CR114271
Available to the Public

DATABOOK FOR HUMAN FACTORS ENGINEERS

VOLUME I: HUMAN ENGINEERING DATA

Prepared by
MAN FACTORS, INC.

Prepared under
Contract NAS2-5298, November 1969

RECEIVED
NASA STI FACILITY
INPUT BRANCH
JUN 1971

N71-25944
(ACCESSION NUMBER) (THRU)
260 G3
(PAGES) (CODE)
CR-114271
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM 602

CR114271
Available to
the Public

DATABOOK FOR
HUMAN FACTORS ENGINEERS

VOLUME I: HUMAN ENGINEERING DATA

Edited by

Charles Kubokawa
NASA - Ames

Wesley Woodson
Peter Selby
Man Factors, Inc.

Prepared Under
Contract NAS2-5298

Nov. 1969

PUBLISHER'S NOTE

Certain nomograms included in this work have been reproduced from DESIGN NEWS with the permission of the publisher, Cahners Publishing Company. Additionally, some materials (tables, equations, etc.) have been reproduced with the permission of The Chemical Rubber Company. The kind permission given for the use in this book of materials copyrighted by the Cahners Publishing Company and The Chemical Rubber Company does not authorize the use of such materials by others without the consent of the copyright proprietors. See Section 8, Title 17 of the United States Code.

NASA - Ames Research Center

VOLUME 1

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

DATABOOK FOR
HUMAN FACTORS ENGINEERS

VOLUME I

HUMAN ENGINEERING DATA

FOREWORD

The information collected together in this databook represents data most often used by practicing human factors specialists as determined by a survey of well known practitioners of human engineering. The purpose of this handbook is to provide a convenient method for taking the most used reference information directly to a job remote from the specialist's regular book shelf. Although it is recognized that such a collection may not be as complete as desired, an attempt has been made to cover as many topics as feasible within the context of a handbook. The included materials have been taken directly from other sources and in a few cases represent original data.

Volume I of the two-volume series contains typical human engineering data useful in determining optimum design characteristics of equipment operated or maintained by human operators and/or maintenance personnel. Volume II contains formulas, nomographs, metrics, conversion tables, symbols, definitions and abbreviations and/or acronyms which may be required at some time during the project activities of typical human engineering specialists. This information, although available from other sources, often requires that the human engineer search through numerous texts, handbooks, specifications or guides in order to find what he needs.

It is hoped that, by providing this collection of information in a more convenient form, the human engineer will find his job simplified. These volumes are not meant as an educational tool and thus, the books provide very little text.

Suggestions for future revisions are solicited. These should be sent to Mr. Charles Kubokawa, Man-Machine Integration Branch, NASA-Ames Research Center, Moffett Field, California, 94035.

REV.SION SUGGESTION FORM

TO : Mr. Charles Kubokawa
Man-Machine Integration Branch
NASA-Ames Research Center
Moffett Field, Calif., 94035

FROM: Name ________________________________

Affiliation ________________________________

Address ________________________________

Phone ________________

SUGGESTIONS: Please be as specific as possible. Identify or provide copy of suggested new material. Give specific address as to where material could be acquired. If errors are found, identify by page and paragraph, figure or table title. Be explicit about suggested changes and provide citations or rationale for suggestions.

(Please attach new material to this page)

ACKNOWLEDGEMENTS

Special acknowledgement is made to the following individuals for their assistance in reviewing the initial draft of the Databook and for the timely suggestions provided to improve the content and organization of the material:

Robert F. Chaillet, U. S. Army
Richard Coburn, U.S. Navy
E. W. Davenport, Ryan Aeronautical Company
John H. Duddy, Lockheed Missiles & Space Co.
Robert C. Hurst, General Dynamics Corporation
Jack A. Kraft, Lockheed Missiles & Space Co.
James R. Milligan, North American Aviation
Gerald E. Miller, Private Consultant
Heber G. Moore, U.S. Navy
Joseph L. Seminara, Lockheed Missiles & Space Co.
Robert B. Sleight, Century Research Corporation

Section 1

ANTHROPOMETRY & EQUIPMENT DESIGN

ANTHROPOMETRY AND EQUIPMENT DESIGN

ANTHROPOMETRY AND EQUIPMENT DESIGN

This section contains information most often used directly in the design of specific equipment. The information is arranged somewhat arbitrarily although similarly to other handbooks. Since all of the data has been drawn directly from other sources there are obvious overlaps. However, any redundancy was considered justified in that each data item appeared to have singular merit, either because of its format or its combination of related information

It should be recognized that data concerning protective garments is subject to constant revision as new equipment is developed. However, the data presented herein provides a reasonable point of departure for development of human engineering layouts and mockups.

It will be noted that certain state-of-the-art component data is provided. Although this material does not represent all of the hardware possibilities, the information should be useful in helping to establish ball-park panel space allocations.

The following specific references are suggested for additional reading:

Damon, A. et al - The Human Body in Equipment Design, Harvard Univ. Press, Cambridge, Mass., 1966.

Dreyfuss, H. - The Measure of Man: Human Factors in Design, Whitney Library of Design, 18 E. 50th St., New York, N. Y., 1967.

Woodson, W. E. & Conover, D. W. - Human Engineering Guide for Equipment Designers, Univ. Calif. Press, Berkeley, Calif., 1964.

Illuminating Engineering Society (I.E.S.) Lighting Handbook (3d Ed), 1860 Broadway, N. Y., 1959.

Morgan, C. T. et al - Human Engineering Guide to Equipment Design, McGraw-Hill Book Co., N. Y., 1963.

MIL-STD-1472 - Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 1968.

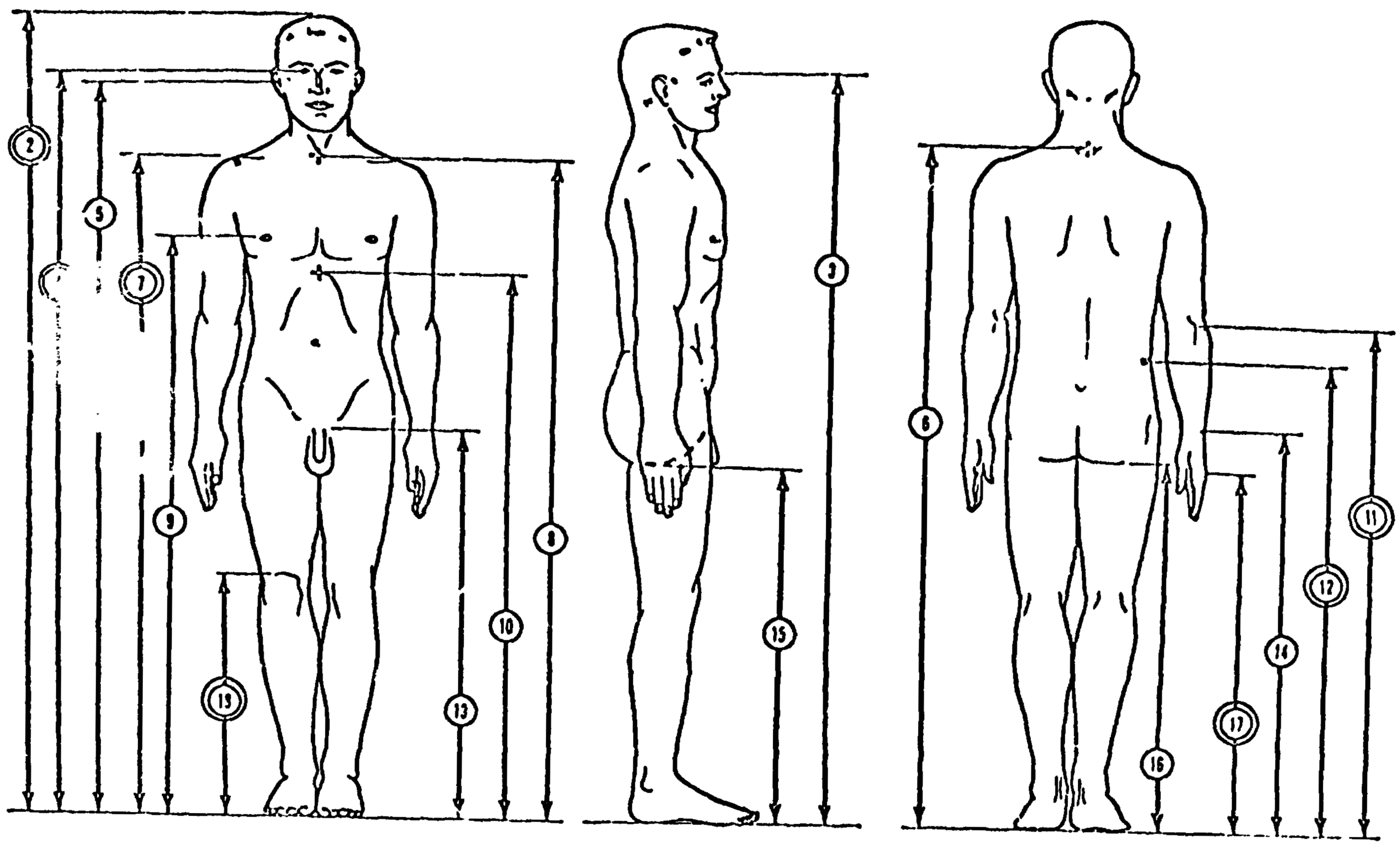
NASA MSFC-STD-267A - Human Engineering Design Criteria Study; Final Report, NASA Marshall Space Flight Center, Huntsville, Alabama, 1966.

Electronic Engineers Master (EEM): Manufacturer's Catalog, United Technical Publications, 645 Stewart Ave., Garden City, N. Y. (current issue).

ANTHROPOMETRY

The following data on human body dimensions are limited to the male military population. It will be noted that both nude and clothed dimensions are provided. The reader is cautioned to regard these data as useful primarily in establishing preliminary constraints in developing initial mockup dimensions. The human engineer is urged to seek further refinement of work place dimensions by evaluating preliminary mockup configurations, using live subjects whose dimensional characteristics are demonstrated in actually performing intended activities of reaching for controls, viewing exterior and interior visual displays, and testing the adequacy of clearances.

Additional information concerning limits of force application may be found in other sections of this volume. General requirements for establishing workplace shape and clearances may be found in the section on Equipment Design.



WEIGHT

1. Weight (Now Shown)

BODY LENGTHS

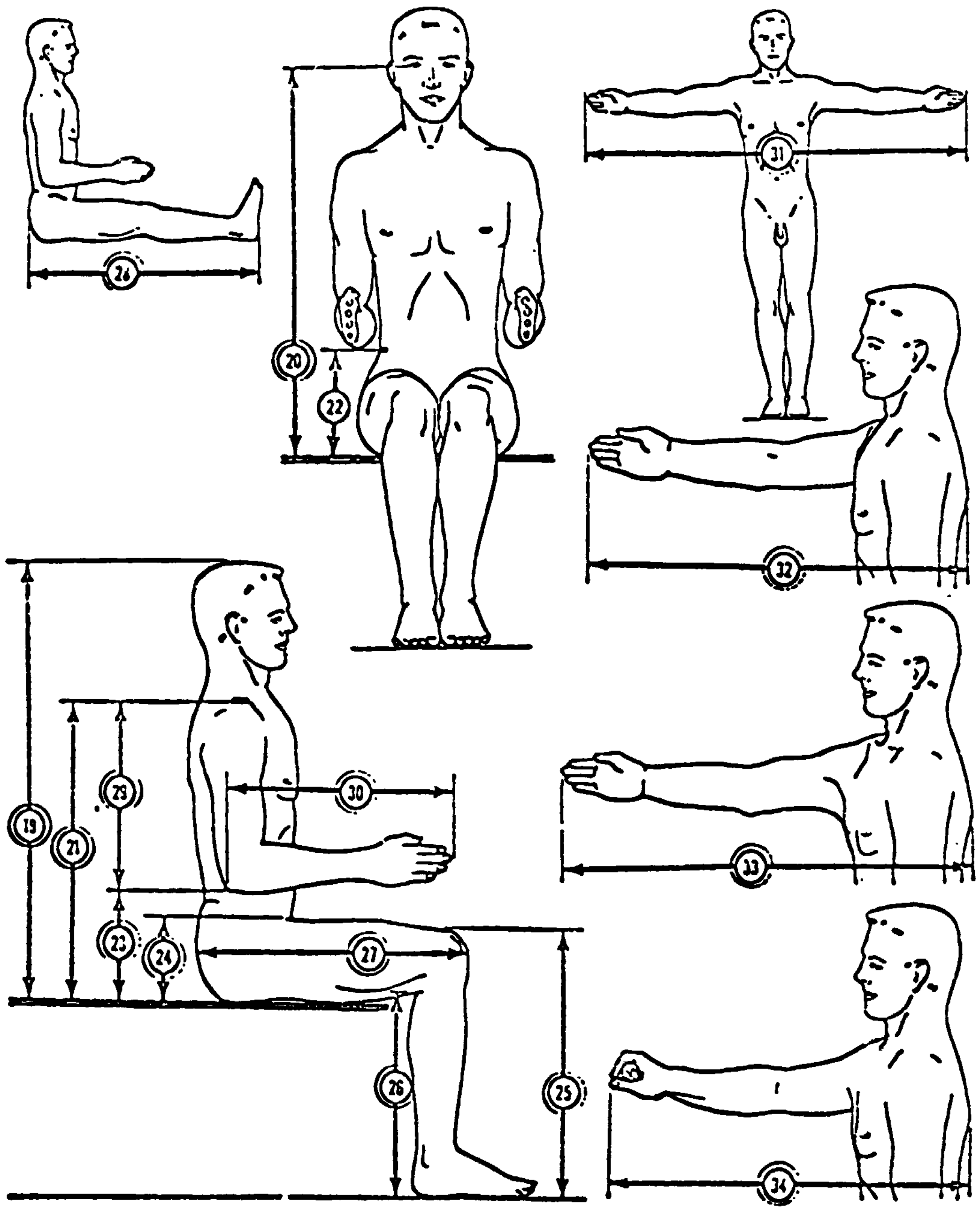
2. Stature
3. Nasal Root Height
4. Eye Height (Internal Canthus Height)
5. Tragion Height
6. Cervical Height
7. Shoulder Height (Acromial Height)
8. Suprasternale Height
9. Nipple Height
10. Substernale Height
11. Elbow Height
12. Waist Height
13. Penale Height
14. Wrist Height
15. Crotch Height (Inseam)
16. Gluteal Furrow Height
17. Knuckle Height
18. Kneecap Height

Body Lengths, Standing

ESTIMATED VALUES FOR ASTRONAUT BODY LENGTHS, STANDING

WADC No.[a]	Measurement Description	5th Percentile Astronaut				95th Percentile Astronaut			
		Basic Nude Dimension (in.)	Shirt-sleeve Design[b] (in.)	EMU Modes[c] (in.)		Basic Nude Dimension (in.)	Shirt-sleeve Design[b] (in.)	EMU Modes[c] (in.)	
				IVC Design 3.7 psia	EVC Design 3.7 psia			IVC Design 3.7 psia	EVC Design 3.7 psia
1	Weight[d]	132.5	139.9	187.7	279.5	200.8	208.2	256.0	347.8
2	Stature	65.2	65.7	68.2	69.5	73.1	73.6	76.1	77.4
4	Eye Height, Standing	60.8	61.1	61.8	62.3	68.6	68.9	69.6	70.1
6	Cervical Height, Standing	55.3	55.6	56.3	56.8	62.9	63.2	63.9	64.4
7	Shoulder (Acromial). Height, Standing	52.8	53.1	55.4	55.9	60.2	60.6	63.4	63.9
11	Elbow Height, Standing	40.6	40.9	42.1	42.6	46.4	46.7	47.9	48.4
12	Waist Height, Standing	39.1	39.4	40.1	40.6	45.0	45.3	46.0	46.5
17	Knuckle Height, Standing	27.7	28.0	29.7	30.2	32.4	32.7	34.4	34.9
18	Kneecap Height, Standing	18.4	18.7	19.4	19.9	21.9	22.2	22.8	23.4

a. Nude dimensions (Ref: WADC-TR-52-321, AF Flying Personnel - 1950.
b. Shirtsleeve garments.
c. Environmental Mobility Unit (EMU) intravehicular configuration (IVC) and extravehicular configuration (EVC). Allowance for portable life support unit not included.
d. Estimated values for clothing and personal equipment weights in pounds.



BODY LENGTHS (SITTING)

19. Sitting Height
20. Eye Height (Internal Canthus Height), S
21. Shoulder Height (Acromial Height), S
22. Waist Height, S
23. Elbow Rest Height, S
24. Thigh Clearance Height, S
25. Knee Height, S
26. Popliteal Height, S
27. Buttock-Knee Length
28. Buttock-Leg Length
29. Shoulder-Elbow Length
30. Forearm-Hand Length

BODY LENGTHS (REACHES)

31. Span
32. Arm Reach from Wall
33. Maximum Reach from Wall
34. Functional Reach

Body Lengths, Sitting

ESTIMATED DESIGN VALUES FOR ASTRONAUT BODY LENGTHS, SITTING

WADC No. (a)	Measurement Description	5th Percentile Astronaut				95th Percentile Astronaut			
		Basic Nude Dimension (in.)	Shirt-sleeve Design(b) (in.)	EMU Modes(c) (in.) IVC Design 3.7 psia	EMU Modes(c) (in.) EVC Design 3.7 psia	Basic Nude Dimension (in.)	Shirt-sleeve Design(b) (in.)	EMU Modes(c) (in.) IVC Design 3.7 psia	EMU Modes(c) (in.) EVC Design 3.7 psia
19	Sitting Height	33.6	34.1	36.5	37.9	38.0	38.3	40.3	41.7
20	Eye Height, Sitting	29.4	29.5	30.1	30.7	33.5	33.6	33.8	34.4
21	Shoulder (Acromial) Height, Sitting	21.3	21.4	23.9	24.3	25.1	25.2	27.3	28.7
23	Elbow Rest Height, Sitting	7.4	7.4	7.4	7.2	10.8	10.8	10.4	10.2
24	Thigh Clearance Height, Sitting	4.8	5.0	7.6	8.0	6.5	6.8	8.7	10.1
25	Knee Height, Sitting	20.1	20.5	22.5	23.8	23.3	23.7	25.4	26.7
26	Popliteal Height, Sitting	15.7	16.0	16.0	15.7	18.2	18.5	18.9	18.6
27	Buttock – Knee Length, Sitting	21.9	22.0	23.3	24.9	25.4	25.5	26.0	27.6
28	Buttock – Leg Length, Sitting	39.4	39.8	41.1	42.4	46.1	46.5	47.4	48.7
29	Shoulder – Elbow Length, Sitting	13.2	13.3	15.5	17.1	15.4	15.5	16.9	18.5
30	Forearm – Hand/Glove Length, Sitting	17.6	17.7	18.8	20.1	20.2	20.1	21.4	22.7
31	Span	65.9	65.9	66.9	67.9	75.6	75.6	76.6	77.6
32	Arm Reach From Wall	31.9	32.0	35.2	36.3	37.3	37.4	41.7	42.8
33	Maximum Arm Reach From Wall	35.4	35.5	38.7	39.8	41.7	41.8	46.1	47.2
34	Functional Reach	29.7	29.8	32.5	33.0	35.0	35.1	38.9	39.4

(a) Nude body dimensions obtained from Ref. 41.
(b) Shirtsleeve complement includes CWG, CWG Sandals, and Communications Cap.
(c) EMU Intravehicular Configuration (IVC) and Extravehicular Configuration (EVC) are shown in Fig. 35 and listed in Table 8; allowance for *PLSS* depth is not included in EVC measurement numbers.

BODY DIMENSIONS OF THE TEMPERATE ZONE CLOTHED 5TH AND 95TH PERCENTILE SOLDIER

	Basic Uniform		Additions to the Basic Uniform					
	Underwear, Khakis or O.D.'s or Fatigues, Socks, Shoes, Helmet and Liner		Blouse or Field Jacket		Blouse or Field Jacket Overcoat		Combat Suit, Overcoat, Gloves, and Wool Cap	
	5th	95th	5th	95th	5th	95th	5th	95th
Weight - in pounds	141.9	210.2	144.3	212.6	151.1	219.4	15[illegible].4	223.7
Body Dimensions - Inches								
A-1 Stature	67.8	75.8	67.8	75.8	67.8	75.8	67.9	75.9
D-1 Sitting Height	35.1	39.4	35.2	39.5	35.4	39.6	35.5	39.7
E-7 Eye Height, Sitting	29.4	33.5	29.5	33.6	29.6	33.7	29.7	33.8
D-2 Shoulder Height, Sitting	21.4	25.3	21.8	25.7	22.2	26.0	22.2	26.0
D-8 Knee Height, Sitting	21.4	24.6	21.4	24.6	21.5	24.7	21.5	24.7
D-6 Buttock-Knee Length	21.9	25.4	22.0	25.5	22.1	25.6	22.3	25.8
D-3 Shoulder-Elbow Length	13.3	15.5	13.7	15.9	14.1	16.3	14.1	16.3
E-1 Shoulder Breadth	16.7	19.6	17.4	20.3	18.0	20.9	18.0	20.9
C-1 Chest Breadth	11.0	13.6	11.1	13.7	11.3	13.9	11.5	14.1
E-2 Elbow Breadth	15.7	20.4	16.2	20.8	17.0	21.6	17.3	21.9
C-3 Hip Breadth	12.6	15.0	12.8	15.2	13.2	15.5	13.5	15.8
E-3 Hip Breadth, Sitting	13.2	16.0	13.4	16.2	13.8	16.5	14.1	16.8
E-4 Knee Breadth (both)	7.6	9.3	7.6	9.3	7.9	9.5	8.8	10.5
B-2 Chest Depth	8.4	10.8	8.9	11.4	9.8	12.2	9.8	12.2
L-6 Foot Length	11.0	12.7	11.0	12.7	11.0	12.7	11.0	12.7
L-4 Foot Breadth	4.0	4.5	4.0	4.5	4.0	4.5	4.0	4.5
M-7 Hand Length								
M-10 Hand Breadth								

NUDE BODY DIMENSIONS OF U. S. ARMY AVIATORS

Dimension	5th %	50th %	95th %
Weight (lbs)	135.9	166.5	199.7
Stature (inches)	65.8	69.4	73.3
Eye height, sitting	28.8	30.9	33.1
Head height	4.6	5.0	5.4
Head length	7.3	7.8	8.2
Sitting height	33.5	35.6	37.7
Crotch height	28.9	31.6	34.6
Shoulder breadth	16.8	18.2	20.0
Seat width, sitting	12.8	14.2	15.7
Kneecap height, sitting	18.9	20.9	22.8
Buttock-knee length	22.1	23.8	25.8
Arm reach forward	33.5	36.0	38.5
Arm reach upward	50.5	54.1	57.4
Leg length, sitting	42.1	44.9	47.6
Hand length	6.9	7.5	8.1
Hand breadth	3.2	3.5	3.8
Foot length	9.9	10.6	11.5
Foot breadth	3.6	4.0	4.4

U. S. Army QM TR-EP-150

PERCENTILES, MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF 25 ANTHROPOMETRIC VARIABLES FOR 1190 NAVY PILOTS (Weight in lbs; all other values in inches)

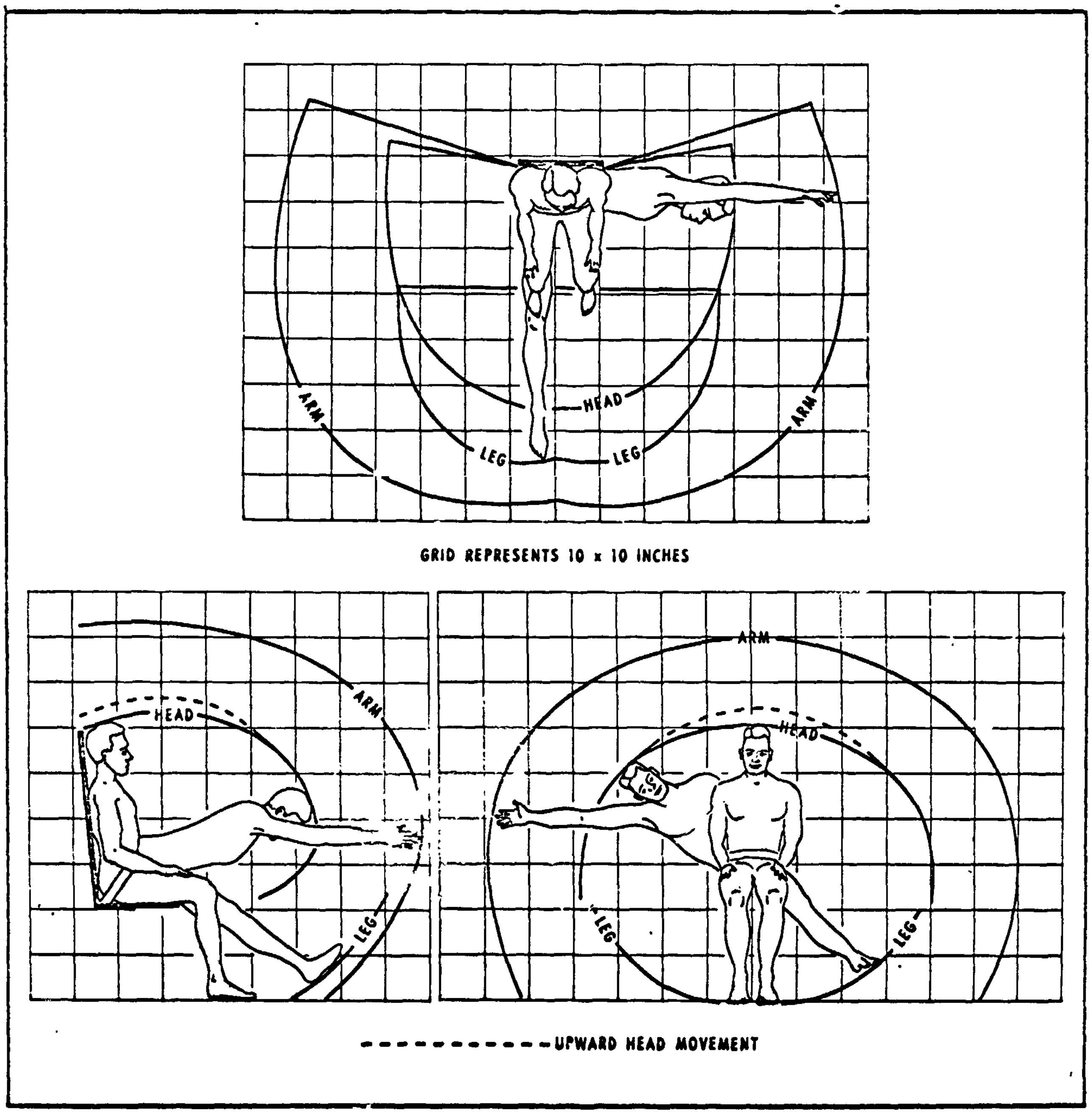
%ile	WEIGHT	SITTING HEIGHT	SHOULDER HEIGHT	EYE HEIGHT	ARM REACH	LEG LENGTH	SHOULDER CIRCUMFERENCE	NECK CIRCUMFERENCE	SCYE CIRCUMFERENCE	BICEPS CIRCUMFERENCE	CHEST CIRCUMFERENCE	VERTICAL TRUNK CIRCUMFERENCE	WAIST CIRCUMFERENCE
1	127.6	32.5	21.6	27.7	24.1	37.0	38.5	13.5	15.7	11.0	32.4	58.1	27.2
2	131.0	32.8	22.1	28.2	24.8	37.4	40.6	13.8	16.1	11.1	33.1	58.7	27.6
3	133.3	33.0	22.3	28.7	24.9	37.8	41.0	13.9	16.2	11.2	33.6	59.3	28.0
5	137.8	33.5	22.5	29.2	25.1	38.4	41.4	14.0	16.5	11.4	34.2	59.9	28.2
10	144.1	34.4	23.0	29.8	25.6	39.2	42.4	14.3	16.9	11.7	35.1	61.0	28.9
15	148.2	34.6	23.4	30.2	26.0	39.8	42.9	14.4	17.1	11.9	35.4	61.7	29.5
20	151.9	34.8	23.5	30.5	27.3	40.4	43.4	14.5	17.4	12.1	35.7	62.2	30.2
25	155.0	35.0	23.7	30.8	28.8	40.7	43.8	14.6	17.5	12.2	36.0	62.7	30.6
30	157.9	35.2	23.9	31.0	29.4	41.1	44.0	14.7	17.7	12.3	36.4	63.1	30.9
35	160.7	35.4	24.1	31.2	30.1	41.4	44.3	14.8	17.8	12.4	36.7	63.5	31.3
40	163.0	35.6	24.2	31.4	30.5	41.8	44.6	14.8	17.9	12.6	37.0	63.9	31.7
45	165.2	35.8	24.5	31.6	30.9	42.1	44.8	14.9	18.1	12.9	37.3	64.4	32.0
50	167.4	36.0	24.6	31.7	31.4	42.5	45.2	15.0	18.3	13.0	37.6	64.9	32.3
55	169.7	36.3	24.8	31.9	31.6	42.8	45.5	15.1	18.5	13.1	37.8	65.3	32.7
60	172.1	36.5	24.9	32.1	31.9	43.1	45.8	15.3	18.7	13.2	38.1	65.6	33.0
65	174.5	36.6	25.1	32.4	32.2	43.4	46.1	15.5	18.9	13.3	38.4	65.9	33.4
70	177.0	36.8	25.2	32.7	32.5	43.8	46.4	15.6	19.1	13.4	38.6	66.3	33.7
75	180.3	37.0	25.5	33.0	32.8	44.2	46.7	15.7	19.3	13.5	39.0	66.7	34.0
80	183.7	37.1	25.8	33.2	33.2	44.6	47.3	15.8	19.5	13.7	39.4	67.2	34.4
85	187.5	37.5	26.0	33.5	33.6	45.2	47.9	16.0	19.8	13.9	39.9	67.7	34.8
90	191.7	37.8	26.4	33.7	34.2	45.8	48.6	16.2	20.0	14.0	40.6	68.6	35.5
95	198.8	38.4	27.1	34.2	35.0	46.6	49.3	16.5	20.7	14.5	41.5	69.8	36.7
97	204.0	38.9	27.5	34.5	35.5	47.3	50.0	16.6	21.1	14.8	42.0	70.6	37.4
98	208.3	39.2	28.0	34.8	35.9	47.8	50.4	16.8	21.3	14.9	42.2	71.6	37.8
99	213.5	39.9	29.3	35.0	36.4	48.6	50.8	17.0	21.6	15.1	43.0	72.7	38.7
Mean:	167.44	36.02	24.65	31.75	30.60	42.48	45.31	15.15	18.39	12.92	37.59	64.76	32.37
	(0.53)	(0.04)	(0.04)	(0.04)	(0.09)	(0.07)	(0.07)	(0.02)	(0.04)	(0.03)	(0.06)	(0.09)	(0.07)
S. D.:	18.25	1.45	1.47	1.50	3.06	2.49	2.38	0.75	1.25	0.91	2.19	2.97	2.48
	(0.38)	(0.03)	(0.03)	(0.03)	(0.06)	(0.05)	(0.05)	(0.02)	(0.03)	(0.02)	(0.05)	(0.06)	(0.05)
Range: (Min.)	118.00	31.25	20.50	26.50	23.00	35.00	34.00	12.50	13.00	10.25	29.25	54.00	26.00
(Max.)	228.00	41.00	35.00	36.00	41.00	51.00	54.75	18.00	22.50	16.00	46.75	74.50	42.00
C. V.: (%)	10.90	4.03	5.96	4.72	10.00	5.86	5.25	4.95	6.80	7.04	5.83	4.59	7.66
	(0.23)	(0.08)	(0.12)	(0.10)	(0.21)	(0.12)	(0.11)	(0.10)	(0.14)	(0.15)	(0.12)	(0.09)	(0.16)

%ile	LOWER ARM CIRCUMFERENCE	UNDERARM TO FINGERTIP	OVERALL HEIGHT	BUTTOCK CIRCUMFERENCE (STANDING)	THIGH CIRCUMFERENCE	CROTCH HEIGHT	CALF CIRCUMFERENCE	BUTTOCK CIRCUMFERENCE (SITTING)	HEAD BREADTH	HEAD HEIGHT	HEAD LENGTH	SHOE SIZE
1	9.7	22.6	64.9	33.1	18.1	28.5	12.3	34.7	5.3	4.3	7.0	6.6
2	9.9	24.2	66.0	33.7	18.9	29.4	12.6	35.2	5.4	4.4	7.0	6.8
3	10.1	24.6	66.2	33.9	19.2	29.7	12.7	35.6	5.4	4.5	7.1	7.0
5	10.3	24.9	66.5	34.4	19.7	30.3	12.9	36.3	5.5	4.8	7.2	7.2
10	10.7	25.5	67.3	35.5	20.3	30.9	13.2	37.3	5.7	5.0	7.4	7.8
15	10.8	25.8	67.7	35.9	20.9	31.3	13.4	37.9	5.8	5.0	7.4	8.1
20	11.0	26.0	68.2	36.3	21.1	31.7	13.6	38.5	5.9	5.1	7.5	8.4
25	11.2	26.3	68.6	36.7	21.4	32.0	13.8	38.9	6.0	5.2	7.5	8.6
30	11.3	26.5	69.0	37.0	21.6	32.4	13.9	39.2	6.0	5.2	7.6	8.8
35	11.4	26.7	69.4	37.3	21.9	32.7	14.0	39.4	6.0	5.3	7.6	9.0
40	11.5	26.9	69.8	37.6	22.1	33.1	14.1	39.7	6.0	5.3	7.7	9.2
45	11.6	27.0	70.1	37.9	22.4	33.4	14.2	40.0	6.0	5.4	7.8	9.4
50	11.7	27.2	70.3	38.1	22.6	33.7	14.3	40.3	6.1	5.4	7.8	9.6
55	11.8	27.4	70.6	38.4	22.8	34.0	14.4	40.6	6.1	5.5	7.8	9.7
60	11.9	27.5	70.8	38.6	23.0	34.4	14.6	41.0	6.2	5.5	7.9	9.8
65	12.0	27.7	71.1	38.8	23.2	34.7	15.0	41.3	6.3	5.6	7.9	9.8
70	12.1	28.0	71.4	39.1	23.4	35.0	15.1	41.7	6.3	5.6	8.0	9.9
75	12.2	28.2	71.8	39.4	23.6	35.4	15.2	42.1	6.3	5.7	8.0	10.0
80	12.3	28.4	72.2	39.7	24.0	35.7	15.3	42.4	6.5	5.8	8.0	10.2
85	12.5	28.7	72.7	40.0	24.3	36.1	15.5	42.9	6.5	5.8	8.1	10.4
90	12.7	29.1	73.4	41.0	24.8	36.6	15.7	43.5	6.6	5.9	8.2	10.8
95	12.9	29.6	74.3	41.8	25.9	37.6	16.1	44.3	6.6	6.0	8.6	11.4
97	13.0	30.2	74.8	42.4	26.5	38.4	16.3	45.2	6.6	6.2	8.7	11.8
98	13.3	30.5	75.0	42.7	26.9	38.9	16.5	45.8	6.7	6.4	8.7	12.1
99	13.6	31.3	75.8	43.5	27.3	39.6	16.5	46.6	6.7	6.8	8.8	12.4
Mean:	11.64	27.26	70.24	38.11	22.56	33.72	14.47	40.43	6.12	5.43	7.82	9.37
	(0.02)	(0.04)	(0.07)	(0.06)	(0.05)	(0.07)	(0.03)	(0.07)	(0.01)	(0.01)	(0.01)	(0.03)
S. D.:	0.77	1.50	2.36	2.11	1.85	2.26	0.91	2.41	0.31	0.44	0.39	1.21
	(0.02)	(0.03)	(0.05)	(0.04)	(0.04)	(0.05)	(0.02)	(0.05)	(0.01)	(0.01)	(0.01)	(0.02)
Range: (Min.)	8.50	19.75	60.00	31.00	16.37	25.50	11.50	32.12	5.00	4.00	6.00	5.53
(Max.)	17.00	34.50	78.50	44.50	30.00	40.75	18.00	52.00	7.00	7.00	9.00	14.04
C. V.: (%)	6.62	5.50	3.36	5.54	8.20	6.70	6.29	5.96	5.07	8.10	4.99	12.91
	(0.14)	(0.11)	(0.07)	(0.11)	(0.17)	(0.14)	(0.13)	(0.12)	(0.10)	(0.17)	(0.10)	(0.27)

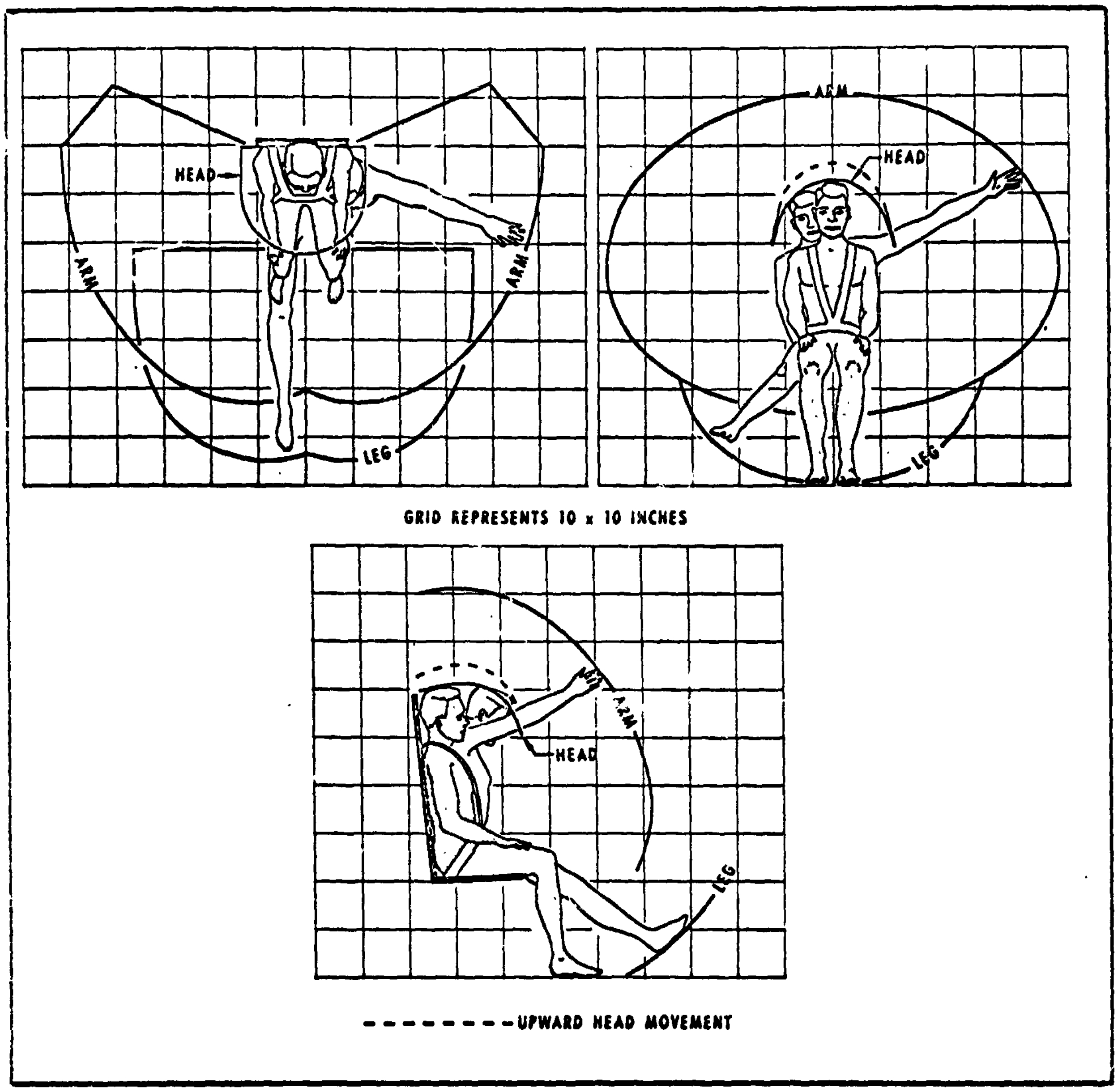
BODY DIMENSION DATA FOR U.S.NAVY TECHNICIANS

Dimension Category	5th %	50 %	95 %
Standing Height	66.2	69.9	73.9
Standing Eye Height	61.3	64.8	68.8
Standing Shoulder Height	53.8	57.1	60.8
Standing Elbow Height	39.4	42.2	45.3
Standing Crotch Height	32.3	34.9	37.8
Sitting Head Height	34.2	36.3	38.4
Sitting Eye Height	29.7	31.5	33.6
Sitting Shoulder Height	22.0	23.8	25.5
Sitting Elbow Height	7.6	9.3	10.9
Knee Height	20.3	21.8	23.5
Knee Clearance	22.5	24.1	26.1
Seat Height	15.9	17.3	18.8
Shoulder Width	15.8	17.6	19.4
Forward Reach	29.3	31.4	34.0
Side Reach	32.3	33.8	36.3
Forearm/Hand Length	17.9	19.1	20.4

NAEC - Air Crew Equipment Laboratory



EXTREMITY STRIKE ENVELOPE: Survival Clearance with Lap Belt

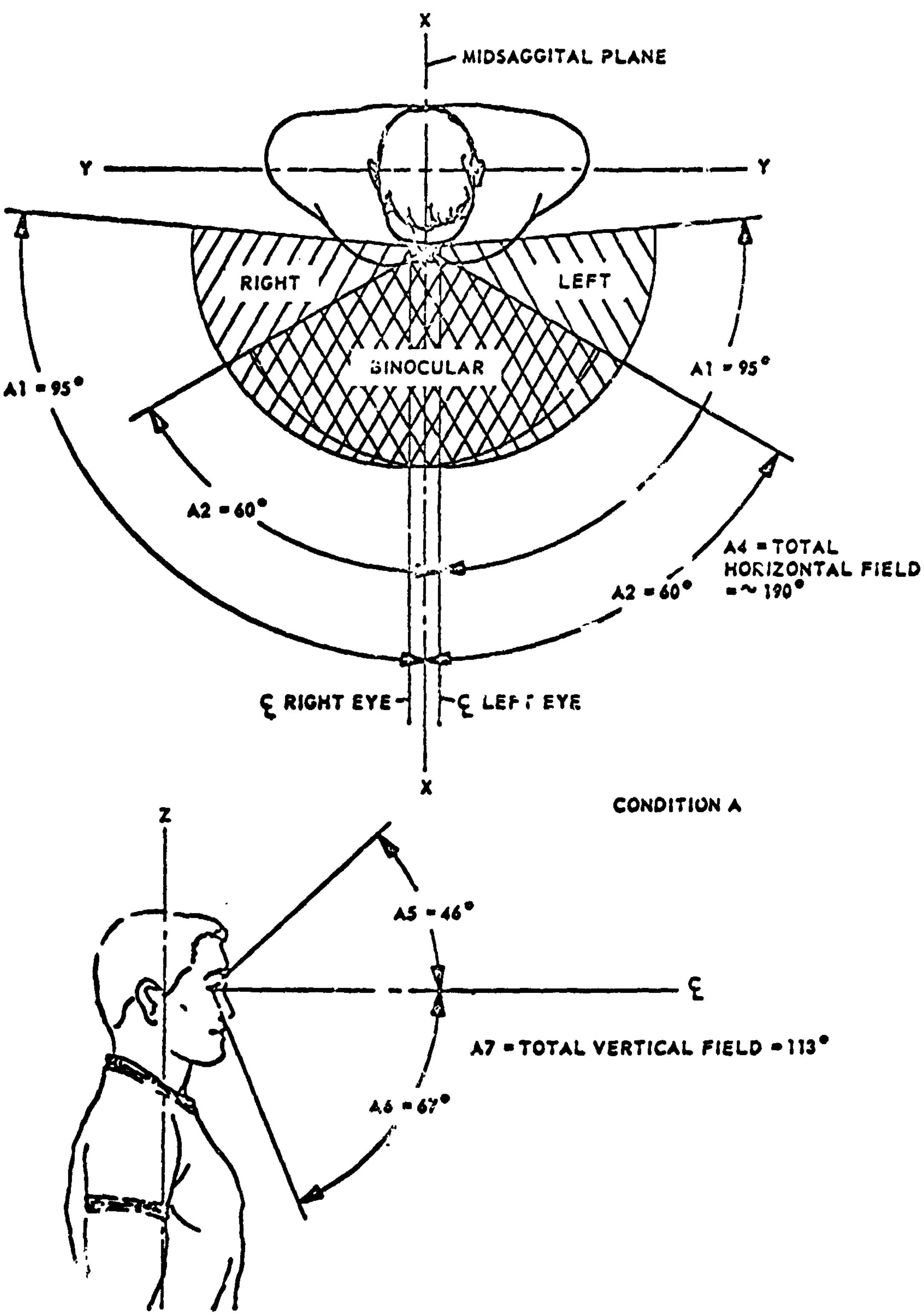


EXTREMITY STRIKE ENVELOPE (with full restraint system)

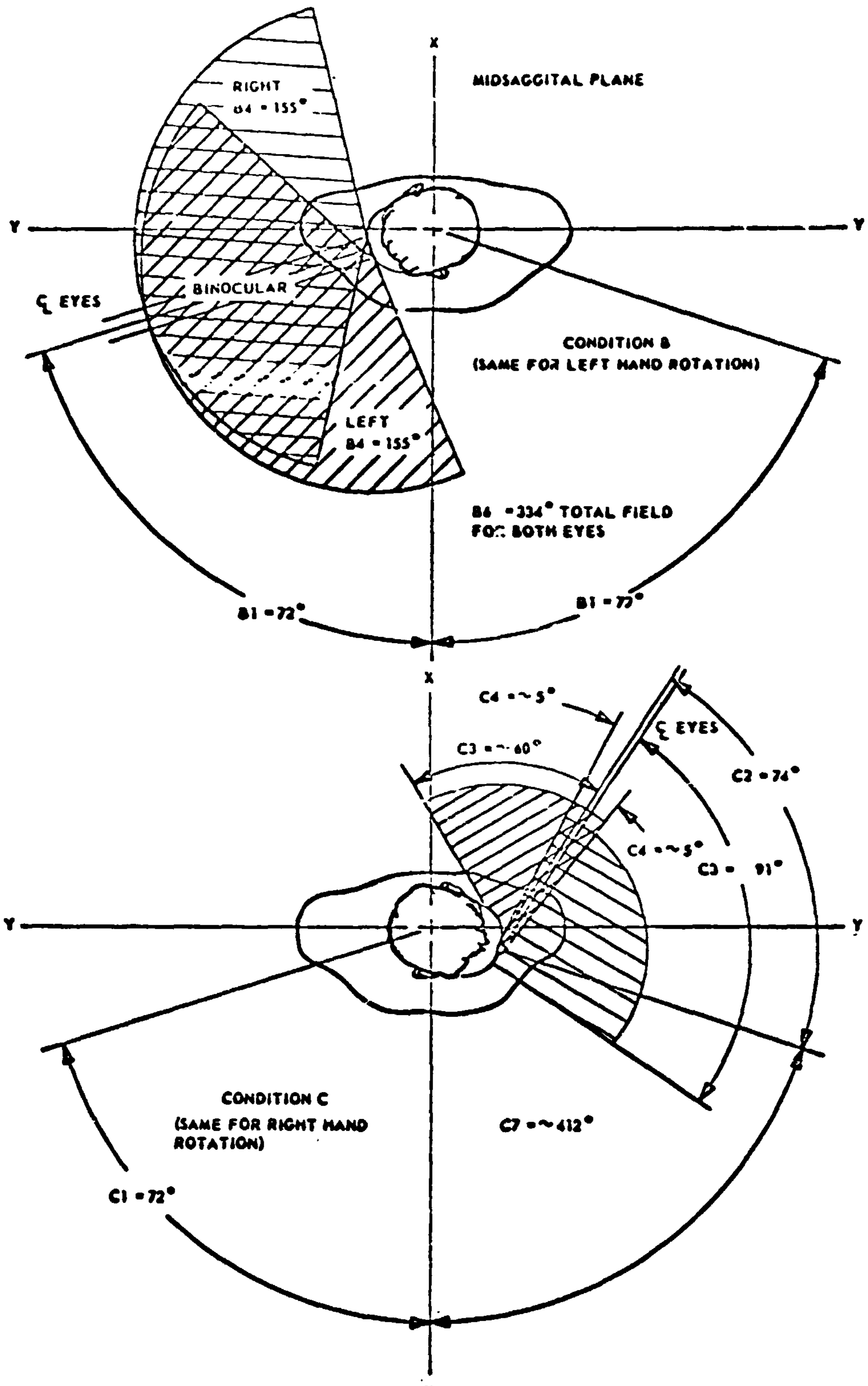
NORMAL AND ESTIMATED VISUAL FIELDS[a]

Condition	Limit Measurement	Shirtsleeve or PGA Helmet Off (deg)	PGA Helmet On, Estimated (deg)	Estimated Decrement Due to Helmet (deg)
A – Head and eyes fixed facing front	A1 – Angle from CL of eye to right and left limits	95	95	0
	A2 – Angle from CL of eye to nose interference	60	60	0
	A3 – Total horizontal field either eye	155	155	0
	A4 – Total horizontal field both eyes	190	190	0
	A5 – Angle from CL of eye to brow interference (up)	46	46	0
	A6 – Angle from CL of eye to cheek interference (down)	67	67	0
	A7 – Total vertical field both eyes	113	113	0
B – Head rotated to normal limits about Z axis; eyes fixed facing front	B1 – Limit of head rotation to right and left	72	30	42
	B2 – Same as A1	95	95	0
	B3 – Same as A2	60	60	0
	B4 – Same as A3	155	155	0
	B5 – Total horizontal visual field for either eye with head rotation	299	215	84
	B6 – Total horizontal visual field for both eyes with head rotation	334	250	84
	B7 – Same as A5	46	46	0
	B8 – Same as A6	67	67	0
	B9 – Same as A7	113	113	0
C – Head rotated to normal limits about Z axis; eyes rotated to normal limits in X-Y plane (See Fig. 71)	C1 – Same as B1	72	72 (30)[b]	0 (42)[b]
	C2 – Limit of eye rotation to right and left	74	74	0
	C3 – Same as A1	91 (60)[b]	91 (35)[b]	0 (25)[b]
	C4 – Same as A2	5 (5)[b]	5 (5)[b]	0 (0)[b]
	C5 – Same as A3	96 (65)[b]	96 (40)[b]	0 (25)[b]
	C6 – Total horizontal visual field for either eye with head and eye rotation	242 (211)[b]	242 (144)[b]	0 (67)[b]
	C7 – Total horizontal visual field for both eyes with head and eye rotation	412 (52 overlap)	278	134
	C8 – Same as A5	46	46	0
	C9 – Same as A6	67	67	0
	C10 – Same as A7	113	113	0
D – Head fixed facing front; eyes rotated to normal limits in X-Z plane	D1 – Normal limit of eye rotation (up)	48	48	0
	D2 – Same as A5	18	18	0
	D3 – Normal limit of eye rotation (down)	66	66	0
	D4 – Same as A6	16	1	15
	D5 – Same as A7	148	133	15
E – Head and eyes rotated to normal limits in X-Z plane	E1 – Estimated limit of head rotation (up)	80	15	65
	E2 – Same as D1	48	48	0
	E3 – Same as A5	18	18	0
	E4 – Estimated limit of head rotation (down)	90	20	70
	E5 – Same as D3	66	45	21
	E6 – Same as A6	16	0	16
	E7 – Same as A7	318	146	172

