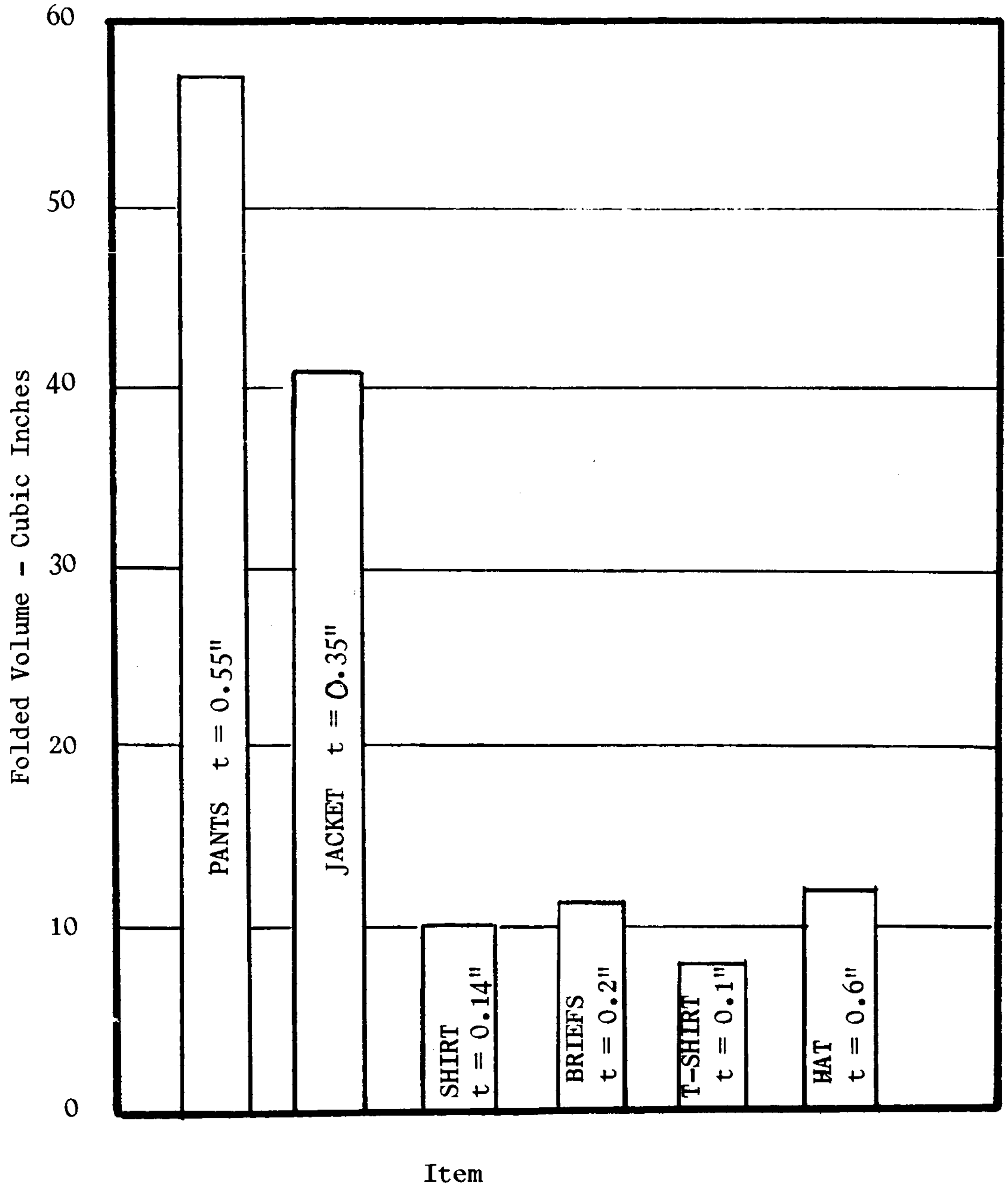
Folded Garment Stack

$t_{max} = 2y$

Folded Garment with Proper Fold Sequence and Superposition

$t_{max} = y + x$

FIGURE 5-2 VACUUM PACKED GARMENT VOLUMES



Local height additions due to accessories:

Ribbed Cuffs - 0.2" x 5" square

Hook and Pile
Fasteners - 0.1" thick

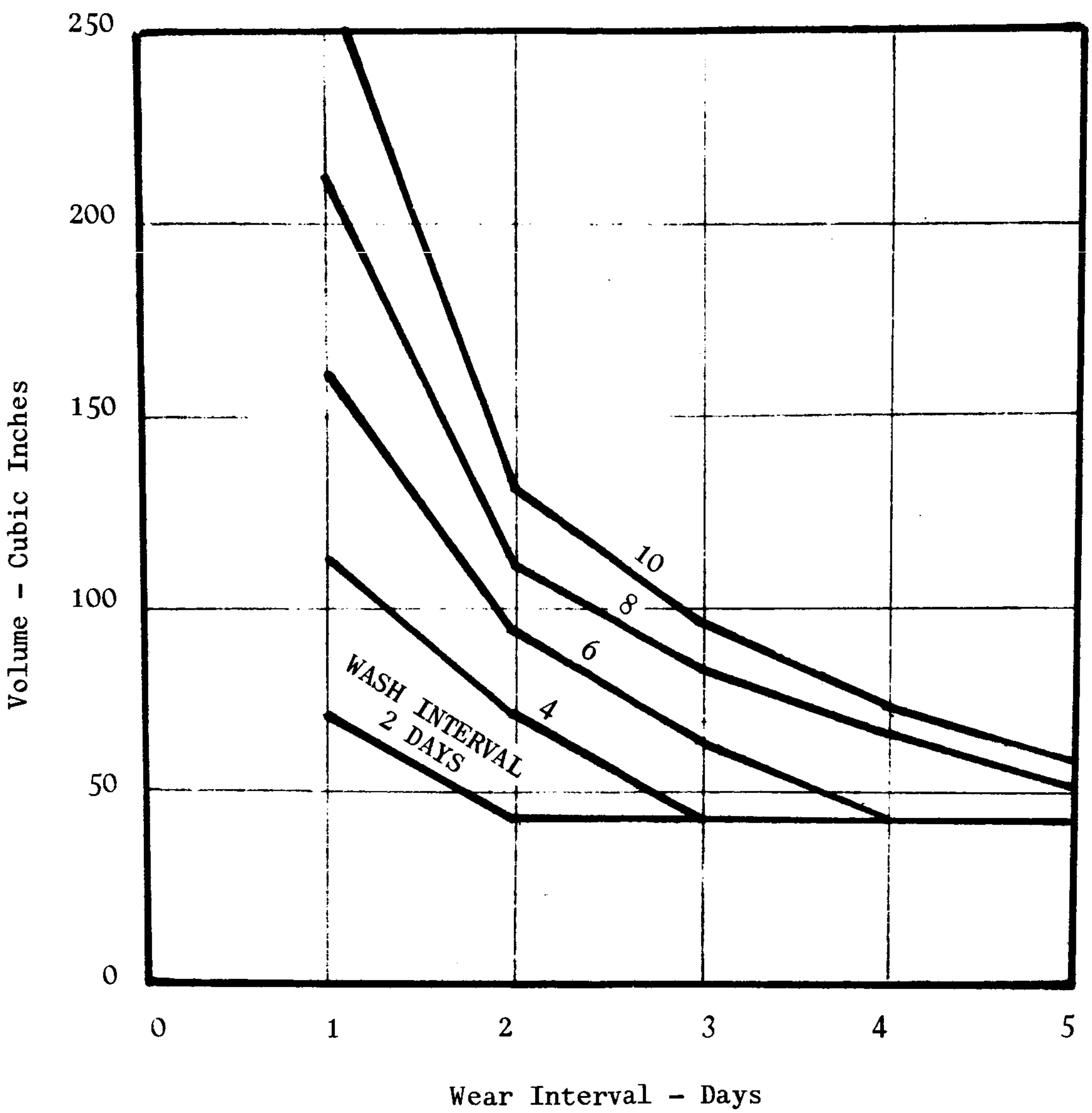
Thickness applied to areas of Figure 5-1

TYPICAL FOLDED VOLUME EXAMPLES

Figure 5-3 shows the typical volume requirements as a function 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 superimposition is applied.

An assumption is made that regardless of the wash interval, two jackets and two pairs of pants will be supplied for a crew member. Figure 5-3 shows that this quantity is the minimum number possible.

FIGURE 5-3 PACKED VOLUME REQUIREMENTS OF UNDERWEAR FOR A CREW MEMBER



Briefs, Socks, T Shirt

SECTION 5.2 SPACE STATION DESIGN CONSIDERATIONS

The design of space station accomodations will be influenced by the crew and their clothing. Consideration of a crew member's wardrobe in the design of the vehicle should take into account the following items.

Don-Doff Envelope

Clothing Storage Area and Restraints

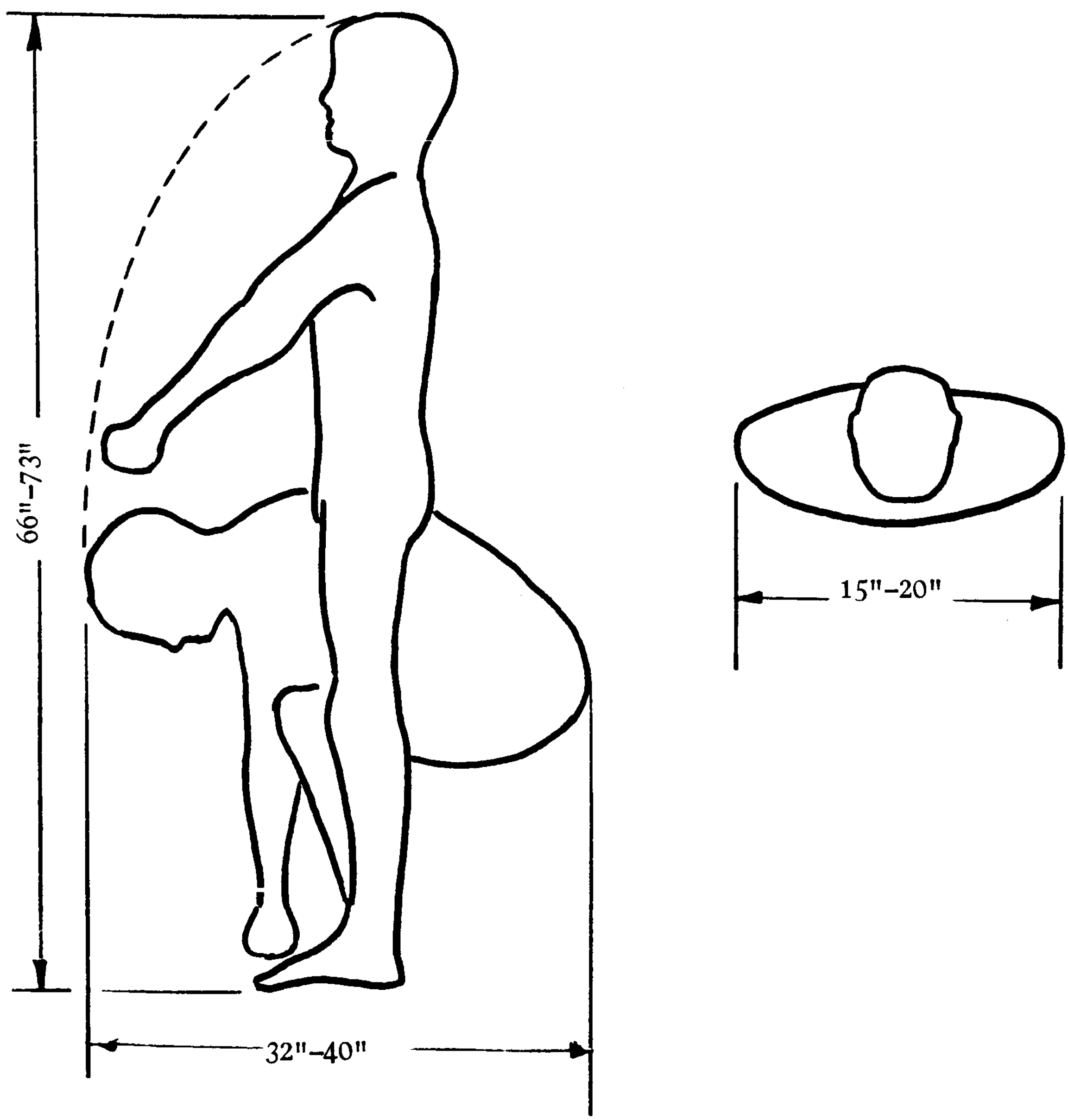
Crew Restraints

Each of these areas are discussed in the following paragraphs.

DON-DOFF ENVELOPE

The maximum and minimum dressing envelopes of a 95th & 5th percentile crew member are presented in Figure 5-3. This envelope is based upon the premise that there shall be no restriction to the motion of dressing.

FIGURE 5-4 DON-DOFF ENVELOPE



Reference; 2,4

CLOTHING STORAGE

Once a crewman's clothing and effects have been transferred from the entry vehicle to the space station, they are to be stored in a more permanent fashion. The two basic requirements for a storage area are:

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

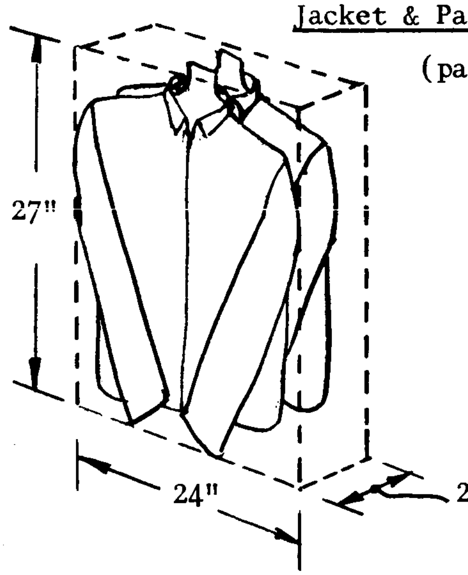
Storage compartment design should consider the total number of items that will accompany a crew member. This includes personal effects, medical and hygienic items. Recognizing that these items will vary in quantity and size, the compartment concepts contained herein are based upon garments alone. Storage of items in a space vehicle is a subject for a design study by itself. Figure 5-5.1 presents the typical volume (and envelope) requirements for a jacket and pants combination. It is assumed that the only items requiring hanging are these and that the remaining garments may be stored in a folded condition.

An example of a storage compartment incorporating combined transit/storage capability is shown in Figure 5-5.2 with the use of a transit carrying case for a locker door. The case offers storage space for the folded and personal items while in orbit.

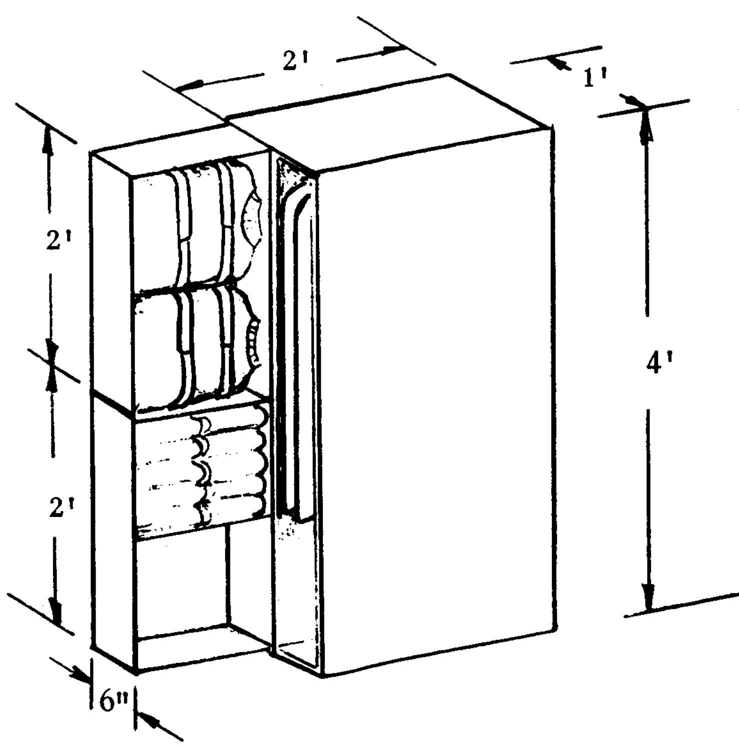
FIGURE 5-5 CLOTHING STORAGE

1. Jacket & Pants

(pants inside jacket)



2. Typical Closet



SLEEPING RESTRAINTS

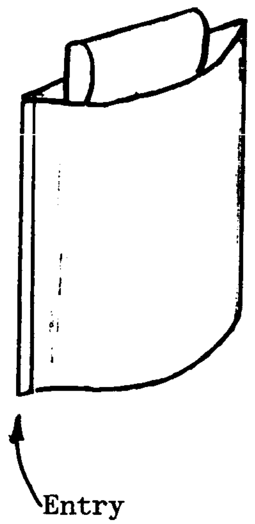
For approximately one-third of the duty cycle, the crew members will be restrained in the living compartment of the station while sleeping. A sleep restraint must contain the qualities of clothing in a thermal sense, and must comfortably contain a man.As in the case of storage, sleep restraint design requires investigation.

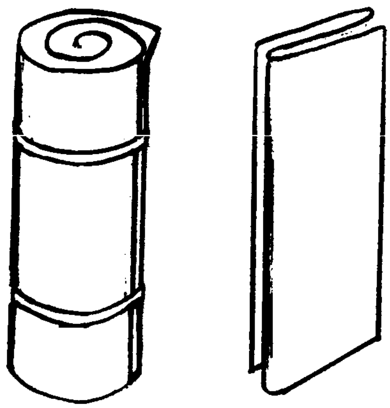
Figure 5-6 shows two typical sleeping restraints to be used in zero gravity condition. Both concepts may be folded and rolled into a smaller envelope and stowed when not in use.

The basic design criteria for a sleep restraint is to contain a man in a soft, comfortable envelope while allowing quick escape provisions. Hook and pile or slide fasteners accomplish this function. The proper drape effect may be obtained by constructing layers of material such as in a quilt. With proper drape and softness, there is no need for crew bed clothes.