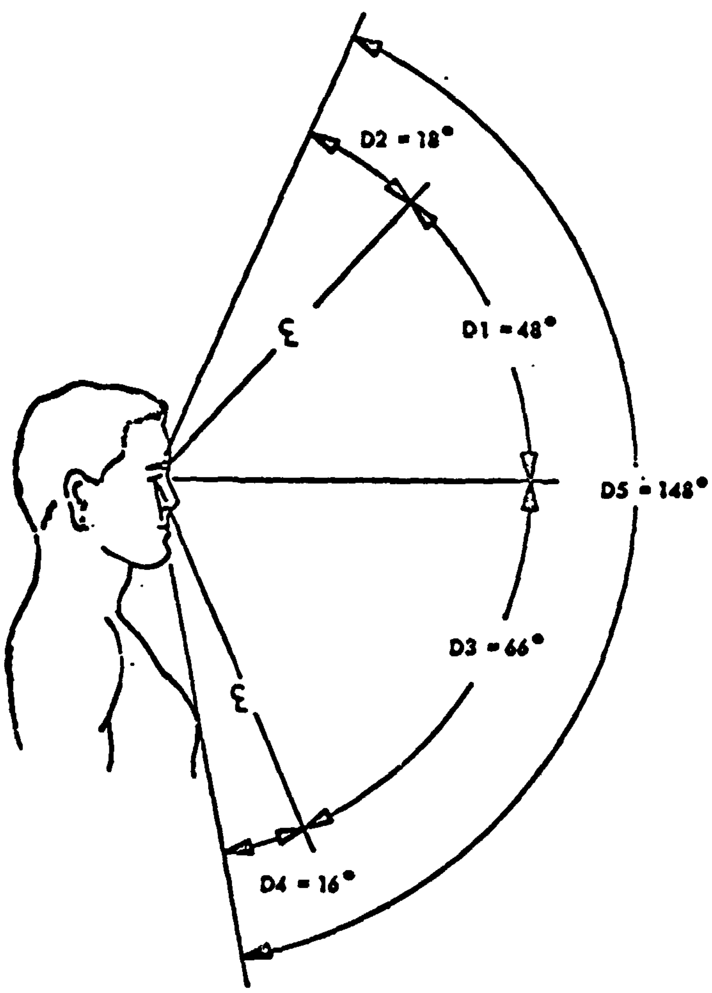
(a) Bioastronautics Databook
(b) Opposite eye



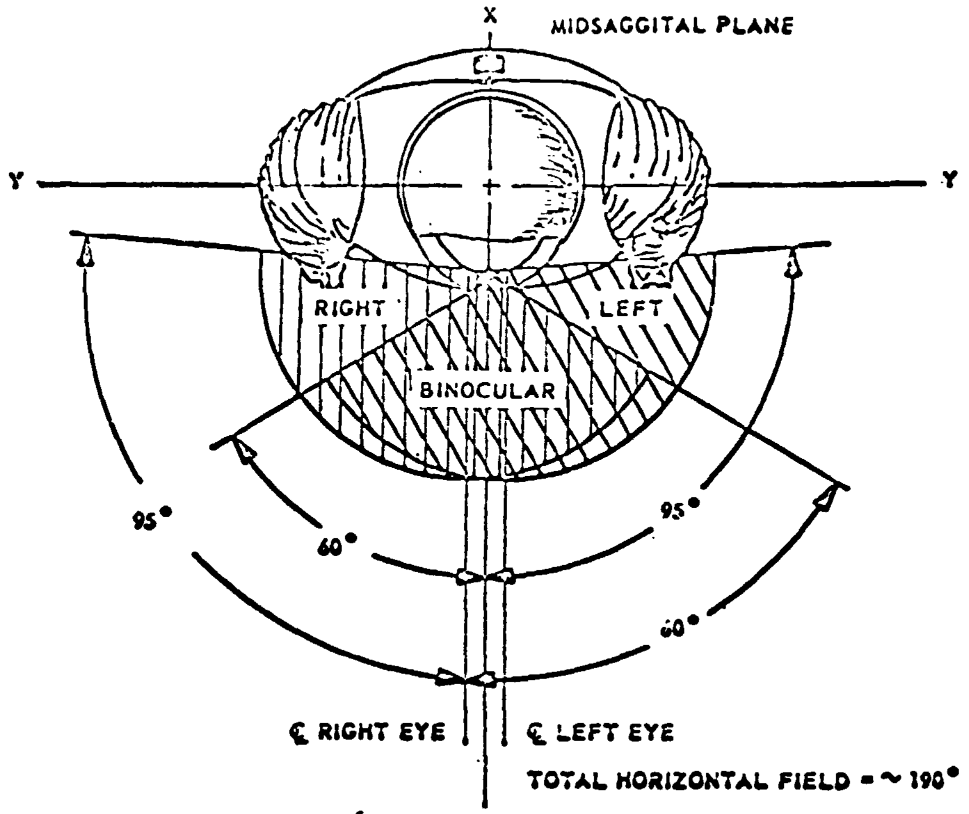
Normal Monocular and Binocular Visual Fields With Head and Eyes Fix

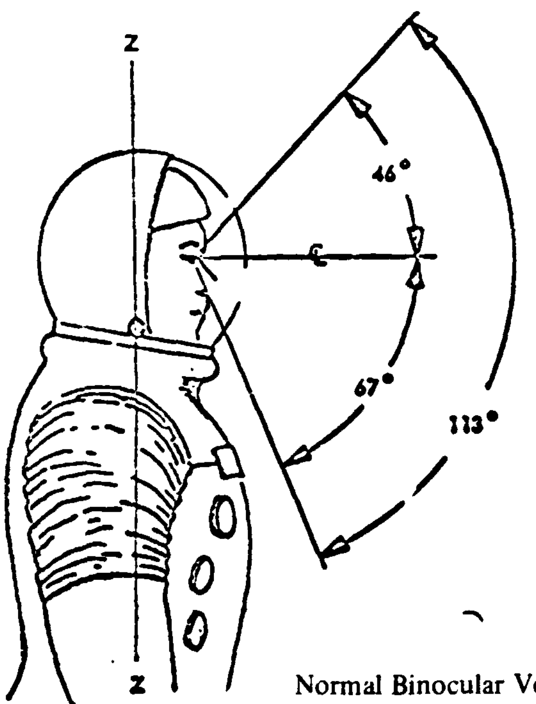


Visibility Afforded by Pressure Suit Assembly
Helmet with Head and Eyes Fixed



Normal Monocular and Binocular Visual
Fields with Head and Eyes Moving





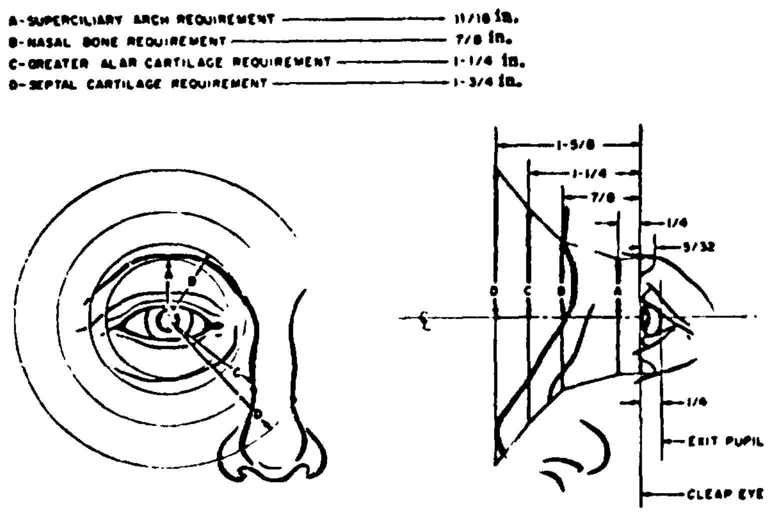
Normal Binocular Vertical Visual Field With Head Fixed and Eyes Moving

AVAILABLE VIEWING ANGLES FOR VARYING WINDOW PORT DIAMETERS AND VARYING VIEWINGS DISTANCES FROM PORTS

Viewing Distance From Port (in Inches)	Diameter of Window Port in Inches					
	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
1	148°	155°	159°	162°	165°	167°
* 2	120°	132°	140°	145°	150°	153°
** 3	98°	108°	121°	130°	136°	141°
4	82°	97°	108°	117°	124°	130°
5	70°	84°	95°	105°	112°	119
6	60°	74°	85°	94°	102°	109°
7	52°	65°	76°	86°	94°	101°
8	48°	59°	69°	73°	87°	94°
9	42°	53°	63°	72°	80°	87°
10	39°	49°	58°	66°	74°	81°
11	35°	44°	53°	61°	68	75°
12	33°	42°	50°	57°	64°	71°
13	30°	37°	46°	53°	60°	66°
14	28°	36°	43°	50°	57°	63
15	26°	33°	40°	46°	53°	59°
16	25°	32°	38°	45°	50°	56°
17	23°	29°	36°	42°	45°	53

*Closest Distance Crewman with Gemini Helmet on and Visor Up can Get to Window Port.

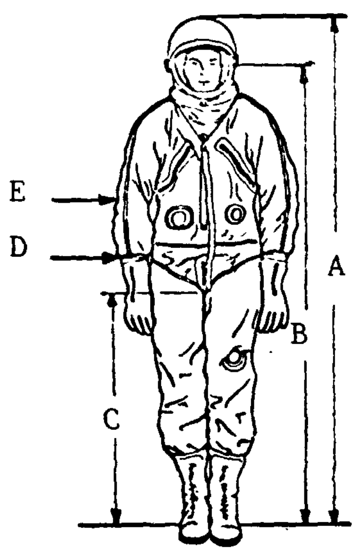
**Closest Distance Crewman with Gemini Helmet on and Visor Down Can Get to Window Port.



ANATOMICAL LIMITS ON AXIALLY SYMMETRICAL OCULAR METAL PARTS

Exit pupil size	
Daylight viewing (mm)	4 (minimum)
Night viewing (mm)	8 (minimum)
Exit pupil - glass surface (mm)	12 (minimum)
Eye relief (with helmet) (mm)	15 (minimum)
Focusing (diopters)	±4 (minimum)
Reticle lines (min)	0.5 (minimum) 2.0 (maximum)
Binocular instruments	
Interpupillary adjustability (mm)	50-76
Magnification difference to the two eyes (%)	2 (maximum)
Emitted light difference to the two eyes (%)	10 (maximum)
Weight of hand-held binoculars (lb)	2.0 (maximum)

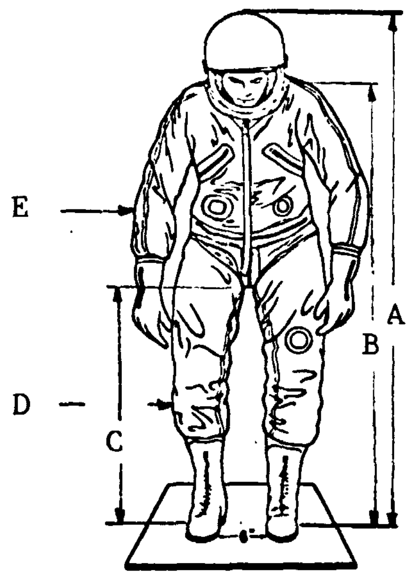
Recommendations for Design of Optical Viewing Devices



A/P22S-2 Full Pressure Suit
(Unpressurized)

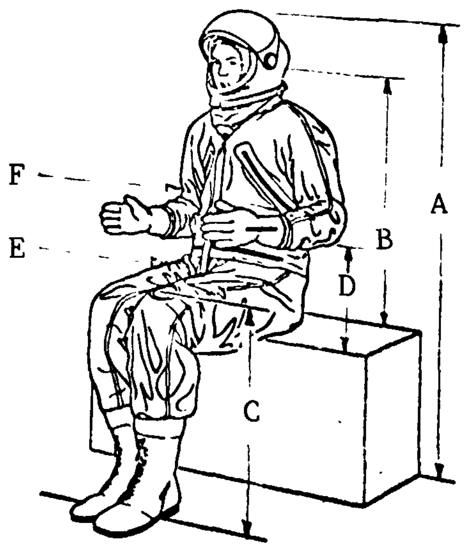
		Dimensions in inches	
		Small	Large
A.	Stature	66.6	75.7
B.	Eye Height	60.5	69.7
C.	Crotch Height	29.0	-
D.	Hip Breadth	-	14.8
E.	Max. Arm/Arm Breadth	-	25.2

Extracted from: AMRL-TR-69-6, Anthropometric Dimensions of Air Force Pressure-Suited Personnel for Workspace and Design Criteria by Milton Alexander et al.



A/P22S-2 Full Pressure Suit
(Pressurized)

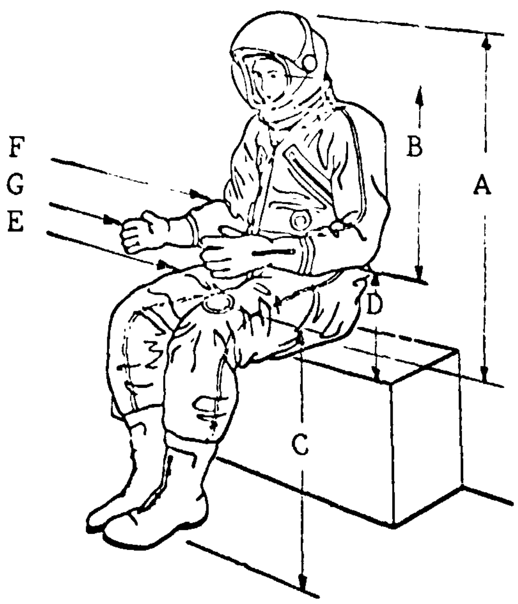
		Dimensions in inches	
		Small	Large
A.	Stature	63.1	72.3
B.	Eye Height	55.7	65.8
C.	Crotch Height	28.3	-
D.	Knee/Knee Breadth, widest point	-	20.5
E.	Max. Arm/Arm Breadth	-	35.2



A/P22S-2 Full Pressure Suit
(Unpressurized)

Dimensions in inches

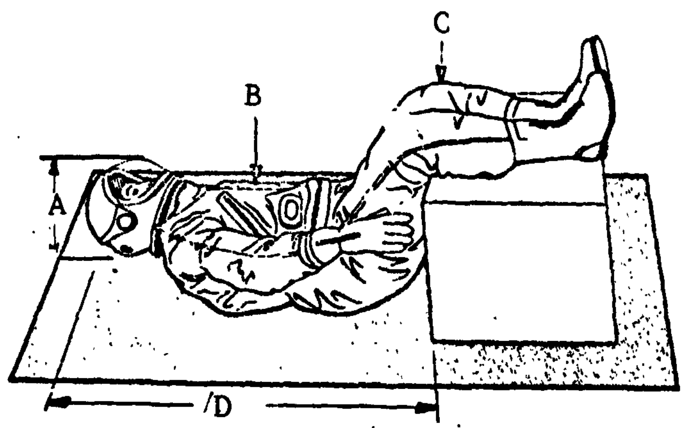
	Small	Large
A. Head Height	35.2	39.4
B. Eye Height	data not available	
C. Max. Thigh Height	-	26.4
D. Elbow Height	7.5	10.7
E. Buttock Width	-	16.0
F. Elbow/Elbow Width	18.3	23.1



A/P 22S-2 Full Pressure Suit
(Pressurized)

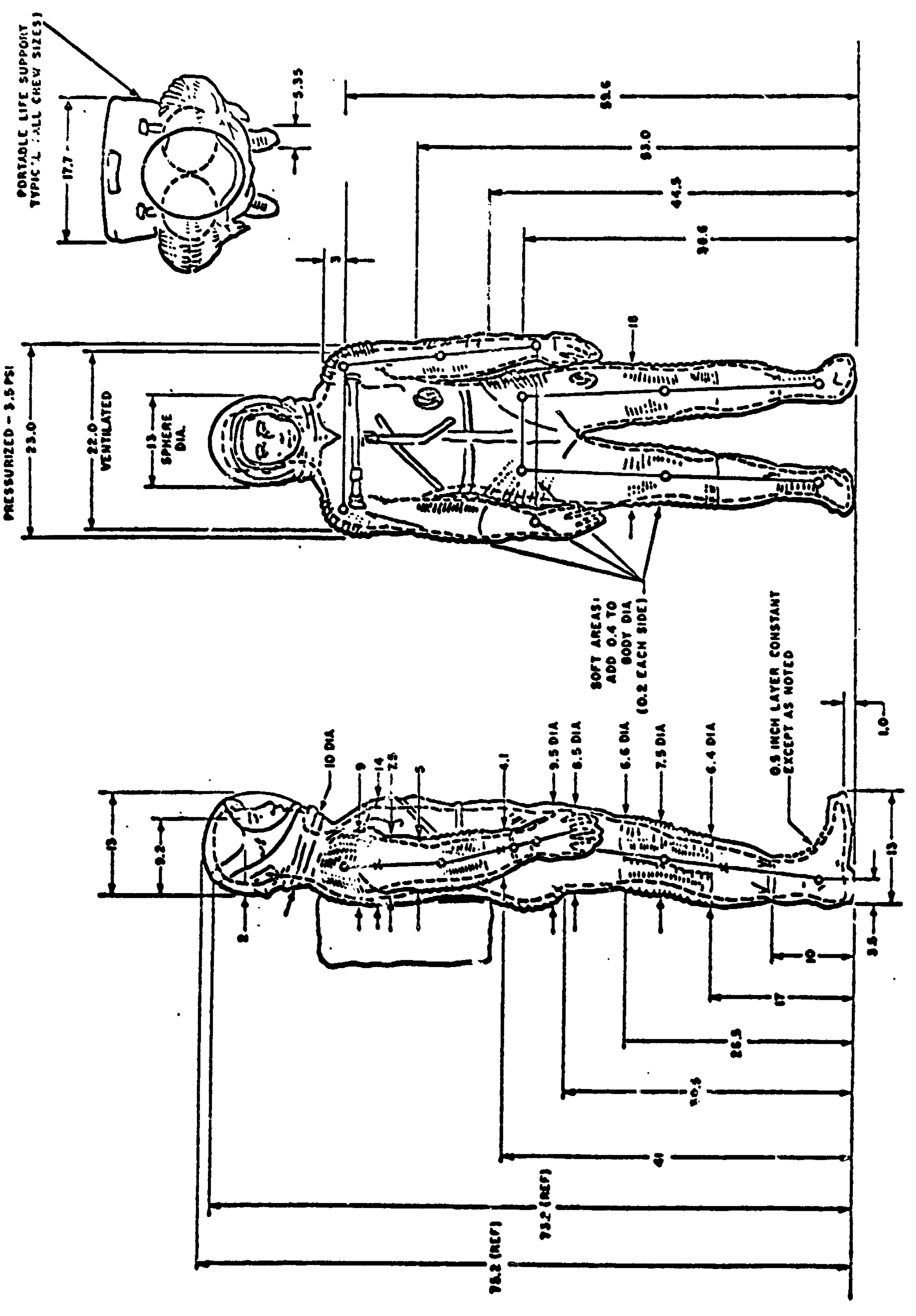
Dimensions in inches

		Small	Large
A.	Head Height	36.0	40.8
B.	Eye Height	data not available	
C.	Max. Thigh Height	-	29.0
D.	Elbow Height	7.8	11.7
E.	Buttock Width, Max.	-	24.7
F.	Elbow/Elbow Width	21.6	31.4
G.	Max. Hand/Hand Breadth	-	34.6



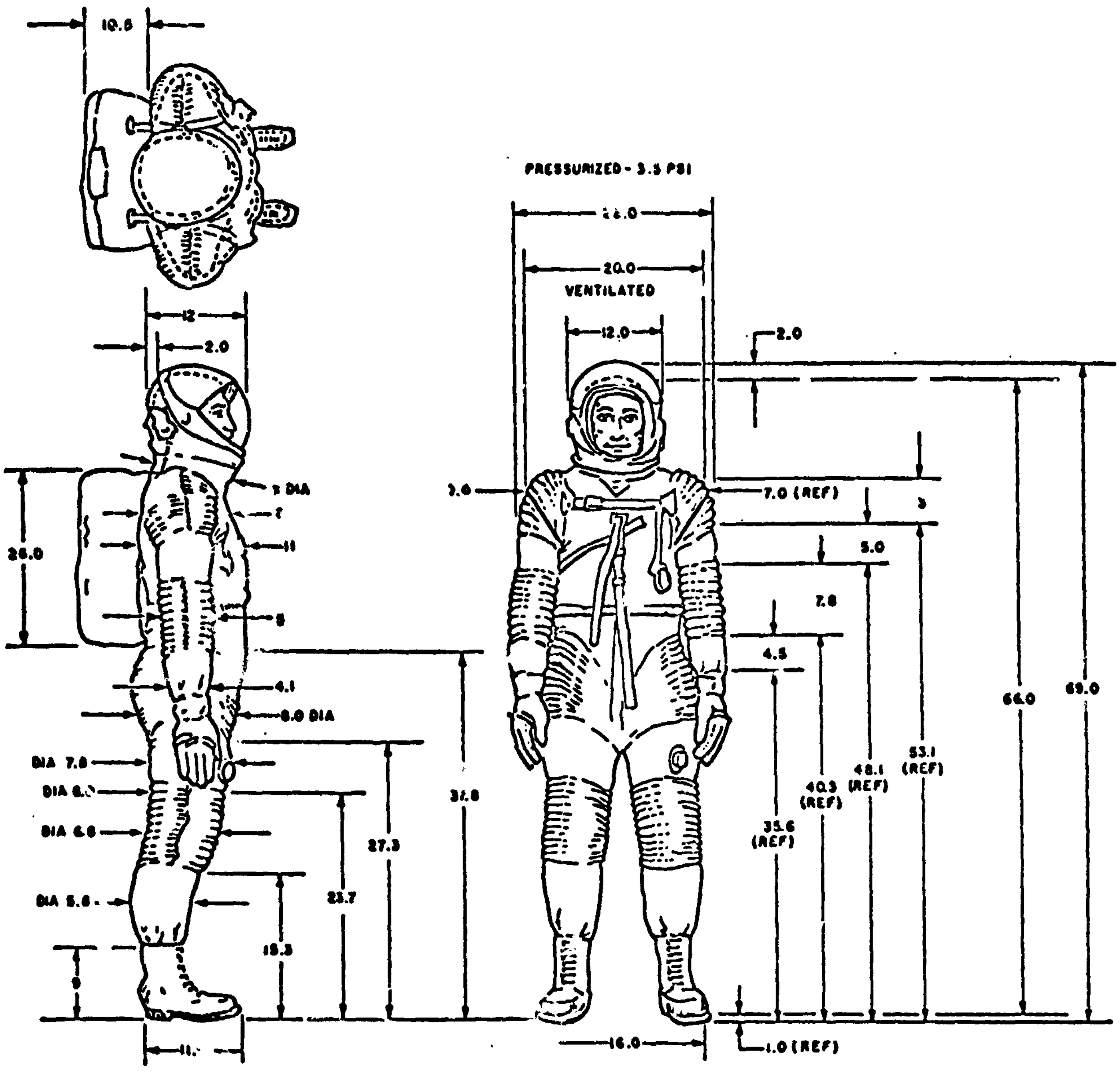
A/P22S-2 Full Pressure Suit
(Supine, Pressurized)

		Large (inches
A.	Helmet Depth	19.7
B.	Chest Depth	15.1
C.	Knee/Buttock Depth	24.1
D.	Buttock/Helmet Length	45.1

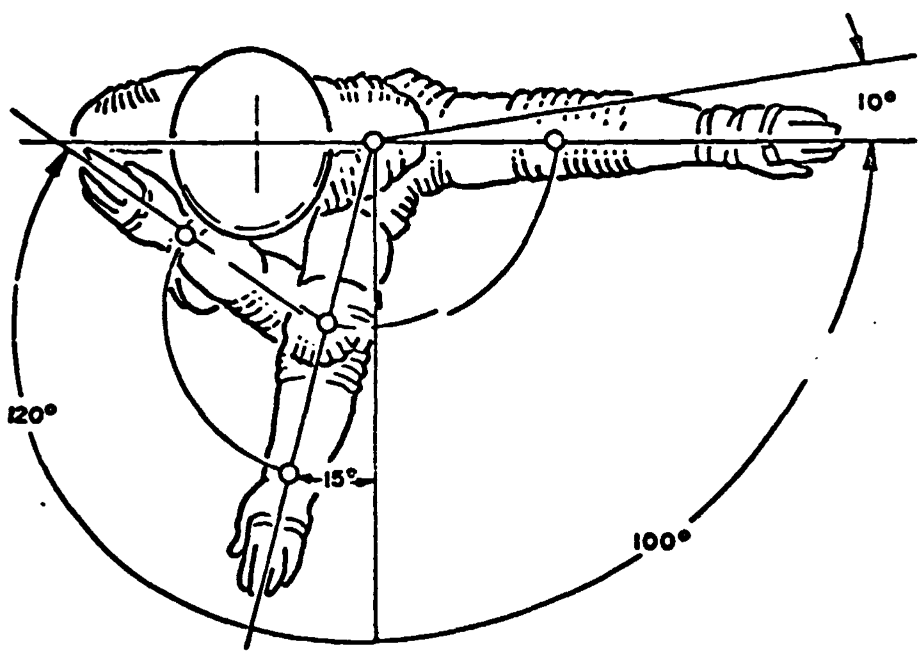


90th Percentile Astronaut, Pressure Garment Assembly (3.5 psi)

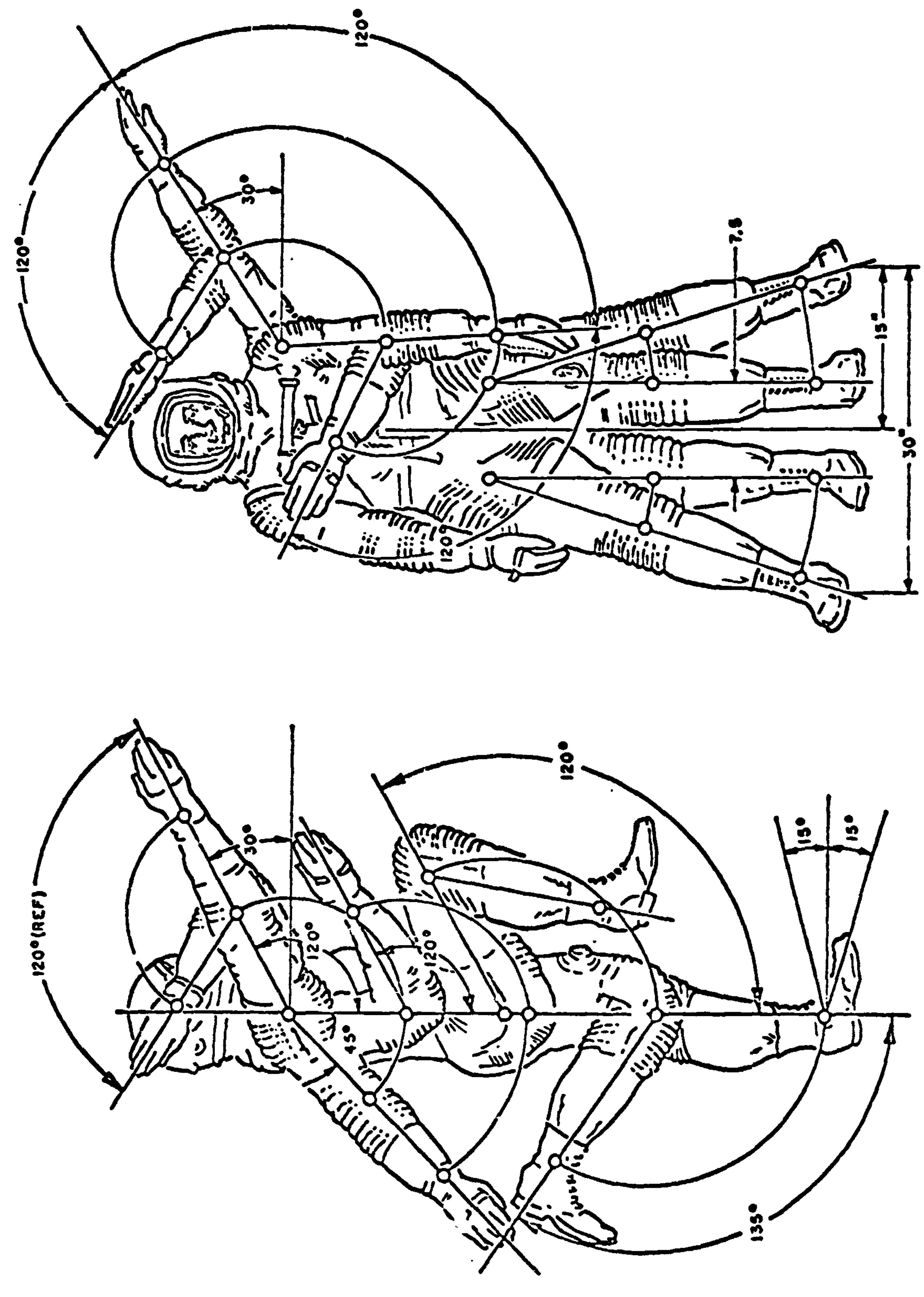
Typical Dimensions (A6-L)



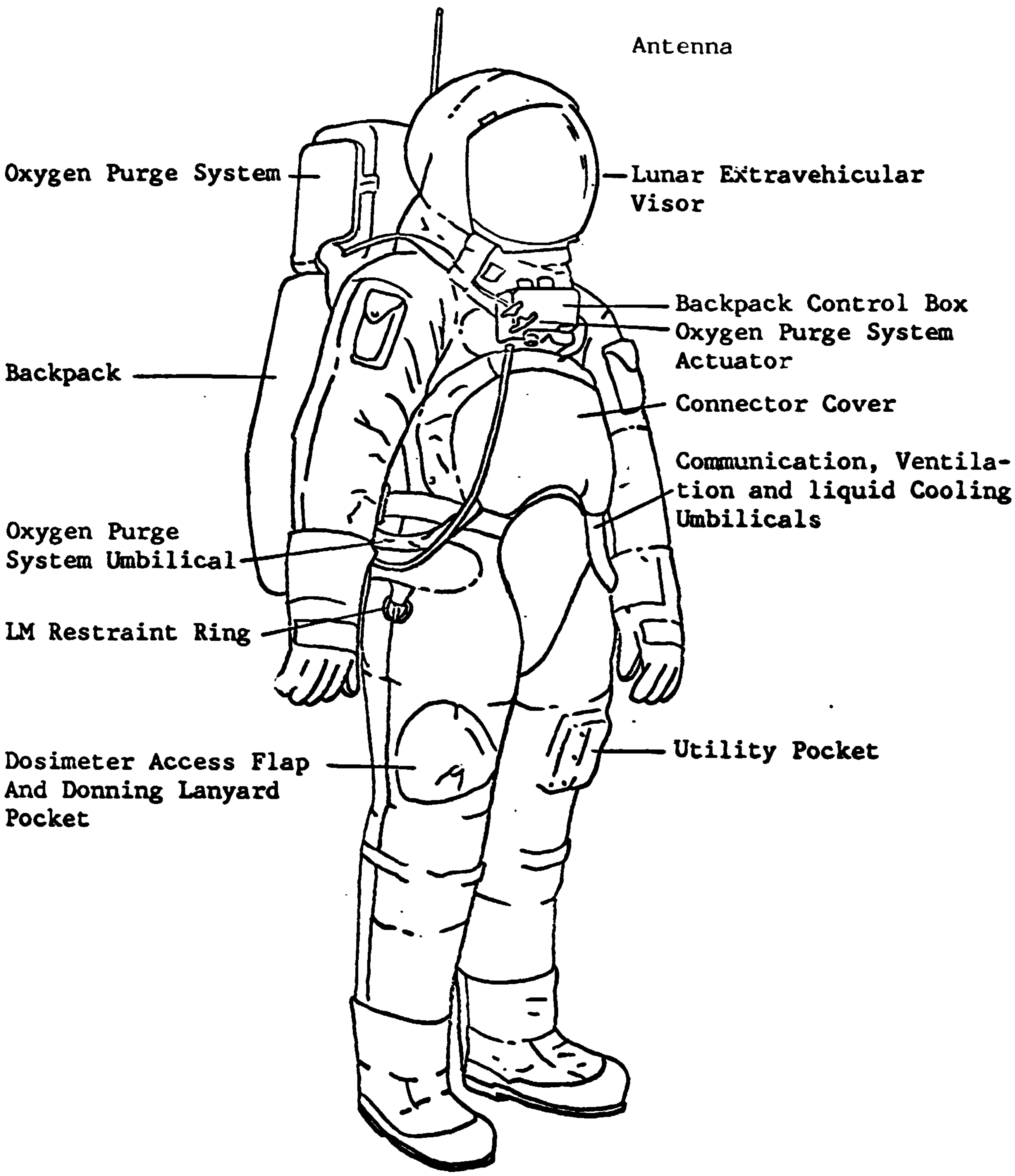
10th Percentile Astronaut, Pressure Garment Assembly (3.5 psi)
Typical Dimensions



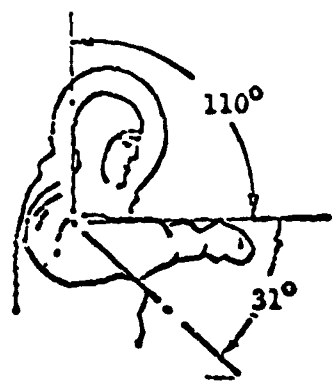
Apollo Suit Arm Mobility Characteristics
(3.5 psi)



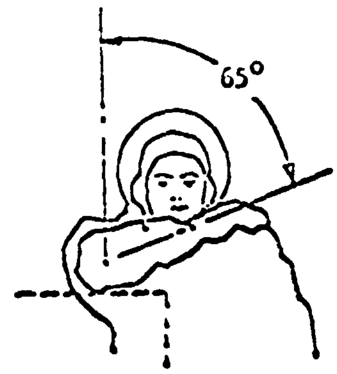
Apollo Suit Mobility Characteristics (continued)



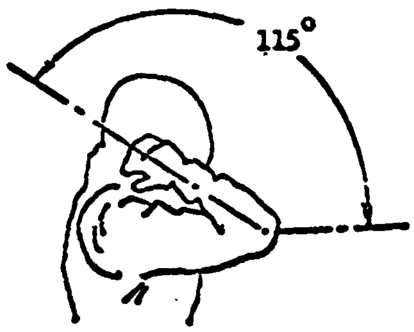
Extravehicular Mobility Unit (EMU) for Lunar Exploration



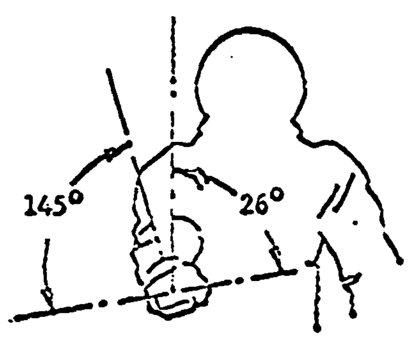
Shoulder Rotation (x-z plane)
(Down-Up)



Shoulder Rotation (y-z plane)
Lateral
Medial



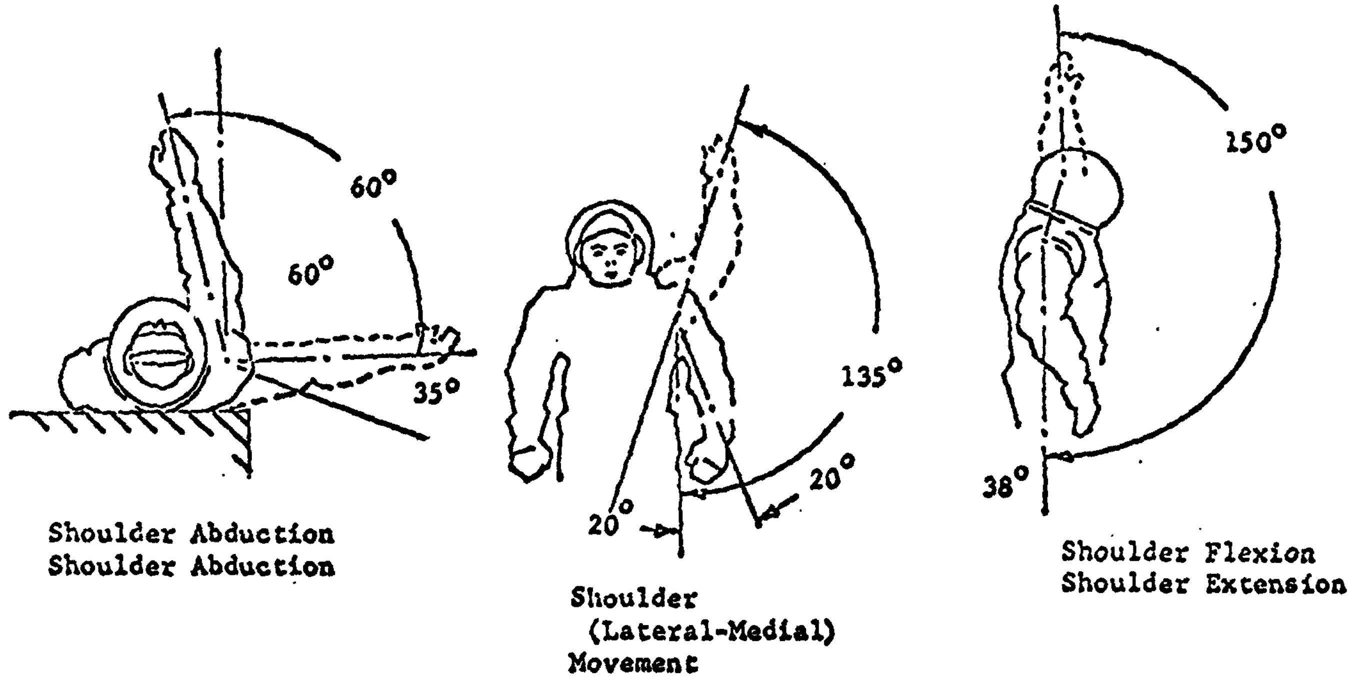
Elbow
(Flexion-Extension)



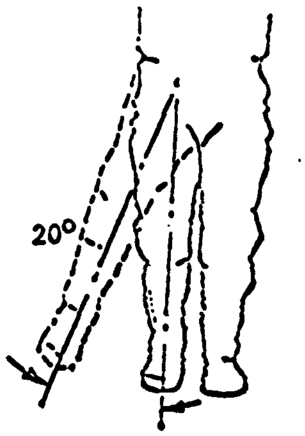
Forearm Rotation
Supination (Palms up)
Pronation (Palms down)

xx° Range of Motion-Degrees

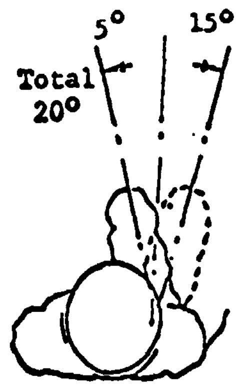
EMU Mobility Characteristics



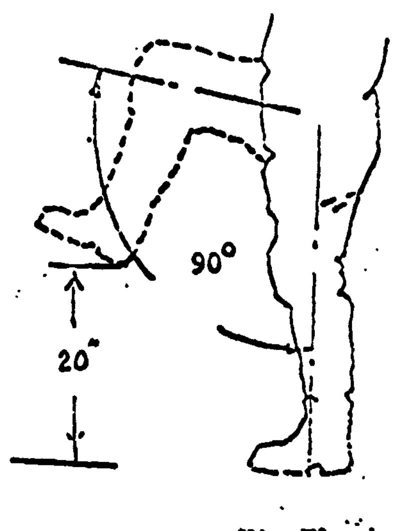
EMU Mobility Characteristics (cont.)



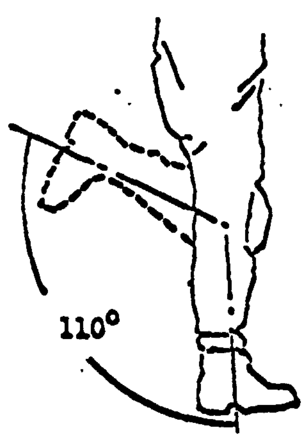
Hip Abduction (Leg Straight)



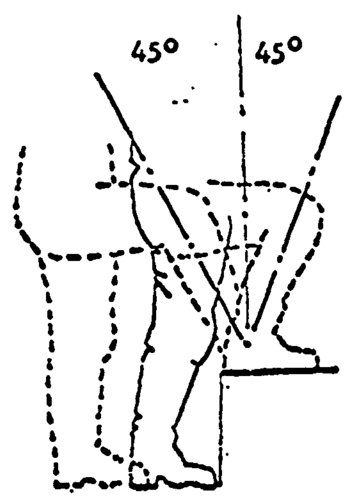
Hip Adduction (Knee Bent)
Hip Abduction (Knee Bent)



Hip Flexion (Step height)

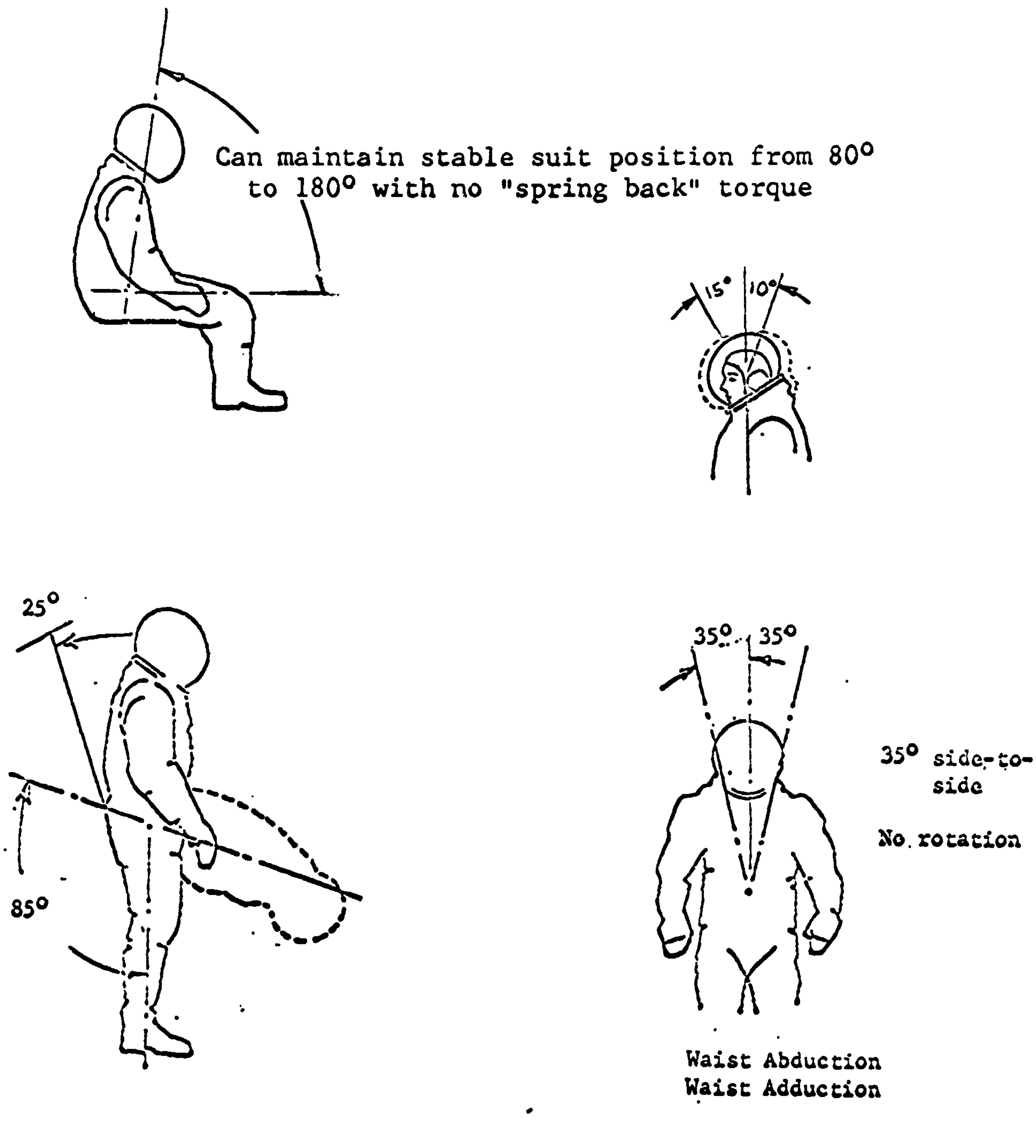


Knee Flextion (Standing)



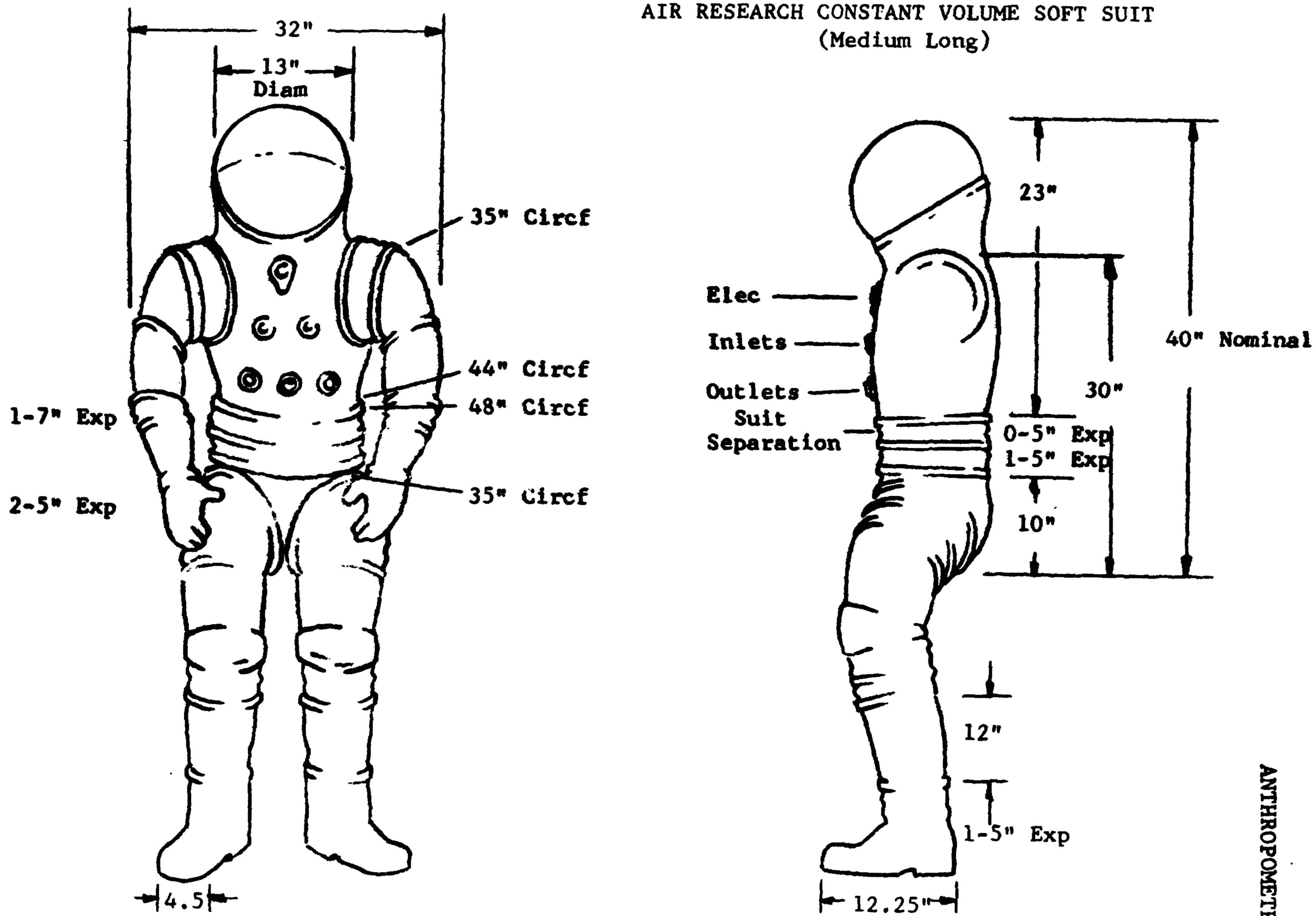
Ankle Extension
Ankle Flexion

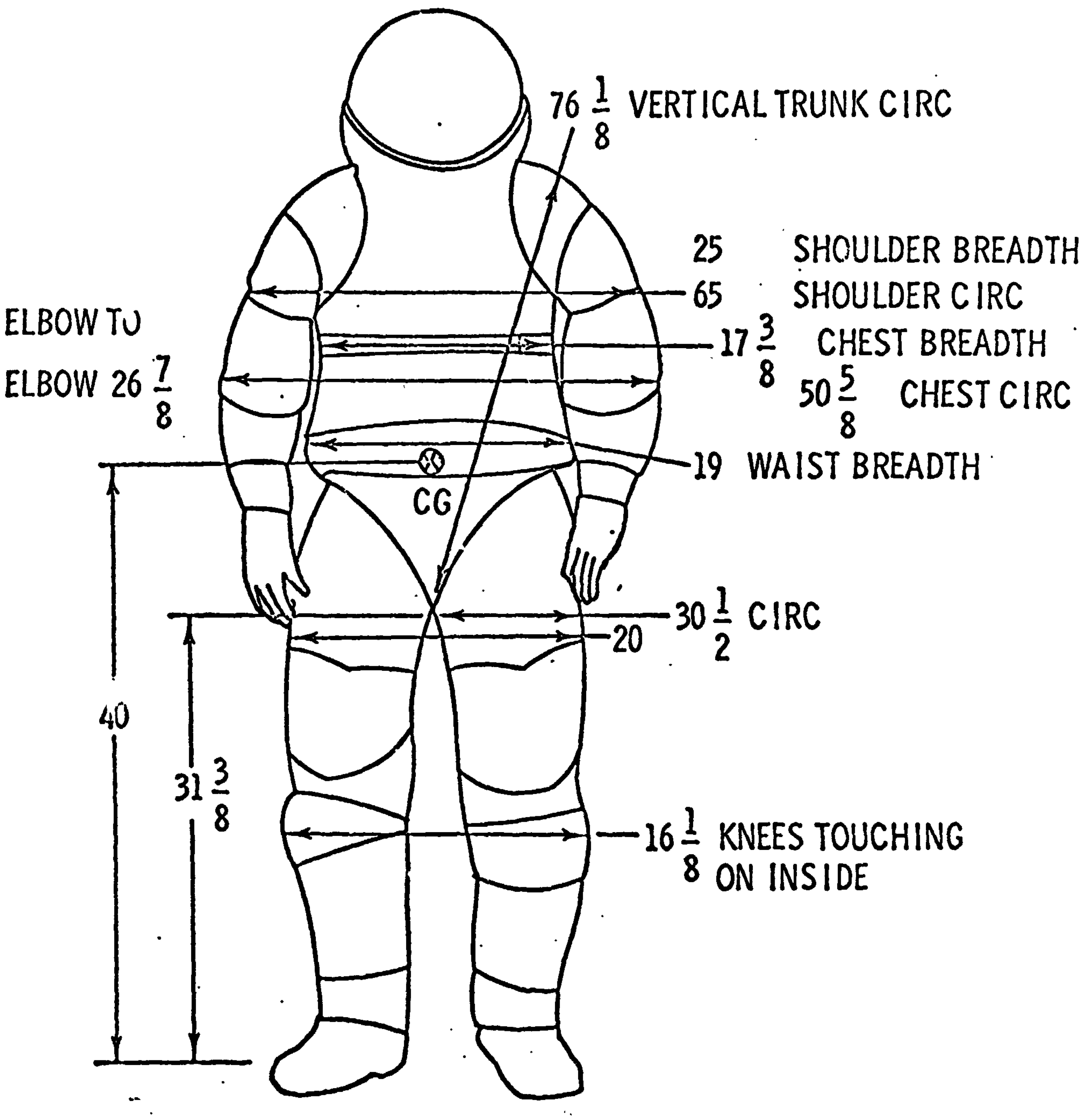
EMU Mobility Characteristics (cont.)



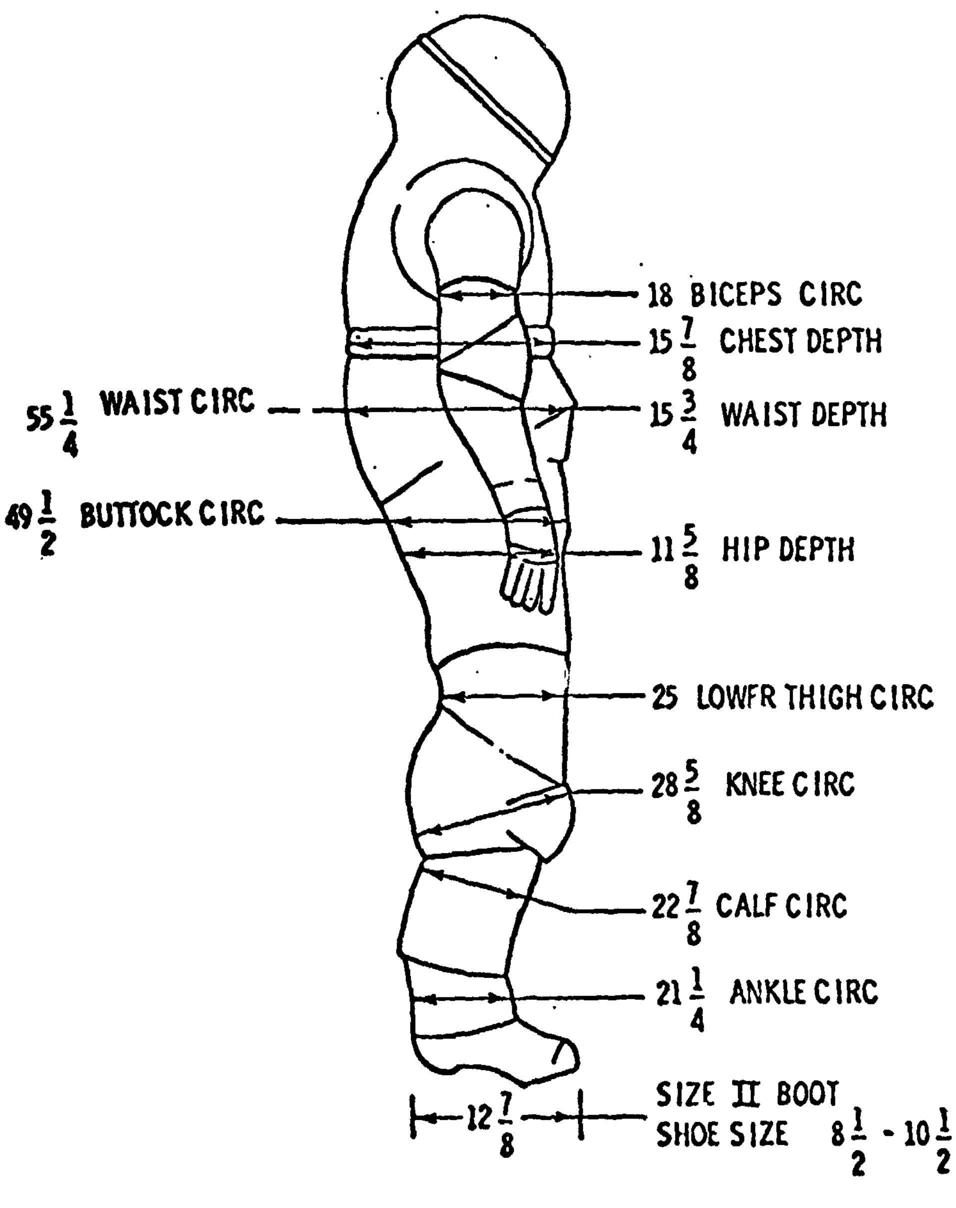
EMU Mobility Characteristics (cont.)

AIR RESEARCH CONSTANT VOLUME SOFT SUIT
(Medium Long)

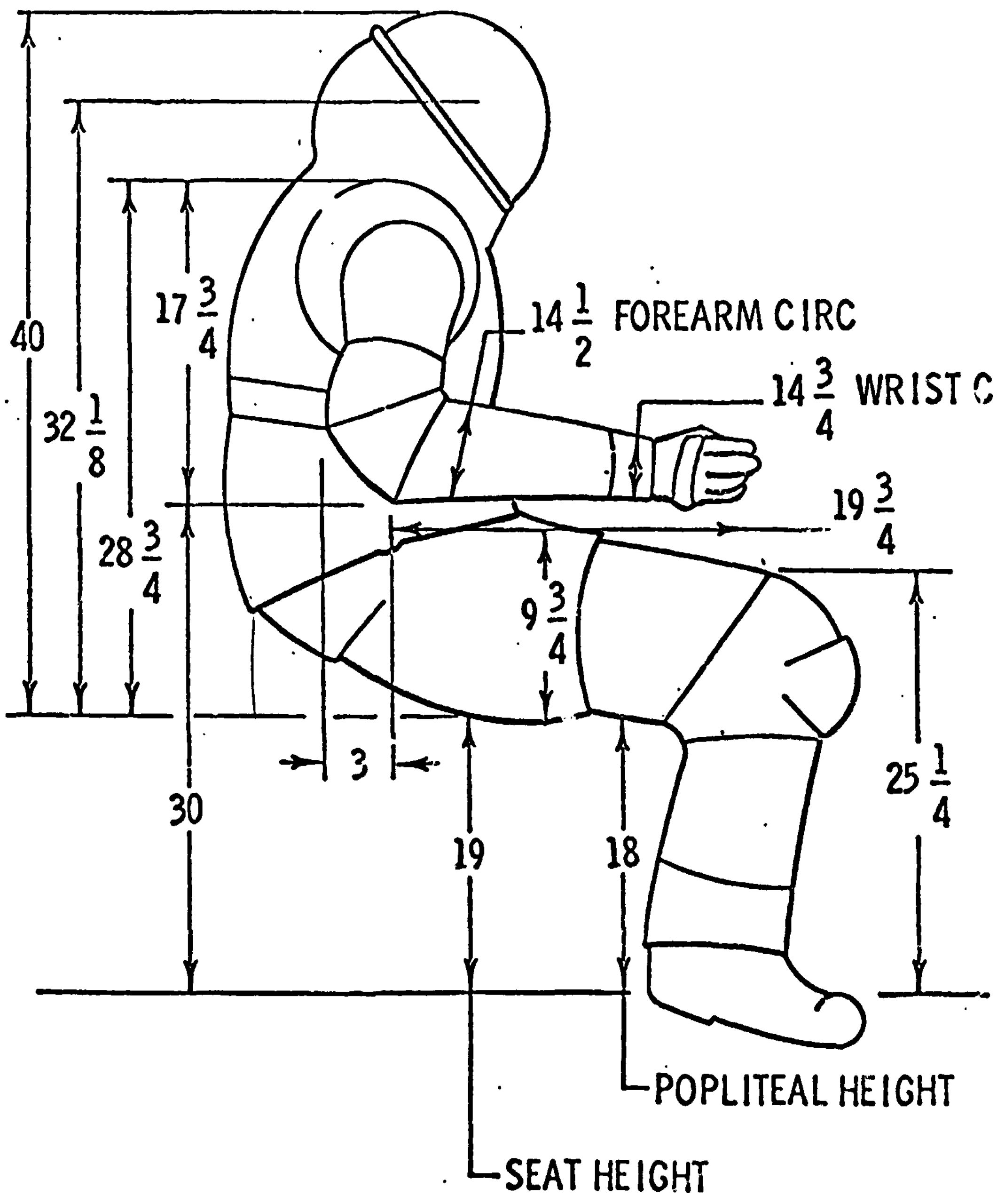




RX-5 CONSTANT VOLUME, HARD LUNAR SUIT



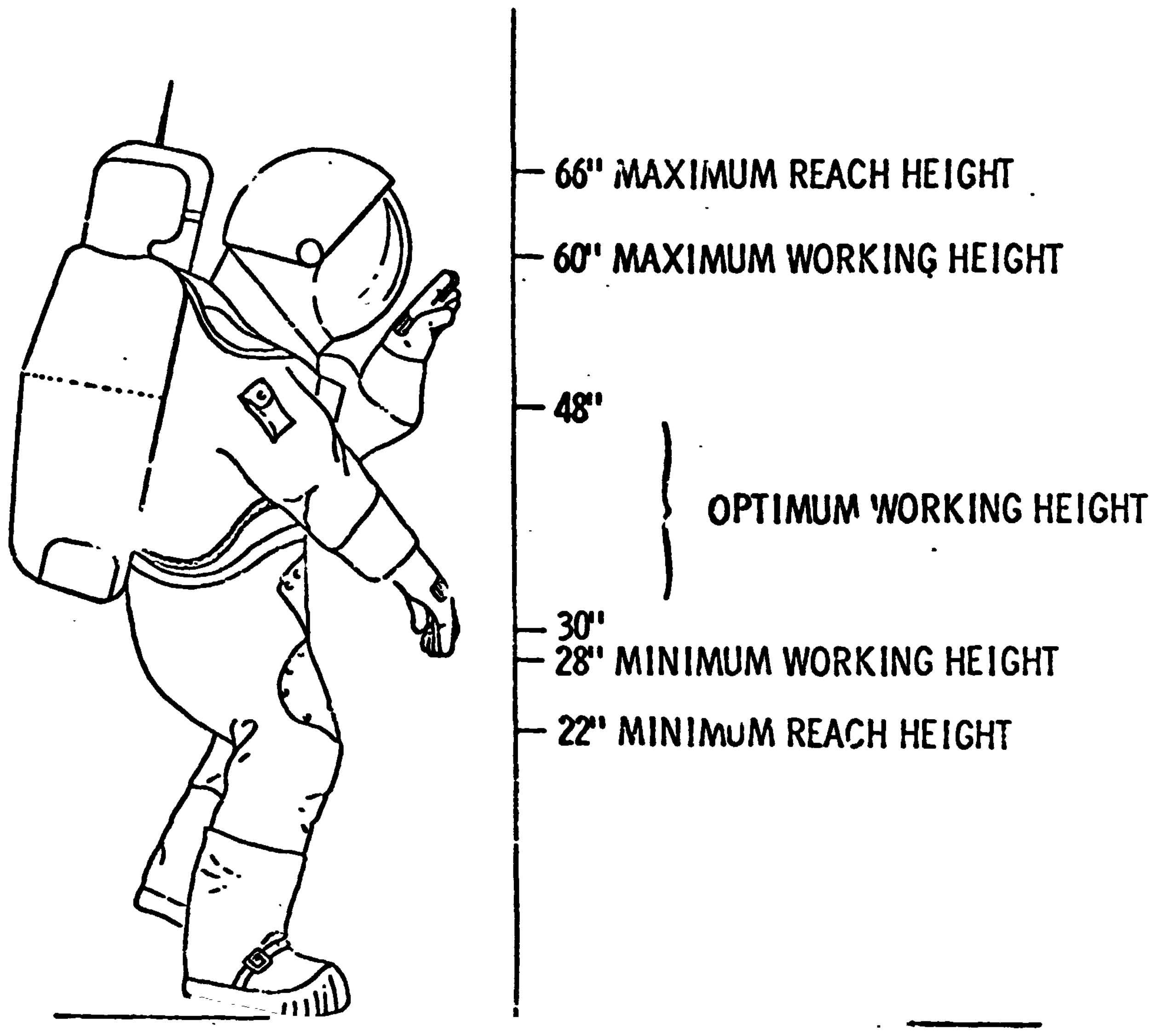
RX-5 LUNAR SUIT (cont.)



RX-5 LUNAR SUIT (cont.)

RX-5 CONSTANT VOLUME' HARD SUIT SIZE VARIATIONS

ELEMENT SIZES OF SUIT MEASURED	DIMENSION ADJUSTMENTS FOR OTHER SIZES
1. UPPER TORSO - SIZE III	SHOULDER BREADTH SIZE IV + 1.00 SIZE I & II NO CHANGE
2. LOWER TORSO - SIZE III (ADJUSTED TO THE SHORT POSITION) (+ 0.75" ADJUSTMENT POSSIBLE)	LENGTH ONLY SIZE I - 1.20 (SHORT ADJUSTMENT) II - 0.60 (SHORT ADJUSTMENT) IV - + 1.35 (LONG ADJUSTMENT) V - + 1.95 (LONG ADJUSTMENT) VI - ± 2.55 (LONG ADJUSTMENT)
3. UPPER ARM - SIZE IV	LENGTH CHANGE ONLY SIZE V + 0.40 I - 1.20 II - 0.80 III - 0.40
4. FOREARM - SIZE III	LENGTH CHANGE ONLY SIZE I - 1.40 II - 0.70 IV + 0.70
5. THIGH - SIZE II (ADJUSTED TO SHORT POSITION) (+ 0.87" ADJUSTMENT POSSIBLE)	LENGTH CHANGE ONLY SIZE I - 0.70 (SHORT ADJUSTMENT) III + 1.56 (LONG ADJUSTMENT) IV + 2.26 (LONG ADJUSTMENT) V + 2.96 (LONG ADJUSTMENT)
6. CALF - SIZE II	LENGTH CHANGE ONLY SIZE I - 0.70 III + 0.60 IV + 1.20 V + 1.80 VI + 2.40



Practical Limits of Lunar Suited Astronaut

Extravehicular Glove Assembly

The extravehicular glove assembly is a full pressure glove designed to allow crewman hand dexterity and tactility while supplying the required thermal/micrometeoroid protection.

Dexterity (on modified peg board)	Percent of Nude Hand Capability		
	¼" Pins -	Right Hand	33%
		Left Hand	19%
		Both Hands	12%
	½" Pins -	Right Hand	65%
		Left Hand	59%
		Both Hands	42%

Torquing Capabilities

Fingertip Functional

0.75 inch diameter 3.8 in. lbs.
1.00 inch diameter 5.2 in lbs.
1.25 inch diameter 7.6 in. lbs.
1.50 inch diameter 9.6 in. lbs.

Finger Curl-Around Functional

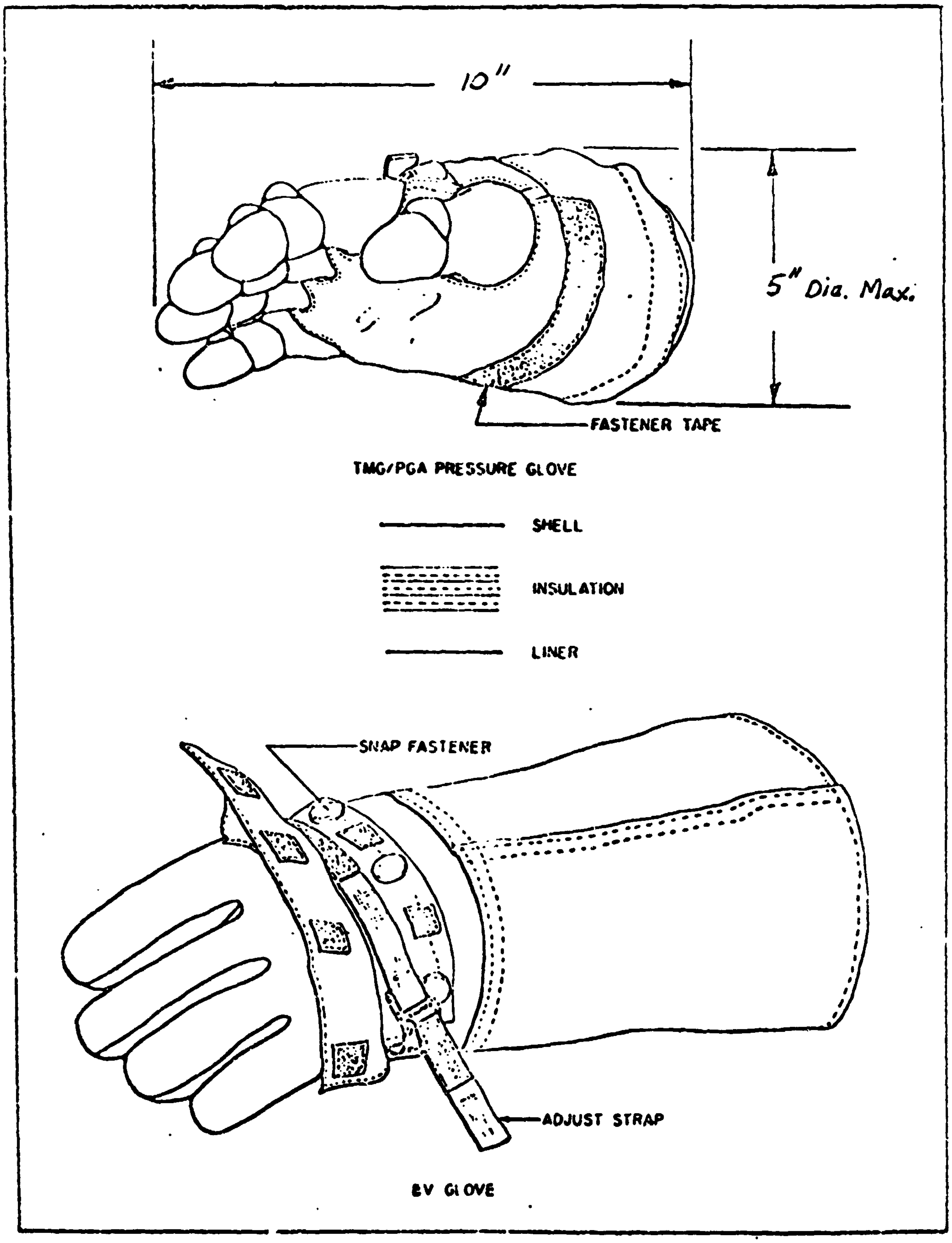
0.75 inch diameter 3.8 in. lbs.
1.00 inch diameter 5.2 in. lbs.
1.25 inch diameter 7.6 in. lbs.
1.50 inch diameter 11.4 in. lbs.

Screwdriver - 4.15" in length
1.0" diameter

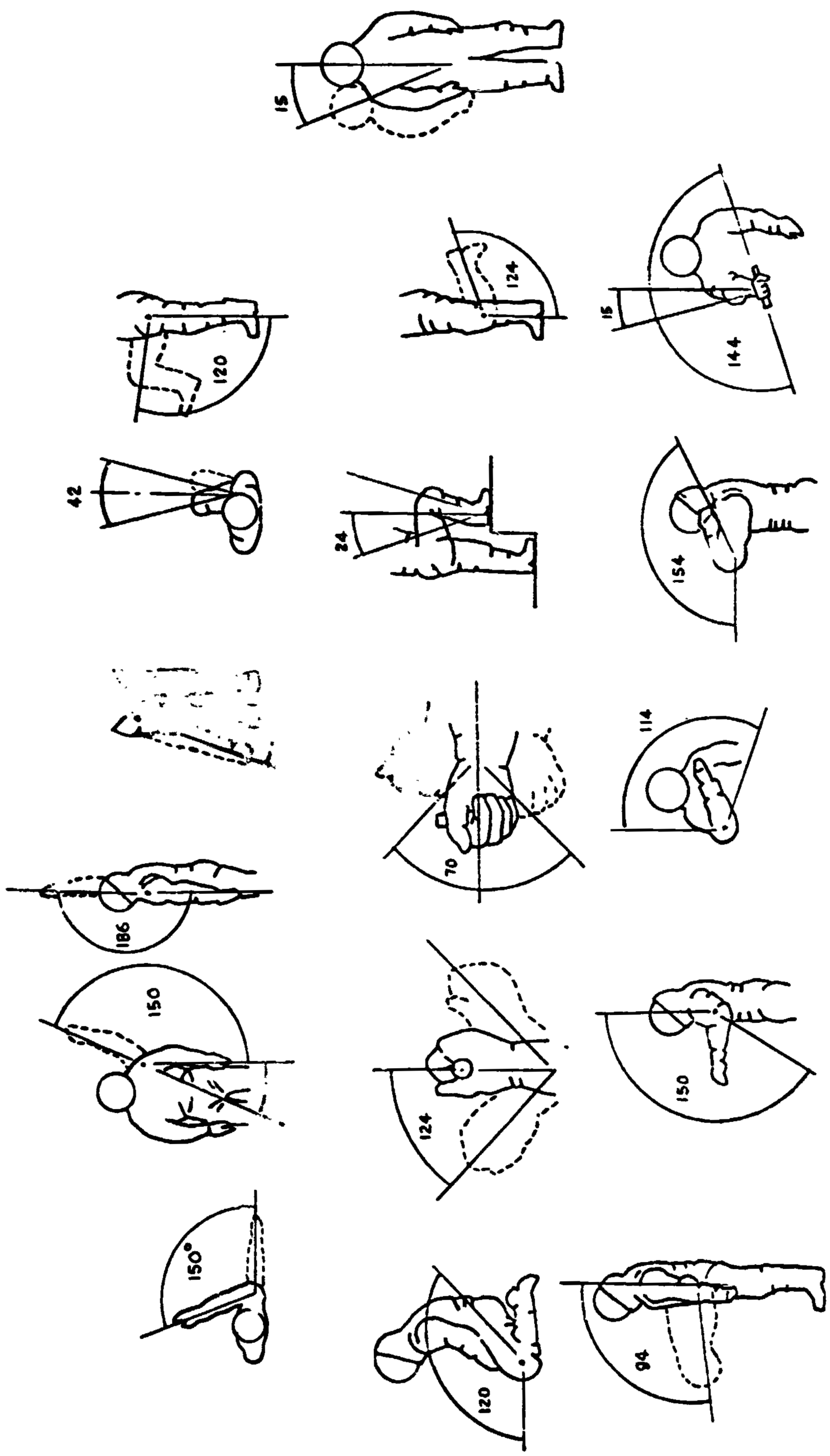
Pronation 51.66 in. lbs.
Supination 48.66 in. lbs.

Ball - Glove 2 inches diameter

Pronation - 56.66 in. lbs.
Supination - 60.83 in. lbs.



Extravehicular Glove Assembly



Typical Mobility Characteristic of Constant Volume Suits

Centers of Gravity and Specific Gravity of Man

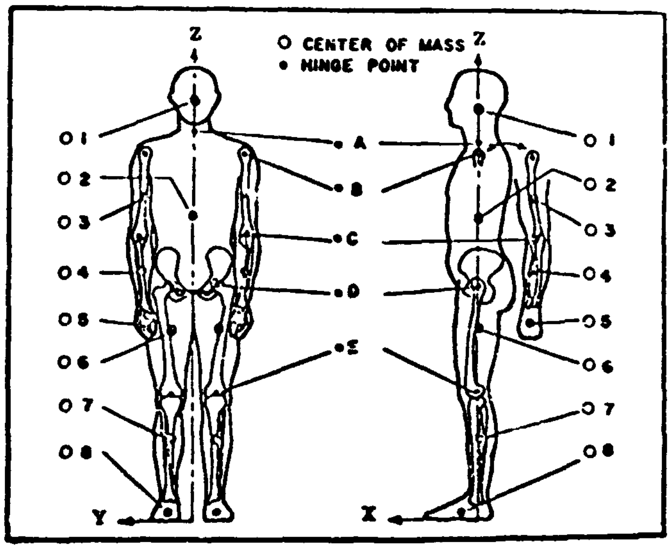


Diagram of Hinge Points and Centers of Mass

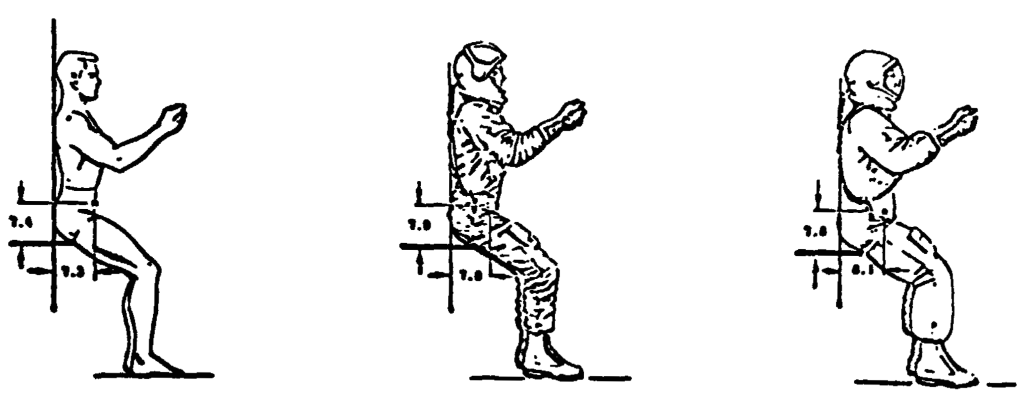
Hinge Point and Symbol*		Coordinates (Inches)		
		X	Y	Z
Neck	• A	0	0	59.08
Shoulder	• B	0	7.88	56.50
Elbow	• C	0	7.88	43.50
Hip	• D	0	3.30	34.52
Knee	• E	0	3.30	18.72
Mass Center and Symbol*				
Head	O 1	0	0	64.10
Torso	O 2	0	0	46.80
Upper Arm	O 3	0	7.88	50.83
Lower Arm	O 4	0	7.88	39.20
Hand	O 5	0	7.88	31.68
Upper Leg	O 6	0	3.30	27.68
Lower Leg	O 7	0	3.30	11.80
Foot	O 8	2.45	3.30	1.37

Coordinates of the Segment Hinge Points and Mass Centers of USAF 50th Percentile Man

Mean Centers of Gravity of Pressure-Suited Subjects

Nude **Unpressurized** **Pressurized**

Sitting

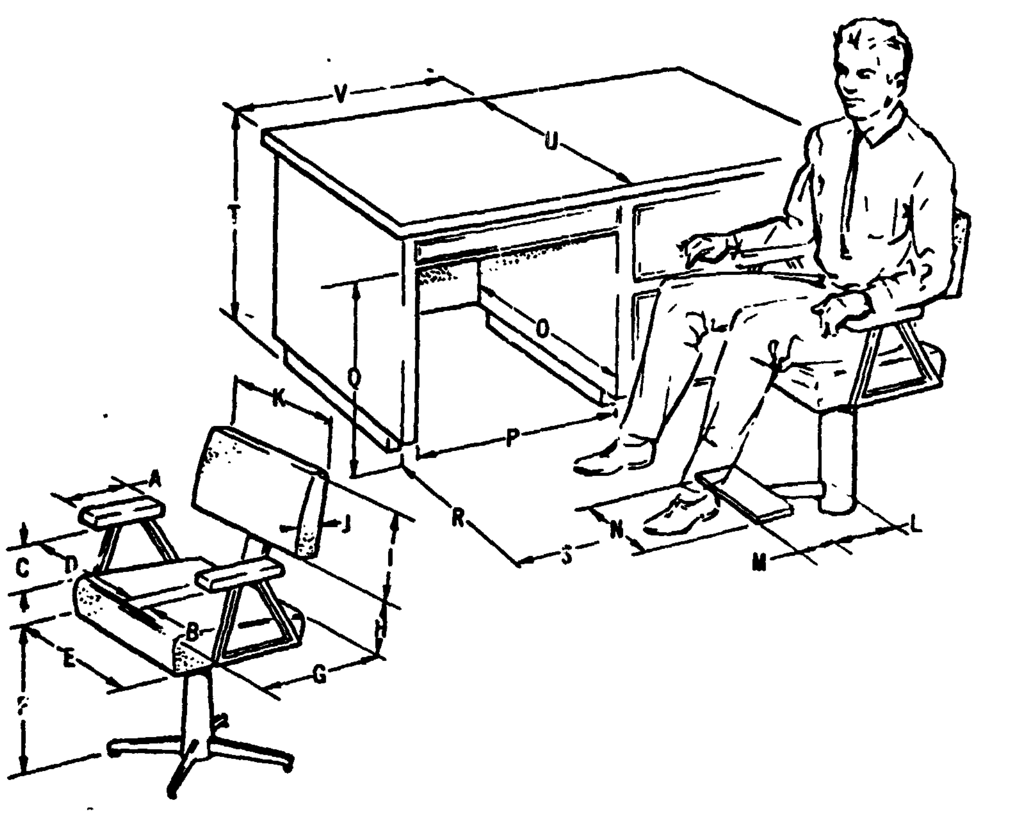


Nude **Unpressurized** **Pressurized**

Relaxed (Weightless)

EQUIPMENT DESIGN

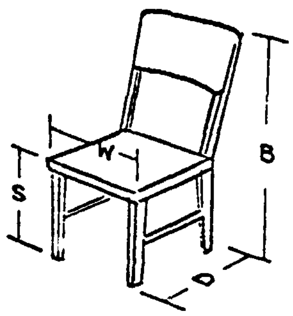
The following pages include information useful in establishing shape and size of furniture and equipment. Included are examples of typical off-the-shelf hardware available from the open market, showing dimensional characteristics important to the human engineer in planning preliminary layout of operator panels and work stations. This information is only representative and is not meant to indicate a recommendation for any specific component - or that these items are all-inclusive. Such information is particularly useful in developing preliminary mockups, indicating how much space is probably required to accomodate certain components - both in terms of the front and rear of a control panel.



CHAIR DIMENSIONS:	FIXED	ADJUST	REQUIREMENTS	FIXED	ADJUST
ARM RESTS:			MINIMUM CLEARANCE REQUIREMENTS:		
A. Length	10"	± 2"	O. Kneehole depth:	18"	
B. Width:	2"		P. Kneehole width:	20"	
C. Height:	8.5"	± 2.5"	Q. Kneehole height:	26"	
D. Separation:	18"		R. Desk to wall:	32"	
SEAT:			S. Lateral work clearance:		
E. Width:	16"		(1) Shoulders	23"	
F. Height:	18"	± 2"	(2) Elbows:	25"	
G. Depth:	16"		(3) Best overall:	40"	
BACK REST:			DESK OR WORK SURFACE DIMENSIONS:	MIN	BEST
H. Space:	6"	± 2"	T. Height of work surface:	29"	30"
I. Height:	15"		U. Width of work surface		
J. Max curve:	4"		(1) Elbow rest alone:	4"	8"
K. Width:	16"		(2) Writing surface:	12"	16"
FOOTRESTS:			(3) Desk work area:		36"
(where required):			V. Length of work area:	30"	-
L. From center	7"				
M. Width:	6"				
N. Length:	10"				

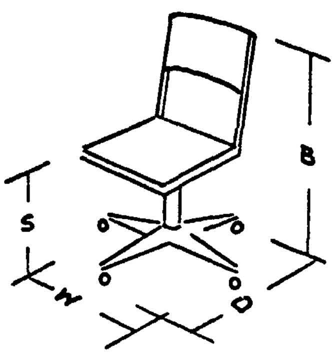
*Adjustment range. Adjustability is preferred for these dimensions.

Desk and Chair Dimensions



W - 23 in.
D - 21 in.
S - 17 in.
B - 30 in.

Standard Office Chair

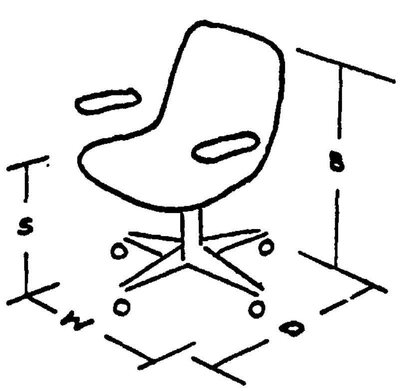


W - 19 in.
D - 19 in.
S - 18 in.
B - 31 in.

Secretarial Chair

W - 17-21 in.
D - 21 in.
S - 17 in.
B - 28-30 in.

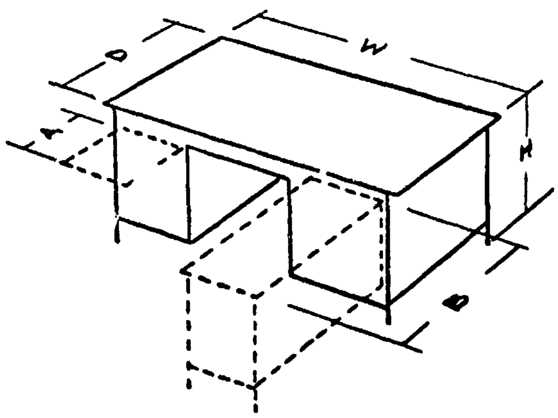
Special Molded Occasional Chair



W - 19-26 in.
D - 19 in.
S - 17 in.
B - 30 in.

Executive Chair

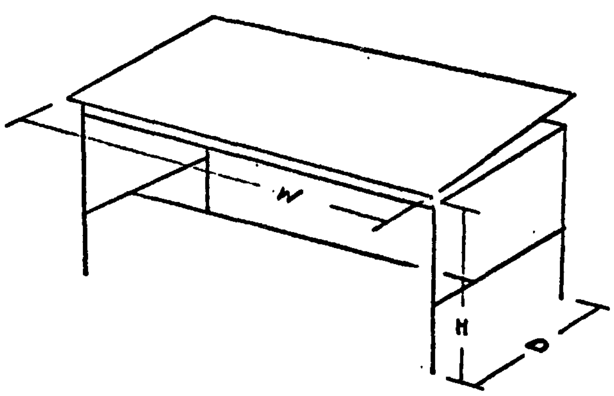
TYPICAL STANDARD FURNITURE CHARACTERISTICS



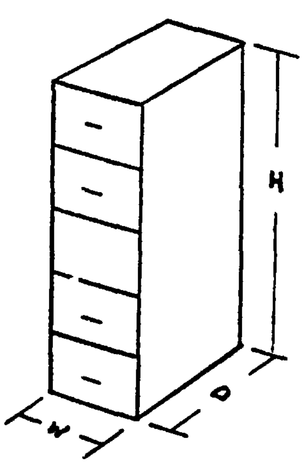
STANDARD DESK - 30Dx60W-29H (in.)

CONFERENCE DESK - 36Dx72Wx29-30H

STENO DESK - 30Dx60Wx29H (in.)
(A 19, B 39 in.)

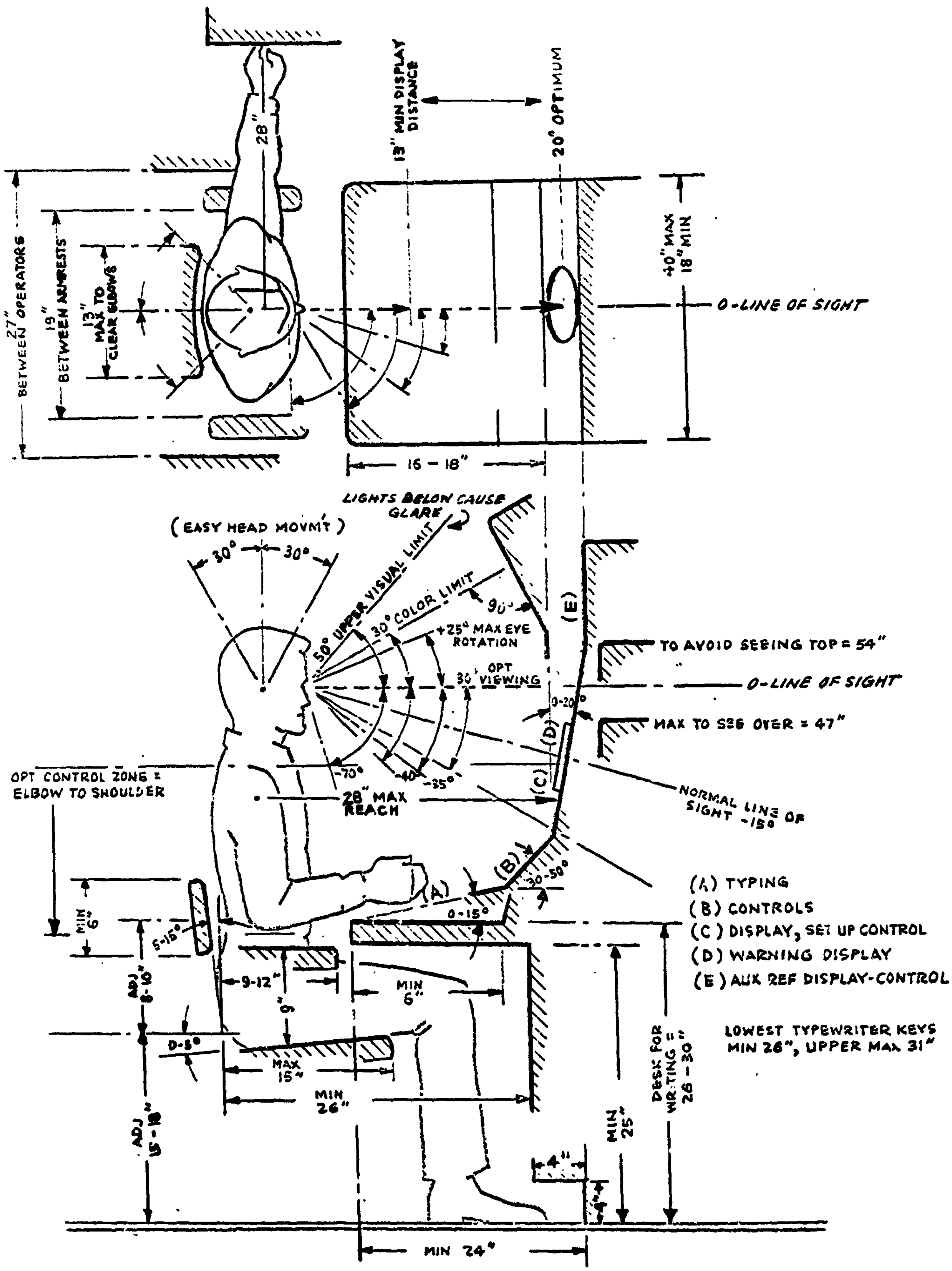


DRAFTING TABLE
D - 30, 36 in.
W - 62, 72 in.
H - 25, 28 in.

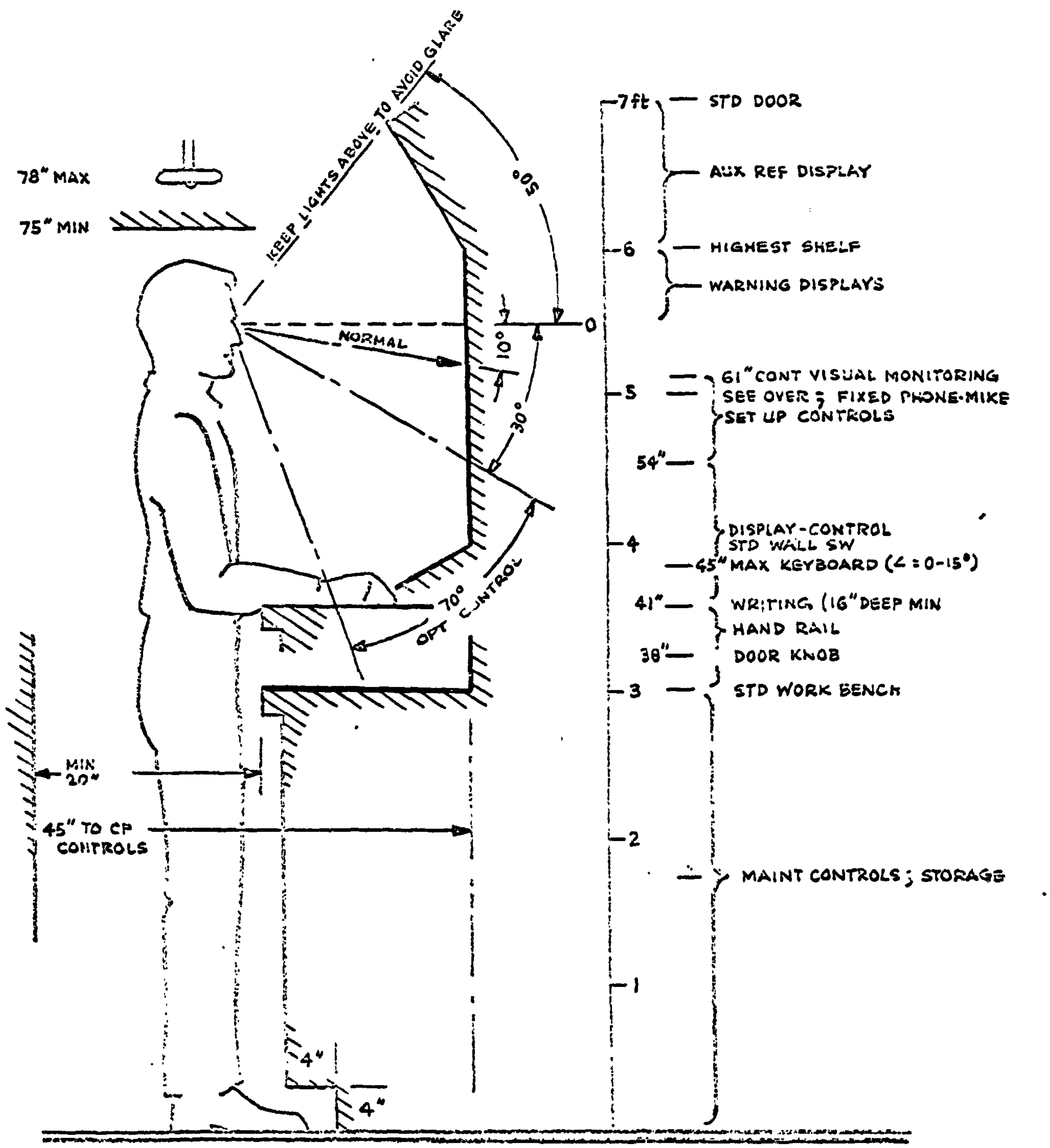


FILING CABINETS

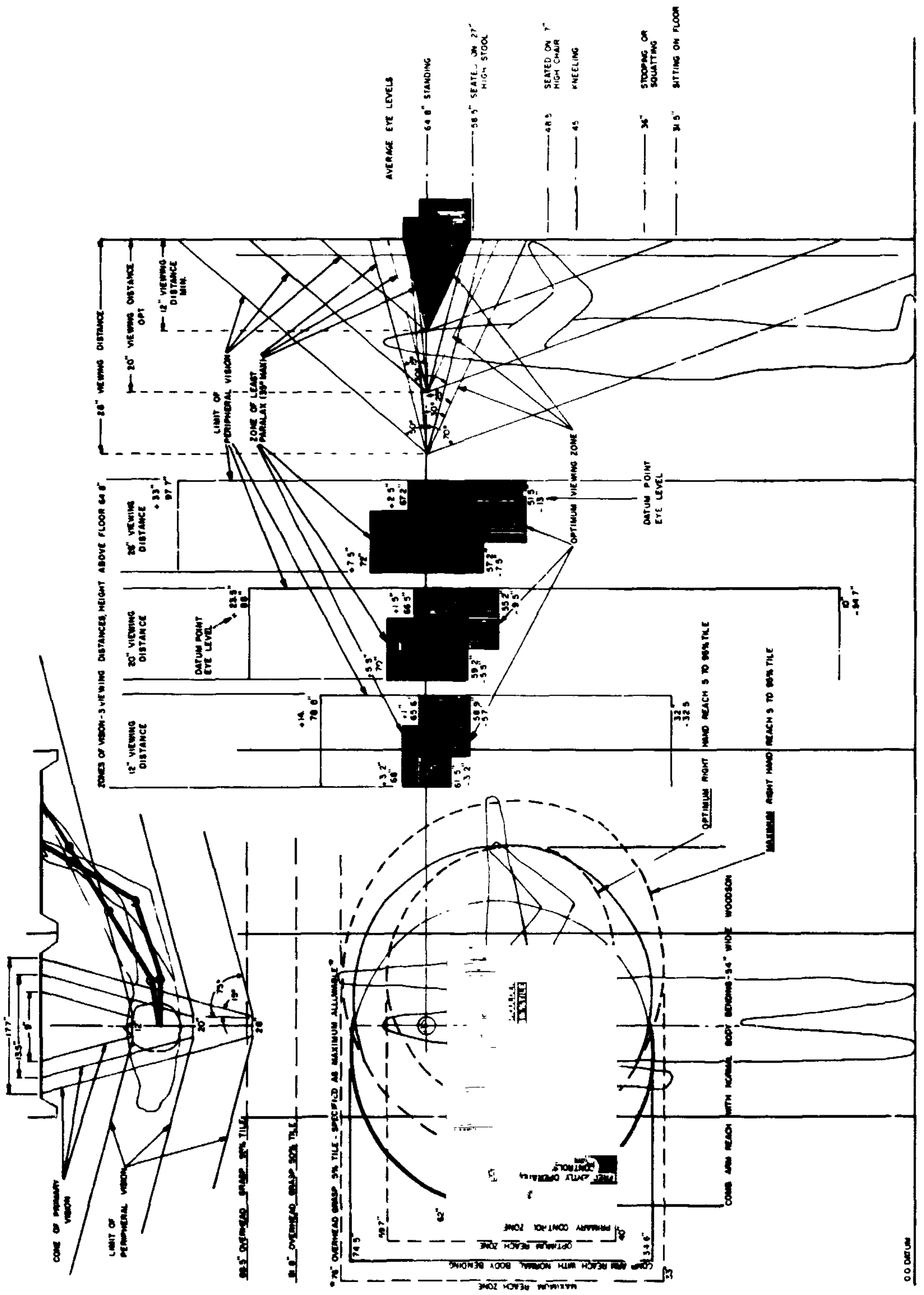
2-Drawer	W 15-18x	D 28x	H 29-1/2	in.
3-Drawer	W "	D "	H 41	in.
4-Drawer	W "	D "	H 52-1/2	in.
5-Drawer	W "	D "	H 64	in.