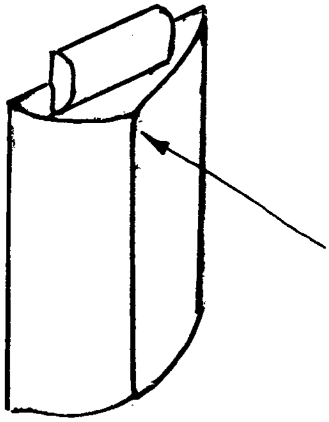
FIGURE 5-6 SLEEP RESTRAINTS

Side Entrance





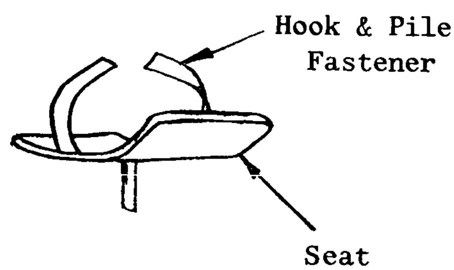
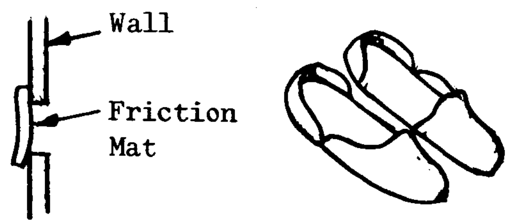
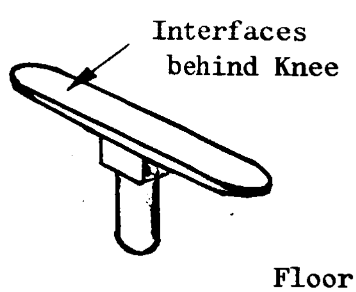
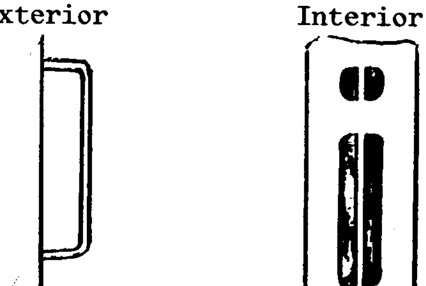
Front Entrance



CREW RESTRAINTS

In a zero gravity space station, the crew will require restraints to hold them in a given location while performing a task. The types of restraints and their designs will be determined by the particular activity and interface with the vehicle. Since the restraints are an integral portion of vehicle (station) design, Figure 5-7 presents a small portion of the presently concepted types of restraints.

FIGURE 5-7 RESTRAINT DEVICES

TYPE		USES
Pelvic Restraint		.Long Period Station Restraint .Operations requiring both hands free. -footwear donning -upper torso clothing -duty,leisure,eating
Foot Restraint	 Wall Type Dutch Shoe	.Momentary Restraint -dressing -temporary tasks
Kneeling Restraint		.Special Tasks .Exercise
Hand Hold	Exterior Interior 	.Steady body locomotion through vehicle .Dressing, Duty -general purpose

SECTION 5.3 INTERFACING SYSTEMS

The garments of a crew will be one of two types, disposable or re-usable,depending upon the mission involved. To date, the garments used in space missions have been the former. With increasing crew sizes and mission times, however, the weight and volume penalty of "throw away" garments becomes a major consideration. With the use of cleanable and maintainable garments, ancilliary equipment is required that is not presently employed in space vehicles. This equipment consist of such items as a washer, dryer, shape retainer frames, mending provisions, and stain removal provisions.

This section presents an overview of the systems required to support a garment system in a space station.The items considered are:

1. Criteria for Extablishment of a Cleaning System
2. Cleaning System Penalties
3. A typical Cleaning System Layout
4. Ancilliary Items to a Garment System

The need for a cleaning system on board a space station is determined by several variables.

The wear rate, (discussed in Section 4), the number of crew men, and the mission duration are the primary considerations. In the following figures each of these variables are treated so that a decision may be made for the use of a cleaning system.

REQUIREMENTS FOR A CLEANING SYSTEM

The trade off between a cleaning system and a disposable garment approach is based upon the following consideration.

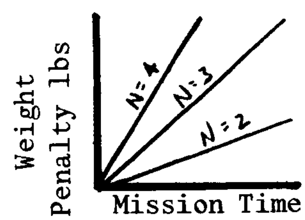
The weight of a disposable garment approach is a function of the basic item weight and the wear interval. The wear rate (established by dividing the fixed weight of an item by the wear interval) is computed for a total wardrobe for each crew member and multiplied by the number in the crew. This is presented in equation form below:

$$WR_{total} = N \times \left(\frac{W_{shirt}}{WI} + \frac{W_{jacket}}{WI} + \text{etc}\right)$$

where:

- WR = Wear Rate (lb/day)
- N = Number in crew
- W = Weight (lbs)
- WI = Wear Interval (period between changing) days

The weight penalty as a function of mission time appears as a straight line for each crew member (with a constant wear rate).



Wear Rate = Constant

The weight of a cleaning system approach consists of the fixed weight of the washer/dryer, the weight of water, a 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.

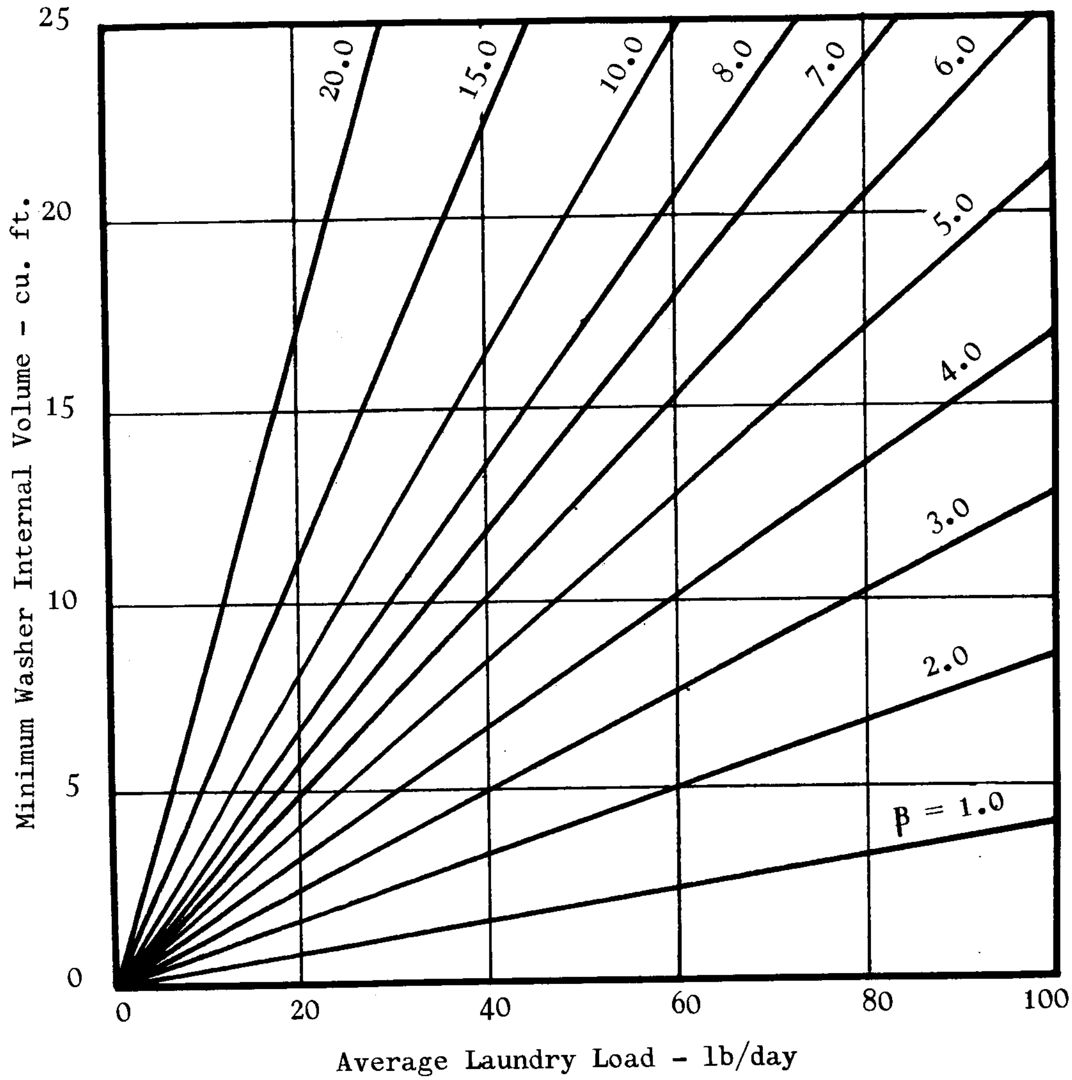
Figure 5-8 presents the relationship between the average laundry rate and the required size of the washer internal volume. Several variables affect the size, and are explained below.

- CT - Total cycle time (washing and drying)
- LF - Loading factors, lb/ft^3 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 influence the size (and weight) of a washer/dryer, the rationale of their selection is an important factor in cleaning system penalty.

The weight penalty for a typical laundry system is shown in Figure 5-9. The weight is based upon the internal volume of the washer of the type shown.

FIGURE 5-8 CLEANING SYSTEM: WASHER/DRYER VOLUME



$$\beta = \frac{(CT)}{(LF)(UF)}$$

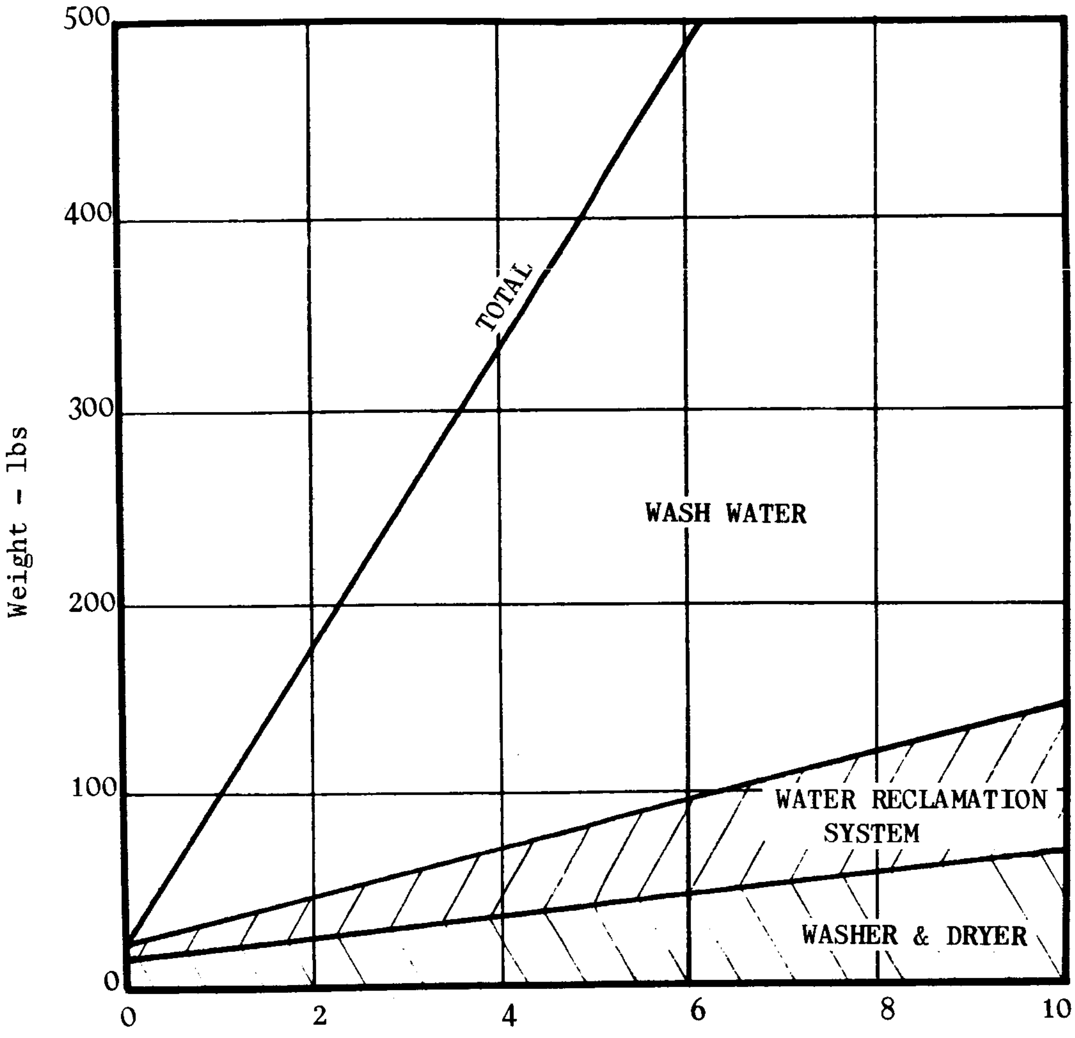
where:

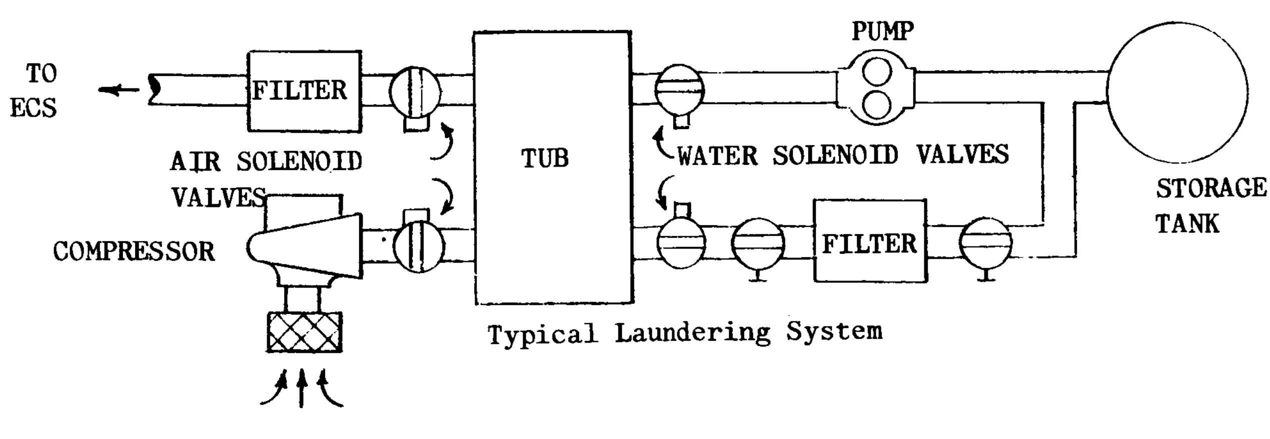
CT = Total Cycle Time

LF = Loading Factor - lb/ft^3

UF = Usage Factor - % $\left(\frac{\text{hrs operated/day}}{24}\right)$

FIGURE 5-9 LAUNDRY SYSTEM FIXED WEIGHT RENALTY

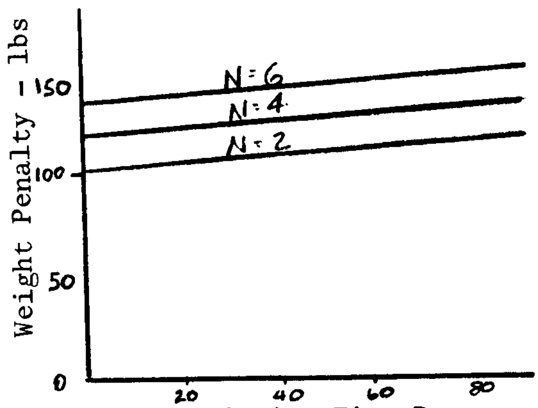




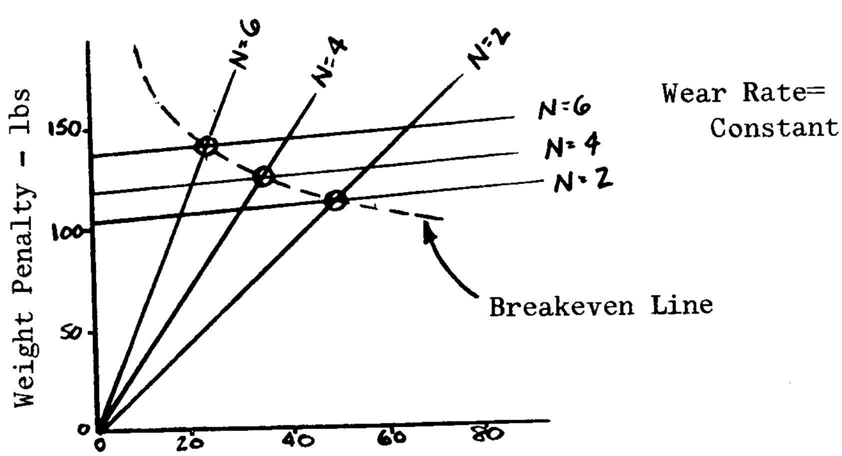
Typical Laundering System

LAUNDRY SYSTEM TRADE OFF

The weight of a laundry system as a function of mission time and crew number (N) depends primarily upon the fixed weight since the only time dependent expendable weight is due to the detergent quantities.