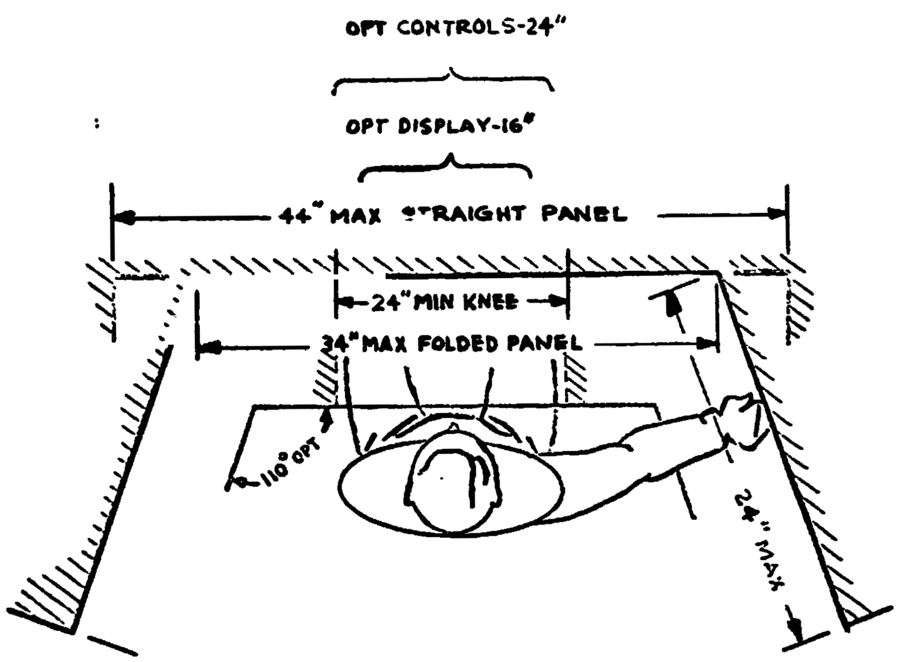
General Dimensions for Mockup of Seated Operator
(5th-95th% Male Operator)



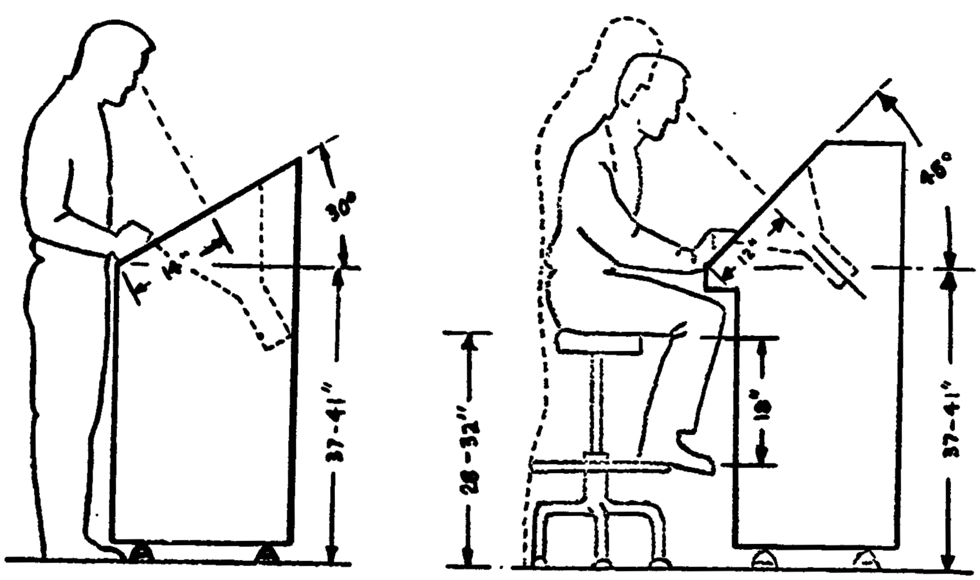
General Dimensions for Mockup of Standing Operator Station (5th-95th% Male Operator)



ANTHROPOMETRIC DATA
RACK - OPERATOR INTERFACE
5 TO 95% TILE OF POPULATION



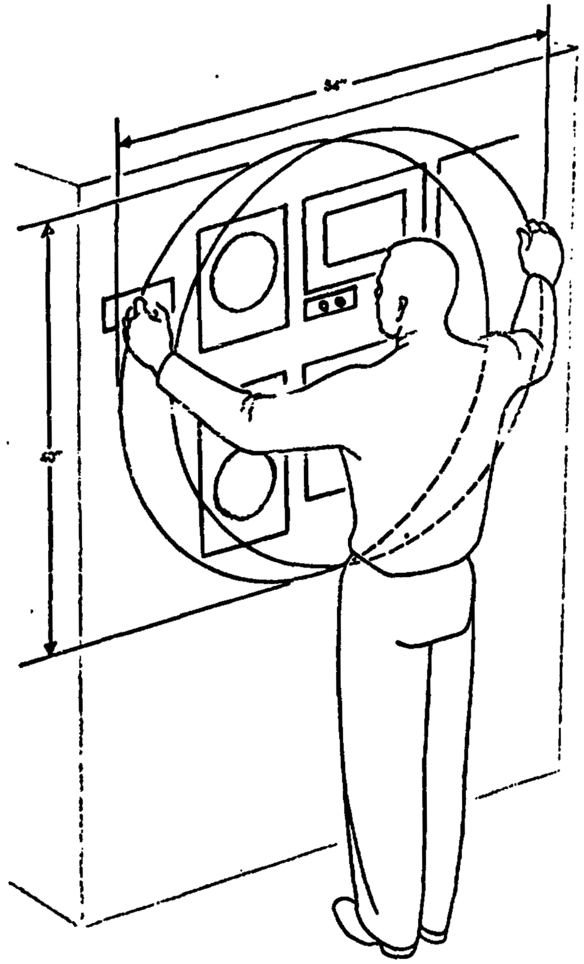
Console Dimensions, Seated Operator



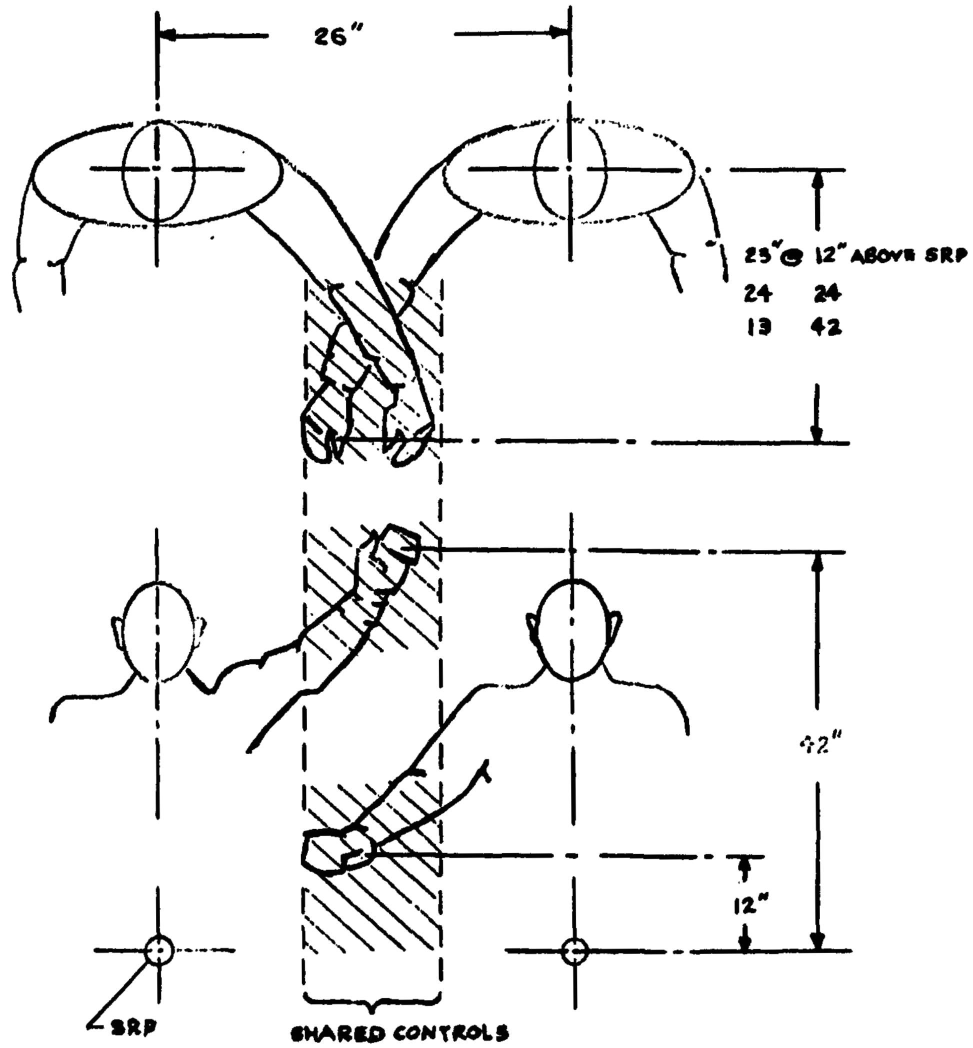
Stand

Sit/Stand

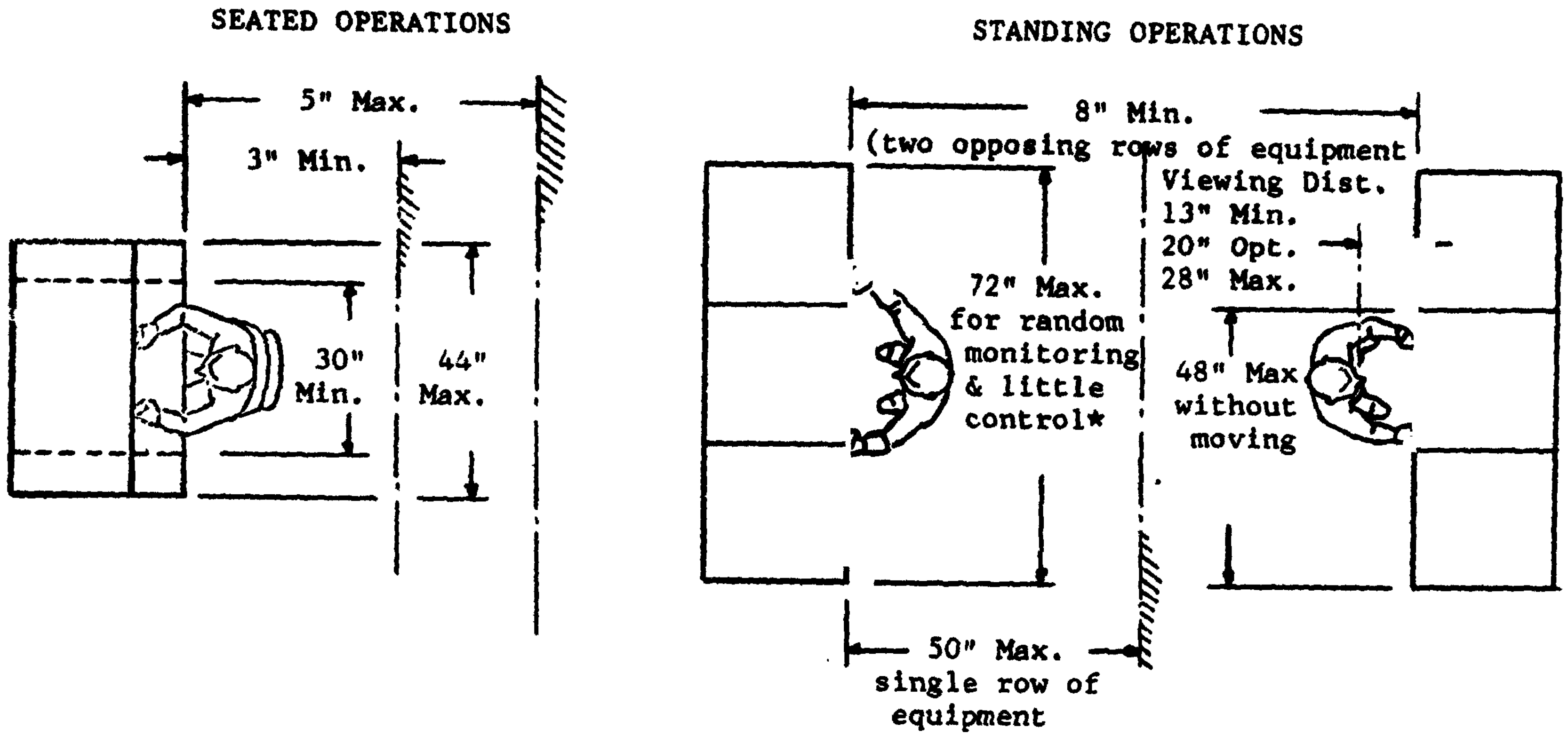
Dimensions for Optimum Scope Viewing



Standing Operator



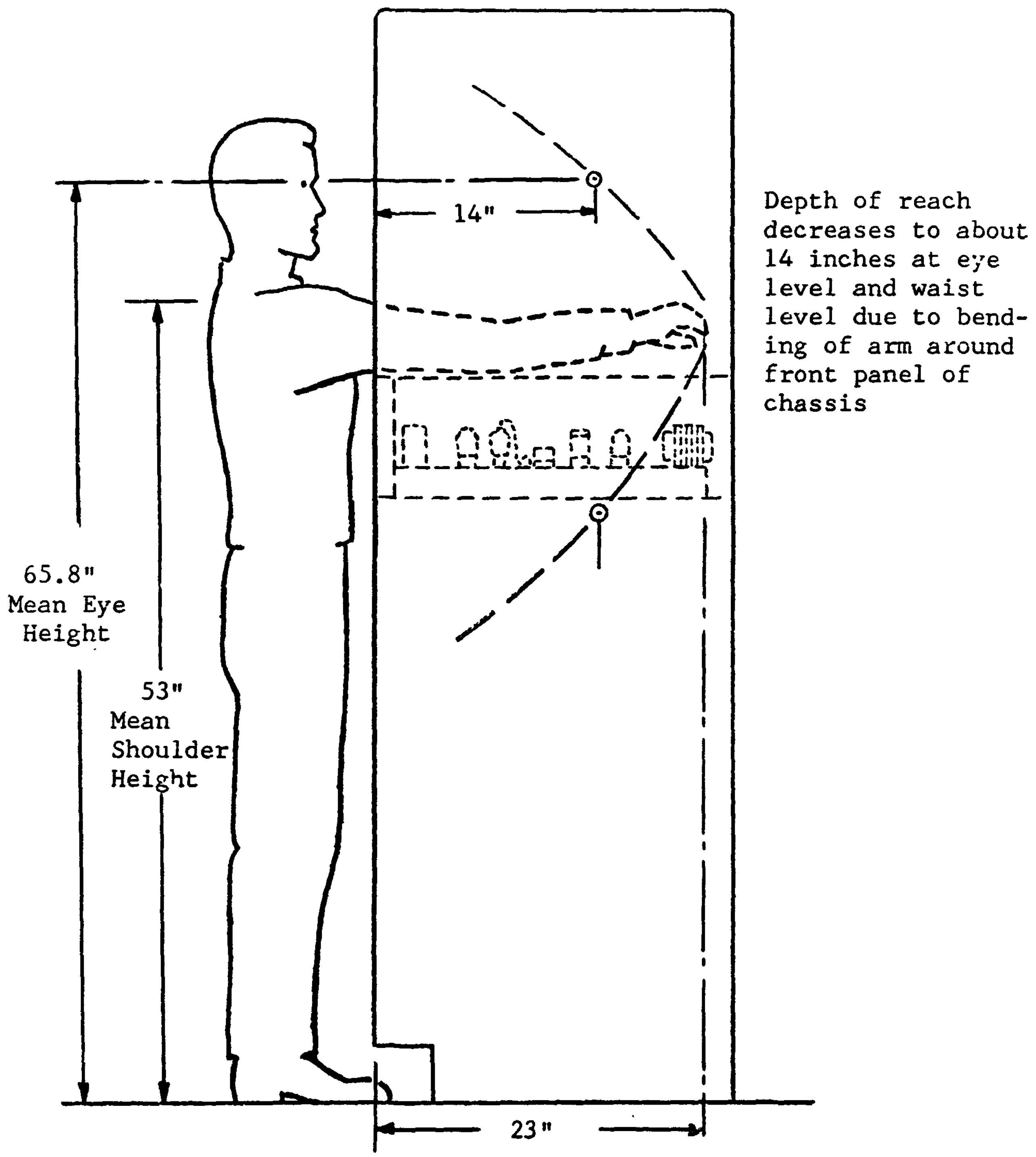
Placement of Controls for Side-by-Side Operator Utilization



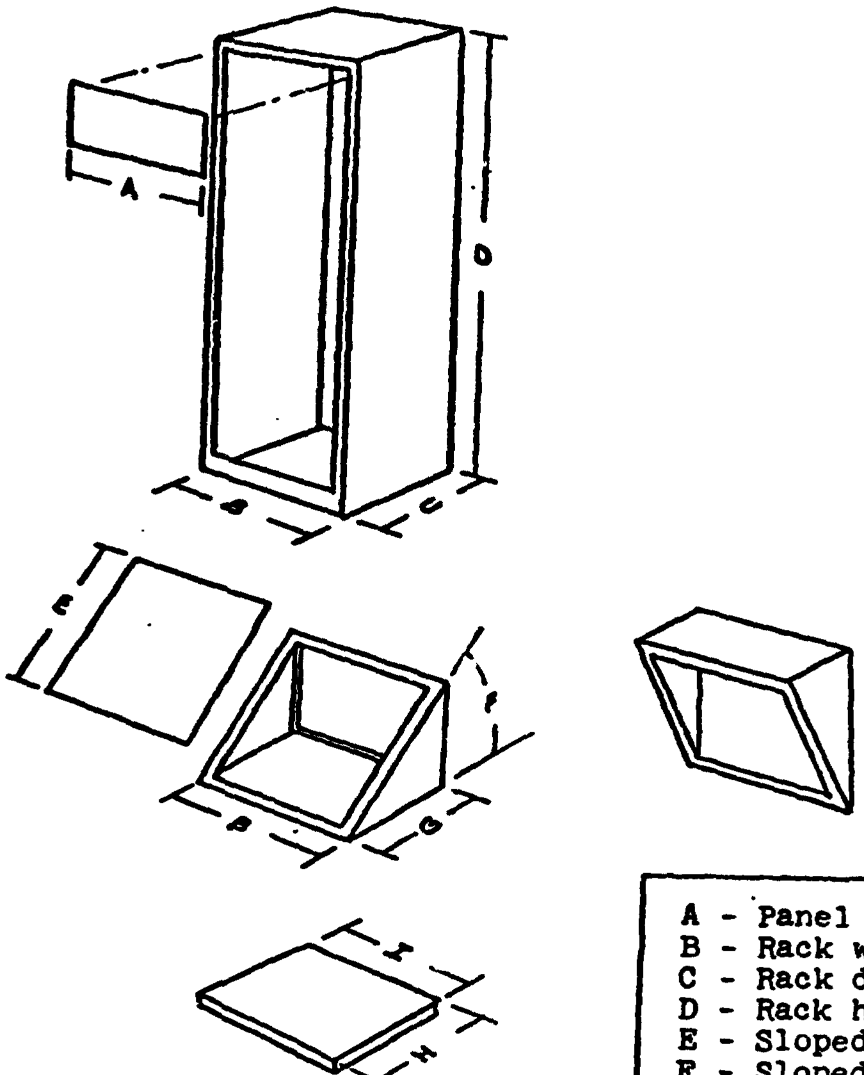
* There is no maximum lateral dimension if equipment racks are positioned in continuous sequential order.

Note: All lateral dimensions are for a single operator; for two or more operators, lateral dimensions become additive.

Maximum and Minimum Standing and Seated Operational Dimensions

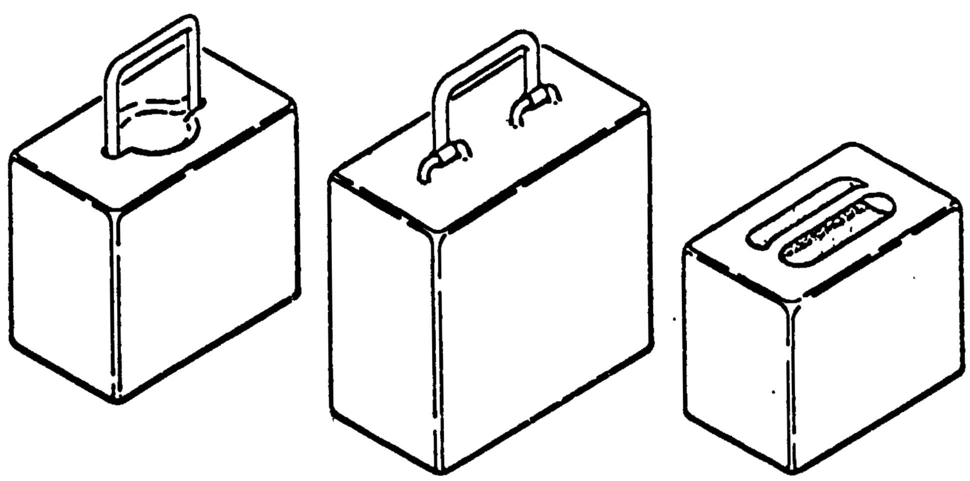


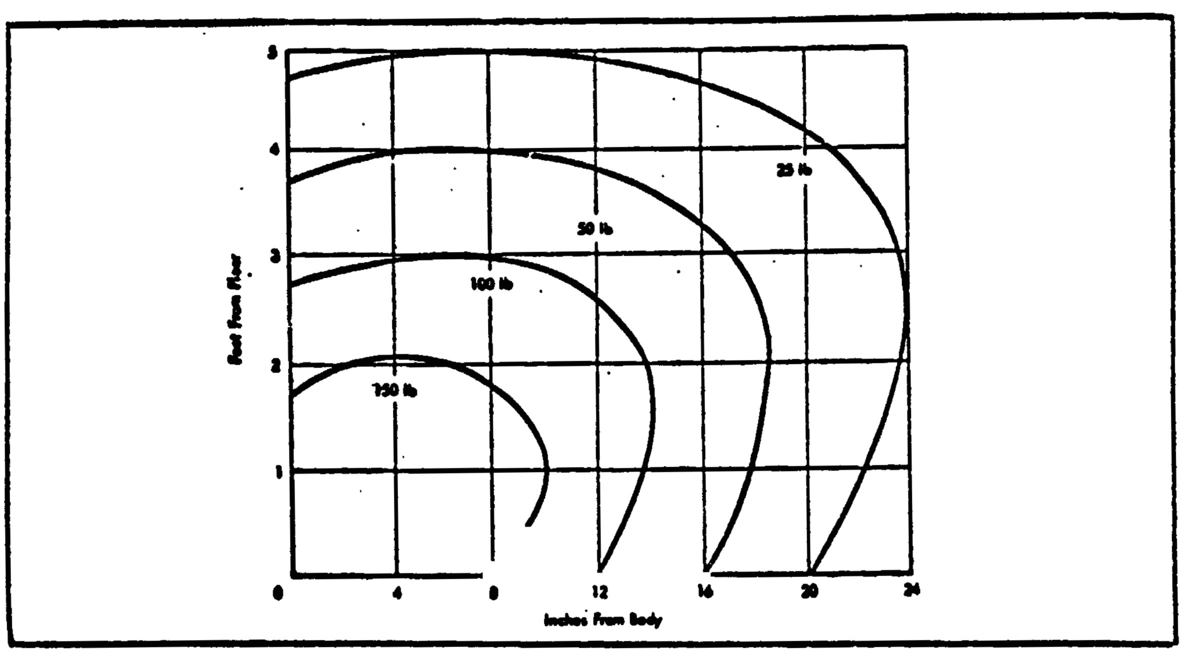
Dimensional Considerations for Internal Cabinet Access



A - Panel width	19-24 in.
B - Rack width	22-27 in.
C - Rack depth	17-1/2-22-1/8 in.
D - Rack height	42,47,66,75,82 in.
E - Sloped panel depth	12, 17, 21 in.
F - Sloped panel angle	37, 53°
G - Turret depth	12, 20 in.
H - Desk depth	11 in.
I - Desk width	16 in.

TYPICAL STANDARD STOCK CABINETRY CHARACTERISTICS



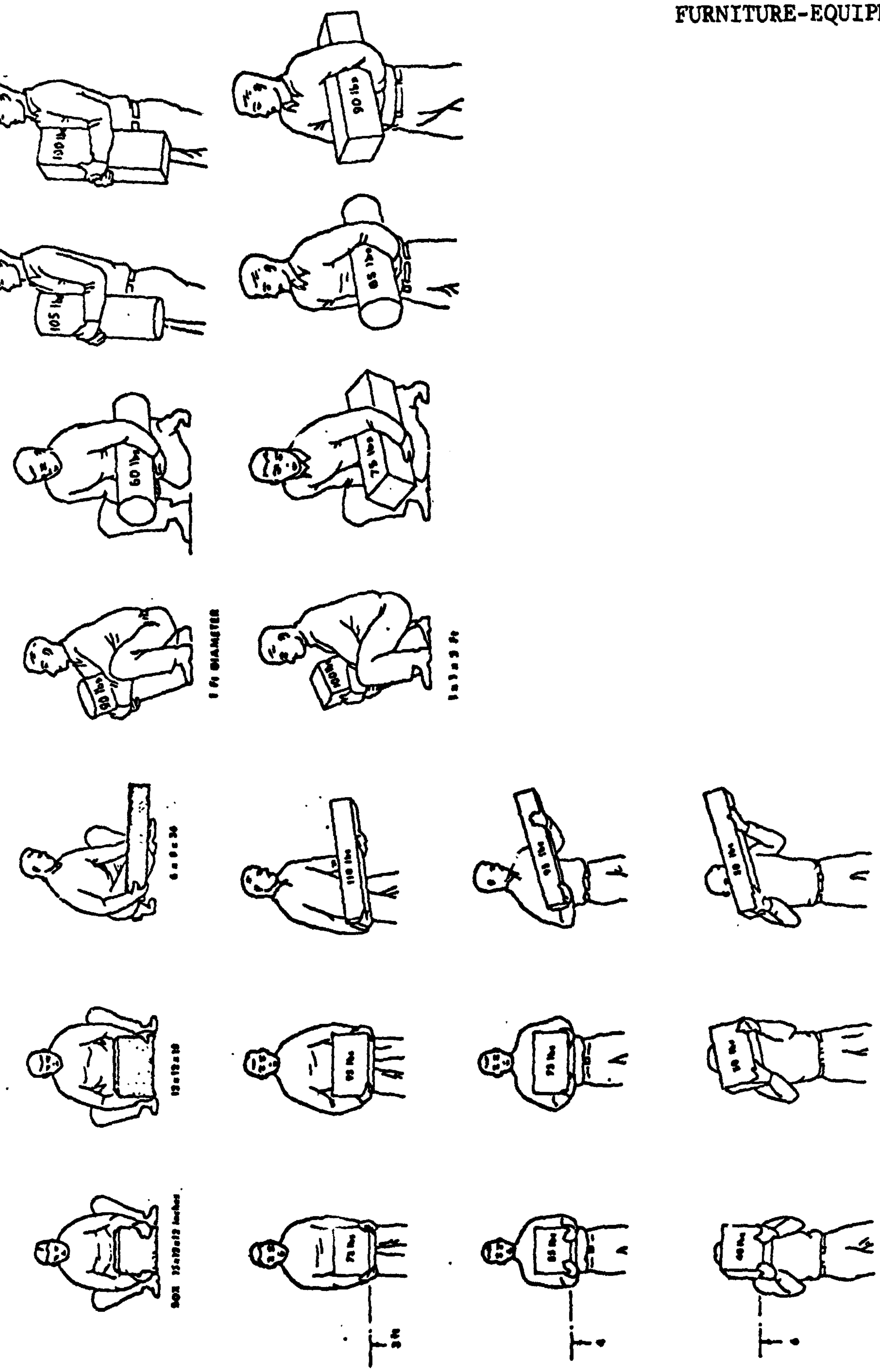


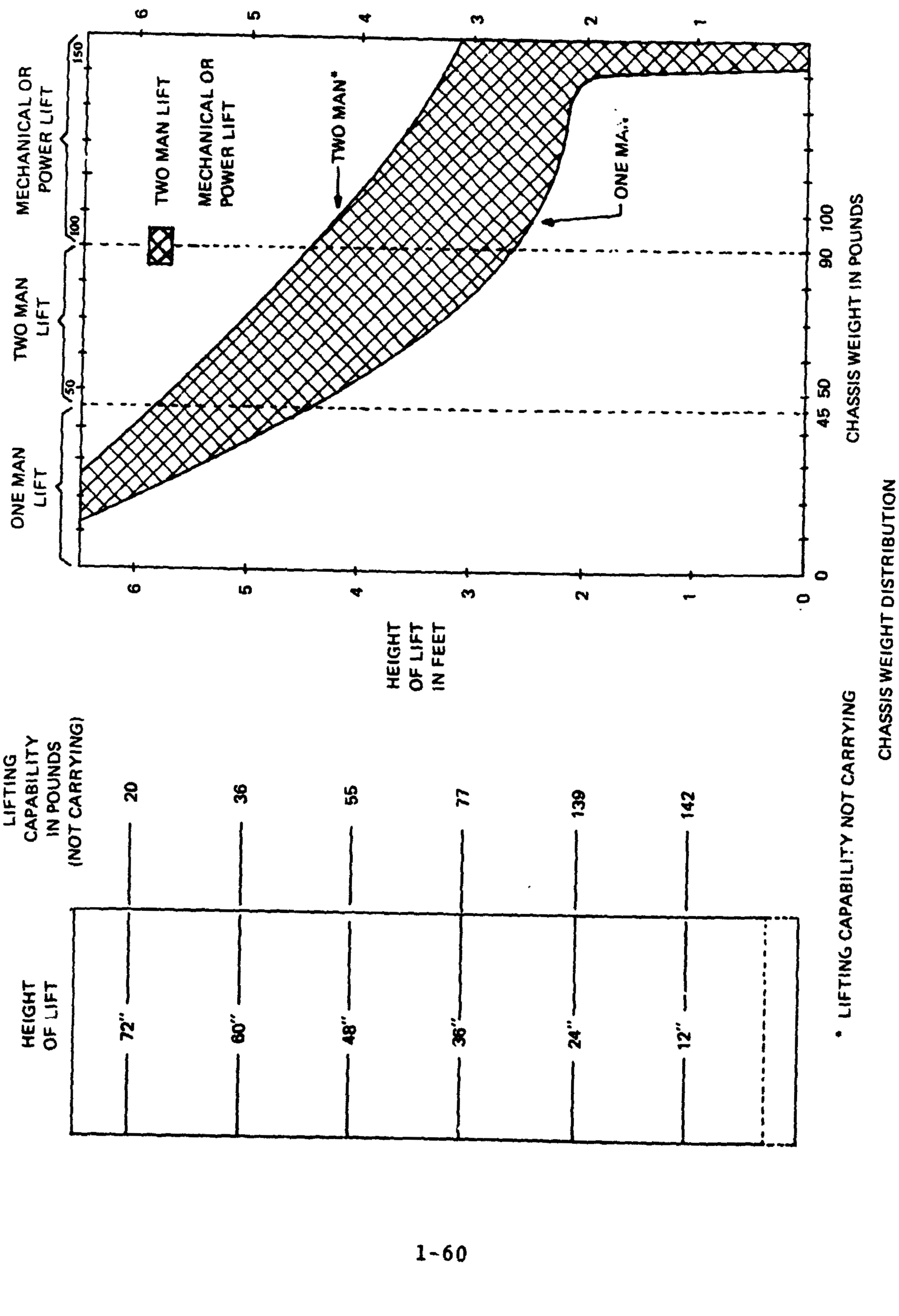
Approximate Lift Capacity of One Man

Manually-Propelled Vehicles (Dollies)

Transport equipment should be specified for modules weighing more than 35 pounds. Manually-propelled transport vehicles are recommended for the smaller of these units. Such vehicles should reflect the following design considerations:

RECOMMENDED WEIGHT LIMITS FOR PACKAGE DESIGN




HEIGHT OF LIFT
72"
60"
48"
36"
24"
12"
LIFTING CAPABILITY IN POUNDS (NOT CARRYING)
20
36
55
77
139
142
HEIGHT OF LIFT IN FEET
ONE MAN LIFT
TWO MAN LIFT
MECHANICAL OR POWER LIFT
TWO MAN LIFT
MECHANICAL OR POWER LIFT
TWO MAN*
ONE MAN*
CHASSIS WEIGHT IN POUNDS
CHASSIS WEIGHT DISTRIBUTION
* LIFTING CAPABILITY NOT CARRYING

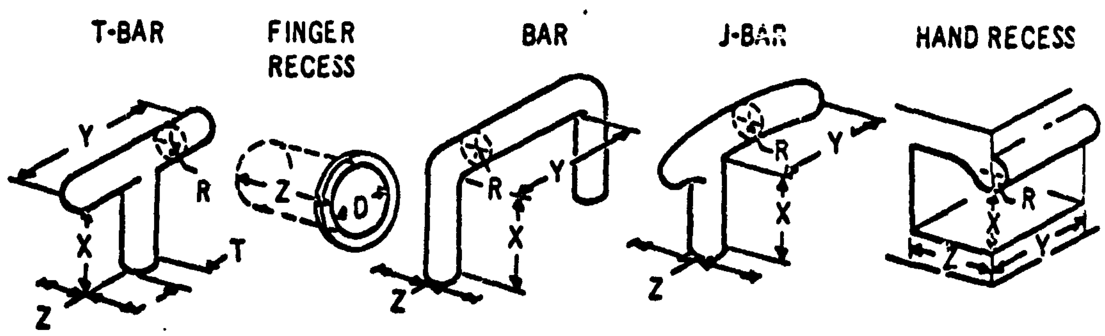
Curvature of handle or edge

WEIGHT OF ITEM	RADIUS OF CURVATURE (MINIMUM)
UP TO 15 LBS:	R – 1/8 IN.
15 TO 20 LBS:	R – 1/4 IN.
OVER 20 LBS:	R – 3/8 IN. BUT 1/5 IN.
T-BAR POST:	T – 1/2 IN.

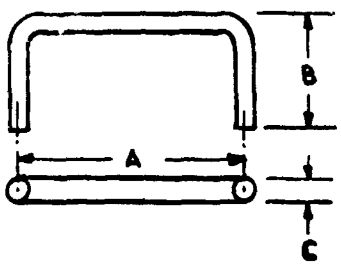
GRIPPING EFFICIENCY IS BEST IF FINGERS CAN CURL AROUND HANDLE OR EDGE TO AN ANGLE OF 120 DEGREES OR BETTER.

Dimensions of handle

DIMENSIONS OF HANDLE	EXPECTED USER CLOTHING								
	BARE HAND			GLOVED HAND			ARCTIC MITTEN		
TYPE OF HANDLE:	X	Y	Z	X	Y	Z	X	Y	Z
ONE-HAND BAR	2.0	4.25	2.0	2.5	4.75	2.0	3.0	5.5	3.0
TWO-HAND BAR	2.0	8.6	2.0	2.5	9.5	2.0	3.0	11.0	3.0
TWO-FINGER BAR	1.25	2.5	1.5	1.5	3.0	1.5	DON'T USE		
ONE-HAND RECESS	2.0	4.25	3.5	2.5	4.75	4.0	3.0	5.5	5.0
TWO-FINGER RECESS	1.25-DIA		2.0	1.5-DIA		2.0	DON'T USE		
ONE-FINGER RECESS	1.25-DIA		2.0	1.5-DIA		2.0	DON'T USE		
FINGER-TIP RECESS	0.75-DIA		0.5	1.0-DIA		0.75	[illegible] USE		
T-BAR	1.5	4.0	1.5	2.0	4.5	2.0	D[illegible] USE		
J-BAR	2.0	4.0	2.0	2.0	4.5	2.0	3.0	5.0	3.0

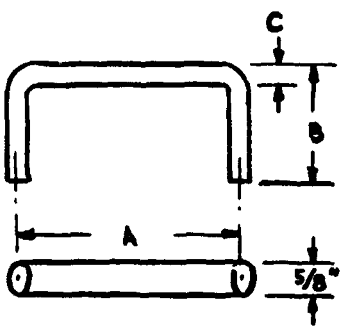


Types of handles



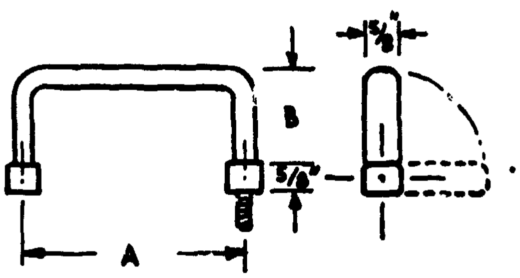
Round Cross-Section

(inches) A	B	C
9	1-3/4	5/16
2	1-5/16	5/16



Oval Cross-Section
(Preferred)

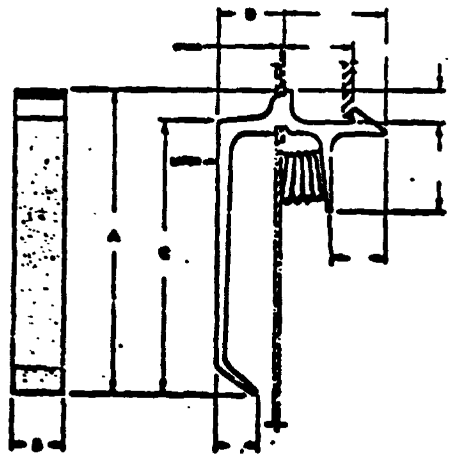
9	1-3/4	1/4
2	1-5/16	1/4



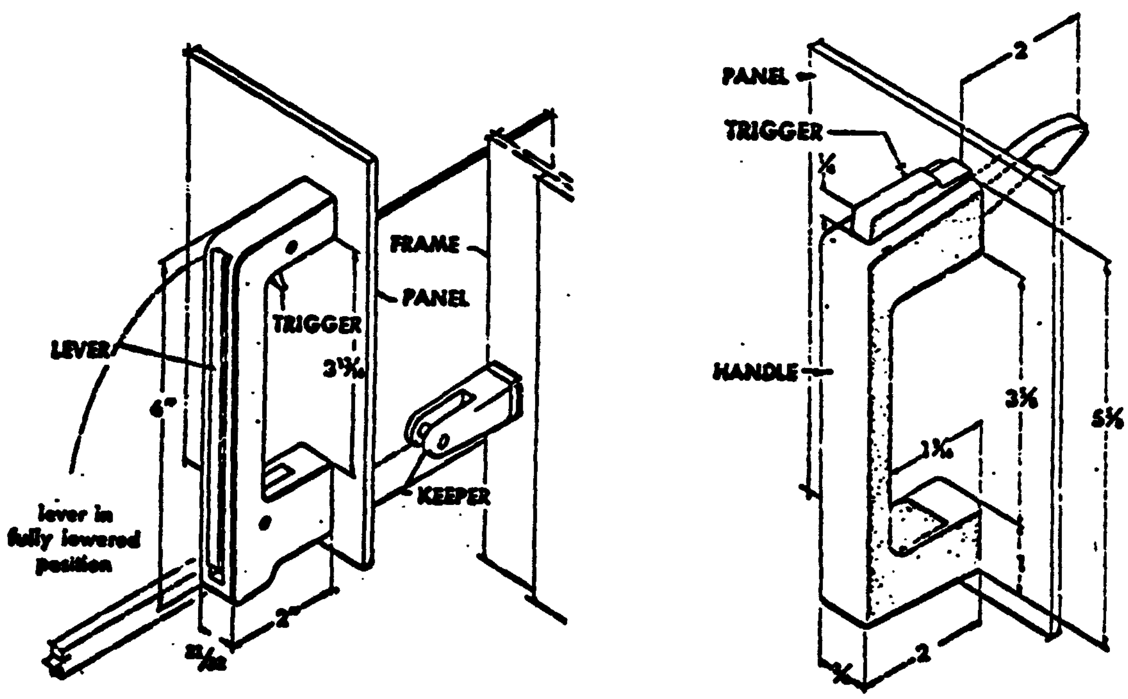
Folding Handle

4	1-17/32	1/4

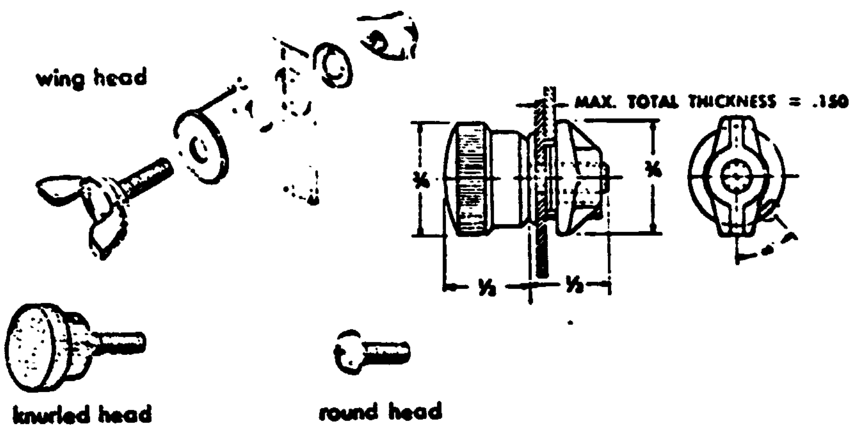
Typical Off-the-Shelf Equipment Handles

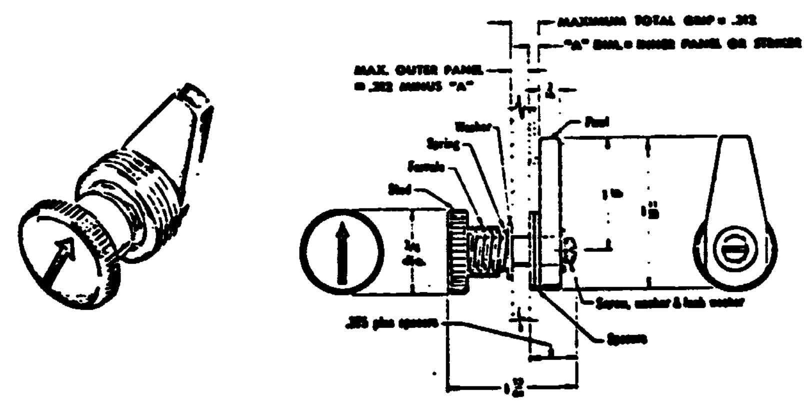


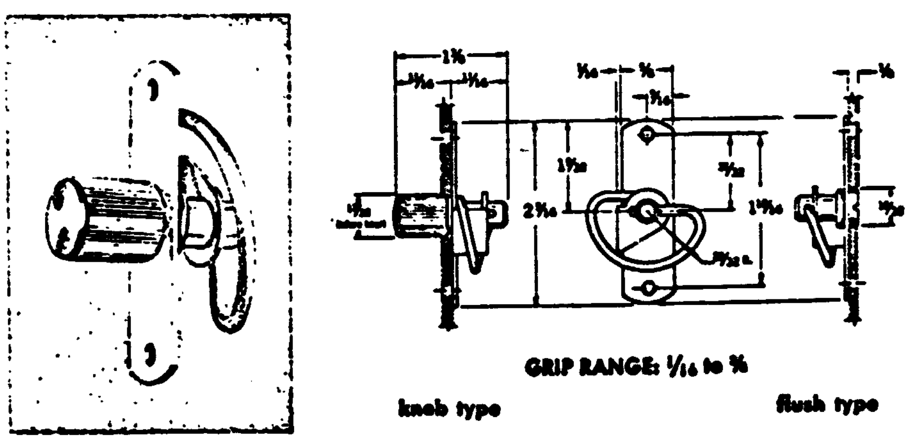
A	B	C	D
5-1/4	3/4	4-3/4	1
2-5/8	29/64	2-3/8	9/16

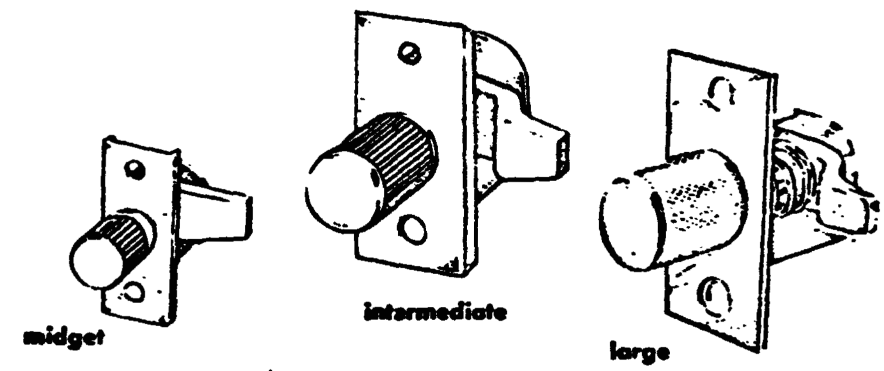


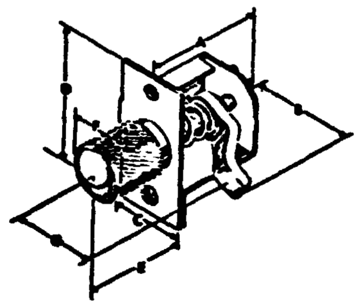
[illegible] [illegible]bination Assemblies Which Serve As
[illegible]ing Device and Chassis Carrying Handle


wing head
MAX. TOTAL THICKNESS = .150
knurled head
round head



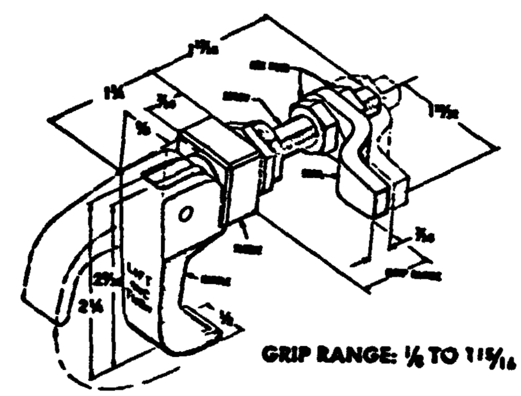

GRIP RANGE: 1/16 to 5/8
knob type
flush type



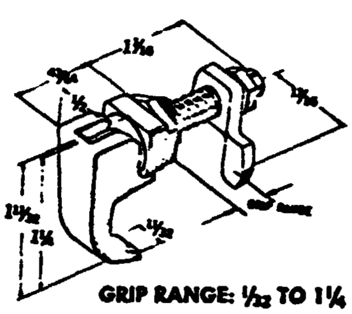


size	A	B	C	D	E	F	G*
midget	[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]	½ ± [illegible]
intermediate	1[illegible]	1	[illegible]	1[illegible]	[illegible]	[illegible]	[illegible] ± [illegible]
large	1[illegible]*	1[illegible]	1[illegible]	2½	1[illegible]	[illegible]	[illegible] ± [illegible]*

* flush head A dimension 2[illegible]
* flush head G dimension is 1[illegible] [illegible]
* edge of frame to centerline

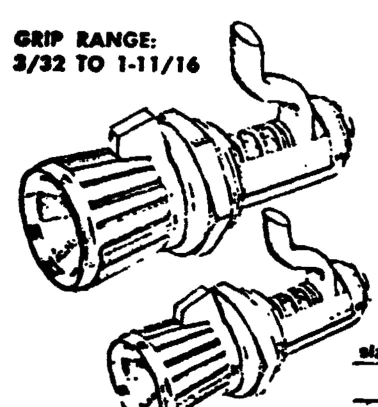


GRIP RANGE: ⅛ TO 1 11/16

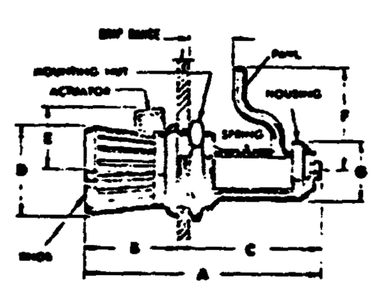


GRIP RANGE: 1/32 TO 1¼

GRIP RANGE:
3/32 TO 1-11/16

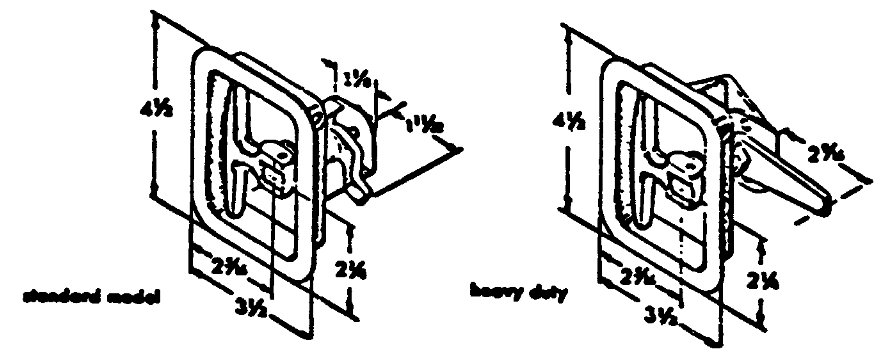


GRIP RANGE: 1/16 TO 1-7/16

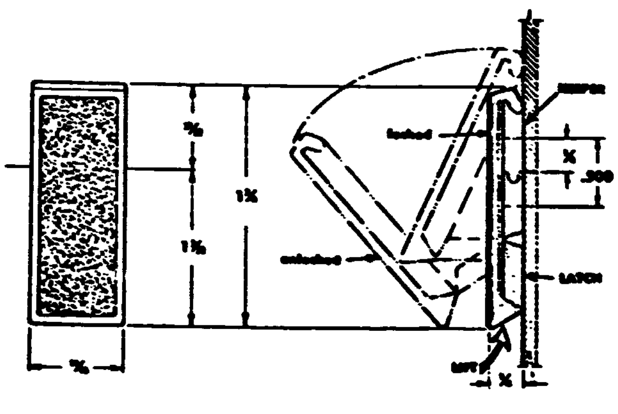


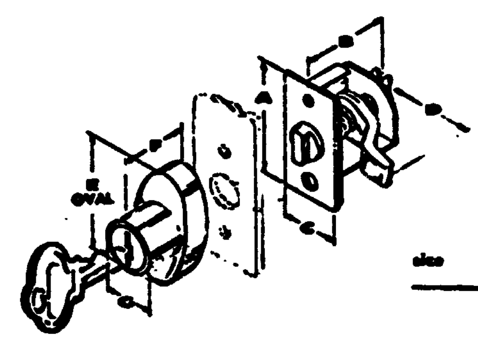
dimensions

size	A	B	C	D	E	F	G
	3 [illegible]	1[illegible]	1[illegible]	1[illegible]	[illegible]	1[illegible]	[illegible]
	2[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]



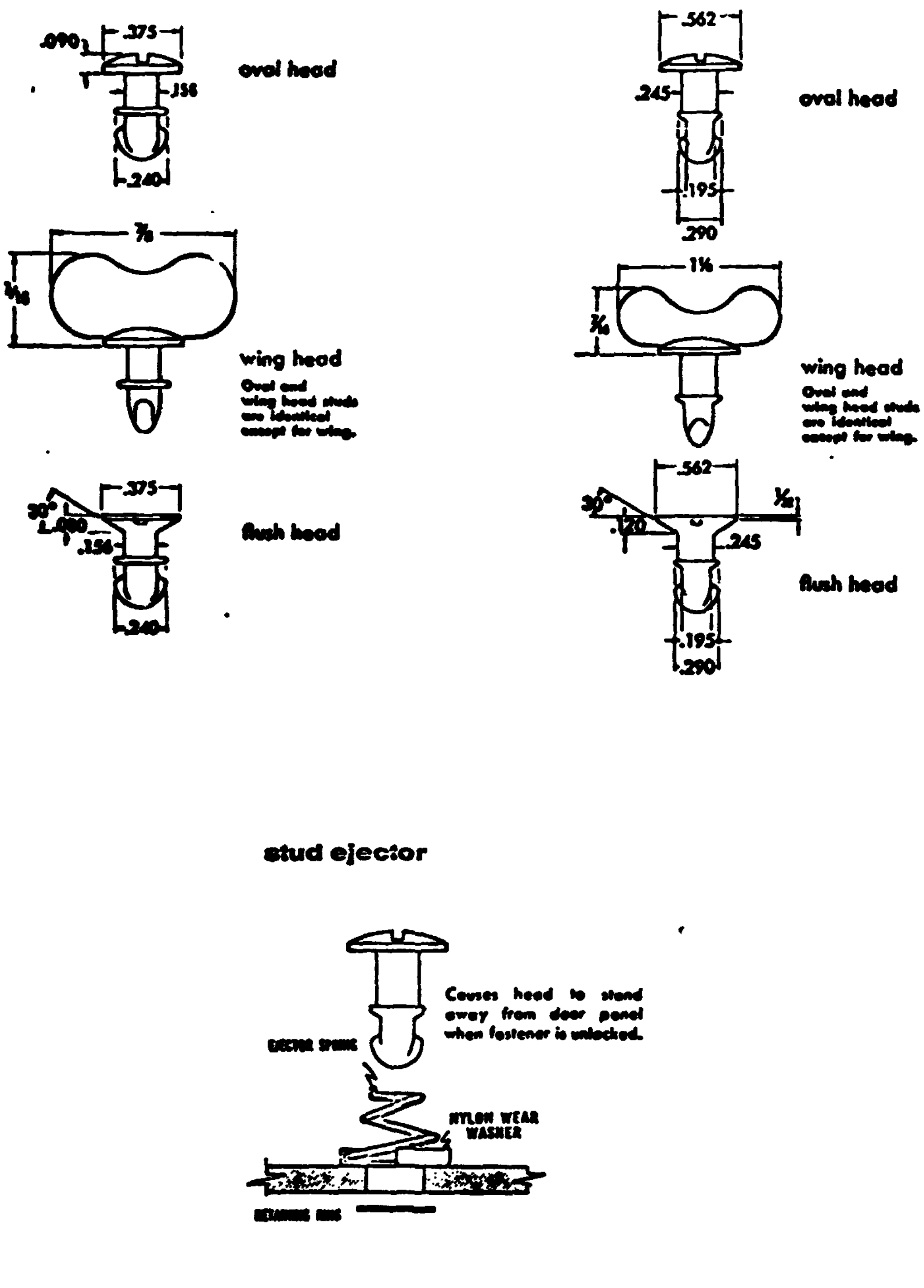
GRIP RANGE: 3/8 TO 2 1/4





size	A	B	C	D	E	F	G
	1 3/8	1 1/8	7/8	1 in.	1 5/8 x 1 in.	9/16	3/4
	2 1/2	1 3/8	1 1/16	1 5/16	2 1/16 x 1 1/2	11/16	3/4

GRIP RANGE: 1/8 TO 1 1/8



Typical Spring-Loaded Panel Fastener

MINIMAL FINGER ACCESS TO FIRST JOINT:

PUSH BUTTON ACCESS:

- Bare Hand: 1.25" dia.
- Gloved Hand: 1.5" dia.

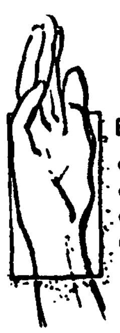
TWO FINGER TWIST ACCESS:

- Bare Hand: 2.0" dia. clearance around object
- Gloved Hand: 2.5" dia. clearance around object

VACCUM TUBE INSERT (tube held as at right):

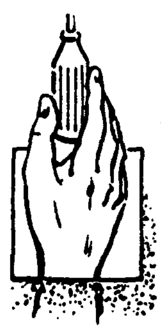
- Miniature tube: 2.0" dia. clearance around object
- Large tube: 4.0" dia. clearance around object

MINIMAL ONE HAND ACCESS OPENINGS:



EMPTY HAND TO WRIST: WIDTH HEIGHT

- Bare hand, rolled: 3.75" sq. or dia.
- Bare hand, flat: 2.25" x 4.0" or 4.0" dia.
- Glove or mitten: 4.0" x 6.0" or 6.0" dia.
- Bulky Protective mitten: 5.0" x 6.5" or 6.5" dia.

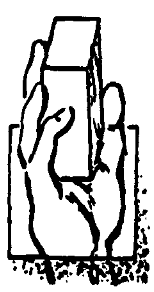


HAND PLUS 1" DIA OBJECT, TO WRIST:

- Bare hand: 3.75" sq. or dia.
- Glove or mitten: 6.0" sq. or dia.
- Bulky Protective mitten: 7.0" sq. or dia.

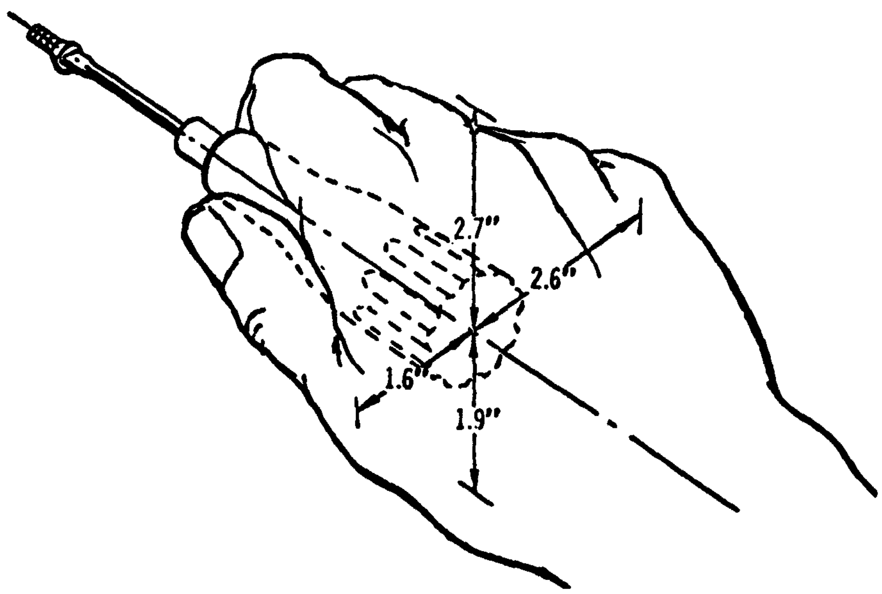
CLENCHED HAND TO WRIST:

- Bare hand: 3.5" x 5.0" or 5.0" dia.
- Glove or mitten: 4.5" x 6.0" or 6.0" dia.
- Bulky Protective mitten: 7.0" x 8.5" or 8.5" dia.



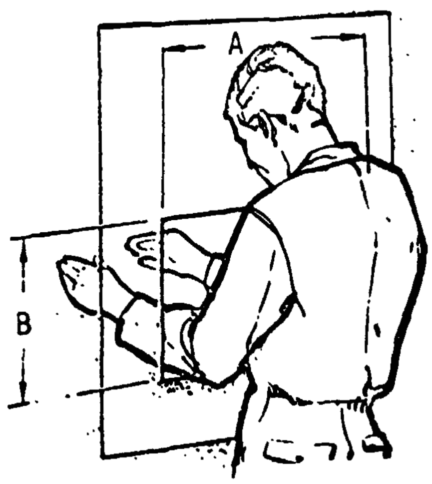
HAND PLUS OBJECT OVER 1" IN DIA TO WRIST:

- Bare hand: 1.75" clearance around object
- Glove or mitten: 2.5" clearance around object
- Bulky Protective mitten: 3.5" clearance around object



DISTANCE FROM END OF FINGERS	HORIZONTAL AXIS				VERTICAL AXIS			
	LEFT WIDTH		RIGHT WIDTH		UP		DOWN	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
1 IN.	1.16	.68–2.00	1.90	1.37–2.50	1.51	.66–2.25	1.26	.50–2.08
2 IN.	1.45	.92–2.25	2.31	1.75–2.85	2.00	1.08–2.91	1.62	.58–2.33
3 IN.	1.49	.93–2.25	2.42	1.88–2.81	2.26	1.25–3.33	1.67	.58–2.58
4 IN.	1.45	.65–2.20	2.40	1.75–3.00	2.39	1.25–3.33	1.52	.58–2.50
5 IN.	1.41	.40–1.95	2.32	1.63–2.95	2.31	1.25–3.50	1.36	.58–2.25
6 IN.	1.31	.35–2.50	2.21	1.68–2.90	2.44	1.83–3.58	1.04	.33–1.83

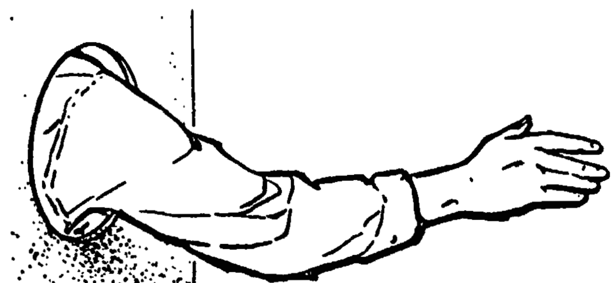
NOTE:
THE POINTS ARE GIVEN IN INCHES FROM AN IMAGINARY LINE EXTENDING ALONG THE AXIS OF THE TOOL INVOLVED. WHEN ALL FOUR UNDERLINED POINTS ARE PLOTTED ON PERPENDICULAR AXES THEY DESCRIBE THE MAXIMUM AVERAGE VOLUME REQUIRED FOR THE OPERATION. A MORE GENEROUS AND COMFORTABLE ENVELOPE IS DESCRIBED BY USING THE MAXIMUM RANGE VALUES INSTEAD OF THE MAXIMUM MEAN VALUES.



TWO HAND REACH 6 TO 25 INCHES IN DEPTH

BLIND ACCESS

LIGHT CLOTHING	A	8" OR 75% OF REACH
	B	5"
BULKY PROTECTIVE CLOTHING	A	6" PLUS 75% OF REACH
	B	7"
VISIBLE ACCESS		
	B	22.6"



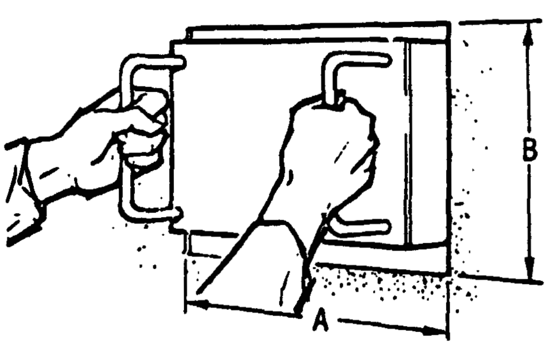
ARM ACCESS

ARM TO ELBOW

LIGHT CLOTHING	4.5" X 4.5" DIA OR 3.5" AROUND OBJECT
BULKY PROTECTIVE CLOTHING	7" X 7" DIA OR 3.5" AROUND OBJECT

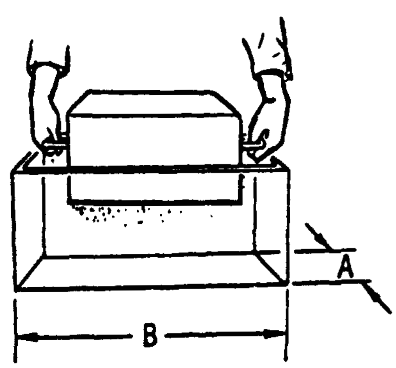
ARM TO SHOULDER

LIGHT CLOTHING	5" X 5", 5" DIA OR 3.5" AROUND OBJECT
BULKY PROTECTIVE CLOTHING	8.5" X 8.5", 8.5" DIA OR 3.5" AROUND OBJECT



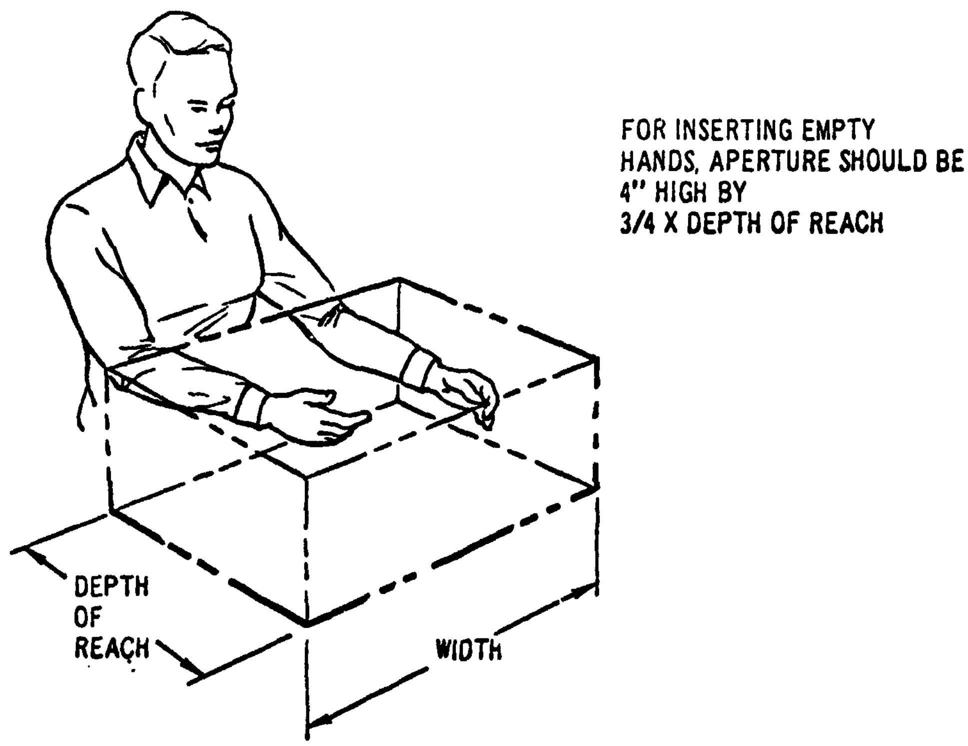
INSERT OBJECT WITH HANDLES ON FACE

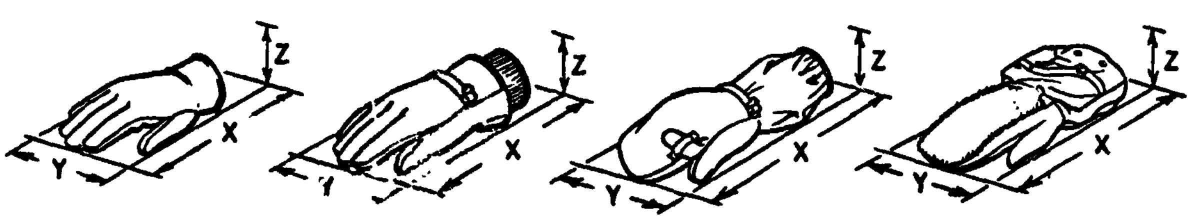
A	BOX PLUS 1.5"
B	8.5" OR BOX PLUS 1.5" WHICHEVER IS GREATER



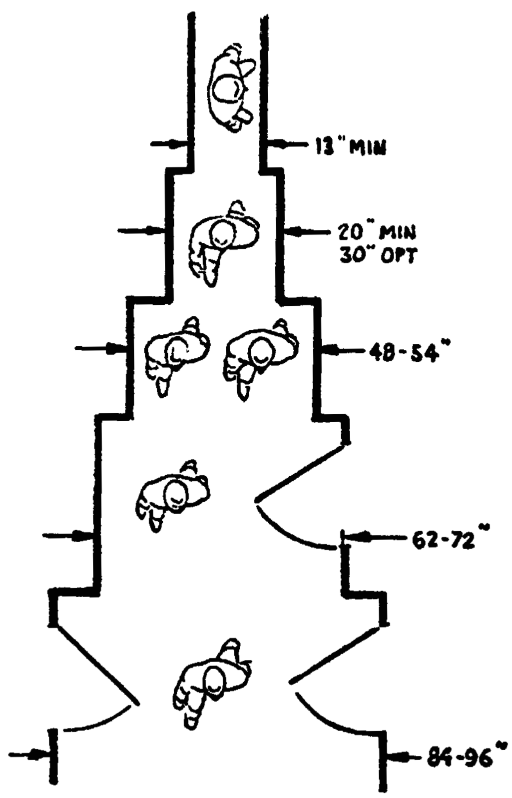
INSERT OBJECT WITH HANDS ON SIDES

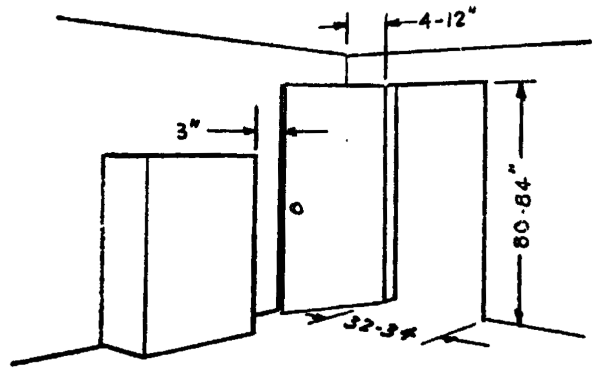
A	BOX PLUS 1.5"
B	BOX PLUS 4.5" (LIGHT CLOTHING) BOX PLUS 7" (BULKY PROTECTIVE CLOTHING)

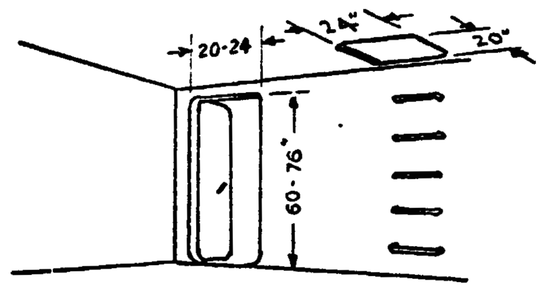


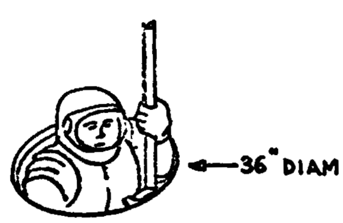


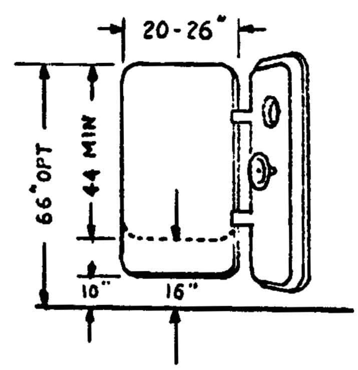
Hand Attitude	Anticontact Glove X	Y	Z	Wet-cold Glove X	Y	Z	Wet-cold Mitten X	Y	Z	Arctic Mitten X	Y	Z
Extended flat:	10.3	4.5	2.5	10.5	5.5	3.0	14.0	5.8	3.2	16.4	5.2	3.6
Closed as fist:	7.0	5.0	3.3	7.3	5.8	3.7	11.5	5.8	3.8	14.3	5.2	5.4
Grasping handle;												
.25" diameter:	7.0	5.0	3.5	7.3	5.5	3.5	11.0	5.7	4.2	14.0	5.5	4.5
1.0" diameter:	7.0	5.0	3.5	7.3	5.3	4.0	11.0	5.2	4.5	14.7	5.2	4.5
2.0" diameter:	7.5	4.5	4.2	8.0	4.7	4.0	12.0	5.2	4.7	15.0	5.4	5.0
Grasping knob;												
.25" diameter:	8.0	3.8	4.3	9.0	4.6	4.0	11.5	5.0	4.2	15.5	4.8	4.5
1.0" diameter:	9.0	3.5	4.0	9.0	4.5	4.0	12.0	5.0	4.0	15.8	4.8	4.8
2.0" diameter:	9.5	3.7	3.7	9.2	4.5	4.2	12.5	4.6	4.4	16.0	4.7	4.5

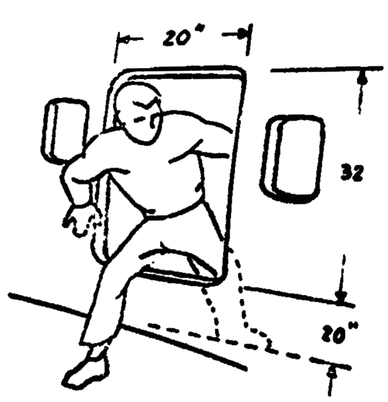

13" MIN
20" MIN
30" OPT
48-54"
62-72"
84-96"

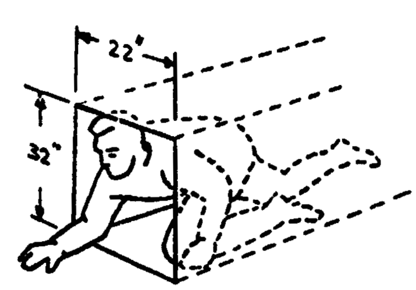

4-12"
3"
80-84"
32-34


20-24
24"
20"
60-76"


36" DIAM


20-26"
66" OPT
44 MIN
10"
16"


20"
32
20"


22"
32"

RECOMMENDED PASSAGEWAY DIMENSIONS

DIMENSIONS		
MINIMUM	MAXIMUM	DESCRIPTION
6 feet	2 feet wider than widest object to pass through the hallway	Main passageways or hallways
6 feet	---	Width when one door opens into passageway
---	8 feet	Width when two opposing doors open into passageway
4 feet	54 inches	Width for light traffic when no doors open into passageway
114 inches	30 inches higher than tallest equipment passing through passageway	Height of passageway to clear mobile equipment
78 inches	---	Height of passageway to clear personnel

Note: Above dimensions do not apply to special facilities such as Vans, Submarines, Military Aircraft, ect. For such facilities refer to anthropometric criteria and consider clearance for special clothing, critical equipment operation and handling of mobile equipment during ingress, egress, remove and replace, and emergency escape.

- ROOM DIMENSION REQUIREMENTS

REQUIRED CLEARANCES		DIMENSION DESCRIPTION AND AREA INVOLVED	FUNCTION
Minimum	Maximum		
6 feet	6 feet	From back of desk or console to wall (for "seeover" to wall display, and maintenance-operational functions).	operational, maintenance
3 feet	3 feet	Front of console or desk (distance from leading edge of writing shelf to back of operator equipment).	operational, administrative
30 inches		Per operator laterally (seated console type operation).	operational
26 inches	30 inches	Per person laterally (seated desk, conference table, training activities).	administrative support
48 inches		Per person laterally (right handed standing operation, 30 inches to the right of the body centerline and 18 inches to the left, vice versa for left handed operation).	operational
50 inches		From front of equipment to opposite facing surface for momentary bending and kneeling activities, and for single row of racks - or equipment.	operational, maintenance
8 feet		For two rows of equipment racks facing each other, requiring operator functions in each row and some kneeling or bending function with use of mobile test equipment.	operational, maintenance
13 inches	18 inches	On each side of rock drawers weighing more than 45 pounds (racks ca[illegible] placed next to one another in a row).	maintenance

ROOM DIMENSION REQUIREMENTS (Continued)

REQUIRED CLEARANCES		DIMENSION DESCRIPTION AND AREA INVOLVED	FUNCTION
Minimum	Maximum		
4 inches	18 inches	4" on one side, 18" on the other for rack drawers 45 pounds or less with drawers in extended position.	maintenance
4 inches	12 inches	For the space between the doorway and the wall.	logistics and support
6 feet		For the spacing of equipment from doorway.	logistics and support
4 feet	5 feet	Clearance in back of consoles and racks requiring maintenance and calibration activities with mobile test equipment. (Back maintenance doors on racks and console).	maintenance
3 feet	5 feet	Clearance and spacing on each side of consoles and rows of rack equipment as passageway (can also be applied to supply, support, and administrative equipment).	operational, maintenance, administrative, communication, logistics, and support
10 feet		Room height necessary to accommodate electronic rack equipment, 15" for air ducts on rack equipment, 15" for lighting fixture, and 3" for electrical cabling.	operational
102 inches		Height of rooms in which no tall electronic equipment racks are to be installed.	operational, administrative, maintenance, storage, communication, logistics and support

ROOM DIMENSION REQUIREMENTS (Continued)

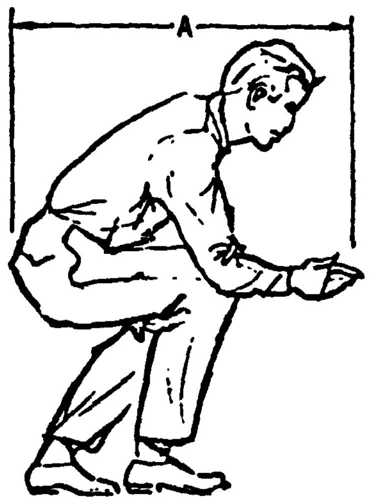
REQUIRED CLEARANCES		DIMENTION DESCRIPTION AND AREA INVOLVED	FUNCTION
Minimum	Maximum		
length = 2 x width	length = 2 x width	Room dimension requirements for clearances and training purposes. (can also be used as a conference room).	training, administrative and support

SQUATTING WORK SPACE

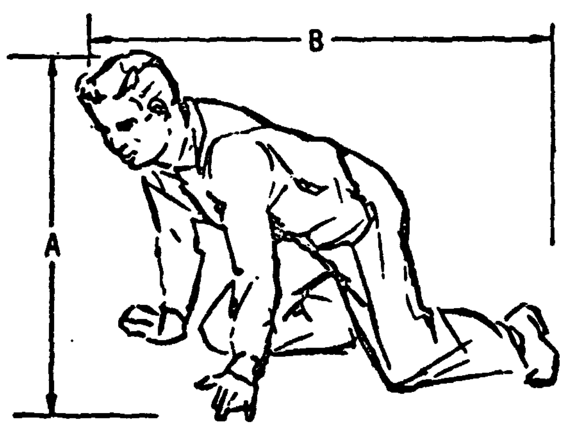
KNEELING WORK SPACE

		BULKY PROTECTIVE CLOTHING	LIGHT CLOTHING
SQUATTING WORK SPACE	"A"	51 MIN	48 MIN
	"B"	40 MAX	36 MIN
KNEELING WORK SPACE	"A"	59 MIN	56 MIN
	"B"	50 MIN	42 MIN
STOOPING WORK SPACE	"A"	44 MIN	36 MIN
KNEELING CRAWL SPACE	"A"	38 MIN	31 MIN
	"B"	62 MIN	59 MIN

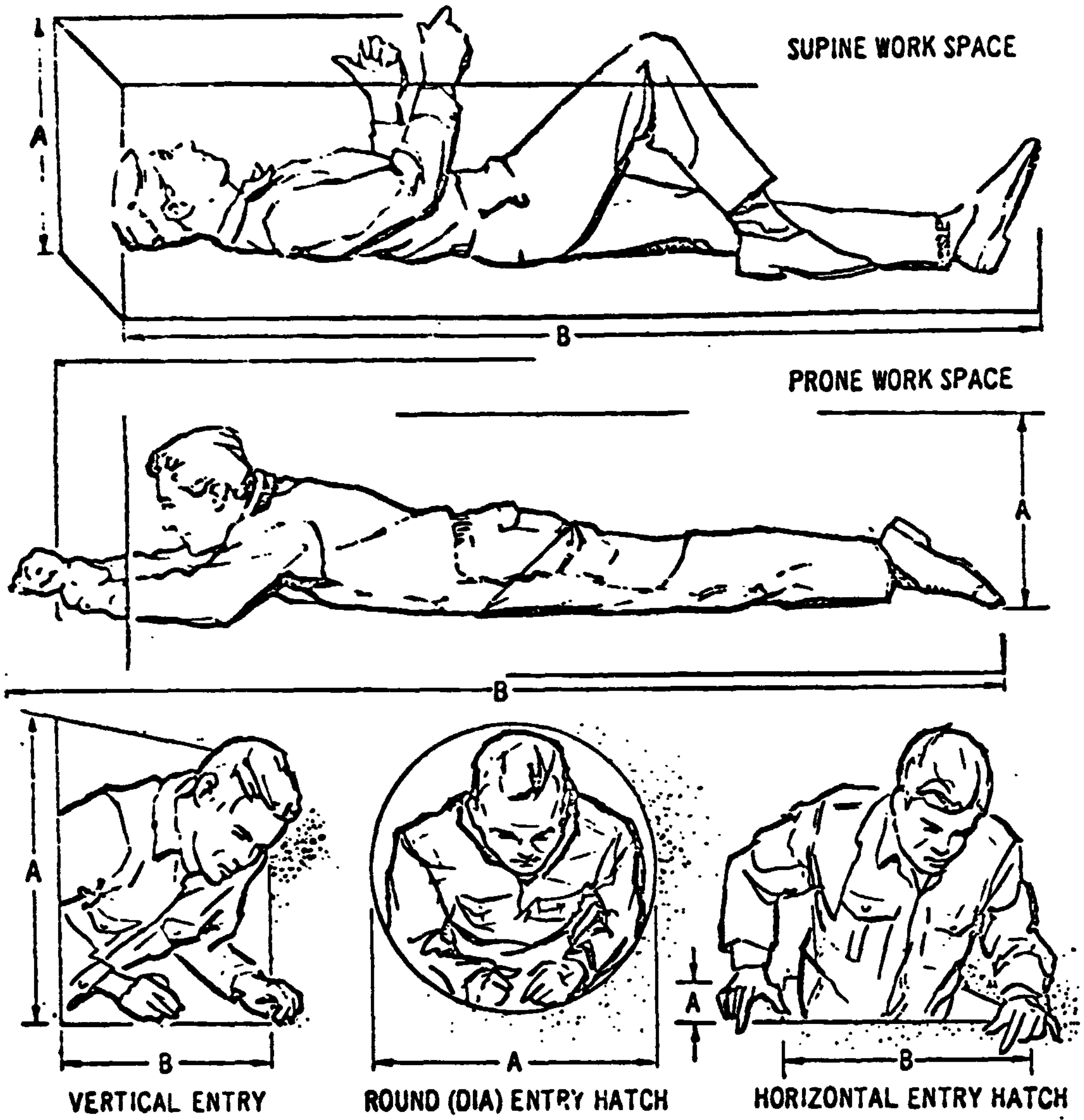
NOTE: ALL DIMENSIONS IN INCHES.



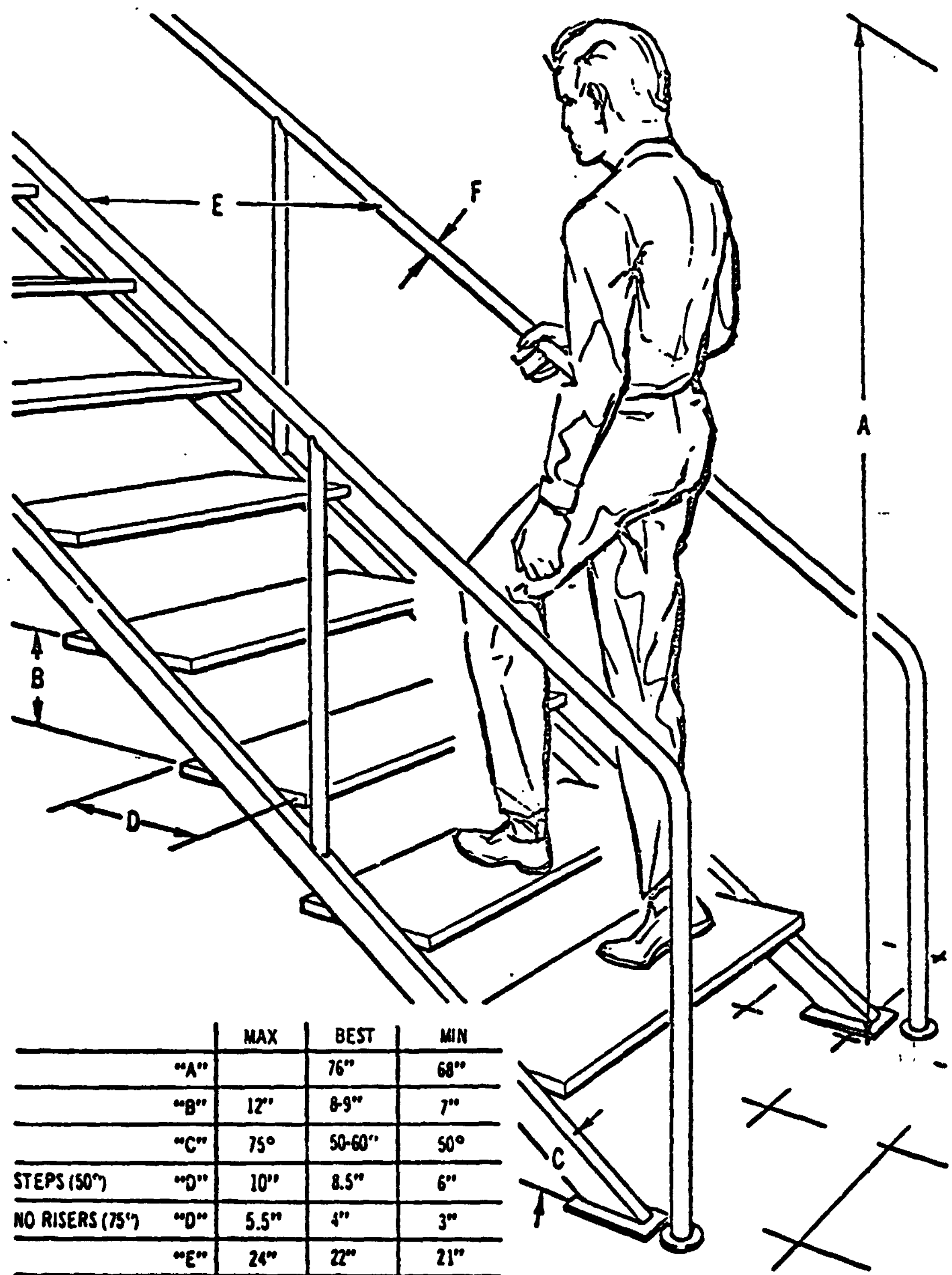
STOOPING WORK SPACE



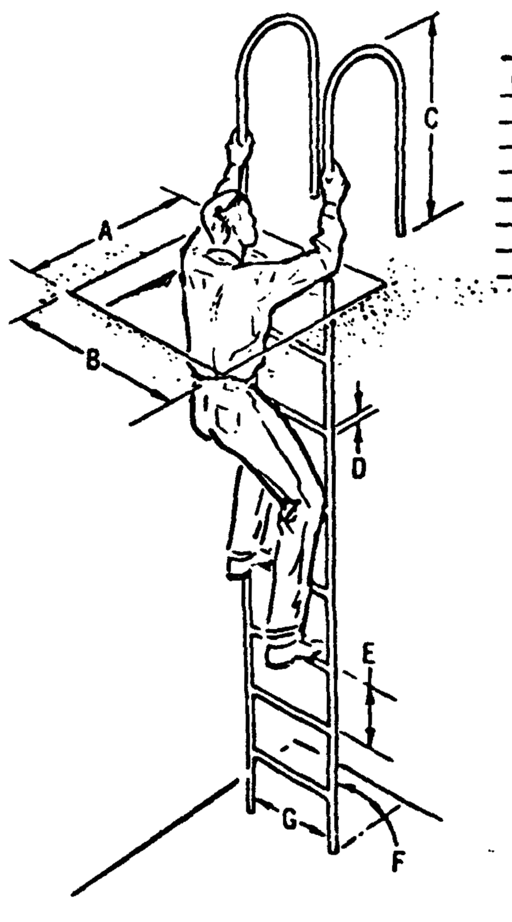
KNEELING CRAWL SPACE



		BULKY PROTECTIVE CLOTHING	LIGHT CLOTHING
SUPINE WORK SPACE	"A"	26" MIN	20" MIN
	"B"	78" MIN	78" MIN
PRONE WORK SPACE	"A"	24" MIN	17" MIN
	"B"	96" MIN	96" MIN
VERTICAL ENTRY HATCH	"A"	20" MIN	12" MIN
	"B"	32" MIN	24" MIN
ROUND DIA. ENTRY HATCH	"A"	32" MIN	24" MIN
HORIZONTAL ENTRY HATCH	"A"	24" MIN	
	"B"	32" MIN	22" MIN

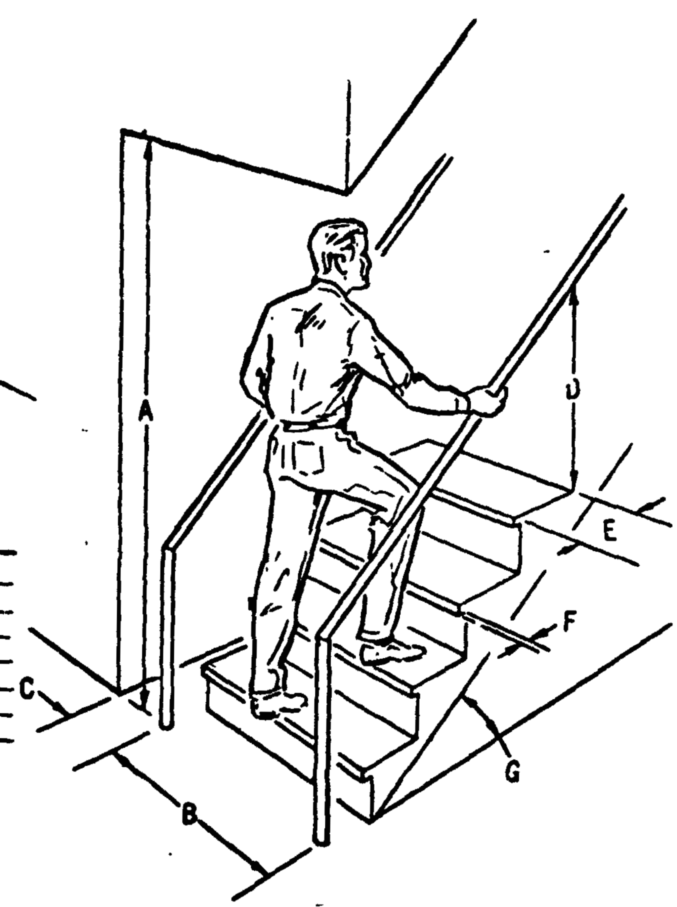


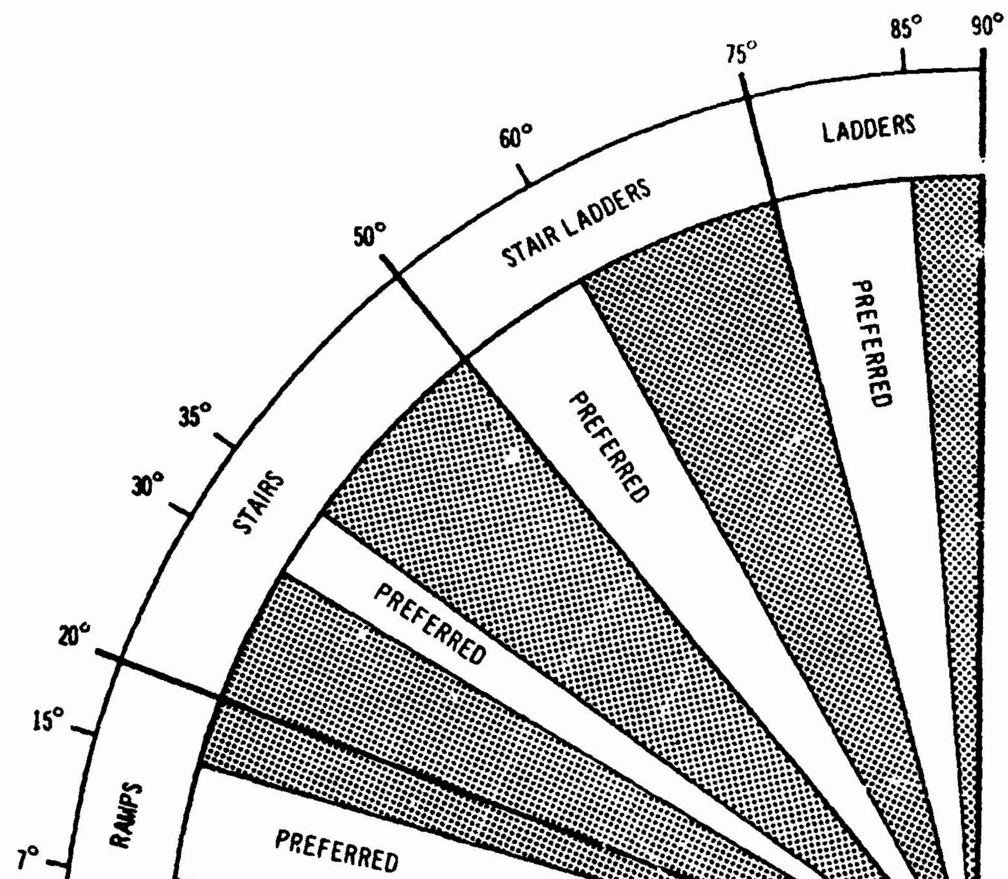
		MAX	BEST	MIN
	"A"		76"	68"
	"B"	12"	8-9"	7"
	"C"	75°	50-60°	50°
STEPS (50°)	"D"	10"	8.5"	6"
NO RISERS (75°)	"D"	5.5"	4"	3"
	"E"	24"	22"	21"
HANDRAILS AND LADDER RUNGS	"F"	3.0	1.25"	1.12"



LADDER	MAX	BEST	MIN
IN BACK OF LADDER "A"		8"	6"
ON CLIMBING SIDE "A"		36" FOR 76°	30" FOR 90°
"B"		30"	24"
"C"		36"	
WOOD "D"	1.5"	1.4"	1.3"
PROTECTED METAL "D"	1.5"	1.4"	1.0"
"E"	16"	11-12"	9"
"F"	90°	80°	75°
"G"		8-21"	12"

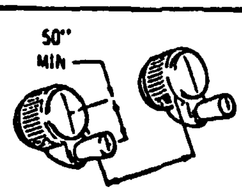
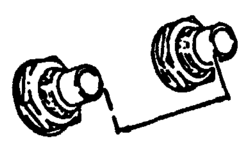
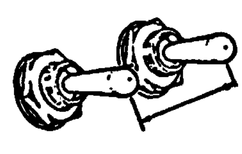
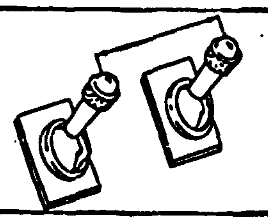
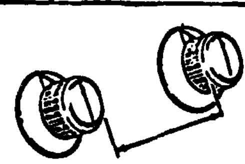
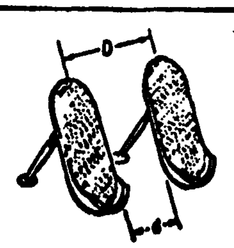
	MAX	BEST	MIN
STAIRS "A"		78"	76"
ONE WAY "B"		22"	20"
TWO WAY "B"		51"	48"
"C"		2.0"	1.75"
"D"	35"	33"	30"
"E"		11-12"	9.5"
"F"	1.5"	1"	
"G"	50"	30"-35"	20"

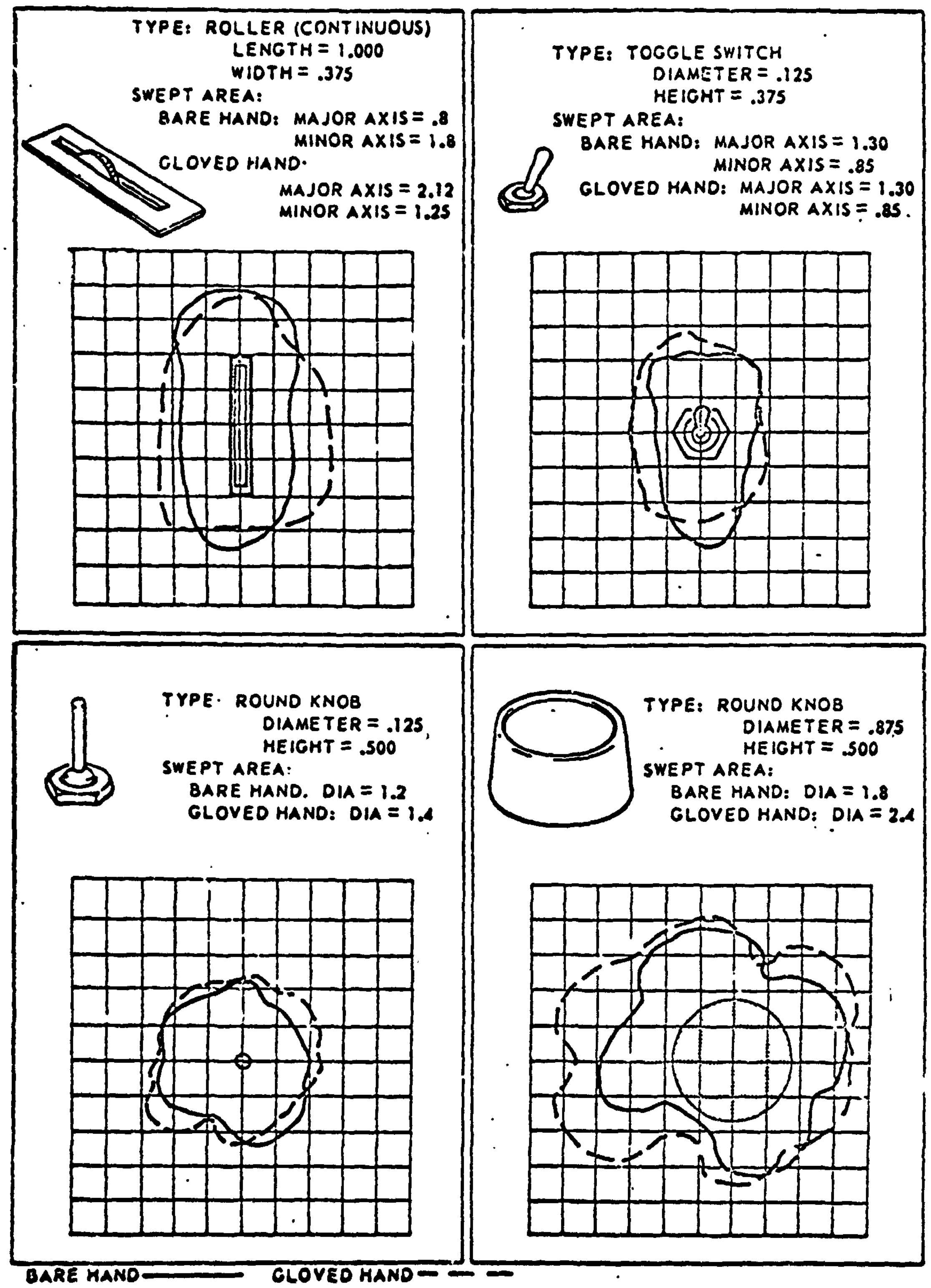




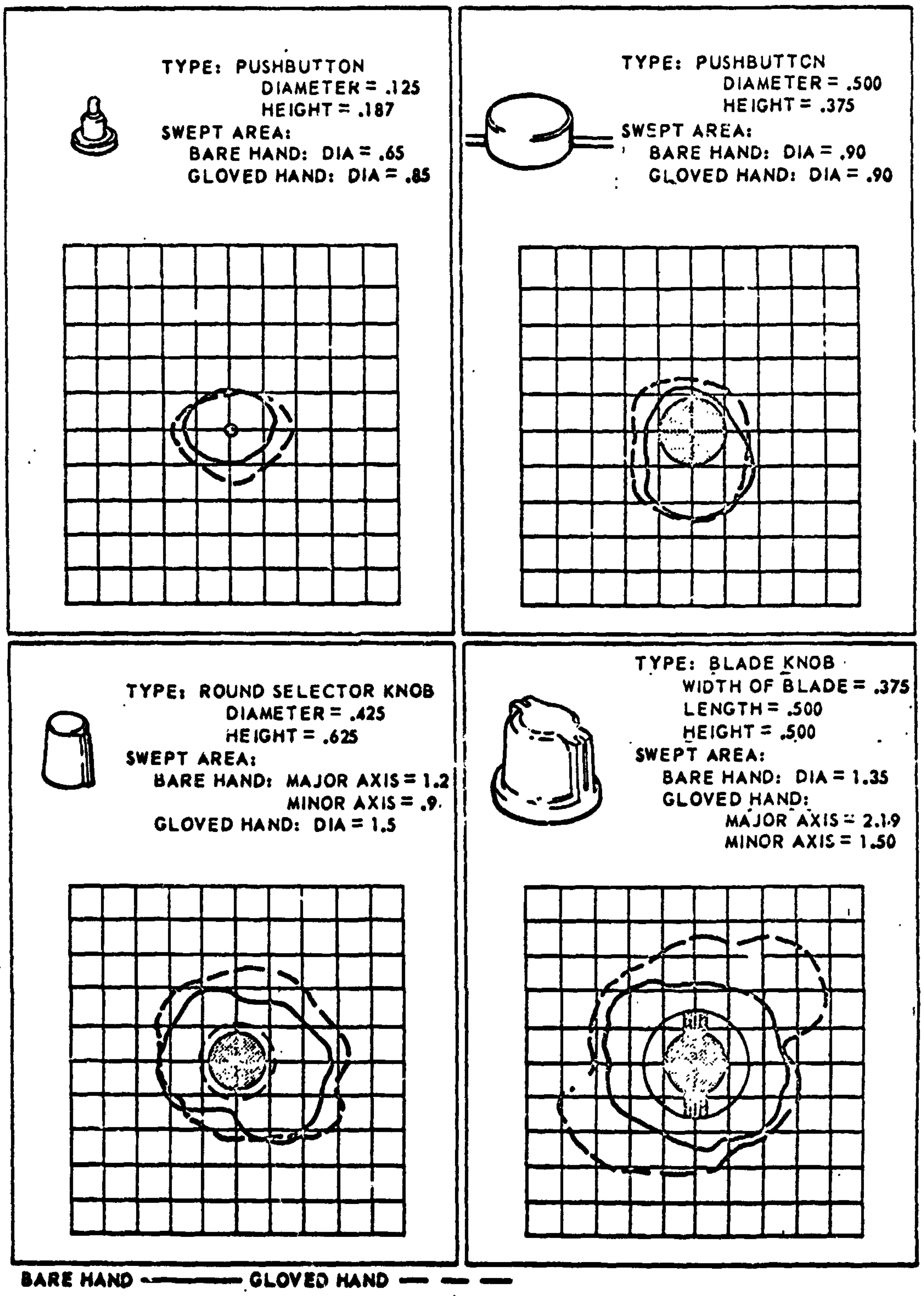
TYPES OF STRUCTURES (IN ORDER OF PREFERENCE)

Recommended Spacing Between Controls

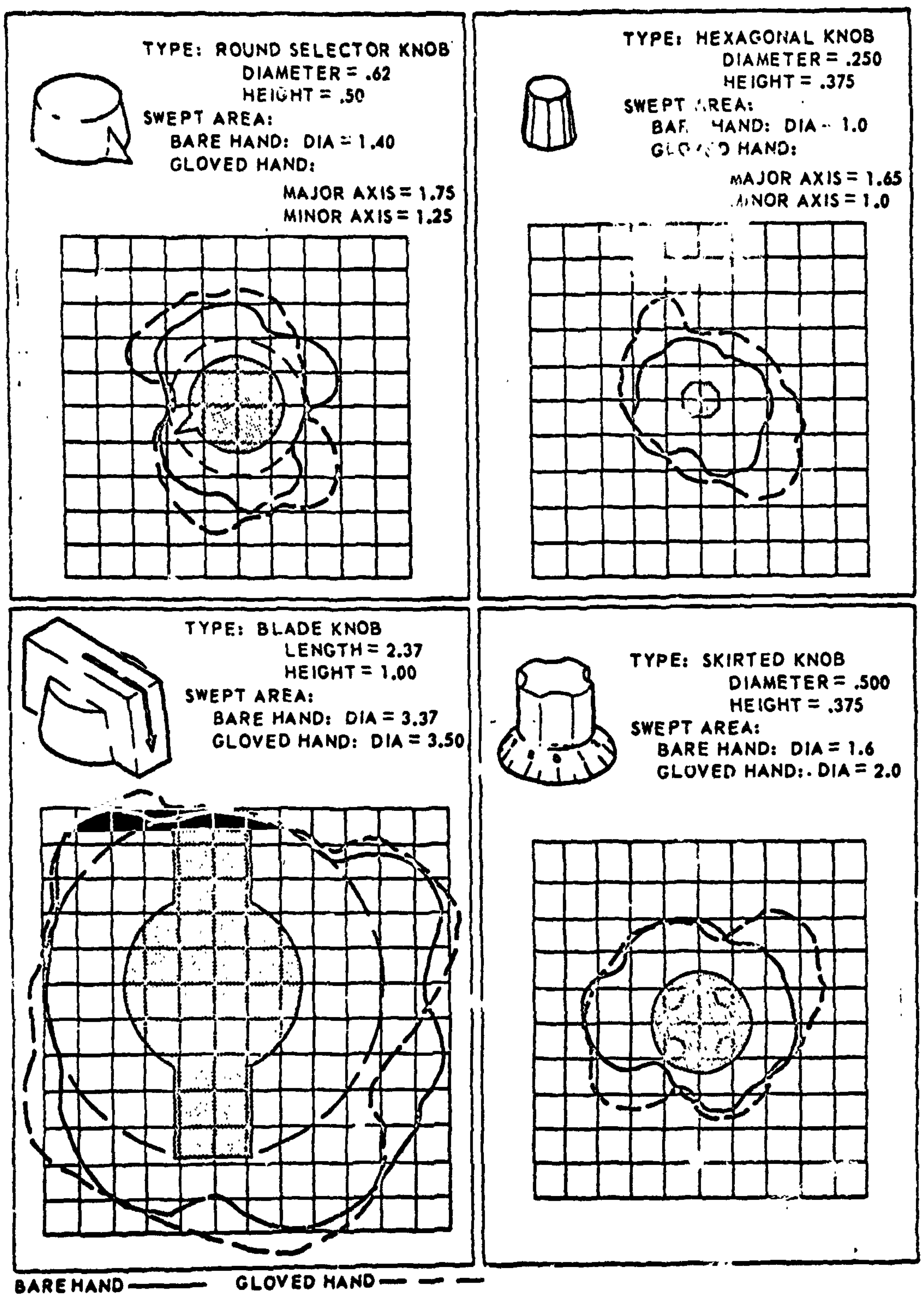
CONTROL	MEASURE OF SEPARATION	TYPE OF USE	EDGE TO EDGE SEPARATION: DESIRABLE MINIMUM FOR STATIONARY SITUATION	EDGE TO EDGE SEPARATION: DESIRABLE DISTANCE FOR MOVING VEHICLE SITUATION
CRANKS		ONE HAND INDIVIDUALLY	2"	4"
		TWO HANDS SIMULTANEOUSLY	3"	5"
PUSH BUTTON		ONE FINGER INDIVIDUALLY	.50"	2"
		ONE FINGER SEQUENTIALLY	.25"	1"
		DIFFERENT FINGERS INDIVIDUALLY OR SEQUENTIALLY	.50"	.50"
TOGGLE SWITCH		ONE FINGER INDIVIDUALLY	.75"	2"
		ONE FINGER SEQUENTIALLY	.50"	1"
		DIFFERENT FINGERS INDIVIDUALLY OR SEQUENTIALLY	.62"	.75"
LEVER LOCK TOGGLE SWITCH		FINGER AND THUMB INDIVIDUALLY	1"	2"
KNOBS		ONE HAND INDIVIDUALLY	1"	2"
		TWO HANDS SIMULTANEOUSLY	3"	5"
PEDALS		ONE FOOT - RANDOMLY	d 4" D 8"	6" 10"
		ONE FOOT - RANDOMLY	d 2" D 6"	4" 8"



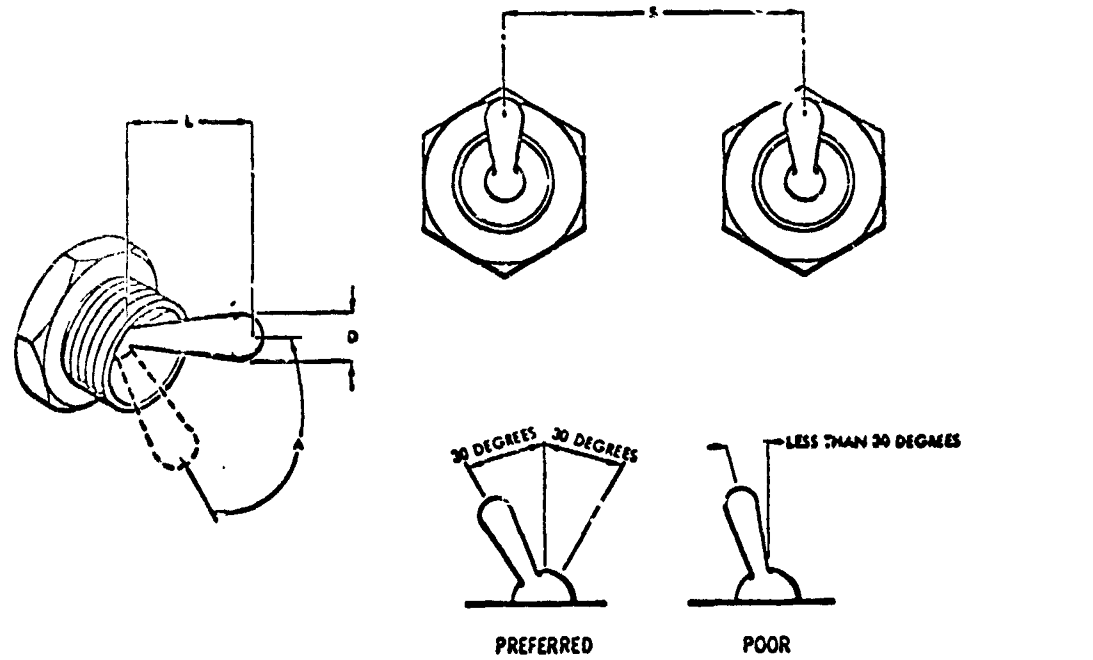
Criteria for Minimum Control Spacing



Criteria for Minimum Control Spacing



Criteria for Minimum Control Spacing



Operating Method	A (Displacement, deg)*	L (Lever Arm Length, in.)	D (Control Tip Diameter, in.)	Resistance (oz)** Small Switch	Resistance (oz)** Large Switch
Minimum	30	0.5	0.125	8	10
Maximum	120	2.0	1.000	16	40

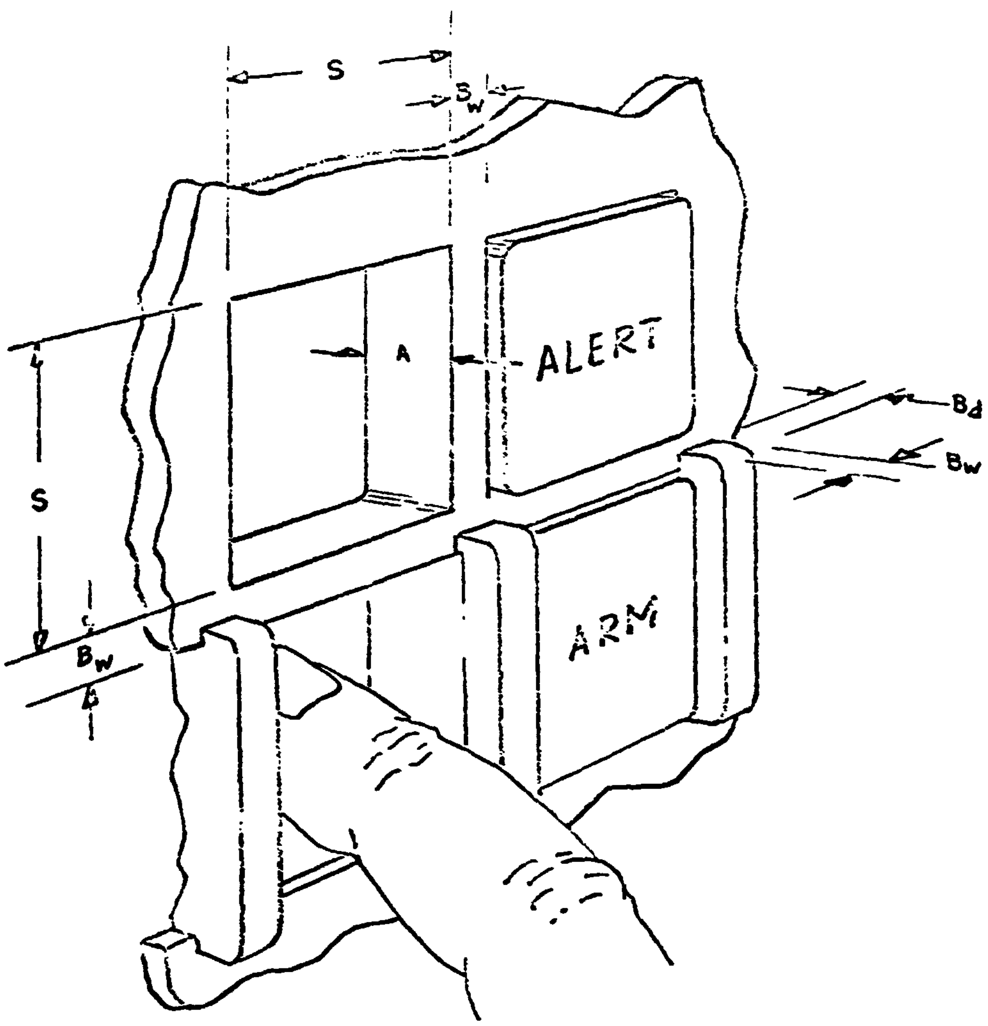
S (toggle switch separation, in.)