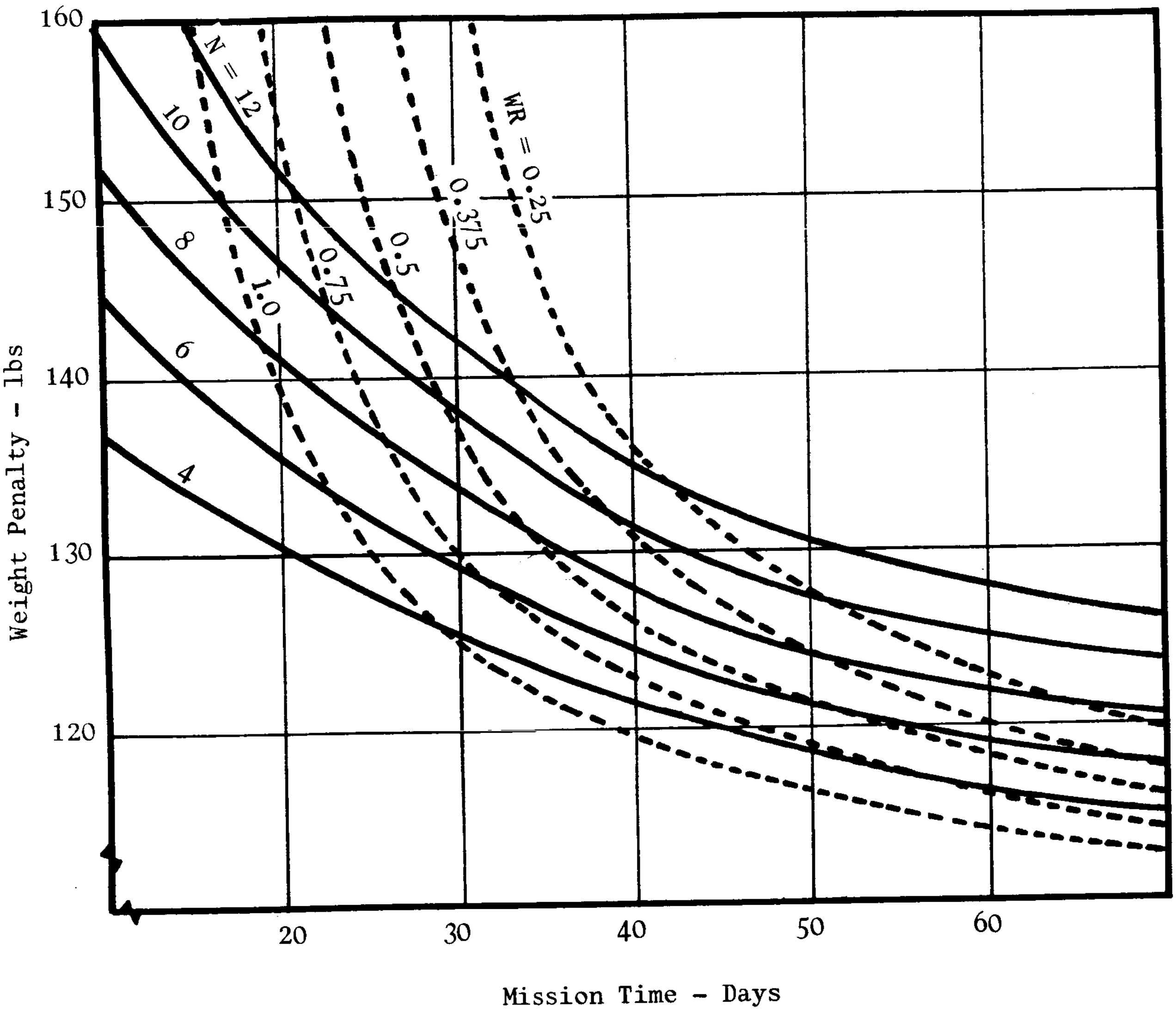
The weight values includes the penalty of the washer and dryer, water storage and reclamation hardware. Superimposing this curve over the characteristic curves of the disposable garment system, a breakeven point is reached for each crew member.



This means that with a given grew size and mission length, the point falls to the left or below the breakeven line, a disposable garment system should be employed. If the point lies to the right or above the line, a laundry system should be used. Figure 5-10 shows a trade off graph applicable for variable wear rates and crew sizes for which the same methods apply. With a given crew size and wear rate, the breakeven mission time may be obtained.

FIGURE 5-10 LAUNDRY SYSTEM - DISPOSABLE GARMENT EVALUATION

(BREAKEVEN POINTS)



N = Number of Crewmen

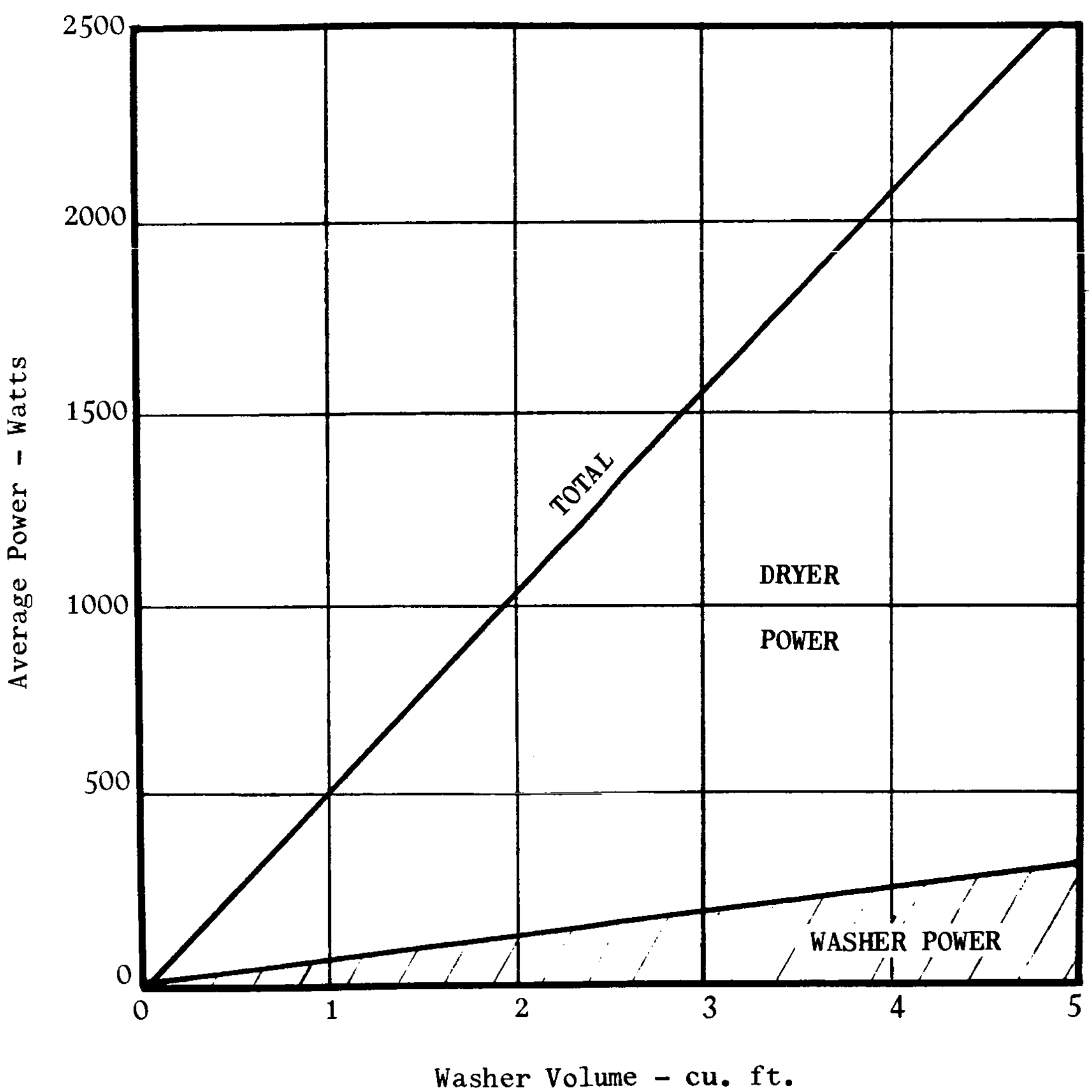
WR = Wear Rate - lb/man day

Free Power

LAUNDRY SYSTEM POWER

The power penalty of a laundry system is due to both the operation of the washer and controller and the heat required for evaporation of water from the clothing during a drying operation. Although clothing can be dried with other methods than by heat, heat allows the least-time method of drying. The penalty of heat addition is relatively low with a nuclear power system when time-shared with other station equipment. Figure 5-11 shows the breakdown of power required to run a washer/dryer. For circumstances that do not allow time sharing, or a power system with a substantial penalty, this penalty must be added to the fixed weight and evaluation of a laundry system.

FIGURE 5-11 POWER REQUIRED FOR A WASHER/DRYER



Total Cycle Time - 1.4 hours

LAUNDRY SYSTEM AREA

The laundry system area in a space station is typified in Figure 5-12. Included in this workspace are a washer/dryer, detergent dispensor, laundry bag stowage area, and crew restraint hardware. An oscillating type of washing machine is shown as an example of installation in a space station. The selection of a laundry system is by itself a subject worthy of extensive study beyond the scope of this handbook. The major areas of study required in the evaluation of a laundry system are:

<u>Washing techniques</u>

water
solvent
sonic and vibratory

<u>Detail Design Concepts</u>

rotary
oscillating
water jet

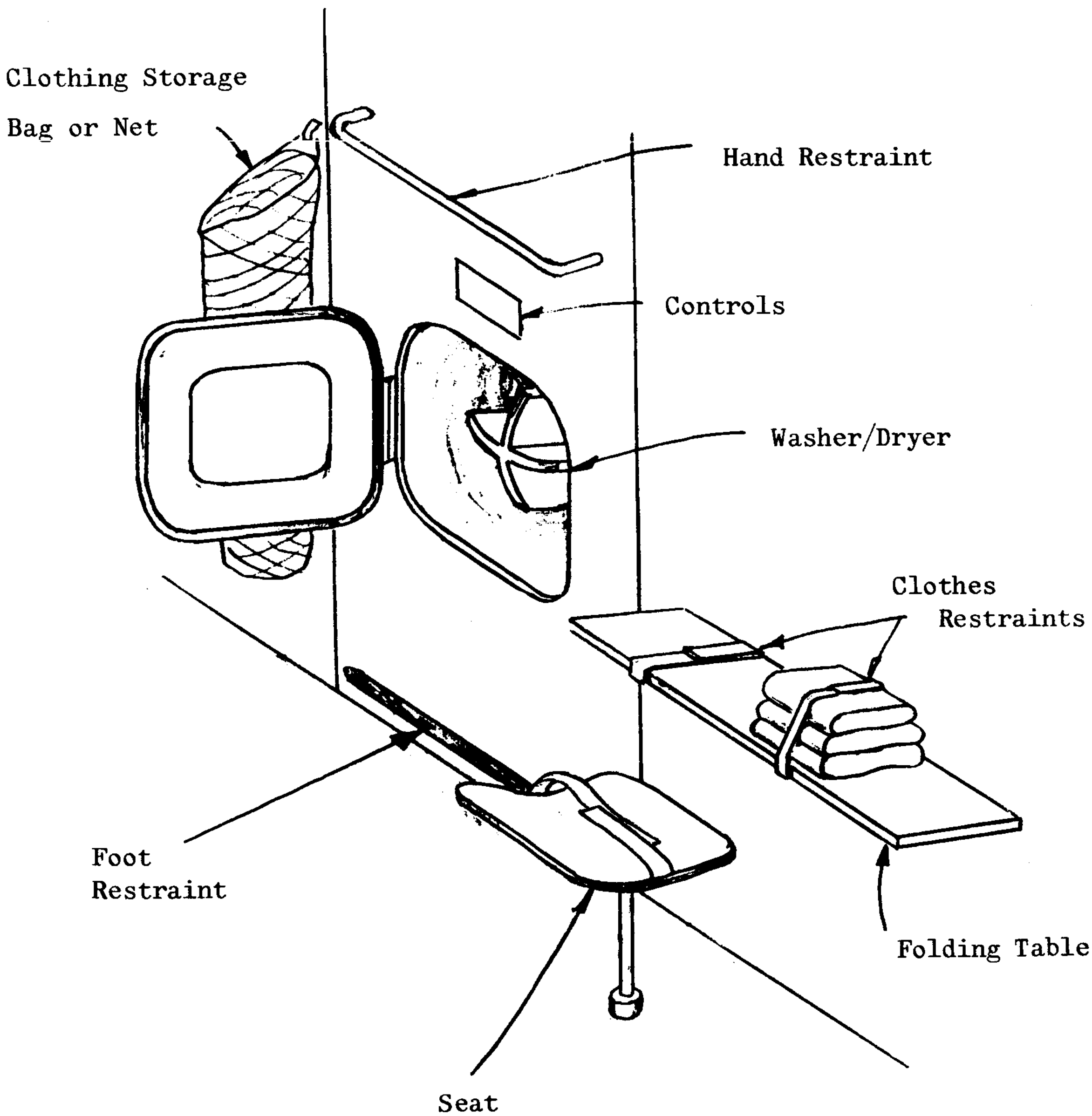
<u>Drying Techniques</u>

vacuum drying
heating

<u>Interface</u>

detergent selection
bleaching and coloring

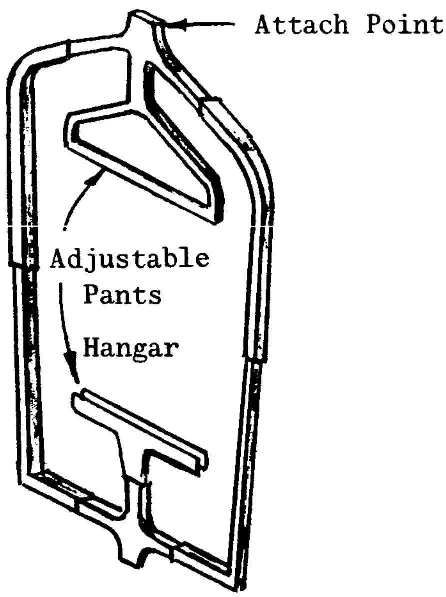
FIGURE 5-12 TYPICAL LAUNDRY SYSTEM AREA



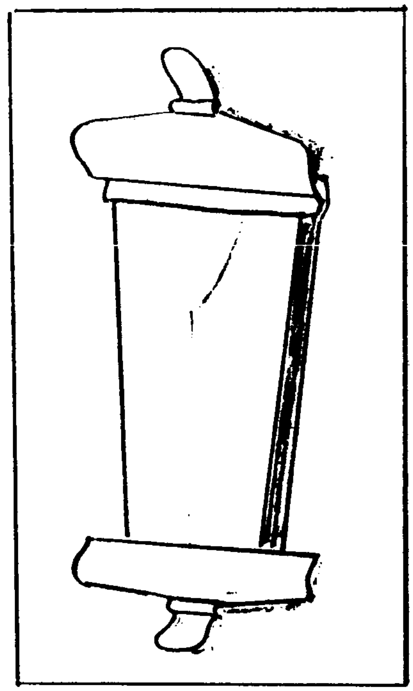
ANCILLIARY ITEMS

The ancilliary items to the garment system are those which allow retention of the proper appearance of the garment during storage. Shown in Figure 5-13 are several hangar concepts which must be compatible with both the station design and the garment systems. The types and amounts of hangars are a function of the crew total wardrobe and as such, their complete definition will be determined with the wardrobe.

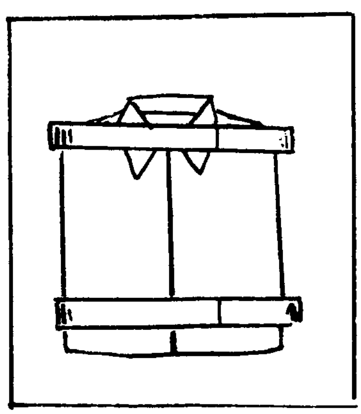
FIGURE 5-13 HANGAR CONCEPTS



HANGAR



CLIP BOARD



STRAP

SECTION 5.0 REFERENCES

1. Johnston L., Interview at American Institute of Laundering, Joliet, Illinois, August 21, 1969.

2. Laboratory Module CEI 207011A and Installed Equipment to Flight Crew, Interface Spaceification IFS MOL-108002, 8 May 1969.

3. Phillips, E. Roland, Drycleaning, National Institute of Drycleaning, Inc. Silver Springs, Md. April 1968.

4. Webb, P. Ed, Bioastronautics Data Book, NASA SP 3006, Washington, D. C. 1964.

APPENDIX A

ILLUSTRATIVE

EXAMPLE

APPENDIX A ILLUSTRATIVE EXAMPLE

INTRODUCTION

The use of the Garment Selection Handbook is presented in this Appendix. Presented herein is a hypothetical mission and its pertinent requirements. 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 into the following steps:

1. Thermal design
2. Construction
3. Materials
4. Crew Considerations
5. Interface

Each of the above considerations in the design of a garment are pertinent to a section the handbook. The output of the evaluations 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^{o}F, the maximum dew point temperature of 60^{o}F, and the gas ventilation velocity is 45 fpm. The crew and interface data is 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	-	50 th Percentile	

Interface Data

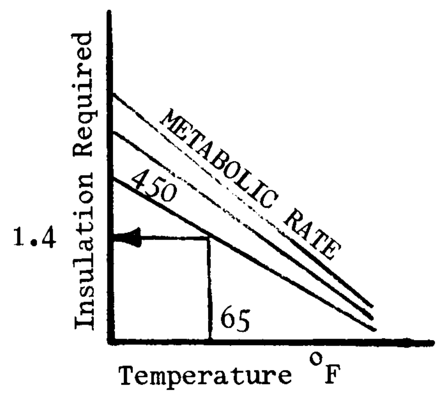
Garment Wardrobe Weight Limit - 10 lbs.

1.0 THERMAL DESIGN

The use of the charts of Section 1 is presented below. The result is 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 1-3.



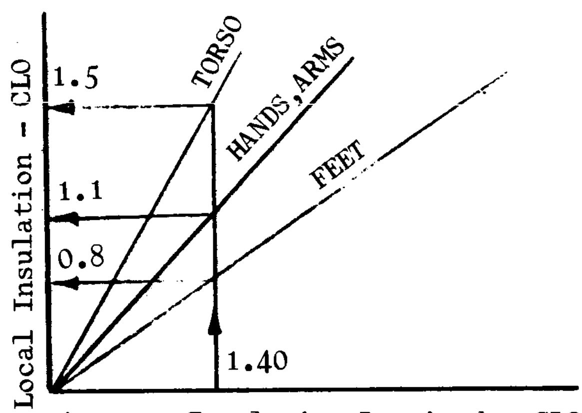
Once entering this curve at the temperature extremes of 65 and 80°F, and metabolic rates of 450 and 2000 BTU/hr, the following data is obtained from the graph.

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 1-4.



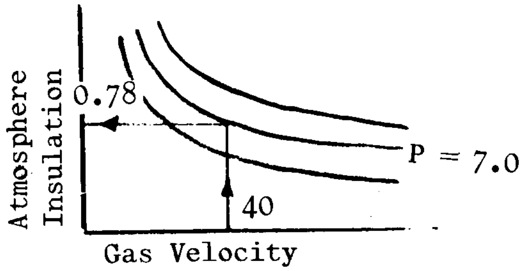
Entering the curve at each of the average insulation values determined in Step 1 above, the following data is derived.