	One Finger	One Finger, sequential	Many Fingers, simultaneously
Minimum	0.75	0.50	0.62
Optimum	2.00	1.00	0.75

*Optimum displacement is 60 degrees.
**Resistance is taken to be linear.

Note: Toggle switches should have an elastic resistance, i.e., resistance should increase slowly until contact is made, then drop to zero as the switch snaps into position. Minimum friction and inertia are recommended. It should not be possible for the switch to stop between positions. Snap action should be provided with an audible click to indicate actuation.

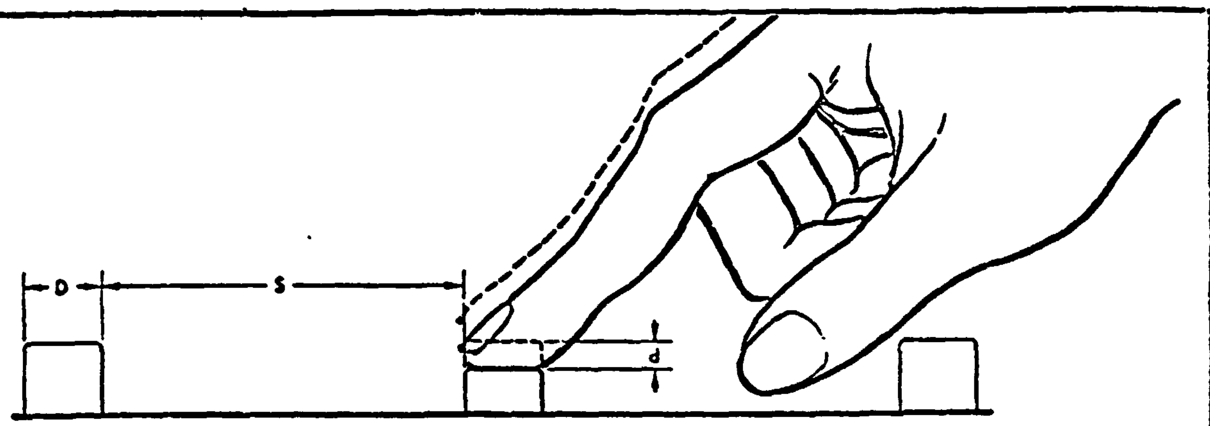
Recommended Dimensions for Toggle Switches



	S (Size)	A (Displacement)	Barriers* B_w	B_d	Resistance
Minimum	3/4"	1/8"	1/8"	3/16"	10 oz
Maximum	1-1/2"	1/4"	1/4"	1/4"	45 oz

*Barriers will have rounded edges.

Legend Switches

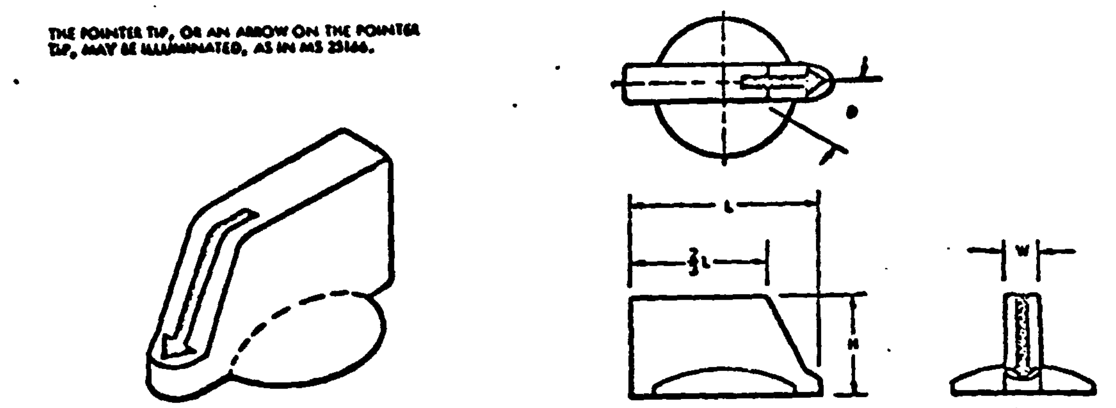


Operating Method	D (dia, in.)		d (displacement, in.)	Resistance (oz)	
	Fingertip	Thumb or Heel of Hand	Thumb or Other Finger	Fingertip	Little Finger
Minimum	0.50	0.75	0.25	10.0	5.0
Maximum	No data available	No data available	1.50	40.0	20.0

S (push-button separation, in.)			
	One Finger	One Finger, sequentially	Several Fingers
Minimum	0.50	0.25	0.50
Optimum	0.75	0.75	0.75

Note: The optimum push-button diameter in the case of multiple push-buttons is 0.5 in., the same as the minimum diameter. Push-buttons to be operated randomly or positioned blindly should be spaced 5.0 in. apart on the center of the panel, and 12.0 in. apart on the periphery. There should be elastic resistance with sliding friction. Push-button controls should have a slight initial resistance, increasing slowly to a sudden drop (accompanied by a definite "feel" and audible click) as the circuit is activated.

Recommended Dimensions for Hand Push-Buttons

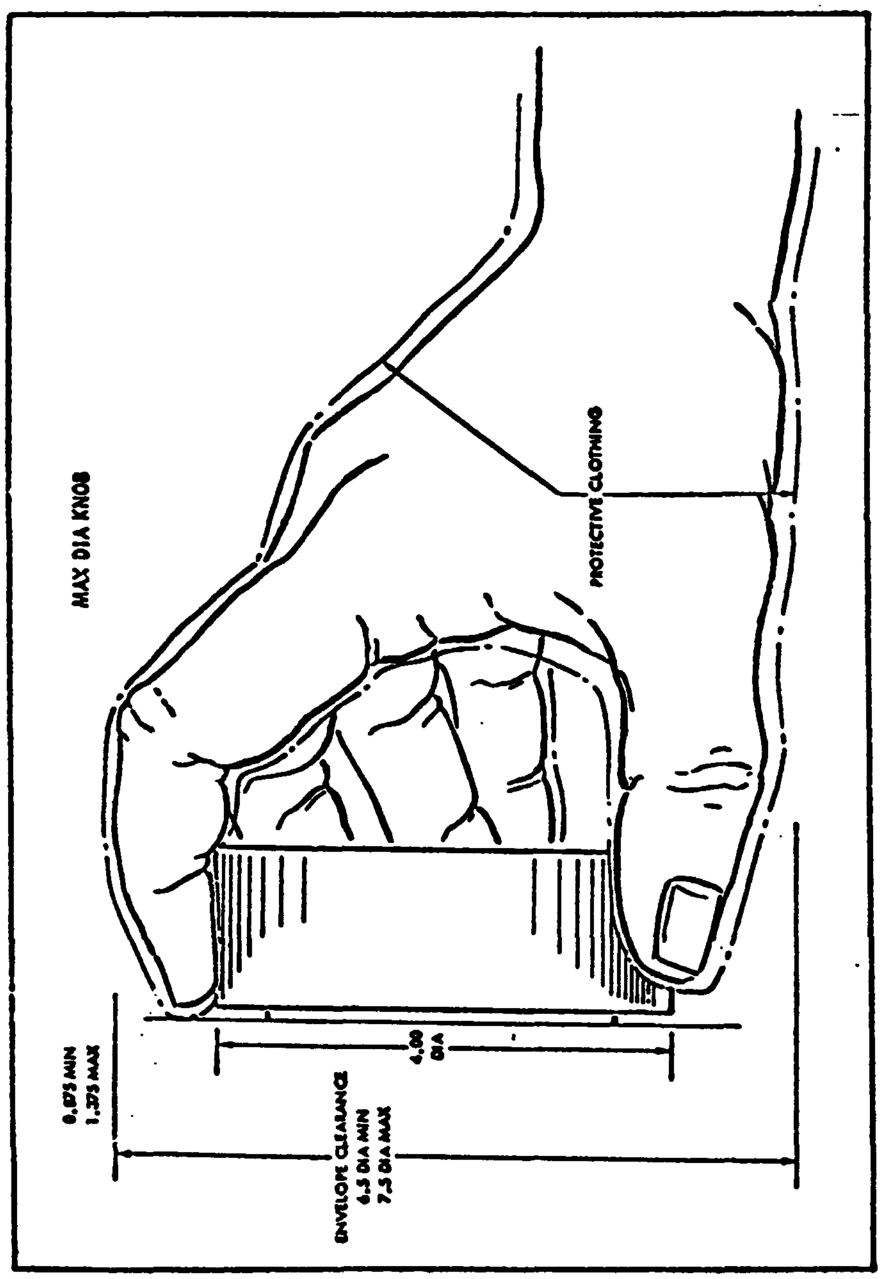


Operating Method	Pointer (in.) L (length)	W (width)	H (depth)	D (Displacement in deg) Visual positioning	Non-visual positioning	Resistance* (oz.)
Minimum	1.00	0.25	0.50	15	30	12
Maximum	3.00	1.00	3.00	40 (90 - when large separations are necessary)	40	48

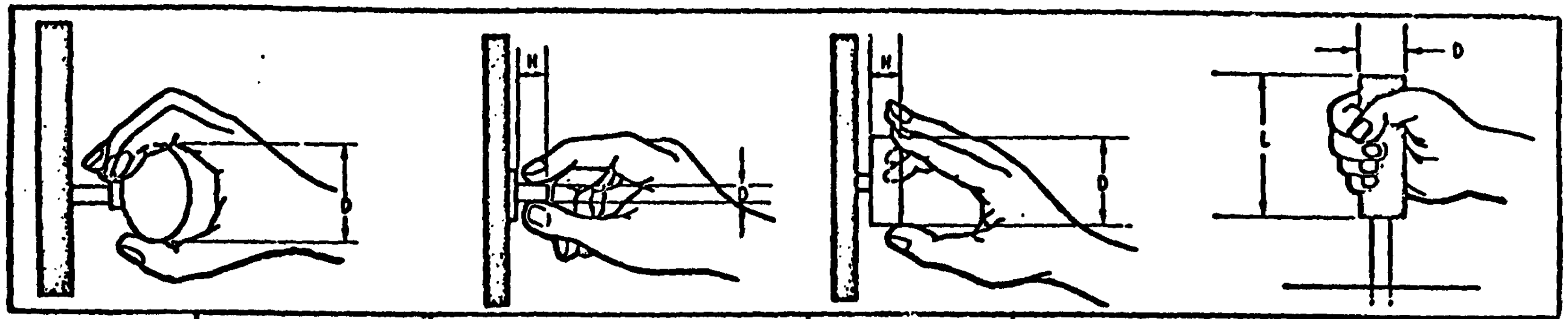
*Use elastic resistance which builds up and then decreases as each detent is approached, so that control will snap into position and cannot easily stop between adjacent positions.

Note: Military Standard MS 25166-Knob, Pointer, Illuminated meets, to a certain degree, the above requirements.

Recommended Dimensions for Rotary Selector Knobs



Knob-Hand Relationship



Operating Method	Fingertip Grasp (in.) H (depth)	Fingertip Grasp (in.) D* (dia)	Palm Grasp (in.) D (dia)	Thumb and Finger Encircled (in.) D (dia)	Thumb and Finger Encircled (in.) L (length)
Minimum	0.5	0.5 Recommend 1.00	1.0	1.0	2.00
Maximum	1.0 1.5	4.000	2.25	3.0	4.0

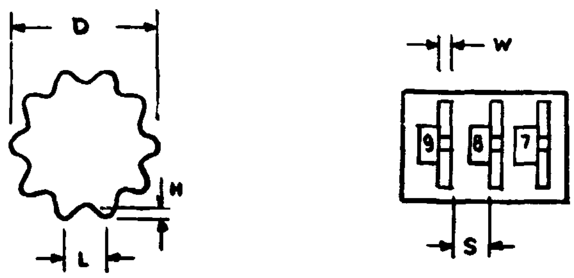
Resistance (ounce/in.)**

Operating Method	To and including 1-in. dia knobs	Greater than 1-in. dia knobs
Minimum	No practical limit set by operator's performance	
Maximum	4.5 oz/in.	6.0 oz/in.

*Optimum diameter for precision settings is 2.0 in.

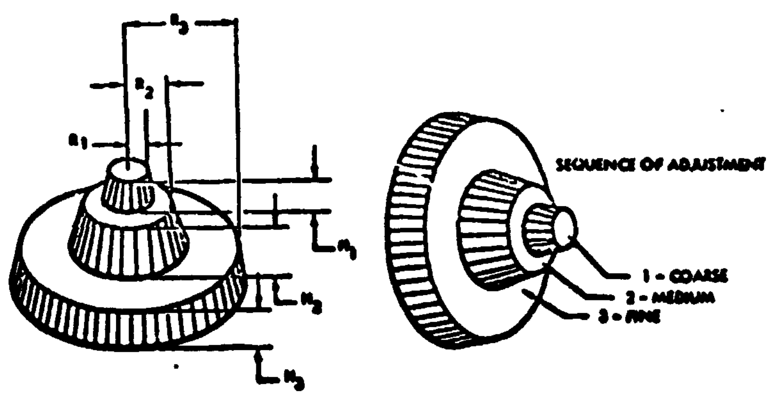
**Use viscous damping, avoid inertial and static resistance. When resistance is low, control may be miniaturized with a depth of 0.50 in. and a diameter of 0.25 in. Resistance should never be so small that inadvertent touching of controls will change the settings.

Knob Selection Criteria



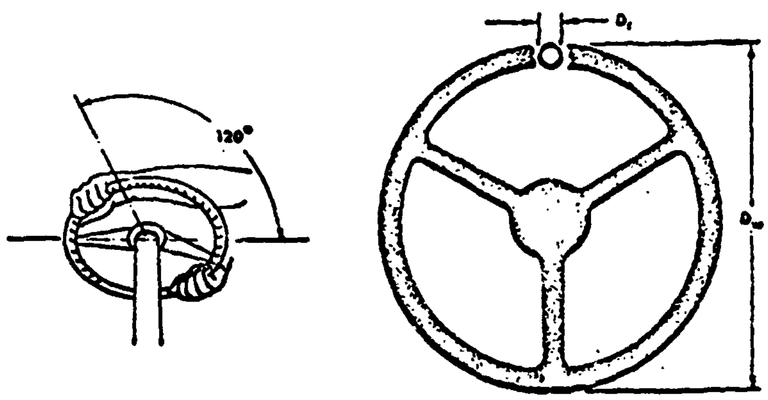
	D Diameter (in)	L Trough Distance (in)	W Width (in)	D Depth (in)	S Separation (in)	Resistance (in-lb)
Minimum	1.5	0.45	0.1	1/8	0.4	1
Maximum	2.5	-	-	1/2	-	3

FIG. Descrete Thumbwheel Control



R (knob radius, in.)			H (knob depth, in.)		
R_1 (coarse)	R_2 (medium)	R_3 (fine)	H_1 (coarse)	H_2 (medium)	H_3 (fine)
0.25	0.875	1.5	0.75	0.75	0.25

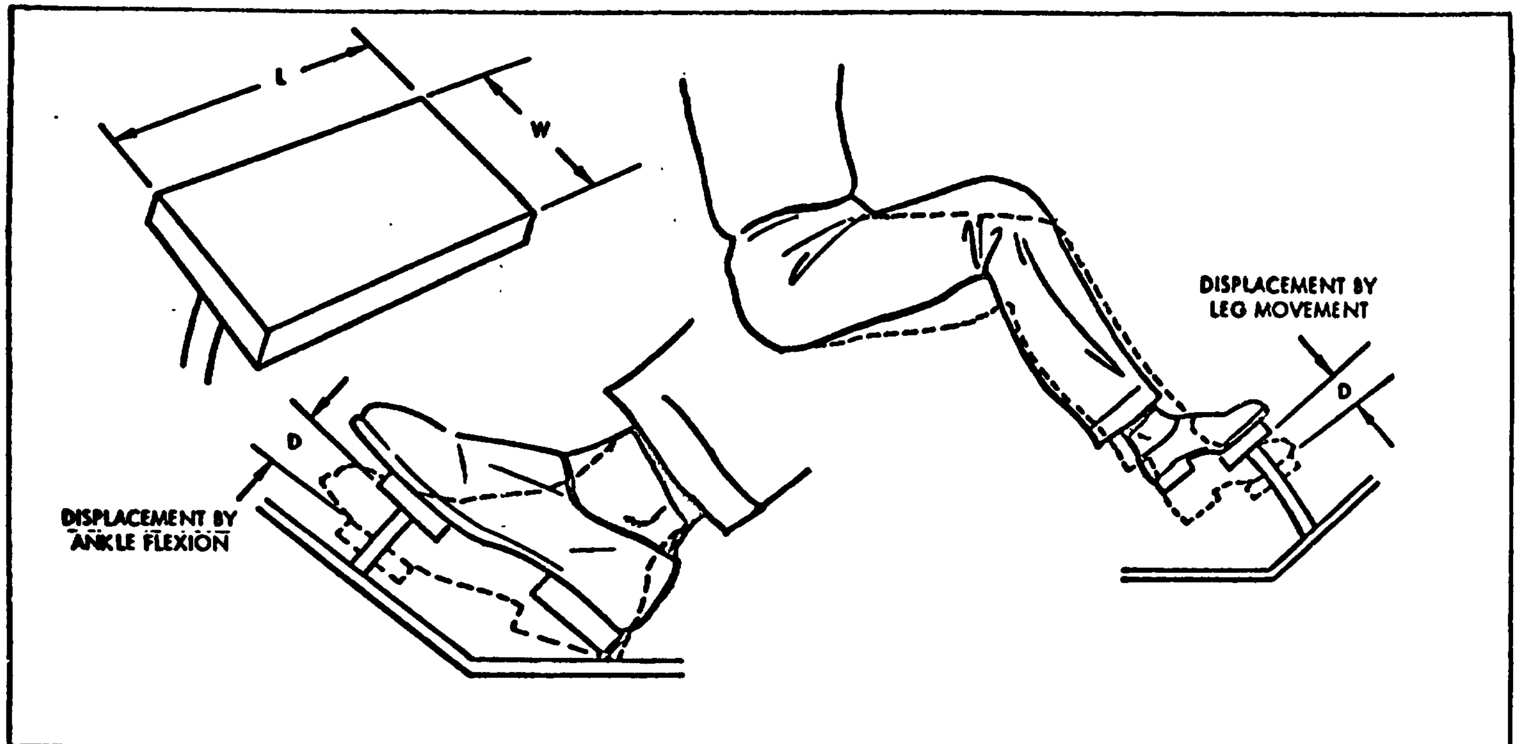
Ganged Knobs, Concentric Shaft



Operating Method	D_W (Wheel dia, in.)	D_r (Rim dia, in.)	A (Displacement, deg)	Resistance (lb)**	
				One-hand operation	Two-hand operation
Minimum	7.0	0.75	No data available	5	5
Maximum	21 (both hands on wheel rim)	2.0	120 degrees	30	50

*For operation with hands opposite each other on wheel rim, optimum diameter is 21 inches (same as maximum).
**There should be minimum inertia when handwheels are operated through small arcs. Displacement will be determined by the desired control-display ratio.

Handwheel Selection Requirements



Operating Method	Pedal size (in.)		D (displacement, in.)			
	L (length)	W (width)	Normal operation	With heavy boots	Ankle flexion only	Total leg movement
Minimum	3.0	1.0	0.5	1.0	0.5	1.0
Maximum	Determine by space available and danger of accidental activation		2.5	7.0	2.5	7.0

Resistance (lb)*				
	Foot not resting on pedal	Foot resting on pedal	Ankle flexion only	Total leg movement
Minimum	4	10	4	10
Maximum	20	40	20	180

*Resistance should prevent forces less than those required for breakout from accidentally activating controls; elastic resistance should permit pedal to return to a neutral position after removal of operating force.

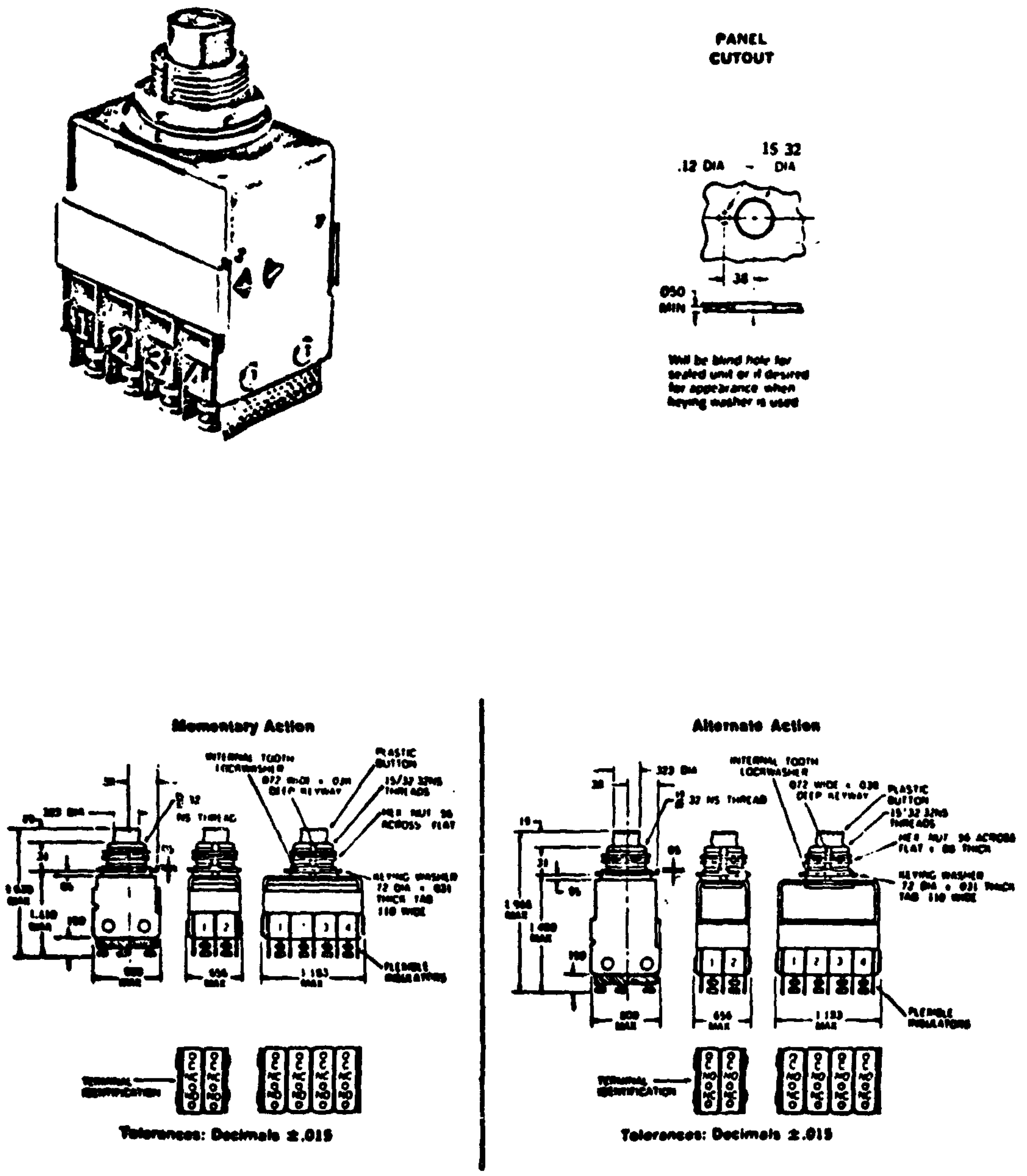
Pedal Selection Requirements

Direction of Motion Conventions for Controls

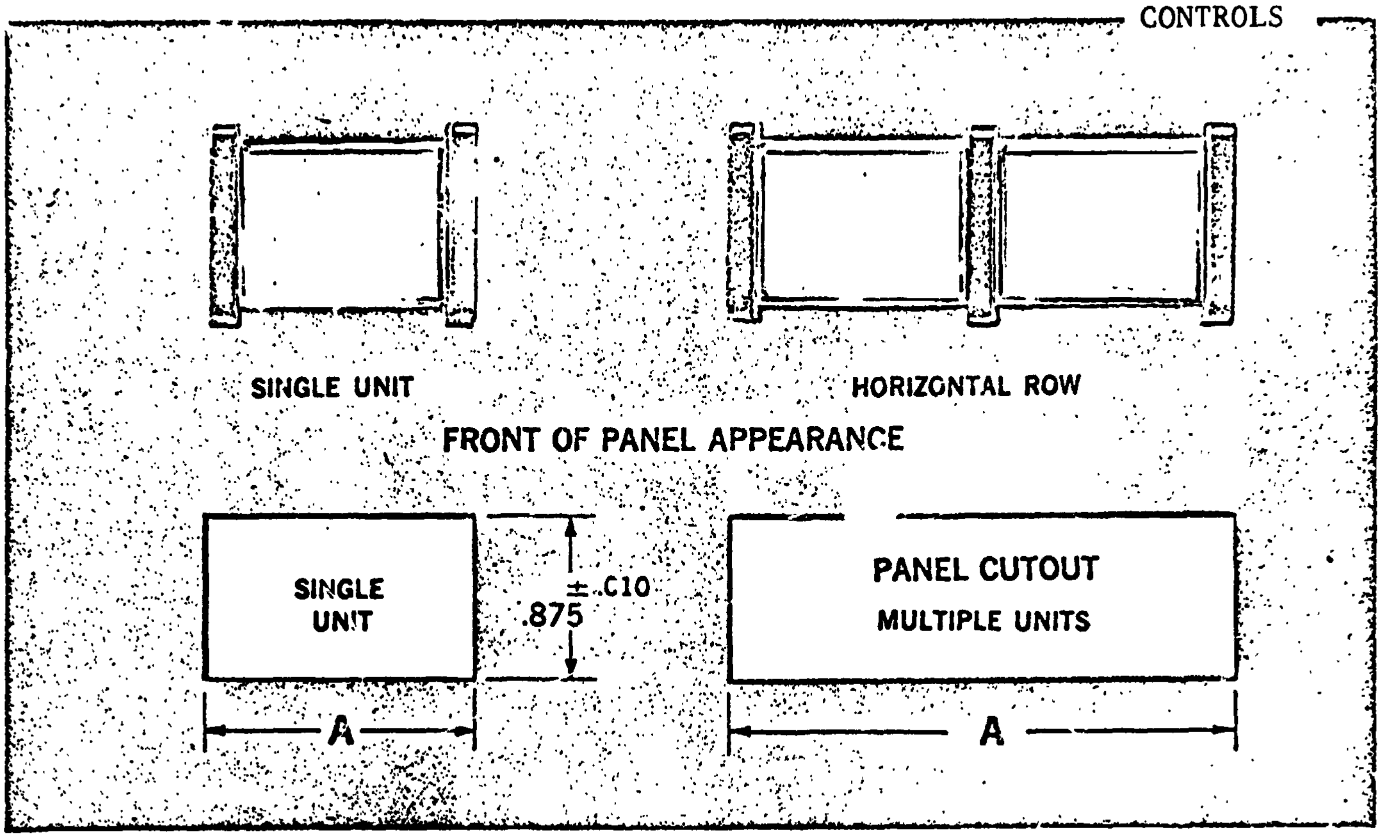
FUNCTION	CONTROL ACTION
On	Up, right, forward, clockwise, pull
Off	Down, left, rearward, counterclockwise, push
Right	Clockwise, right
Left	Counterclockwise, left
Raise	Up
Lower	Down
Retract	Up, rearward, pull
Extend	Down, forward, push
Increase	Forward, up, right, clockwise
Decrease	Rearward, down, left, counterclockwise

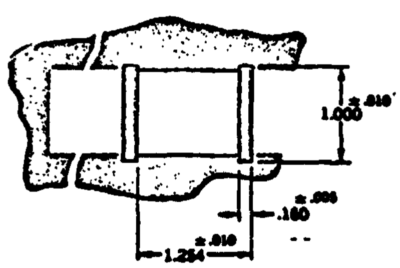
OPTIMUM CONTROL-DISPLAY RATIOS

Control	Approximate Control Movement	Display Movement
Knob, coarse setting	1 complete turn	6 inches
Knob, fine setting	1 complete turn	1 - 2 inches
Lever, coarse setting	3 units	1 unit
Lever, coarse setting, two dimensions	2-1/2 units	1 unit
Counter	1 complete turn (or reset knob)	Approximately 50 counts (right drum rotates 5 times)

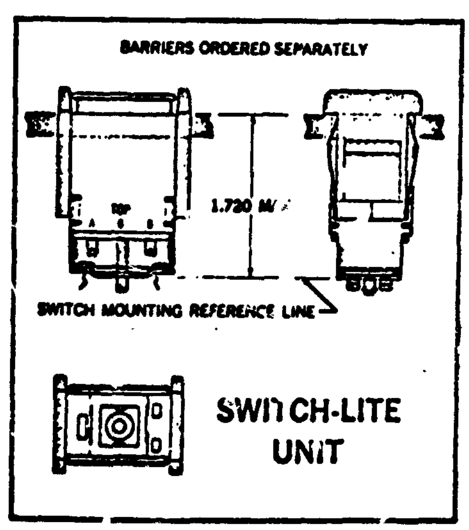


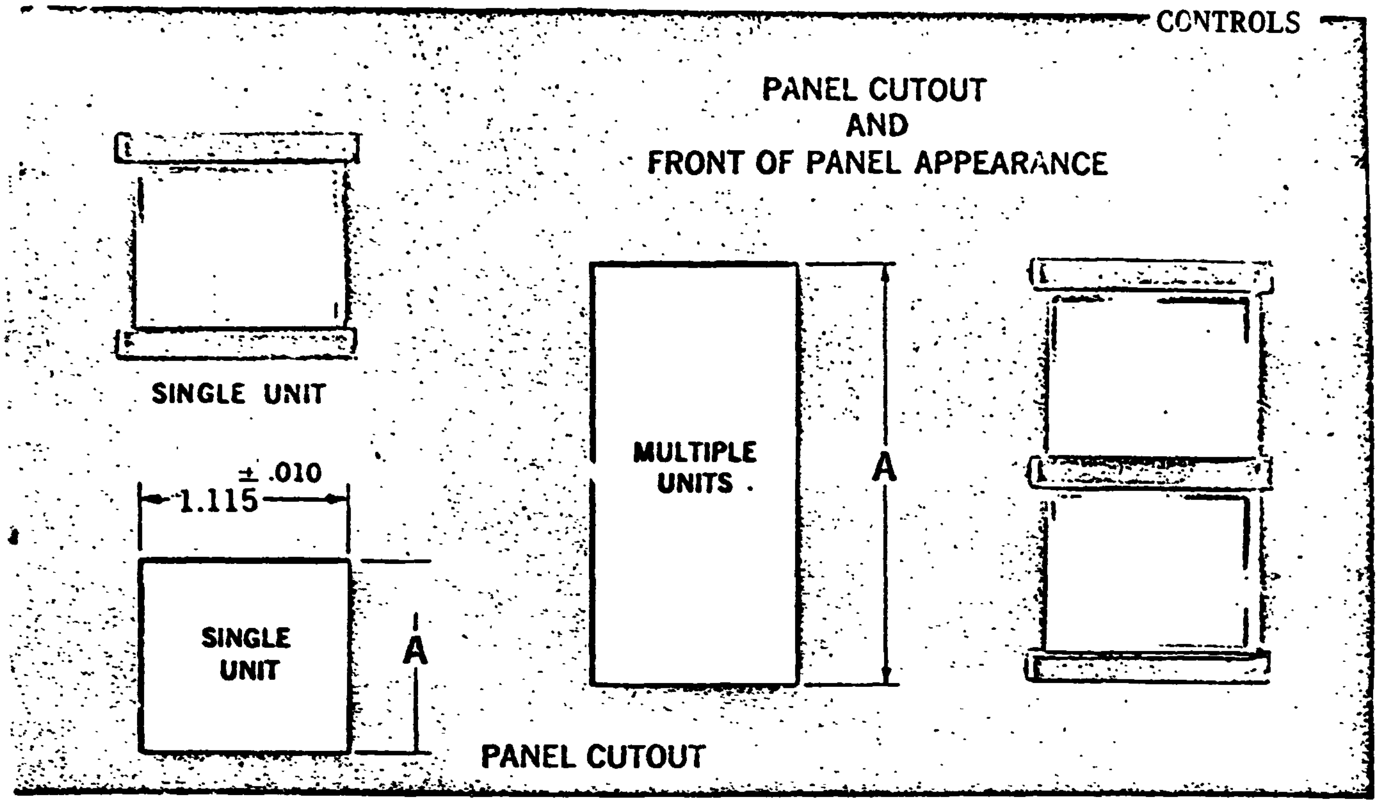
TYPICAL PUSHBUTTON SWITCH COMPONENT

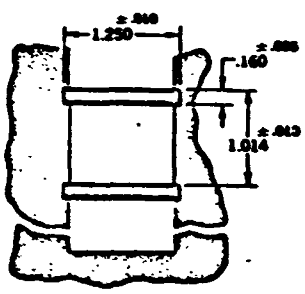




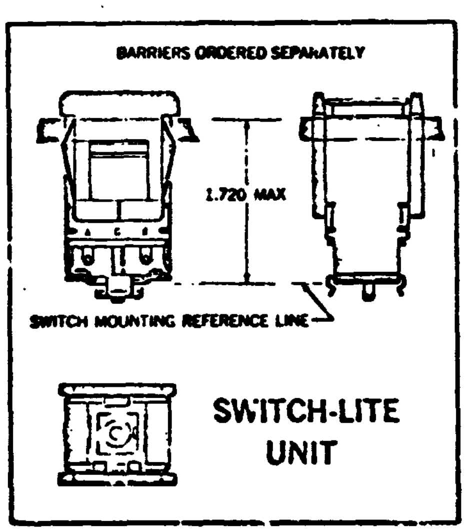
PANEL CUTOUT		(DIMENSIONS IN INCHES ±.010)			
NO. UNITS	DIM. "A"	NO. UNITS	DIM. "A"	NO. UNITS	DIM. "A"
1	1.421	5	6.441	9	11.460
2	2.677	6	7.69[illegible]	10	12.715
3	3.932	7	8.951	11	13.969
4	5.186	8	10.205	12	15.224

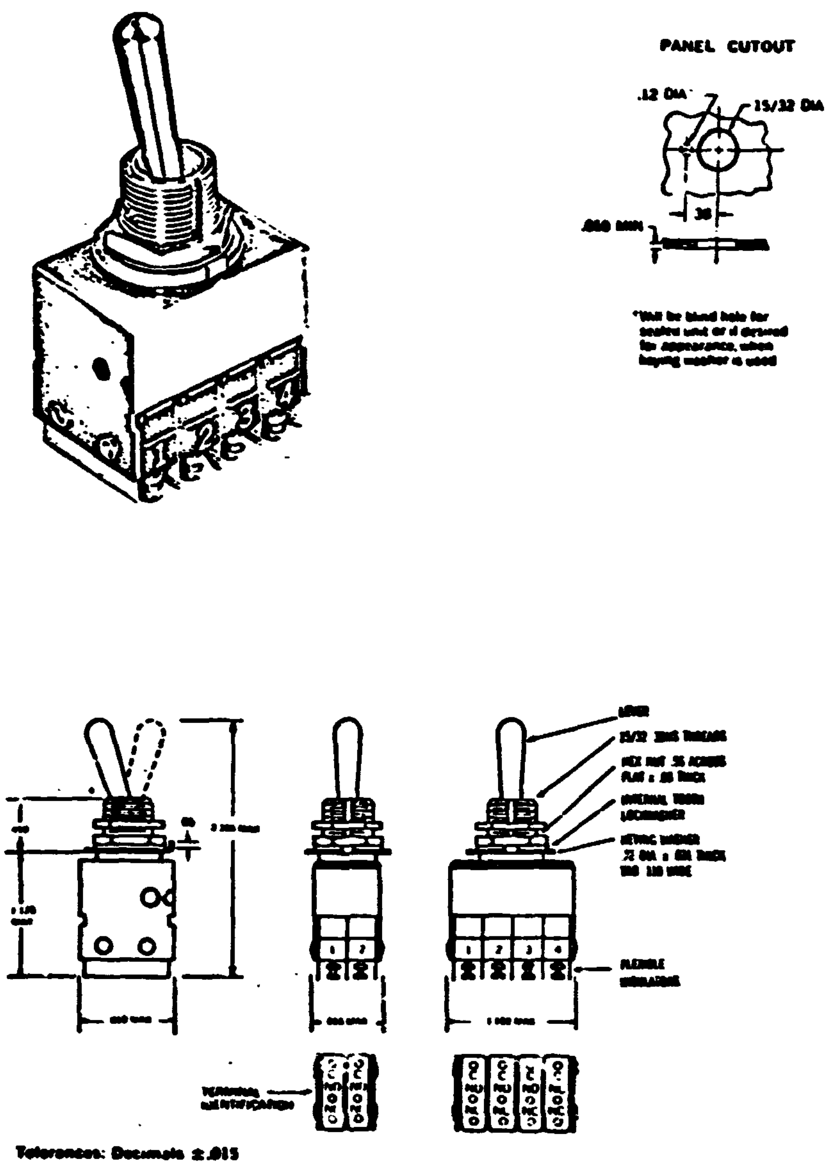




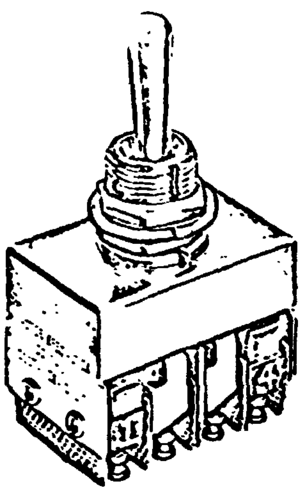


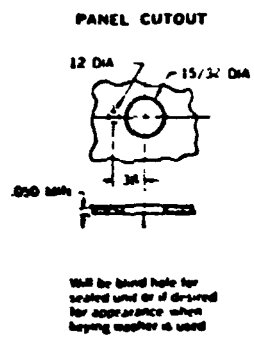
PANEL CUTOUT		(DIMENSIONS IN INCHES ± .010)			
NO. UNITS	DIM. "A"	NO. UNITS	DIM. "A"	NO. UNITS	DIM. "A"
1	1.181	5	5.241	9	9.300
2	2.196	6	6.256	10	10.315
3	3.212	7	7.271	11	11.329
4	4.226	8	8.285	12	12.344

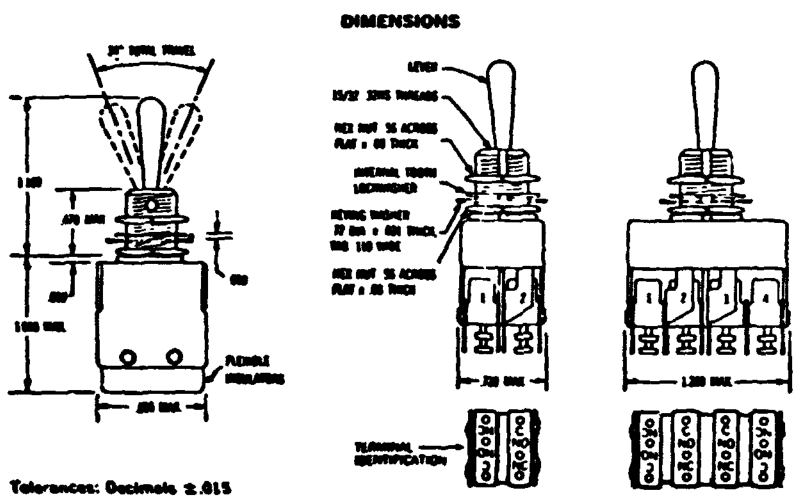




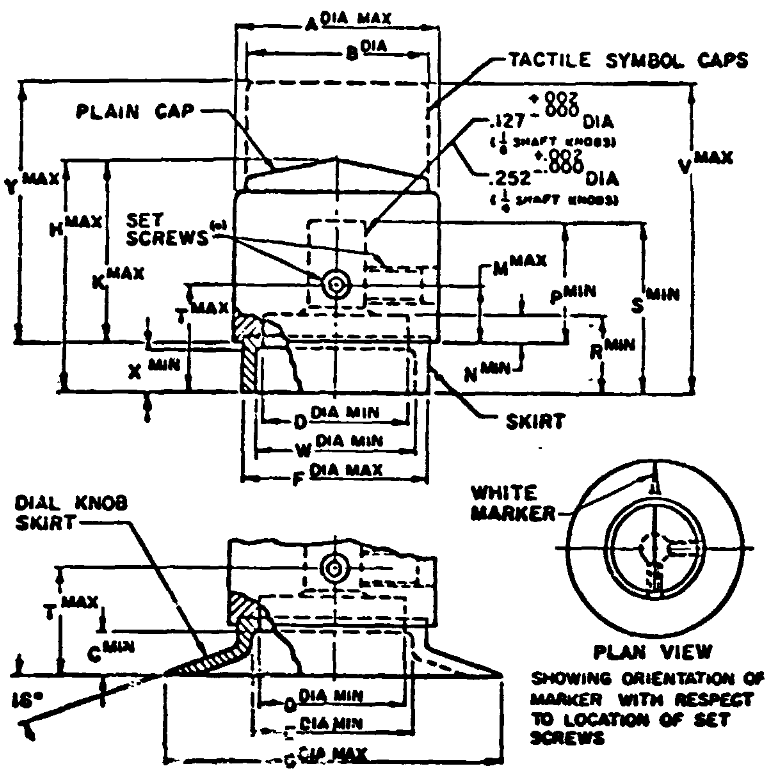
TYPICAL TWO-POSITION TOGGLE SWITCH



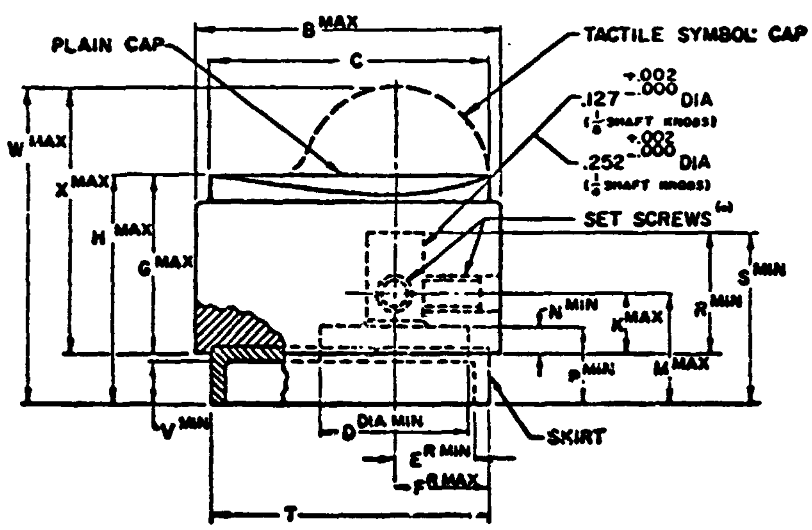




TYPICAL THREE-POSITION TOGGLE SWITCH

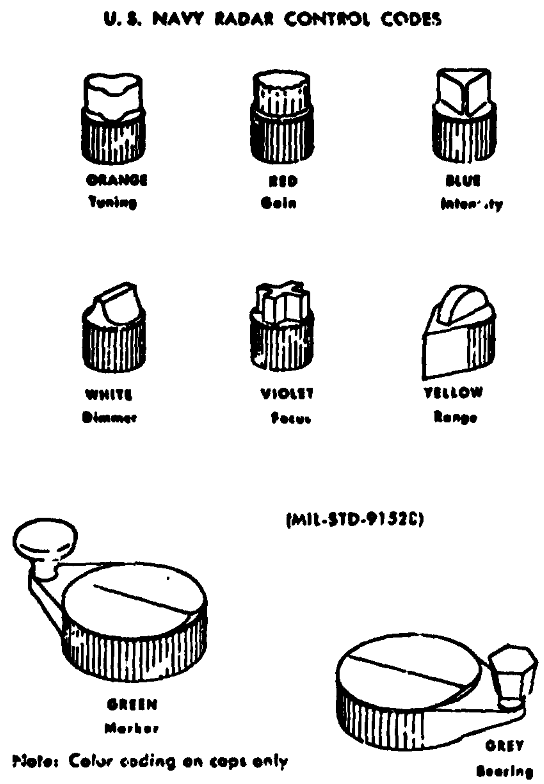


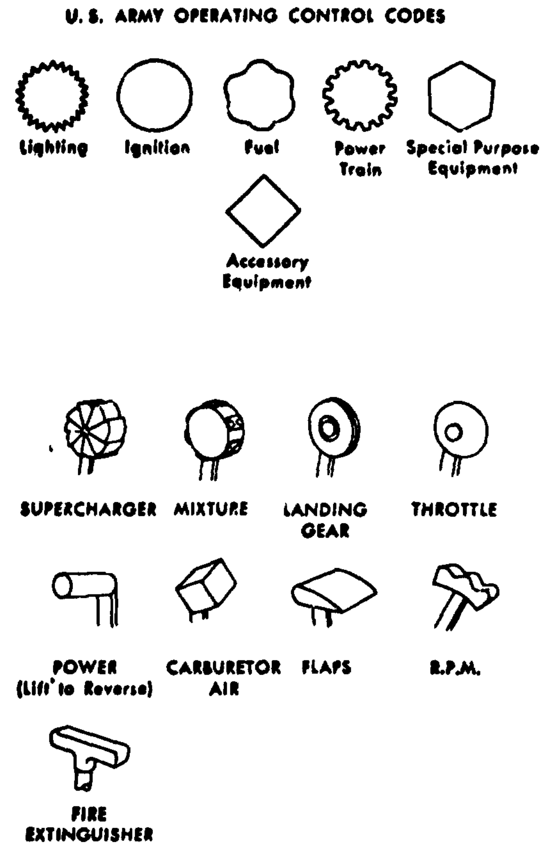
DIM.	SERIES		
	S	M	L
A	.708	.911	1.255
B	.634	.820	1.166
C	.153	.190	.128
D	.486	.645	.974
E	.554	.721	1.052
F	.670	.826	1.155
G	1.135	1.510	1.822
H	.805	1.027	.870
K	.626	.798	.703
M	.158	.255	.260
N	.026	.114	.115
P	.406	.521	.458
R	.188	.323	.262
S	.568	.730	.605
T	.340	.484	.427
V	1.099	1.399	1.400
W	.580	.721	1.052
X	.162	.209	.147
Y	.917	1.170	1.233



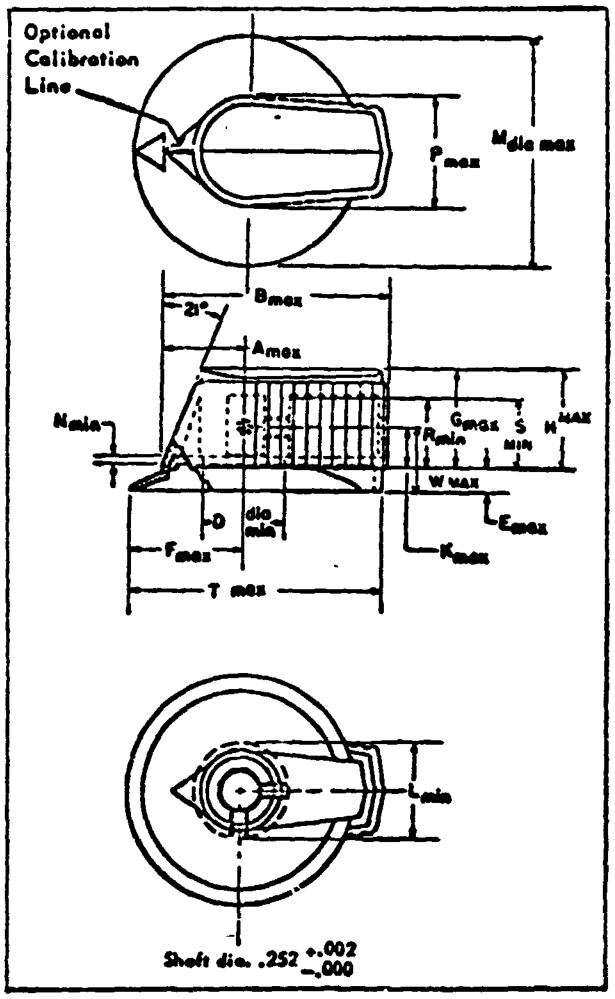
DIM.	SERIES	
	Med	Large
A	.690	.894
B	1.038	1.344
C	.946	1.221
D	.486	.645
E	.289	.395
F	.335	.445
G	.619	.796
H	.791	1.015
K	.187	.255
M	.364	.479
N	.026	.114
P	.193	.328
R	.406	.555
S	.573	.769
T	.940	1.251
V	.153	.190
W	1.100	1.400
X	.918	1.171
Y	.708	.912

Typical Panel Knob for Use With Shape Coded Cap Applications



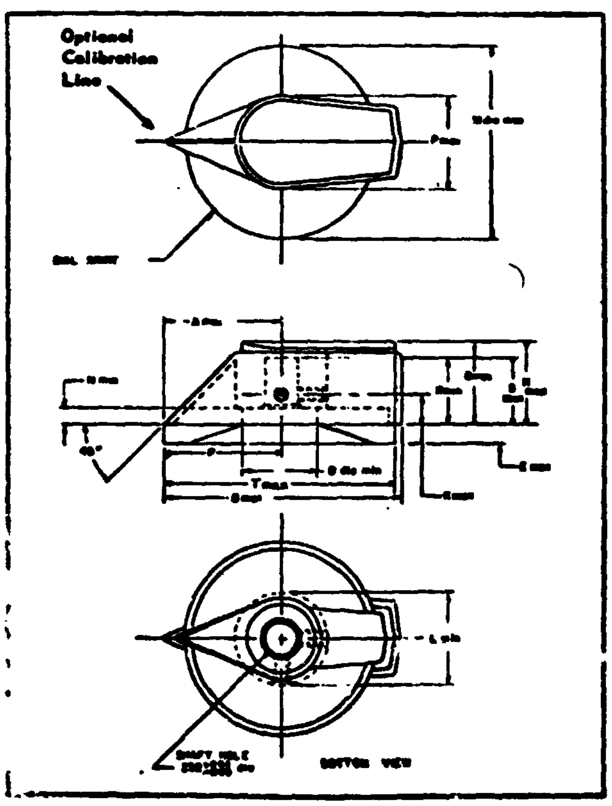


Shape Code Standards for Panel and Vehicle Controls

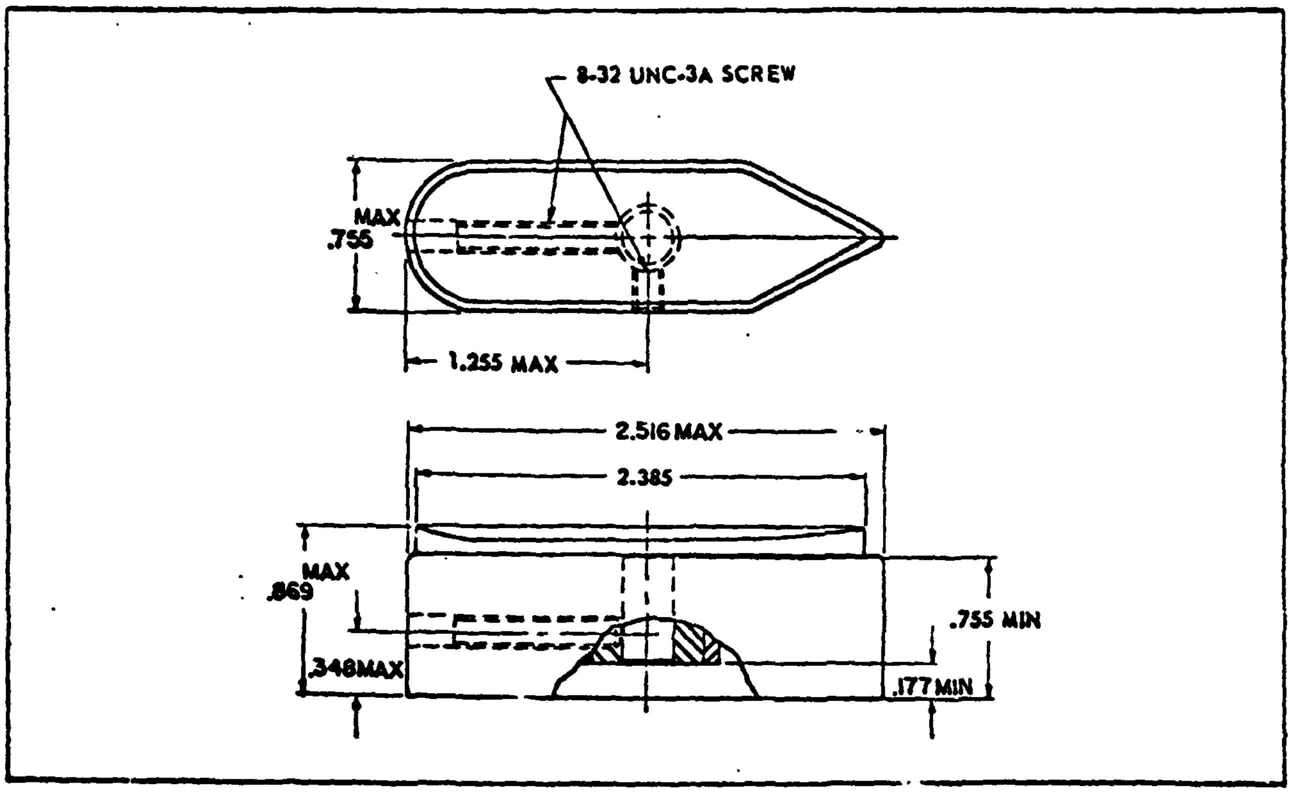


Dimension	Inches
A	.570
B	1.515
D	.526
E	.162
F	.765
G	.654
H	.825
K	.229
L	.595
M	1.525
N	.123
P	.721
R	.445
S	.590
T	1.660
W	.400

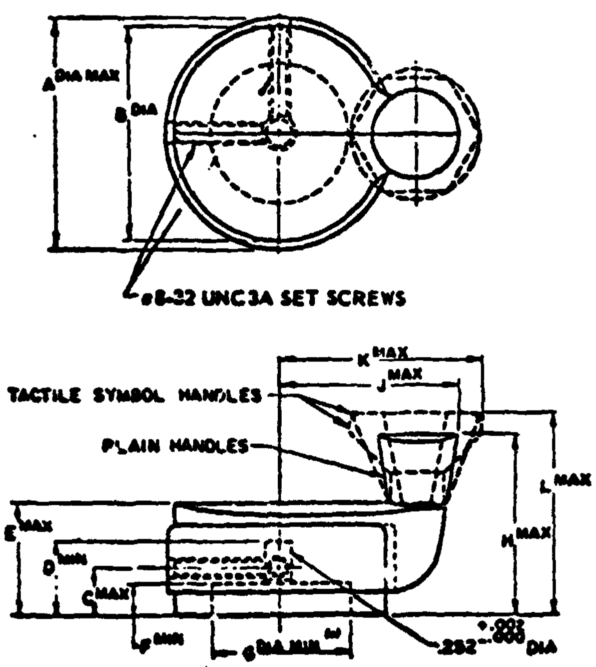
Typical Pointer Type
Control Knobs



Dimension	Inches
A	.885
B	1.828
D	.526
E	.162
F	.885
G	.654
H	.825
K	.229
L	.595
M	1.520
N	.123
P	.721
R	.445
S	.590
T	1.633



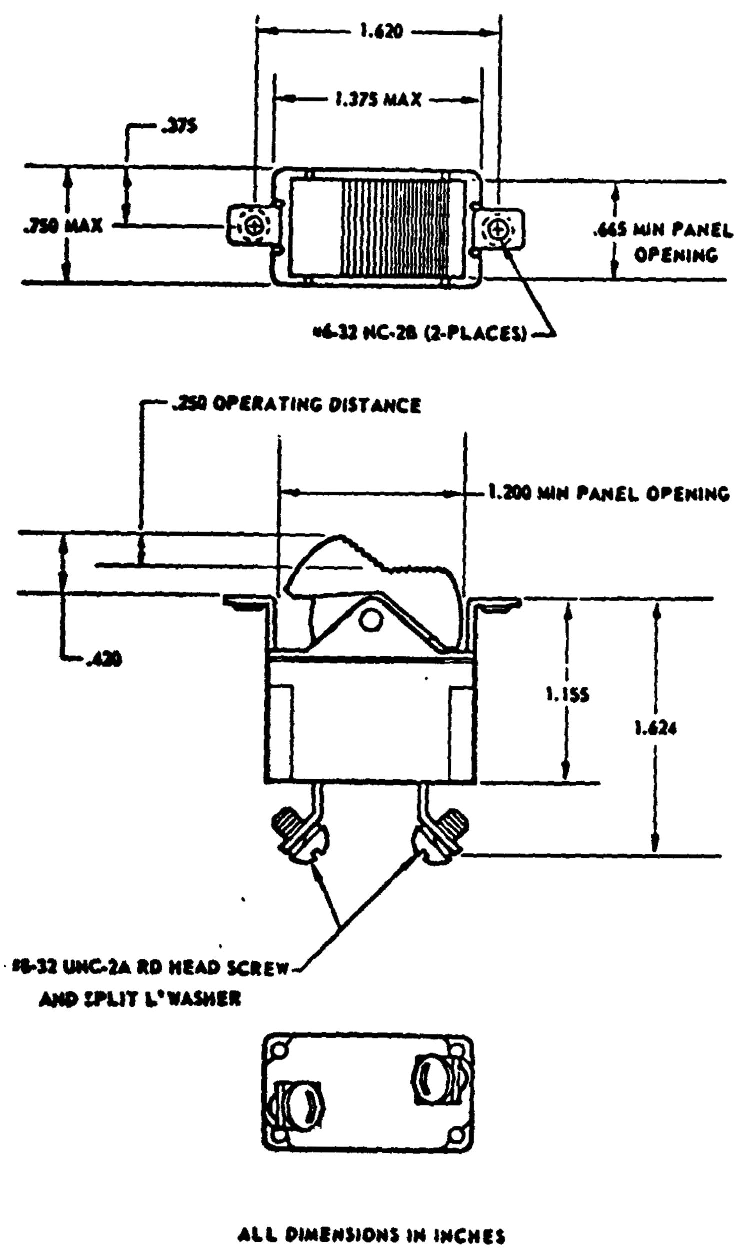
Typical Large Control Knob (Pointer Type)



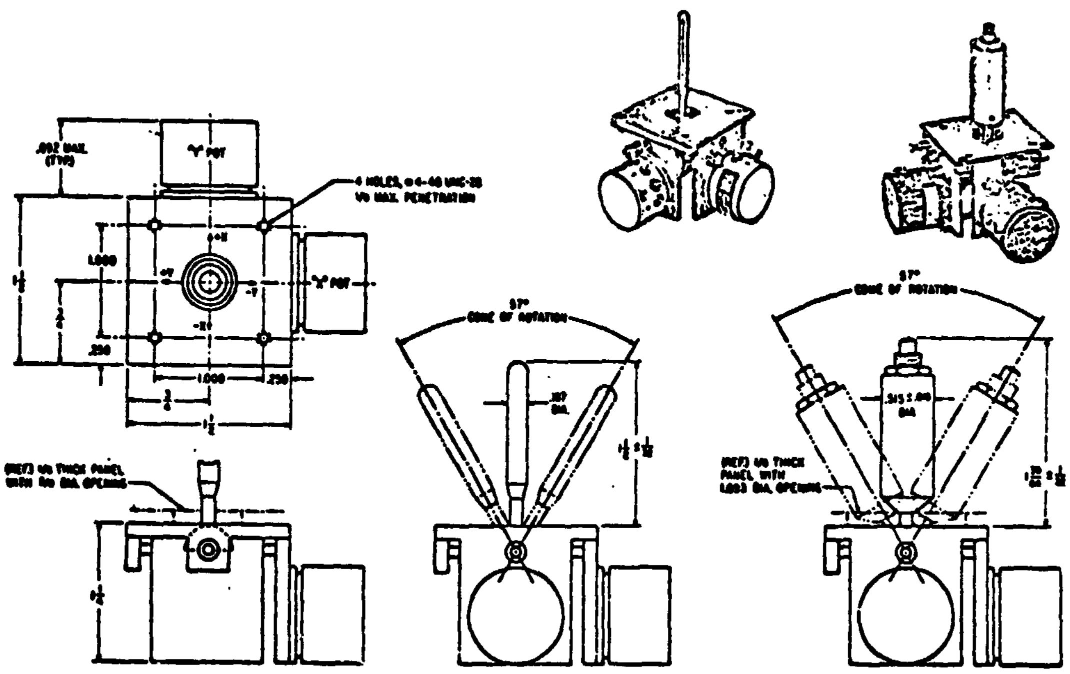
DIM.	SERIES		
A	1.269	1.775	2.255
B	1.156	1.594	2.094
C	.427	.489	.489
D	.605	.740	.740
E	.870	1.088	1.114
F	.267	.328	.327
G (a)	.700	.894	.925
H	1.379	1.773	1.799
J	1.110	1.504	1.754
K	-	1.719	1.969
L	-	1.961	1.987

(a) This dimension represents the amount of clearance available. It is not the actual configuration.

Typical Crank-Type Control (Coded Handle Applications)

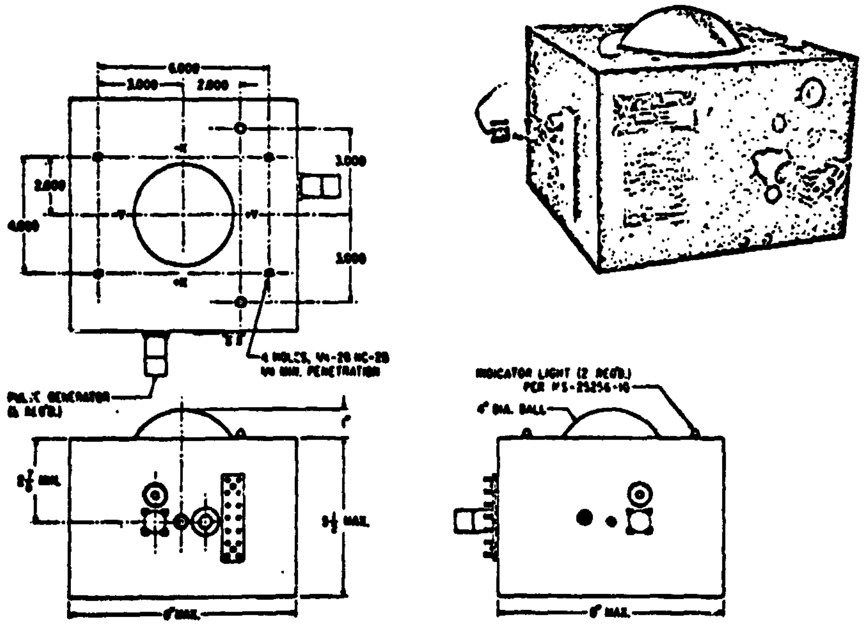


Typical Rocker Switch (Circuit Breaker)



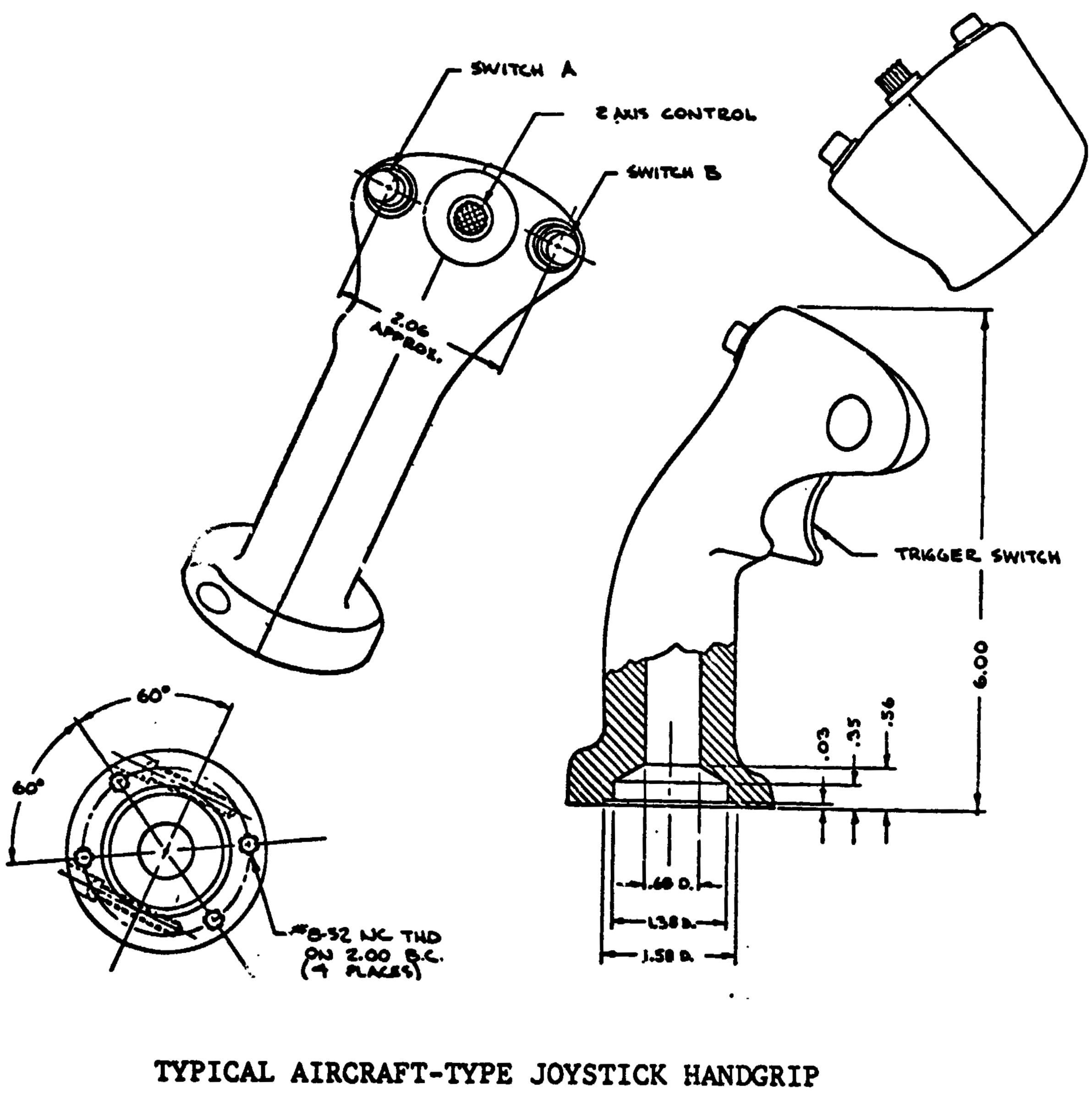
Unless Otherwise Specified, Decimal Dim. ±0.005, Fractions ±1/64

Example Electric Joystick Controllers

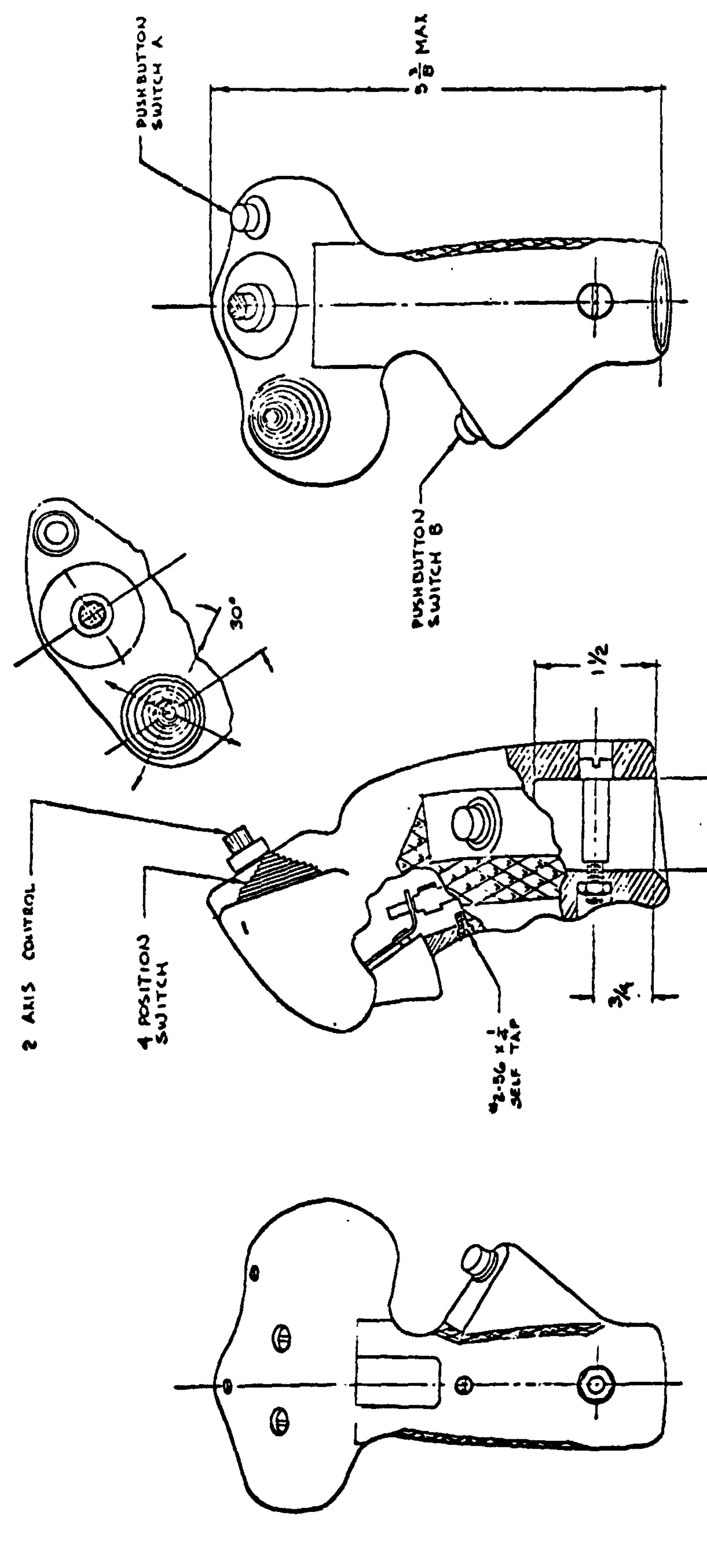


Unless Otherwise Specified, Decimal Dim. ±.005, Fractions ±1/64

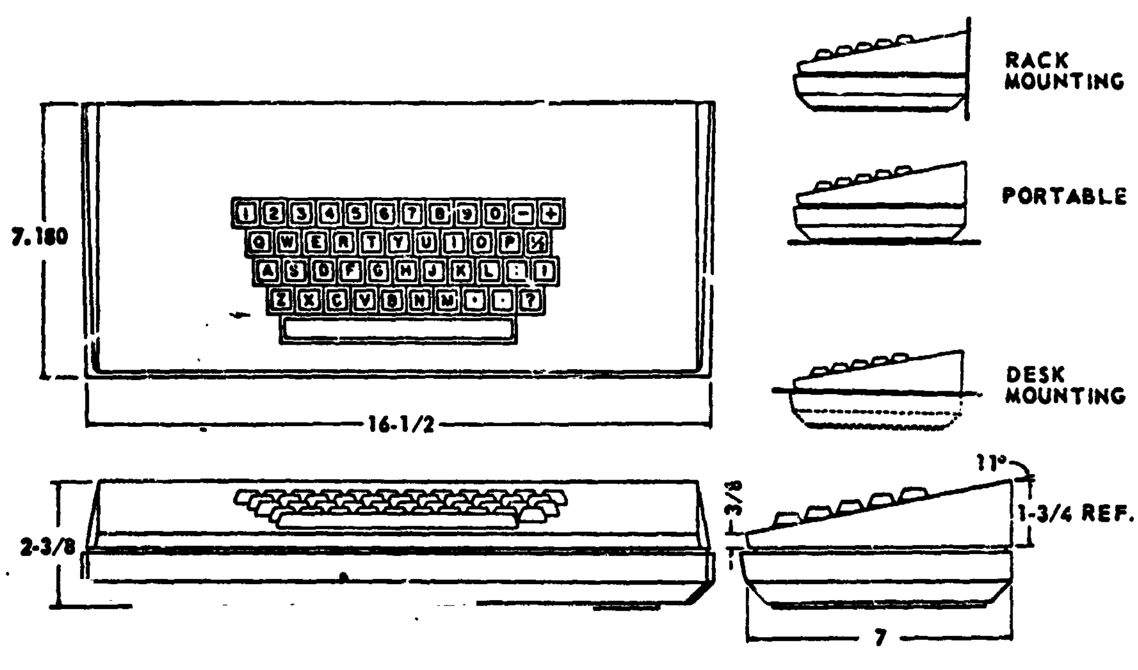
Example Rolling Ball Controller



TYPICAL AIRCRAFT-TYPE JOYSTICK HANDGRIP



.YPICAL AIRCRAFT-TYPE JOYSTICK HANDGRIP



TYPICAL ELECTRONIC KEYBOARD MODULAR SUBASSEMBLY

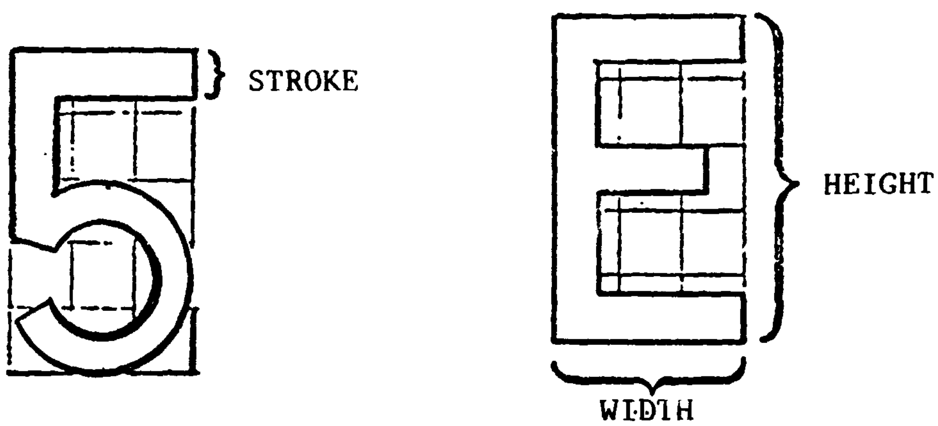
DESIRABLE CHARACTERISTICS FOR AUDITORY WARNING SIGNALS

AUDIO	
Aircrew Stations	MIL-STD-411 (where applicable)
Two-phase signal	
Alerting	0.5 sec
Action	Essential information in first 2.0 sec
Single phase signal	Essential information in first 0.5 sec
Frequency	
Major energy concentration	250 - 2500 Hz
Identifiable components	Below 2000 Hz
Intensity	At least 20 db above ambient
VERBAL	
Intensity	At least 20 db above SIL
Temporal relationship	
Alerting	2 - 8 sec before isolated action signals
	0.3 - 2 sec before sequential action signals

DESIRABLE CHARACTERISTICS FOR VOICE COMMUNICATION SYSTEMS

Telephone or Radio Communications	See MIL-STD-188
Speech transmission equipment	
Optimal frequency response	150 - 4800 Hz
Minimum frequency response	200 - 3000 Hz
Microphone dynamic range	Signal input variations of 30 db minimum
Noise cancelling microphones	Improvement at least 10 db peak speech to RMS noise ratio
Pre-emphasis	9 db/ocatve, positive, over 140 - 4800 Hz
Speech reception equipment	
Multichannel/multispeaker f range	± 5 db over range 100 - 4800 Hz
Separation of speakers for multi-channel monitoring	10^{o} apart radially relative to central operator position
Filtering for multichannel speaker monitoring	2 channels F_c = 1800 Hz(lo-pass) on one channel 3 channels F_c = 1000 Hz(hi-pass) = no cutoff = 2500 Hz(lo-pass)
De-emphasis	9 db/octave, negative, over 140 - 4800 Hz

Letter-Numeral Design Criteria for Labeling



STYLE (Do Not Use Stencils)

Letters and numerals shall be simple block type

a. Typical Fonts for Engraving

- Gorton Extended
- Gorton Normal
- Gorton Condensed

b. for printing

- Airport Semi-bold
- Vogue Medium
- Futura Demi-bold
- Lining Gothic #66

HEIGHT/WIDTH RATIO

3:5 to 1:1 (1:1 used for mechanical counters only)

STROKE WIDTH

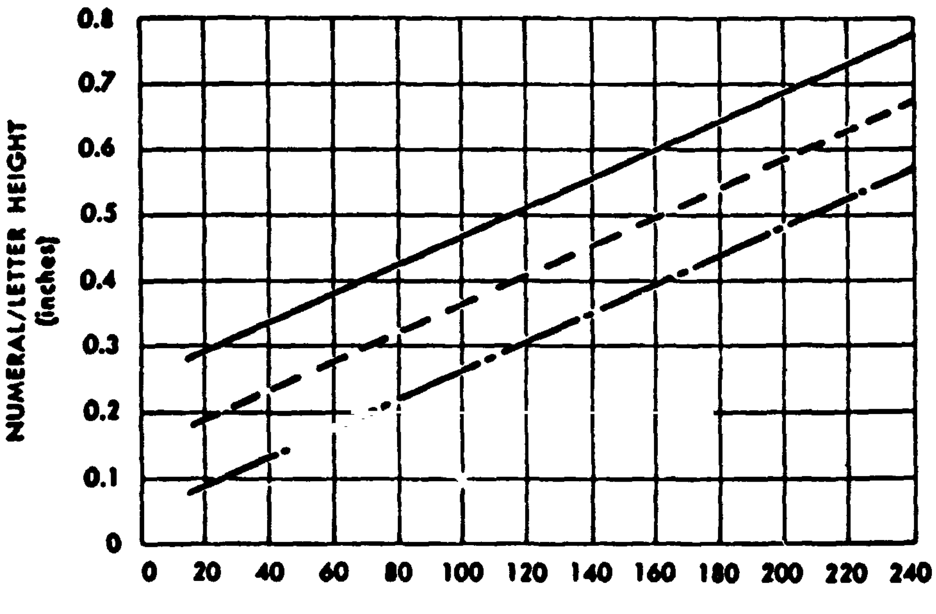
Dark figure on light background = 1/6 of letter height
Light figure on dark background = 1/8 of letter height

LIGHT/DARK CONTRAST

Contrast between figure and background shall be 12 or greater. $C = \frac{B_2 - B_1}{B1}$ where B_2 is brightness of light color, and B_1 is brightness of darker color.

LETTER HEIGHT VS VIEWING DISTANCE AND ILLUMINATION LEVEL

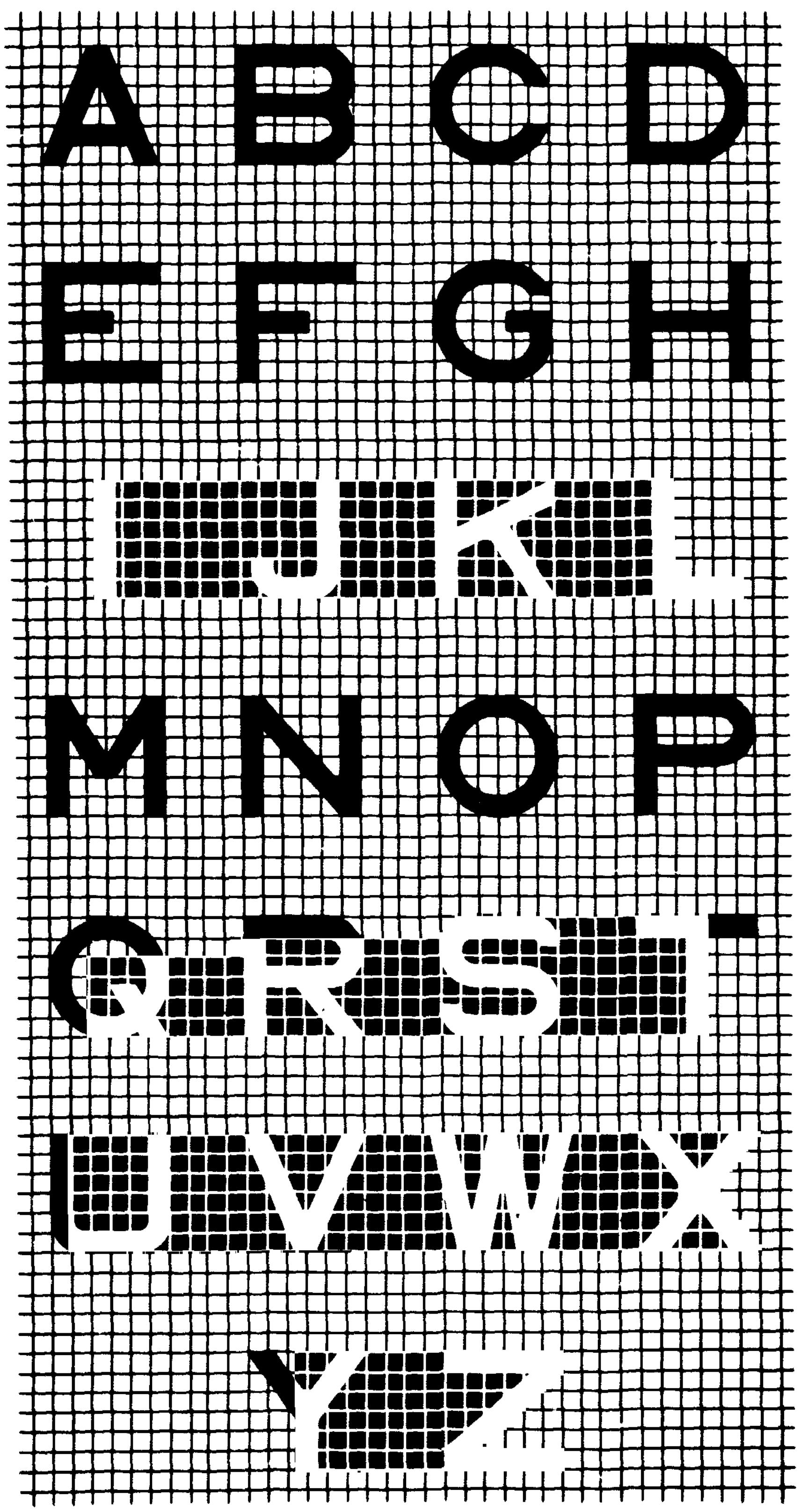
(MINIMUM SPACE BETWEEN CHARACTERS, 1 STROKE WIDTH; BETWEEN WORDS, 6 STROKE WIDTHS)



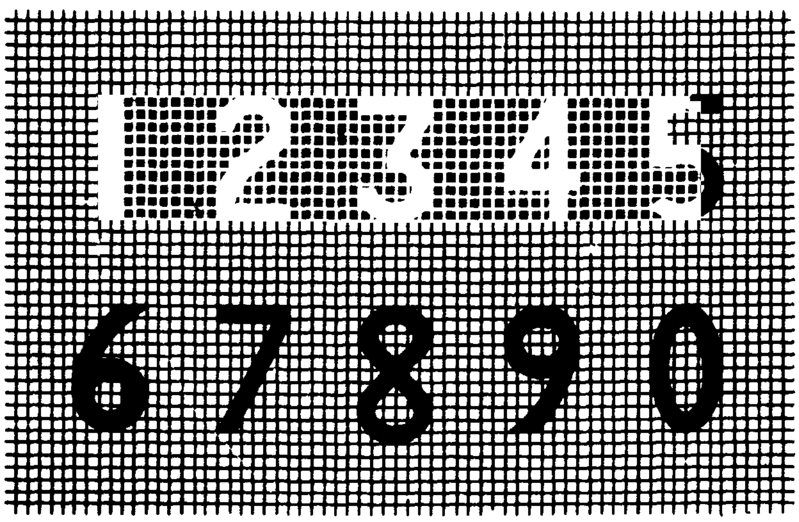
— For instruments where the position of the numerals may vary and the illumination is between 0.03 and 1.0 ft-l.

- - - For instruments where the position of the numerals is fixed and the illumination is 0.3-1.0 ft-l, or where position of the numerals may vary and the illumination exceeds 1.0 ft-l.

—·— For instruments where the position of the numerals is fixed and the illumination is above 1.0 ft-l.

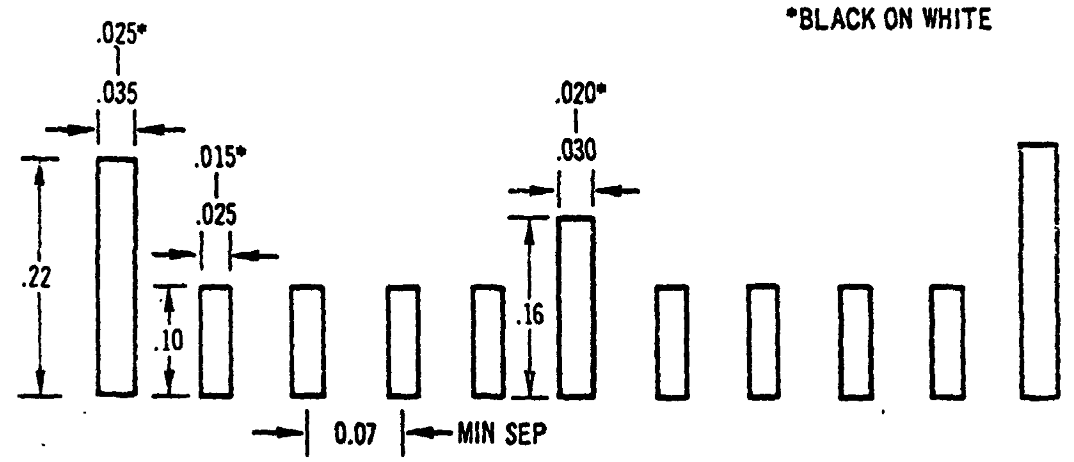


Optimum Letter Style for Instrument/Panel Use
(Available in LeRoy Letter Guide)



Optimum Numeral Style for Instrument/Panel Use
(Available in LeRoy Letter Guide)

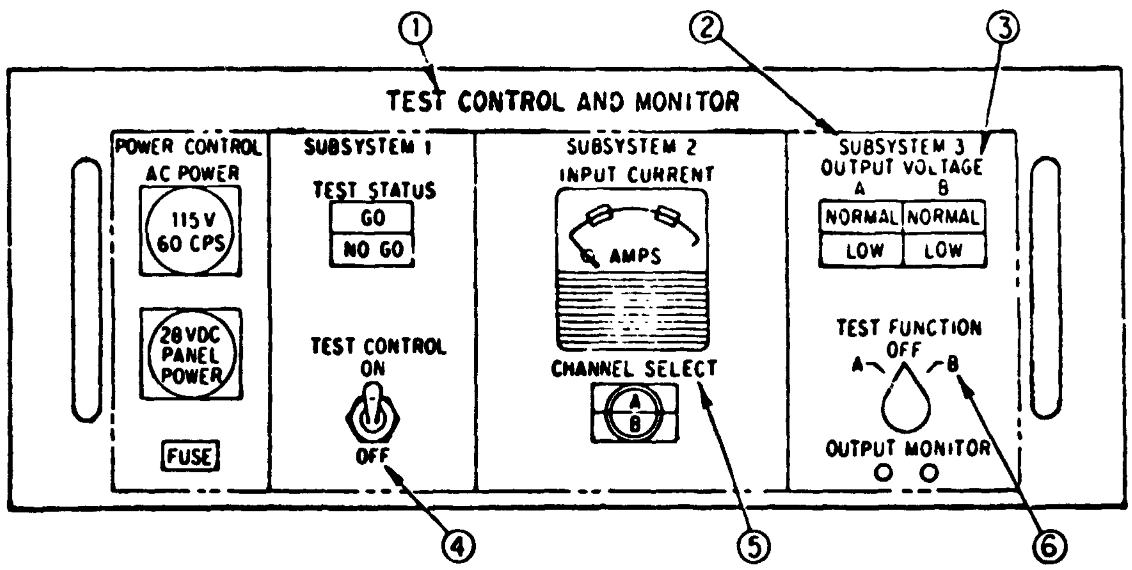
Optimum Scale Mark Dimensions for 28-inch Viewing Distances



NOTE: THESE DIMENSIONS APPLY TO ALL MARKINGS, BLACK ON WHITE OR WHITE ON BLACK, EXCEPT AS INDICATED BY ASTERISKS.