Insulation Distribution - CLO

Average Insulation	1.40	0.25	0.60	.15
Torso	1.5	0.25	0.65	0.15
Legs	1.4	0.20	0.60	0.11
Hands & Arms	1.1	0.17	0.50	0.10
Feet	0.8	0.15	0.35	0.10

Step 3 - Atmosphere Insulation

This step involves the determination of the atmosphere insulation properties for a 7 psia, oxygen/nitrogen mixture. With a ventilation velocity of 40 fpm, the atmosphere insulation value is determined from Figure 1-5A.



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:

$$I_l = I_c + I_a$$

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 $I_{local} - I_a$

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 & 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 1-4 and reading temperature in Figure 1-3 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 is presented below: (from Step 4)

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 removeable jacket with shirt. (For nearly constant temperatures at the design point a single piece garment would be desirable.)

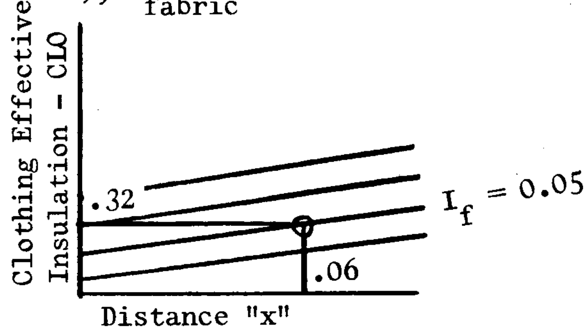
Step 6 - Drape Effect

The determination of the drape effect is found in Figure 1-6. Dressed in a jacket and shirt, the respective distances are 0.06 inches for a knit shirt and another 0.10 inches 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 .32 CLO, the chart is entered at .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 .72 CLO - .32 CLO = 0.40 CLO. Since entering the graph at 0.40 CLO and a clothing distance of .10 inches falls below the curve, a minimum value of .01 CLO is assumed for I_{fabric}. Neglecting the effect of briefs, the fabric insulation for the pants is likewise .01 CLO, obtained by entering the graph at an effective insulation value of 0.62 CLO and a distance of .15 inches. The fabric insulation data is summarized below:

Fabric Insulation Requirements

Shirt - 0.05 CLO

Jacket - 0.01 CLO

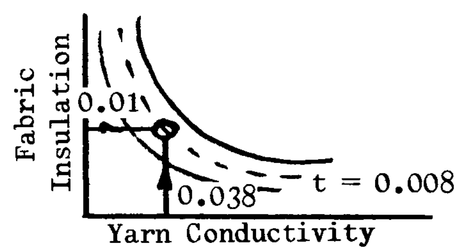
Pants - 0.01 CLO

Step 7 - Cloth Insulation Properties

The thickness of the material may be obtained from Figure 1-7 knowing the fabric insulation property. 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 3-2 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-^oF-ft) are assumed.

Entering the curve with the yarn conductivity and the required fabric insulation the thicknesses are determined.



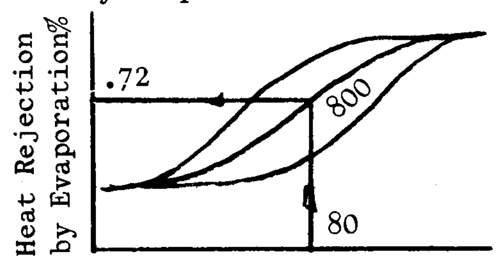
For k = 0.038, and the insulation requirements of Step 6, the following thicknesses are determined.

Cloth Thickness	
Jacket	- 0.008 inches
Pants	- 0.008 inches
Shirt	- 0.023 inches

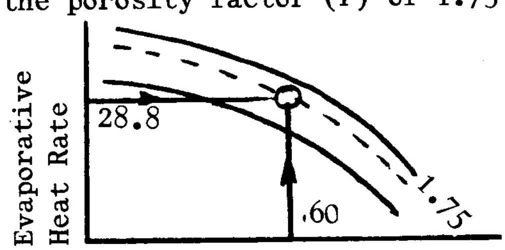
Since all of the items will contain high material area ratios, the weave factor of Figure 1-8 is assumed to be 1.0. Although these thicknesses are those calculated due to thermal considerations, they represent minimum values. In reality, the pants and jacket may have equal or greater thickness due to endurance requirements.

Step 8 - Effect of Dew Point

With a metabolic rate of 800 BTU/hr 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 $80^{\circ}F$, Figure 1-2 is used to determine the amount of latent heat rejection. With a temperature of $80^{\circ}F$ and a metabolic rate of 800 BTU/hr, 72% of the body heat is rejected by evaporation of water.



Taking 72% of 800 BTU/hr, 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 $60^{\circ}F$, Figure 1-10 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 relationships $P = \frac{1 - A_{mr}}{x}$, is applicable for a shirt and pants.

The values of x (from Step 6) are:

knit shirt = .06 inches
pants = .15 inches

Then the maximum material area ratio for the shirt is:

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

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

SUMMARY - THERMAL DESIGN STEPS 1 THROUGH 8

From the above, knowing the data in the left hand column and making a few assumptions, the garment data in the right hand column has been determined.

Knowing	Features Defined
Metabolic Rates	Total Insulation
Atmosphere	Local Insulation
Gas Velocity	Fabric Distribution
Dew Point	Fabric Material
Temperature	Fabric Thickness
	Fabric Porosity

2.0 CONSTRUCTION

Continuing in the definition of a garment, the charts of Section 2.0 yield more data applicable to the penalty and design of a garment. Presented below are the steps involved to determine the fabric geometry and weight of a garment.

Step 1 - Determine General Construction

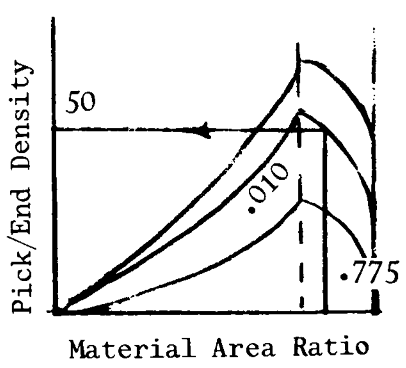
The first step is the determination of the construction techniques to be used. For the shirt and socks a knit construction is advisable on the basis of porosity, warmth, conformity. Pants and jacket are woven due to rigidity and high strength.

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 Tee Shirt range in weight from 3 to 5 oz/yd^2 and knits for sports clothes from 5 to 7 oz/yd^2.

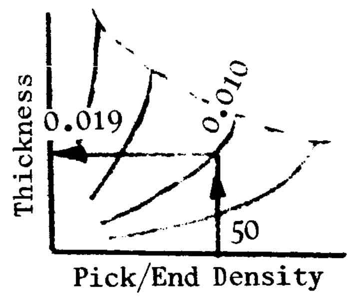
For weaves, however, the geometry and yarn properties may be needed. Recalling that the material area ratio of the pants is .775 (Thermal Step 8), the geometry relationships may be established, for these Figures 2-2 and 2-3 are used.

Knowing the required thickness or porosity, the geometry (pick and end density) may be determined with given yarn properties. Assuming that a PBI yarn diameter of 0.010 and 0.005 inches is available, Figure 2-2 indicates that a pick/end density of 50 yarns/inch is required with a jacket of material area ratio of 0.775 (from thermal design Step 8).



Step 3 Thickness

Remembering from thermal Step 7 the required minimum thickness is 0.008 inches and noting that $A_{mr} > .75$ Figure 2-3 (curve B) is used to check th thickness. Entering at a pick/end density of 50 and a yarn original diameter of 0.010 inches the thickness will be .019 inches.



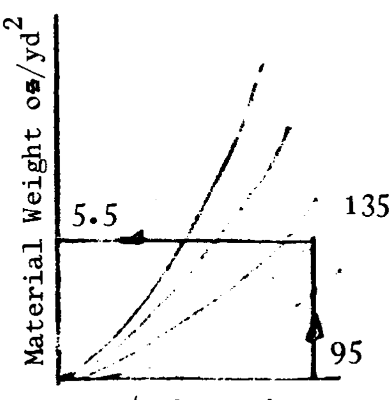
Since this thickness is twice the required value, the weight will be twice as heavy as required. The desirable choice at this point is to select the smaller diameter yarn. With half sized yarn, (0.005 inches), a pick/end density of 95 and thickness of 0.008 results with a material area ratio of 0.775.

Step 4 - Material Weight

If the fabric is to be purchased by specification of yarn geometry and material, Figure 2-4 is used to determine the weight of a square yard. Computing the denier value for PBI - (density value found on page 3-13):

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

Entering the curve with a pick/end density of 95, the resulting weight is 5.5 oz/yd^2



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 pants for determining weight penalty. Section 2.4 contains the data to accomplish this. Figure 2-19 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. Looking in the Section 4.0, crew data on Figure 4-4, a fiftieth percentile crew member corresponds to medium regular size. The following data may be determined directly from the data of Figure 2-19.

Area Requirements - yd^2	
Jacket	1.7
Shirt	0.85
Pants	1.9
Socks	0.1

Step 6 - Computation of Weight

Multiply the area by the fabric weight and add the fixed parasitic weights of Table 2-4:

Item	Area	x	Fabric Weight	+	Fixed Weight	= Total Weight
Jacket	1.7		5.5		4 oz	13.4 oz
Pants	1.9		5.5		2.5 oz	12.9 oz
Shirt	0.85		4.0*		.5 oz	3.9 oz
Socks	0.1		4.0*		-	.4 oz
Briefs	0.5		4.0*		.3 oz	2.3 oz

*Estimate

The fixed weight may be altered by incorporation of any of the design details presented in Section 2.2 and 2.3. The fixed weights above include ribbed cuffs, entry zipper fasteners and internal pockets.

SUMMARY - CONSTRUCTION STEPS 1 - 6

In Section 2.0, it is possible to determine the following data:

Knowing	Features Defined
Fabric Thickness and yarn size or yarn size and material Area Ratio	Fabric Geometry
Crew Stature	Weight of Garment

3.0 MATERIALS SELECTION

The major criteria for material selection is flammability at this time. As the environments become closer to an earth atmosphere, more freedom will be allowed in the selection of materials. The charts and curves in Section 3.0 present the relative performances of materials with respect to structural, environmental and performance parameters. Depending upon the priority of criteria in the selection of materials for a given mission, the relative standings are presented for review. The table below lists the materials that would be selected if the criteria in the left hand column were the only important features.

Criteria	Material
Weight	Nylon
Strength	Fiberglas
Endurance	Nylon
Elastic Recovery	Nylon
Cleaning Compatibility	Nylon
Moisture Absorption	Cotton
Chemical Stability	Teflon
Shrinkage due to water	Fiberglas
Quick Drying	Teflon

4.0 CREW CONSIDERATIONS

Wardrobe selection is one of the prime considerations in the design of storage areas and baggage compartments in a shuttle vehicle. The selection of garment system is a function of mission time and crew number. For short missions, garment cleaning does not appear to be of great importance, and, depending upon crew time allowable, may be done by hand if required at all. The ground rule in garment selection is to allow as much as practical which is defined by the space station or shuttle vehicle weight or volume limitations. If the volume or weight is unlimited an earth-base cycle is the most desirable with certain clothes changes each day. Presented below is the weight and volume technique for wardrobe selection,

The Weight Approach

Given - A weight allocation of 10 pounds of clothing is specified for a space station crew member. What is the best wardrobe and its frequency of cleaning.

Step 1 Determine Garments Required

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

Jacket	Briefs	Pants
Shirt	Socks	Shoes
	Hat	

Step 2 - Allocate Fixed Articles

The fixed articles in the wardrobe are the footwear and the pants and jacket combination. 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. Allowing for cleaning, 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 amount of underwear and shirts to be determined.

Step 3 - Select Fixed Weights from Total

From Section 2, the weights of the shoes, jacket and pants have been determined.

Jacket	2 x 0.84 lbs	= 1.68 lbs
Pants	2 x 0.81 lbs	= 1.62 lbs
Shoes		= 0.5 lbs
Hat		= 0.5 lbs
		4.30 lbs

To find allowable weight of underwear subtract 4.30 from 10.0 lbs. = 5.70 lbs.

Step 4 - Find Garment Changes Permissible

From Section 2 Calculations

Briefs	= 0.144 lbs.
Shirt	= 0.25 lbs.
Socks	= 0.025 lbs.
	.419 lbs/change

Then total changes permissible is $\frac{5.70}{.419}$ = 13.6 or 13 changes. Since one must be clothed while washing his clothing, the wash interval is every 12 days.

The Volume Approach to Wardrobe Selection

The volume approach to garment selection is the same technique used in the weight approach. The data used in the computation of a wardrobe volume is presented in the handbook Section 5.1, Logistics Considerations. The illustrative example in the use of this data is shown in the next section of this appendix.

5.0 VEHICLE INTERFACES AND LOGISTICS

The vehicle interface considerations are presented in this section. Although portion of the section is concerned with station restraint concepts, cleaning systems and the like, these are the subjects of separate studies to be performed in the near future. The data presented in this section is to acquaint the reader with the interface aspects of crew equipment.

There are, however, several uses of Section 5.0 in the decision made regarding interface items to the crew garment system. They are:

1. Volume Determination - In Orbit and
   During Transit
2. Establishment of a Cleaning System

Presented below is the description of the use of the Section 5.0 data.

Volume Determination

The data of Figures 5-1 and 5-2 is concerned with the folded garments for vacuum packed conditions (during transit) and non-vacuum packed conditions (in orbit).

Taking the wardrobe determined in Section 4.0, the indicated charts are used to define the applicable volumes for a medium size.

FIGURE 5-1 IN ORBIT FOLDED VOLUME

Item	Quantity	Item Volume (in^3)	Total Volume	Envelope (in)
Jacket	2	62	124	12 x 10.2 x 1
Pants	2	77	154	12 x 8.6 x 1.5
Shirt	13	14.4	187	12 x 12 x 1.3
Briefs	13	16.2	210	12 x 9 x 1.95
Socks	13	5	65	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			782 in^3	

FIGURE 5-2 TRANSIT FOLDED VOLUME (VACUUM PACKED)

Item	Quantity	Item Volume	Total Volume	Envelope
Jacket	2	43	86	12 x 10.2 x .7
Pants	2	57	114	12 x 8.6 x 1.1
Shirt	13	10	130	12 x 12 x 0.9
Briefs	13	10.8	140	12 x 9 x 1.3
Socks	13	5	65	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			577 in^3	

Establishment of a Cleaning System

As the mission lengths and crew sizes grow, the need for a cleaning system increases. In Section 5.3, one may assess the desirability of a cleaning system and the impact if one is to be used.

Using the mission model established at the beginning of the appendix and the wardrobe allowed by the computation in Section 4, 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

From page 5 - 17

$$\text{Wear Rate} = N \times \frac{W_{shirt}}{WI} + \frac{W_{jacket}}{WI} \times \text{etc}$$

Allowing a change of shirt, underwear and socks each day the wear interval is 1. Knowing that a wash period of 12 days is required (step 4 - Crew Wardrobe Determination), then the wear interval of the pants and jacket is 12 days each. With 3 crew men and the weight from Step 4 of Section 4:

$$WR = 3 \times \left[\frac{0.25}{1} + \frac{.144}{1} + \frac{.025}{1} + \frac{.84}{12} + \frac{.81}{12}\right]$$

$$= 0.556 \text{ lb/crew member}$$

$$= 1.76 \text{ lb/day}$$

Step 2 - Determine Laundry System Restrictions

The least penalty method of cleaning clothes is by hand. The only reasons for considering a cleaning system are convenience and crew time criticality. In terms of weight penalty, a system with changeable garments and water reclaimable hand washing is by far the most advantageous with the only penalties being the garment weight and the detergent.

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

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

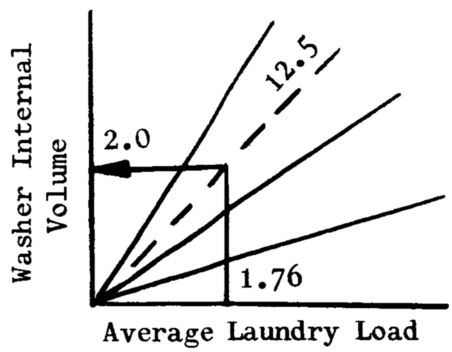
Loading Factor (determined by drying cycle)= 2.0 lb/ft^3

Usage Factor - 12 hours every 12 days* $= \frac{12}{12 \times 24} = .0416$

* determined by crew time availability

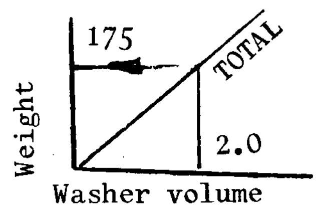
Step 3 - Laundry System Internal Volume (B = 12.5)

Entering Figure 5-7 with a laundry load of 1.76 lb/day and a laundry factor of 12.5, a tub volume of 2.0 cubic feet is required.



Step 4 - Weight Determination

Figure 5.9 presents the weight of a laundry system as a function of tub internal volume. This value includes washer, dryer, water reclamation system weights and the stored water. With a 2.0 cubic foot tub, the system weight is 175 lbs.

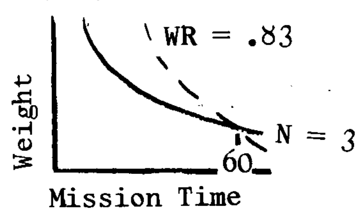


This value may be altered greatly by the allowable washing periods.

If the wash time were increased from 12 hours every 12 days (1 hr/ day) to 2 hours/day the weight penalty would be reduced to 100 lbs.

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 done by the use of Figure 5-10. This curve determines the breakeven weight point between a laundry system and a disposable garment system. At the 60 day mission point on the curve for 3 men, a wear rate of 0.83 lb/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 .83 lb/day to equal the penalty of a laundry system. This is 50% more than the specified amount of .577 determined in Step 2.

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.

The subject of laundering is a new one for space vehicles and is undergoing the initial phases of study. A great deal of data is necessary in this field in order to adequately assess the relative penalty of their inclusion in a space vehicle.