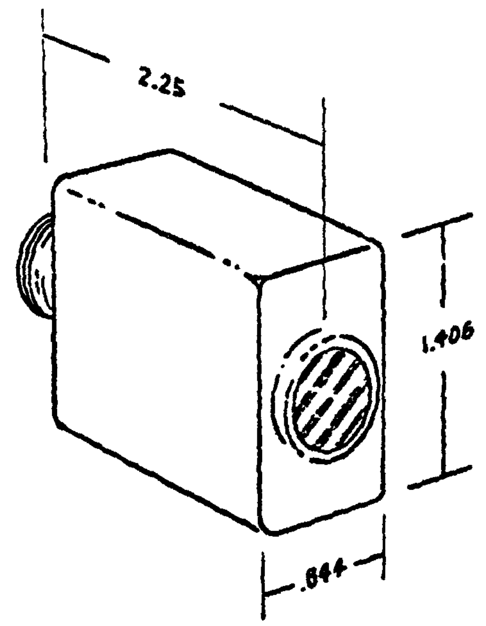
Criteria for Instrument Scale Breakdown Definition

Good					Fair					Not Acceptable			
1	2	3	4	5	2	4	6	8	10	0	2.5	5	7.5
5	10	15	20	25	20	40	60	80	100	4	8	12	16
10	20	30	40	50	200	400	600	800	1000	0	15	30	45
50	100	150	200	250						30	60	90	120
100	200	300	400	500						0	60	120	180

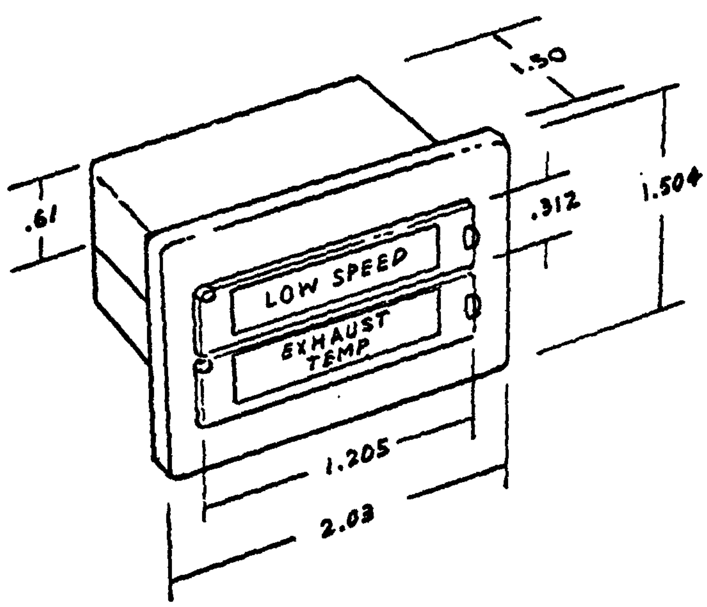


Typical Panel Labeling Standards

Label Designation	Letter Size	Location
1. Panel title	18 pt (0.187 in.)	Centered; 1/4 in. from top edge of panel
2. Panel subsection	14 pt (0.156 in.)	Centered at top of subsection; 3/4 in. from top edge of panel
3. Subtitle	12 pt (0.125 in.)	1/4 in. above component(s) or 1/8 in. above labels of individual components
4. Toggle switch	10 pt (0.093 in.)	1/4 in. above and below standard switch
5. Single component	12 pt (0.125 in.)	1/4 in. above component
6. Rotary switch positions	10 pt (0.093 in.)	1/4 in. from apex of pointer, line from pointer to label



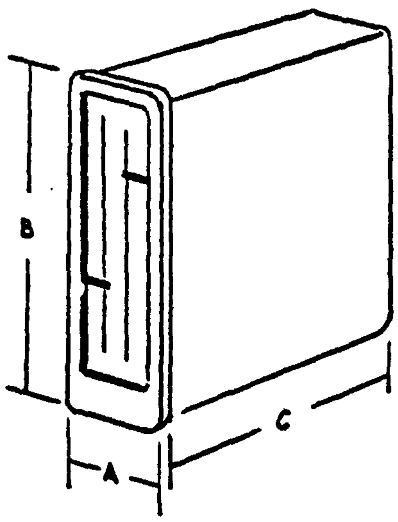
MECHANICAL FLAG DISPLAY

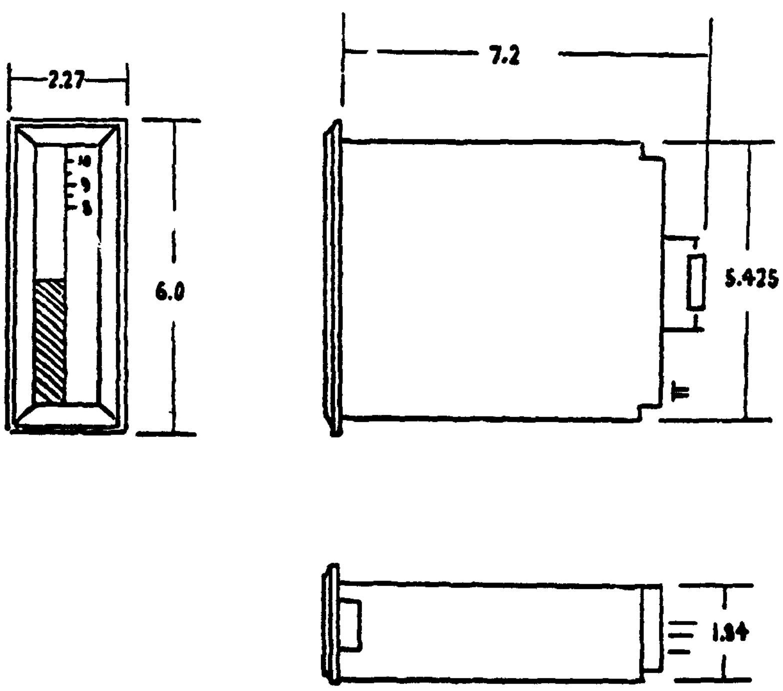


AIRCRAFT-TYPE PLACARD INDICATOR

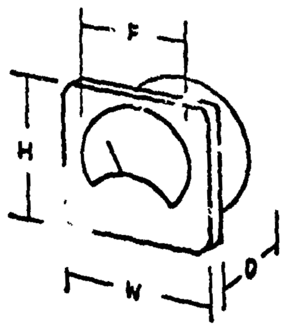
AIR DATA TAPE DISPLAY

A - 1.0 to 3.50
B - 7.75 to 10.0
C - 8.0



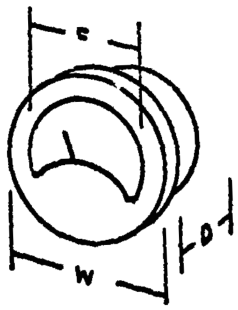


SOLID STATE METER DISPLAY

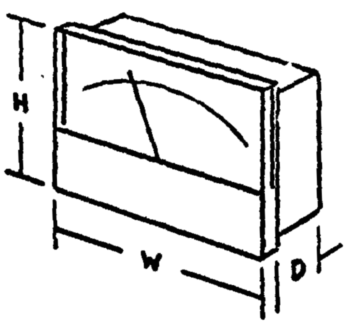


TYPICAL METER DISPLAY

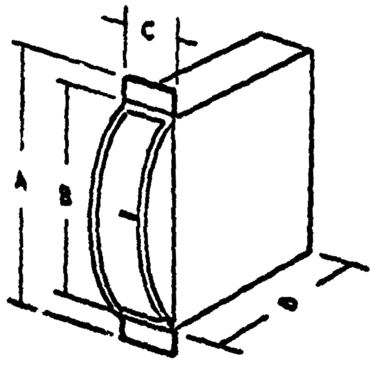
H -- 2.375 to 4.6
W -- 1.75 to 5.75
D -- 1.437 to 1.7
F -- 1.0 to 1.5



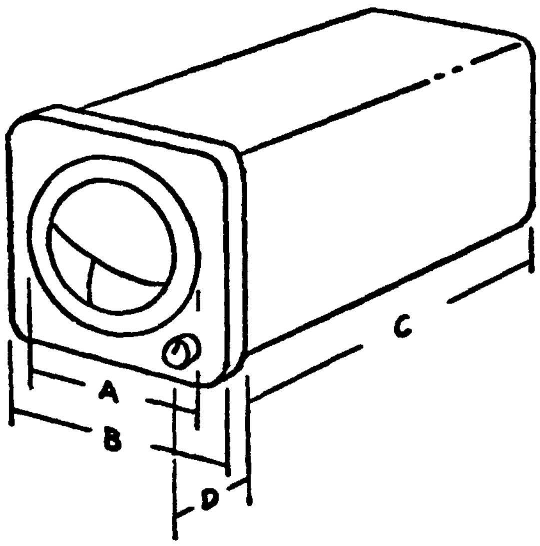
W -- 1.25 to 4.6
D -- 1.875 to 2.0
F -- 1.0 to 1.5



H -- 2.25 to 6.5
W -- 2.625 to 8.00
D -- .593 to 1.23

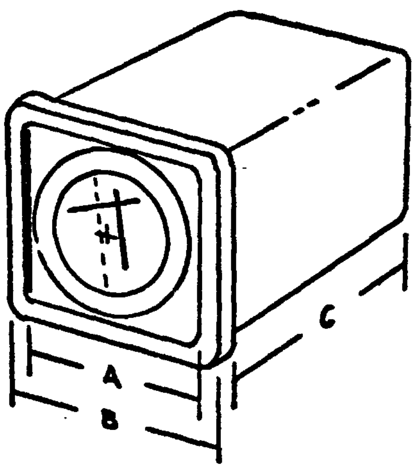


A -- 4.0 to 6.69
B -- 1.6 to 4.885
C -- .77 to 1.5
D -- 2.25 to 3.988



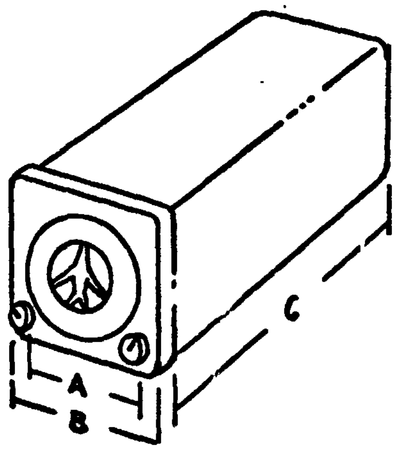
ATTITUDE INDICATOR

A - 1.9 to 4.25
B - 2.5 to 5.0
C - 6.5 to 8.0
D - 1.25 to 1.5



HEADING/SITUATION INDICATOR

A - 4.25
B - 5.0
C - 7.0



STANDBY HEADING INDICATOR

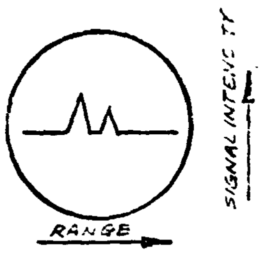
A - 1.875
B - 2.375
C - 7.0

TYPICAL FLIGHT INSTRUMENTS (Dimensions in inches)

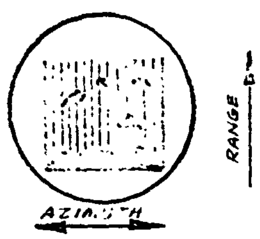
VISUAL DISPLAY

SCOPE TYPES

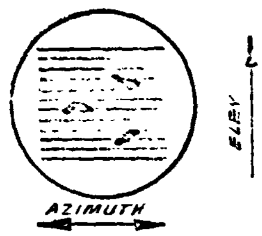
TYPE A



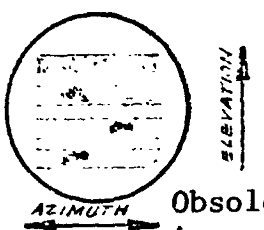
TYPE B



TYPE C

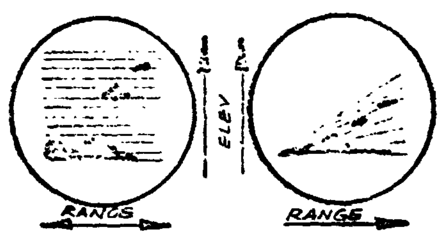


TYPE D

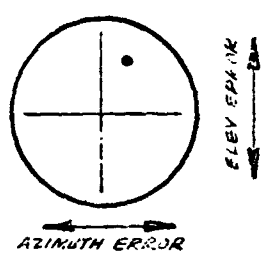


Obsolete: used in prototype A,I

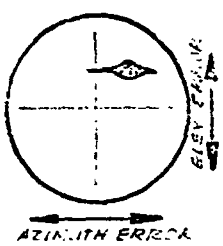
TYPE E



TYPE F

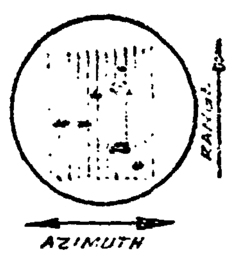


TYPE G



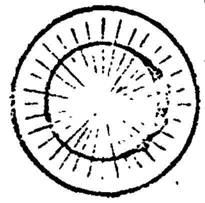
Length of wings inversely proportional to range

TYPE H



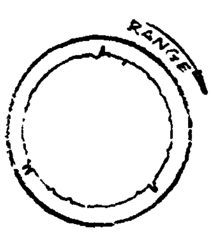
Left dot gives Rng Az. Right dot gives rough Elev.

TYPE I



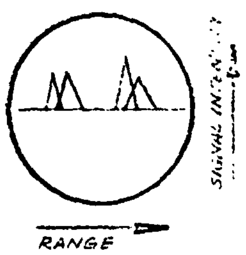
Radius of circle proportional to Range. Brightest part of circle indicates direction axis of cone to target

TYPE J



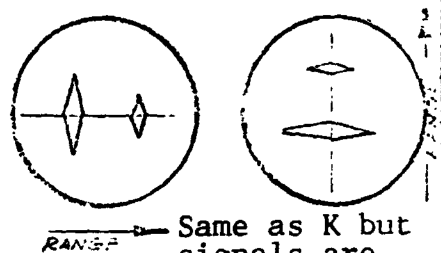
Like Type A, but time base is circular & signals appear as pips

TYPE K



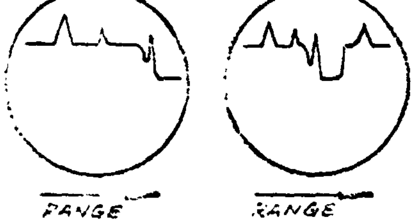
When pips of equal size, antenna on Tgt.

TYPE L

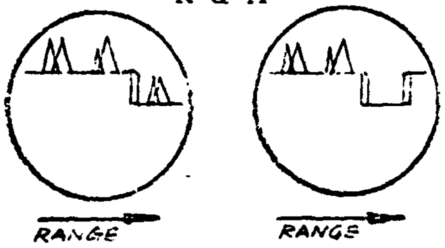


Same as K but signals are back to back

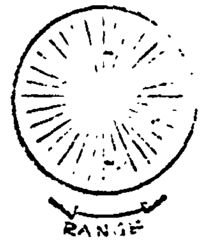
TYPE M On Tgt when pip aligned with notch



TYPE N combination of K & M

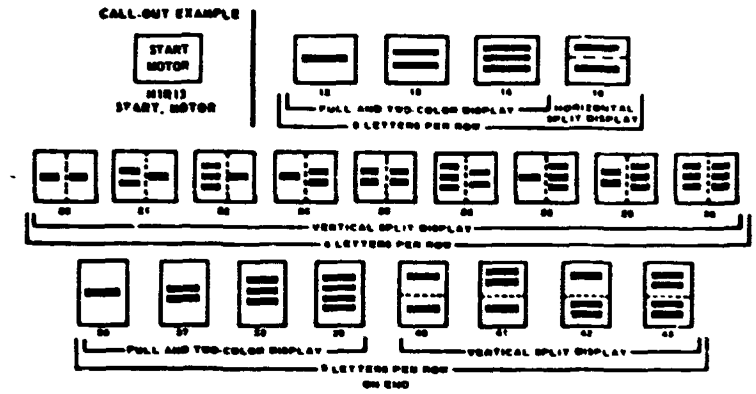


TYPE P (PPI)

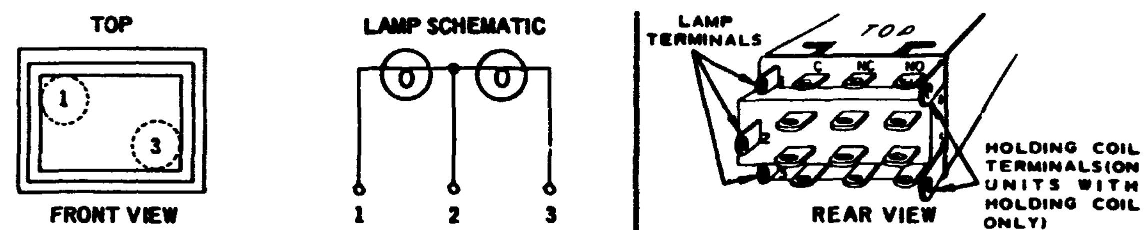


Range measured radially from center

Engraving Configurations



Lamp and Switch Terminal Identification



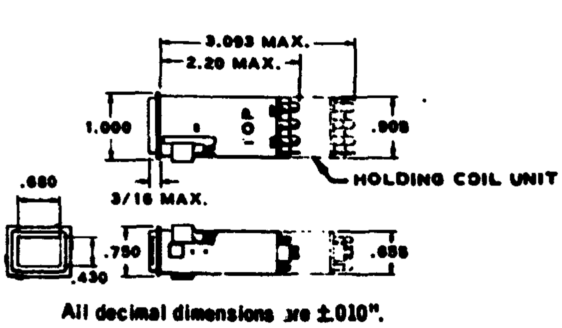
(Numbers correspond to lamp terminals) *4-lamp units also available*

LAMP LOCATION AND LAMP TERMINAL IDENTIFICATION | SWITCH TERMINAL IDENTIFICATION

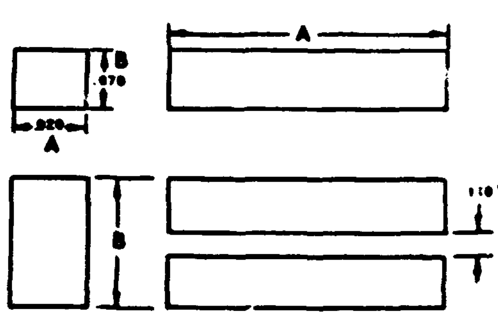
NOTES:

1. On 2 PDT switches, switch terminals are furnished in center only.
2. Terminals will accept two No. 20 AWG wire leads.
3. Electrical ratings: 3 amps resistive, 1½ amps inductive, 1 amp lamp load.
4. Holding coil power requirement: Maximum 3 watts.

Outline Dimensions and Panel Cutout



All decimal dimensions are ±.010".



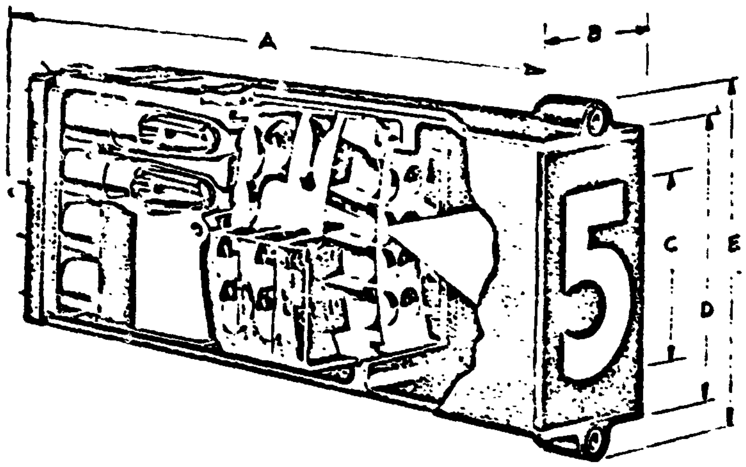
NOTES:

1. The unit will mount in panels 3/32" to 3/16" thick. For units to fit other panel thicknesses, contact the factory.
2. When mounting unit on end, the side marked "top" is on the left as viewed from the front of the panel.

PANEL CUT-OUT DIMENSIONS IN INCHES (±.010)

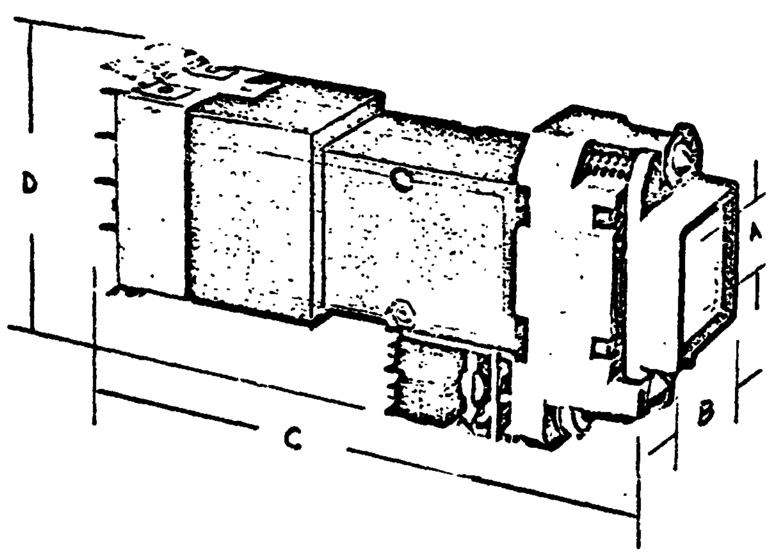
NO. OF UNITS IN ROW	1	2	3	4	5	6	7	8
Horizontal Row "A"	.920	1.925	2.930	3.935	4.940	5.945	6.950	7.955
Vertical Row "B"	.670	1.425	2.180	2.935	3.690	4.445	5.200	5.955

*For matrix arrangement, allow .110" in panel between cut-outs for adjacent horizontal or vertical rows.



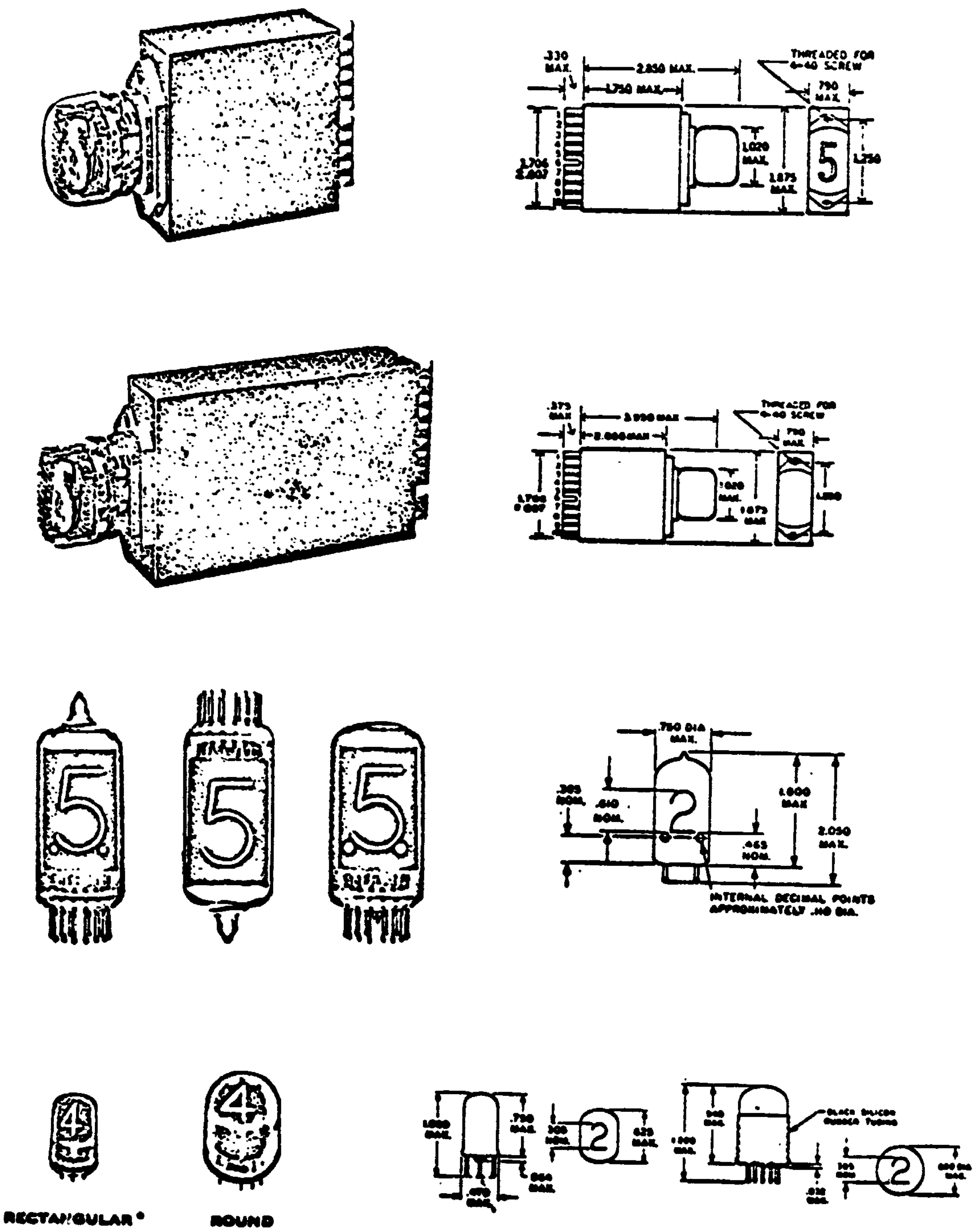
A - .375
B - 1.0
C - 4.5
D - 2.0

PROJECTION-TYPE DIGITAL READOUT



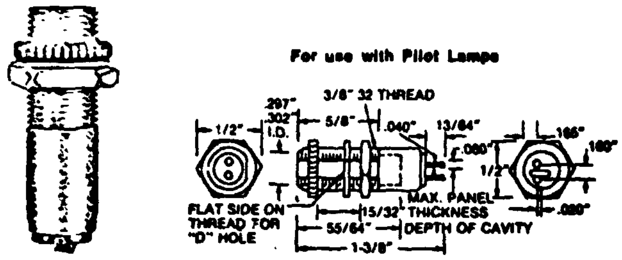
A - .375
B - 1.0
C - 4.5
D - 2.0

PROJECTION-TYPE DIGITAL READOUT/SWITCH



TYPICAL ELECTRONIC DIGITAL READOUTS

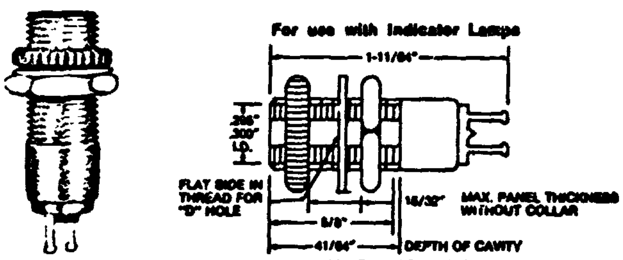
For use with Pilot Lamps



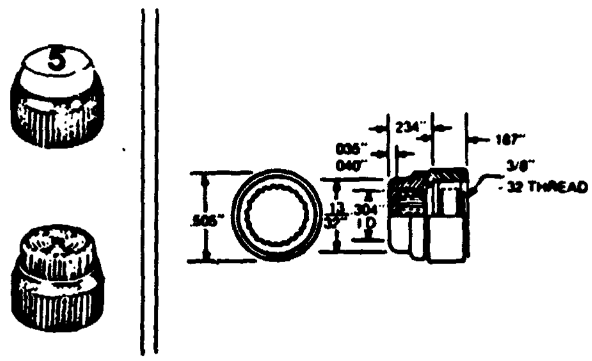
HOLE SIZE: .375"

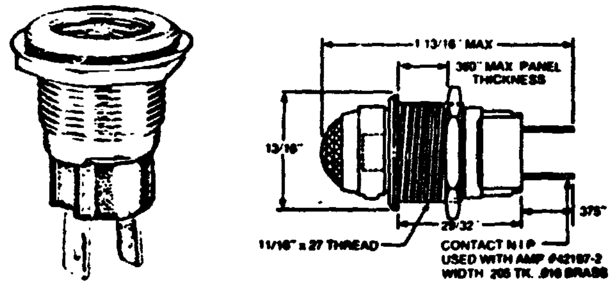
FIGURE 2

For use with Indicator Lamps

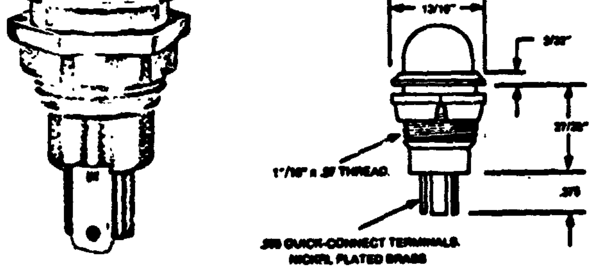


HOLE SIZE: .375"



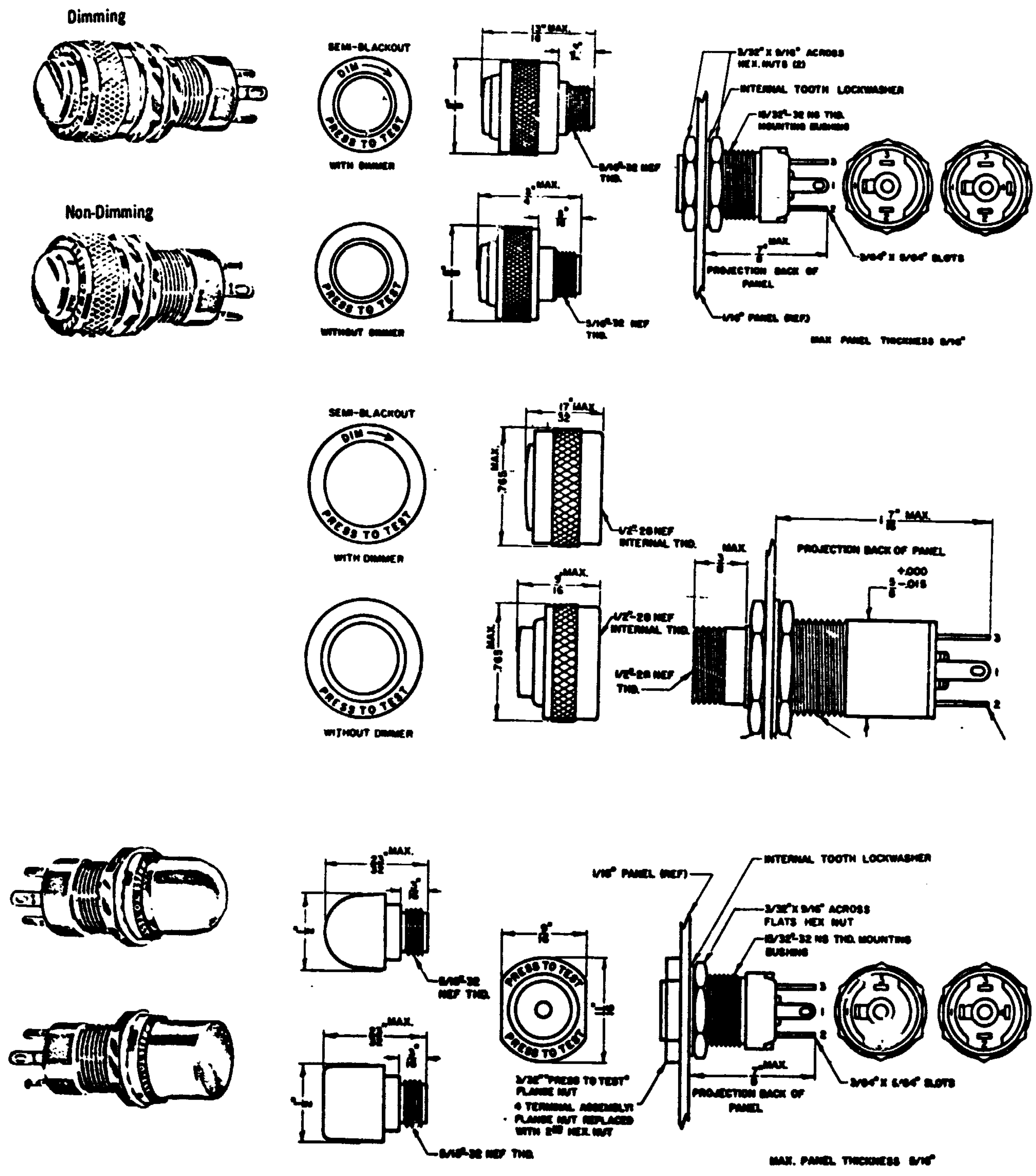


HOLE SIZE .750"



HOLE SIZE .750"

TYPICAL PILOT LIGHT ASSEMBLIES

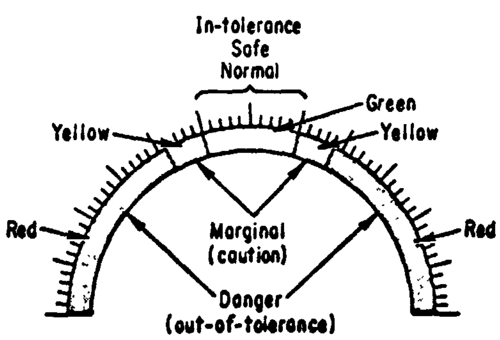


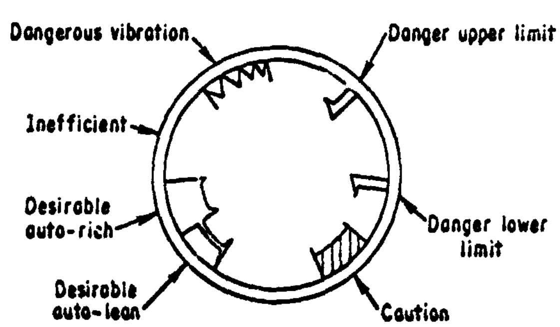
PRESS TO TEST INDICATOR LIGHTS

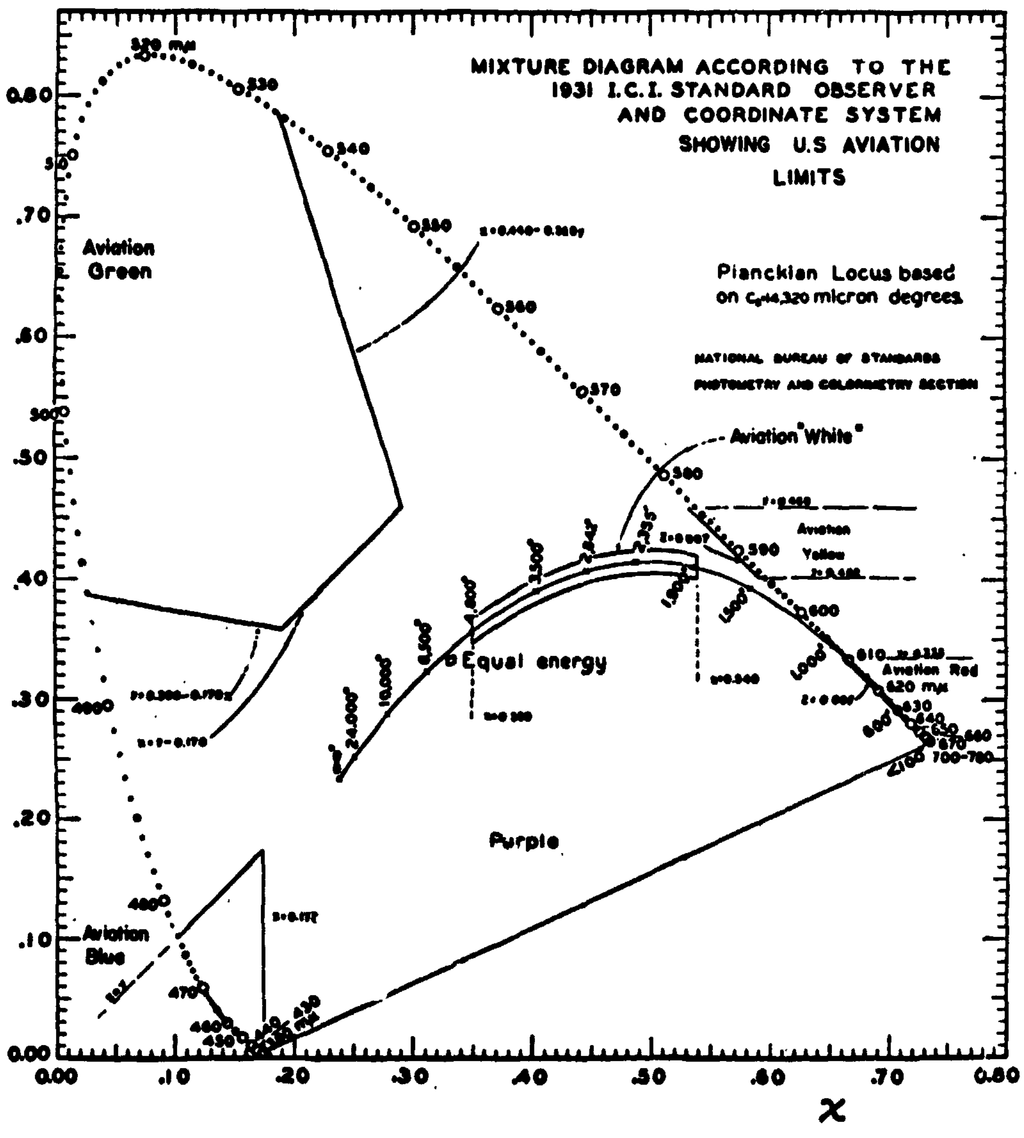
COLOR CODES FOR INDICATOR LIGHTS & ANNUNCIATORS

Color	Operator Response	Meaning
Identification RED	Operator should adopt some abnormal procedure or initiate remedial emergency action Immediate action required	Danger Killer warning Master summation Malfunction, action, stopped, failure, stop action
Identification AMBER	Operator should monitor in preparation to adopt abnormal procedure or remedial action	Extreme Caution Technical hold, temporary interruption
Identification GREEN	Operator should continue normal monitoring and/or operating procedures	Master summation Go ahead, in tolerance, acceptable, ready, normal
Identification LUNAR WHITE	Awareness of functional conditions, no action required	Function, physical position, action in progress

CODES FOR IDENTIFICATION OF DISPLAY OPERATING RANGE







C.I.E. Diagram Shcwing Aviation Color Limits

General Standards for Color Coding

Color	Safety Code*	Ground Equipment Colors**
Red	Fire protection equipment Fire exit signs Danger Stop	Safety and protective equipment (with red streamers where attached to spacecraft) Crash fire and rescue vehicles Fire protection equipment Danger and stop signs
Light amber	—	—
Orange	Dangerous parts of equipment High voltage areas	High voltage areas
Orange-yellow	—	Vehicles used on launching complex Caution signals (with black stripes)
Yellow	Caution: physical hazards (also yellow and black stripes)	Flight line equipment Physical hazards
Green (olive drab)	Safety and first aid equipment	Safety and first aid equipment First aid boxes (green cross on white) Astronaut breathing oxygen cylinder (with white band) Interiors of closed ground vehicles Gas masks Safe signal
Blue	Caution: do not start or equipment under repair	Covered electrical outlets Fuse box exteriors Exteriors of ground vehicles
Purple	Radiation hazards	—
Black	Traffic markings within enclosed areas (also black-white combinations)	Top surface of vehicles used on snow or sand

*American Standards Association (Z53. 1 - 1953) and National Safety Council.
**HIGED A. 2. 7; See reference for color codes for fluid lines, fuses chassis wiring, compressed gas cylinders, capacitors, resistors, and electrical cables.

Electrical Conductor Color Coding

Instructions	Cable Coding Standards: Number of Conductors Desired	Cable Coding Standards: Basic Color	Cable Coding Standards: Tracer
1. Enter the table at the	1	Black	None
particular number of	2	White	None
conductors desired to	3	Red	None
be color coded.	4	Green	None
	5	Orange	None
2. The colors appearing	6	Blue	None
to the right of the	7	White	Black
entry are the appro-	8	Red	Black
priate combination	9	Green	Black
for the particular	10	Orange	Black
number of conductors	11	Blue	Black
	12	Black	White
3. For example, if a	13	Red	White
cable consists of 12	14	Green	White
conductors, the 12th	15	Blue	White
color combination	16	Black	Red
would be black and	17	White	Red
white. The eighth	18	Orange	Red
color combination	19	Blue	Red
could be red and	20	Red	Green
black.	21	Orange	Green

Note: 1. If a cable has concentrically laid conductors, the first combination or color applies to the center conductor. If a cable contains various sizes of conductors, the first color applies to the largest and the sequence continues in order of conductor size.

Hydraulic Conductor Color and Pattern Coding

Hydraulic Coding Standards			
Function	Color	Zip-A-Tone Pattern and No.	Definition of Function
Intensified pressure	Black		Pressure in excess of supply pressure induced by a booster or intensifier.
Supply pressure	Red		Pressure of the power actuating fluid.
Charging pressure	Intermittent red		Pump-inlet pressure, higher than atmospheric pressure.
Reduced pressure	Same	Same	Auxiliary pressure lower than supply pressure.
Metered flow	Yellow		Fluid at a controlled flow rate (other than pump delivery).
Exhaust	Blue		Return of the power actuating fluid to reservoir.
Intake	Green		Sub-atmospheric pressure, usually on the intake side of the pump.
Drain	Same	Same	Return of leakage of control actuating fluid to reservoir.
Inactive	Blank	Blank	Fluid within the circuit but not serving a functional purpose during the phase being represented.

Note: See also Rocketdyne Design Manual 2-1701, Specifications FA6-4 and 10375, and NA Standards 5T1 - 5T17.

Source: J.I.C. Hydraulic standards for industrial equipment, JIC-H1.4 Fluid Color and Pattern Code (Rev. January 1953; October 1957 ed.)

Pneumatic Conductor Color and Pattern Coding

Pneumatic Coding Standards			
Function	Color	Zip-A-Tone Pattern and No.	Definition of Function
Intensified pressure	Black		Pressure in excess of supply pressure induced by an intensifier or booster.
Supply pressure	Red		Pressure of the power actuating air.
Charging pressure	Intermittent red		Compressor-inlet pressure, higher than atmospheric pressure.
Reduced pressure	Same	Same	Auxiliary pressure lower than supply pressure.
Metered flow	Yellow		Controlled flow rate.
Exhaust	Blue		Return of the power actuating medium to the atmosphere.
Intake	Green		Sub-atmospheric pressure, usually on the intake side of the compressor.
Inactive	Blank	Blank	Air pressure within the circuit but not serving a functional purpose during the phase being represented.

Note: See Also NA Standards 5T1 - 5T17.

Source: J.I.C. Pneumatic Sta[illegible]ds for industrial equipment, JIC-A1.4 Color and Pattern Co[illegible]ev. January 1955; March 1957 ed.)

Equipment Color Codes

Color	Coding
Red:	
Meaning	Fire protection equipment and apparatus
Typical use	Fire alarm boxes, fire exit signs; fire extinguishers, buckets, and pails; fire hose locations, fire blanket boxes; fire hydrants, pumps, and sirens; fire sprinkler piping
Meaning	Danger
Typical use	Danger signs, safety cans or other portable containers of flammable liquids having a flash point at or below 80 F (excluding shipping containers), red lights on temporary obstructions or construction
Meaning	Stop
Typical use	Stop button used for emergency stopping of machinery, emergency stop bars on hazardous machinery
Orange:	
Meaning	Dangerous parts of machines or energized equipment which may cut, crush, shock, or otherwise injure. Purpose is to emphasize danger when enclosure doors or guards are open and a safety hazard exists
Typical use	Safety starting buttons, exposed edges of pulleys, gears, cutting devices, rollers, power jaws, etc.

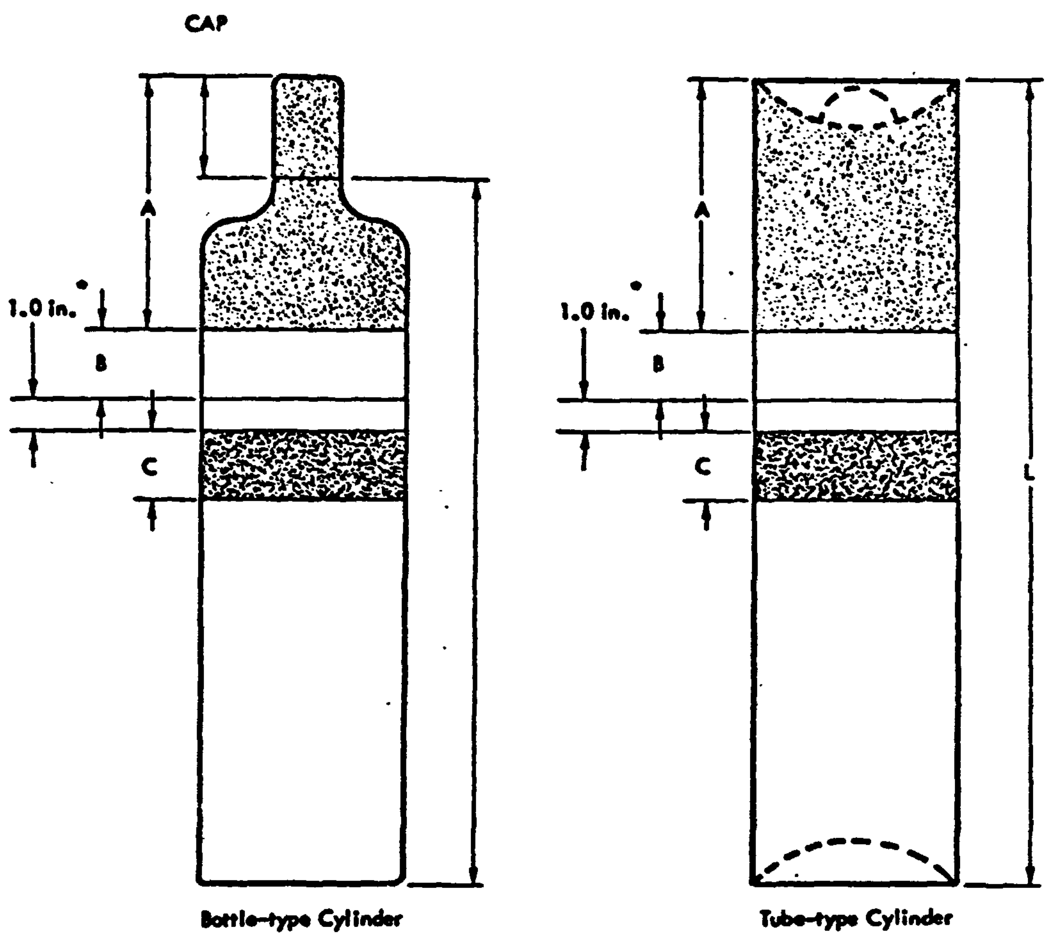
Equipment Color Codes (Cont.)

Color	Coding
Yellow:	
Meaning	Physical hazards, such as stumbling, tripping, falling, or striking against an object
Typical use	Handrails, guardrails, or top and bottom treads of stairways where caution is needed; lower pulley blocks and cranes; pillars, posts, and columns which might be struck; material handling equipment, such as industrial tractors, trucks, trailers, fork-lifts, conveyors, or gantry cranes; piping systems containing dangerous materials
Meaning	Caution
Typical use	Caution signs
Green:	
Meaning	Safety
Typical use	Safety bulletin boards
Meaning	Location of first-aid equipment
Typical use	Gas masks, first-aid kits, stretchers, safety deluge showers, safety signs

Equipment Color Codes (Cont.)

Color	Coding
Blue:	
Meaning	Caution against starting, using, or moving equipment under repair or in use
Typical use	Scaffolding and ladders, electrical controls, valves
Purple:	
Meaning	Radiation hazards (used in combination with yellow for tags, labels, signs, and floor markers)
Typical use	Containers of radioactive materials, disposal cans for contaminated materials, signal lights to indicate when radiation-producing machines are in operation
Black and/or White:	
Meaning	Traffic and housekeeping markings
Typical use	Directional signs, dead ends of aisles or passageways

Authority: ASA Z53.1-1953; ASA A9.1-1953; ASA A13-1928, R 1947; ASA Z35.1-1941, R 1945.



* 1.0 in. space between bands to be omitted if B and C are of same color

Dimensions of Color Coded Areas (in)		
L (Cylinder length)	A (Cap and shoulder)	B and C (Color bands)
30.0 and under	Bottle-type: one-fourth of L - Cap Tube-type: one-fourth of L (Independent of cylinder length)	2.0
Over 30.0		3.0

Gas Cylinder Color Coding Requirements

Gas Cylinder Color Codes

Type of Gas	Area To Be Coded: A (Top)	B (First band)	C (Second band)	Remainder of cylinder
Fuel:				
Petroleum, liquefied	Yellow	Orange	Yellow	Yellow
Petroleum, non-liquefied	Yellow	White	Yellow	Yellow
Hydrogen	Yellow	Black	Yellow	Yellow
Manufactured gas	Brown	Yellow	Yellow	Yellow
Acetylene	Yellow	Yellow	Yellow	Yellow
Refrigerant:				
Ammonia	Brown	Yellow	Orange	Orange
Freon	Orange	Orange	Orange	Orange
Methyl chloride	Yellow	Brown	Orange	Orange
Oxidizing gas:				
Oxygen	Green	Green	Green	Green
Oxygen, aviator's	Green	White	Green	Green
Air, oil-pumped	Black	Green	Green	Black
Air, water-pumped	Black	Green	Black	Black
Helium, oxygen	White	Green	Black	Black
Oxygen, carbon dioxide	Gray	Green	Black	Black
Inert gas:				
Carbon dioxide	Gray	Gray	Gray	Gray
Helium, oil-pumped	Gray	Orange	Gray	Gray
Helium, oil-free	Gray	Orange	Orange	Gray
Nitrogen, oil-pumped	Gray	Black	Gray	Gray
Nitrogen, water-pumped	Gray	Black	Black	Gray
Fire extinguisher:				
Carbon dioxide	Red	Red	Red	Red
Methyl bromide	Red	Brown	Red	Red

Source: Handbook of instructions for ground equipment designers, ARDCM 80-5.

Gas Cylinder Color Code Meanings

Color	Fed. Std. 595	Meaning
Orange Yellow	13538	Flammable materials; materials commonly known to be flammable
Brown	10080	Toxic and poisonous materials; extremely hazardous to personnel
Light blue	15102	Anesthetics and harmful materials
Green	14110	Oxidizing materials; materials which readily furnish oxygen for combustion
Aircraft gray	16473	Physically dangerous because of state of temperature, pressure, etc
Insignia red	11136	Fire extinguishing materials
Jet	17038	No significant meaning
Insignia white	17875	For general use where specified
Orange	12246	No significant meaning
Middlestone	30266	For use on selected groups for segregation purposes

COLOR STANDARDS (Reference FED-STD-595)

Instrument Panel:	Avoid white, yellow, red; other colors may be used to obtain interior color coordination as long as reflectance is 25% or lower.
Instrument face:	# 37038 - Black
Label lettering and instrument or panel markings:	# 37875 - White
Non-color coded control knobs, handles, etc:	Avoid white, yellow, red; other colors may be used to obtain interior color coordination as long as reflectance is 50% or lower.
Color coded controls:	# 11105 - RED
	# 13538 - Yellow
	# 14187 - Green
	# 15123 - Blue
Indicator Lights:	Aviation RED
	Aviation Yellow
	Aviation Blue
	Aviation Green
Meter/Instrument Banding:	# 11105 RED
	# 13538 Yellow
	# 14187 Green

Notes:

a. Non-glossy finishes shall be used on any surface normally exposed to (driver's) view whether they are metal, plastic or painted.

b. RED should be reserved for WARNING or emergency elements, or conditions.

AMBER or yellow should be reserved for CAUTION elements, or conditions.

GREEN should be reserved for READY/SAFE conditions.

COLOR/FINISH RECOMMENDATIONS FOR CONSOLES

CHARACTERISTICS OF CATHODE RAY TUBE PHOSPHORS

Phosphor	Phosphorescence	Persistence*	ICI Coordinates $\bar{x}$	$\bar{y}$
P1	Yellow-green	Medium	0.218	0.712
P2	Yellow-green	Medium	0.279	0.534
P3	Yellow-orange	Medium	0.523	0.469
P4	White	Med.short	0.270	0.300
P5	Blue	Med.short	0.169	0.132
P6	White	Short	0.338	0.374
P7	Yellow-green	Long	0.357	0.537
P8	Replaced by P7			
P9	Withdrawn			
P10	Dark trace screen	Very long		
P11	Blue	Med.short	0.139	0.148
P12	Orange	Long	0.605	0.394
P13	Reddish-orange	Medium	0.670	0.329
P14	Yellow-orange	Med.short	0.150	0.093
		Medium	0.504	0.443
P15	Green	Short-V.short	0.246	0.439
P16	Bluish-purple	Very short	0.175	0.003
P17	Yellow	Long	0.302	0.390
P18	White	Med to m.short	0.333	0.347
P19	Orange	Long	0.572	0.422
P20	Yellow-green	Med.to m.long	0.426	0.546
P21	Reddish-orange	Medium	0.539	0.373
P22	Tricolor: essentially P1 + P4 + P27			
P23	Low temp.white	Med.short	0.375	0.390
P24	Green	Short	0.245	0.441
P25	Orange	Medium	0.557	0.430
P26	Orange	Very long	0.582	0.416
P27	Reddish-orange	Medium	0.674	0.326
P28	Yellow-green	Long	0.370	0.540
P29	Alternate stripes of P2 and P25			

*** Persistence: Time to decay to 10% of initial brightness**

Word Description	Time
Very long	1 sec. or over
Long	100 msec. - 1 sec.
Medium	1 msec. - 100 msec.
Medium short	10 μsec. - 1 msec.
Short	1 μsec. - 10 μsec.
Very short	Less than 1 μsec.

TASK CONDITIONS	FOOT-CANDLES AT WORK POINT
ROUGH SEEING TASKS INACTIVE STORAGE, HALLWAYS, LARGE OBJECTS	1 TO 5
CASUAL SEEING TASKS ACTIVE STORAGE, SERVICE AREAS, STAIRWAYS	5 TO 10
VISUAL TASKS COMPARABLE TO READING 10 OR 11 POINT PRINT ON GOOD QUALITY PAPER (I.E., GOOD LEGIBILITY)	10 TO 15
VISUAL TASKS COMPARABLE TO READING NEWSPRINT	15 TO 20
ORDINARY SEEING TASKS INVOLVING MODERATELY FINE DETAIL WITH NORMAL CONTRASTS READING, HANDWRITING, ORDINARY BENCH AND ASSEMBLY WORK	20 TO 30
VISUAL TASKS REQUIRING VERY FINE DISCRIMINATION, SMALL DETAIL, FINE FINISHING, FINE ASSEMBLY	30 TO 50*
DIFFICULT VISUAL TASKS WITH POOR CONTROL AND PRECISION REQUIREMENTS EXTRA FINE FINISHING OR ASSEMBLY UNDER LOW BRIGHTNESS CONTRAST CONDITIONS	50 TO 100*

GENERAL: Seeing Task vs Illumination Level

Specific Illumination Levels

Specific Illumination Level Requirements

Work Area or Type of Task	Lighting (foot-candles*)	
	Recommended	Minimum
Aerospace Component Assembly	30	
Assembly, general:		
1. course	20	
2. medium	50	
3. fine	100	
4. precise	300	200
Bench work:		
1. rough	20	
2. medium	60	50
3. fine	100	
4. extra fine	300	200
Business machine operation	50	
Corridors	5	
Dials	30	
Drafting		50
Electrical equipment testing	50	
Emergency lighting		3
Gages	30	
Hallways	5	
Inspection tasks, general:		
1. rough	20	
2. medium	60	50
3. fine	100	
4. extra fine	300	200

* As measured on the task object or 30 in. above floor.

Specific Illumination Level Requirements (Cont.)

Work Area or Type of Task	Lighting (foot-candles*) Recommended	Minimum
Machine tool repair	100	
Machine operation, automatic	30	
Meters	30	
Missile; Aircraft		
1. repair and servicing		50
2. storage areas	10	
3. assembly	30	
4. general inspection	50	
Office work, general	30	25
Ordinary seeing tasks	30	
Panels:		
1. front	50	30
2. rear	10	
3. inside	5	
Passageways	5	
Precision work, extreme (such as diemaking)	700	
Reading:		
1. large print	10	5
2. newsprint	25	10
3. handwritten reports, in pencil	20	10
4. small type	30	
5. prolonged reading	50	
Recording	50	
Repair work:		
1. general	50	
2. instrument		100

* As measured on the task object or 30 in. above floor.

Specific Illumination Level Requirements (Cont.)

Work Area or Type of Task	Lighting (foot-candles*) Recommended	Minimum
Scales	30	
Screw fastening	30	
Service areas, general	10	
Severe visual tasks, in general work situations	50	40
Sheet metal work	20	
Stairways	10	
Storage:		
1. inactive or dead	5	2
2. general warehouse	5	
3. live, rough or bulk	5	
4. live, medium	10	
5. live, fine	20	
Switchboards	30	
Tanks	20	
Testing:		
1. rough	20	
2. fine	30	
3. extra fine	100	
Transcribing and tabulation	50	

* As measured on the task object or 30 in. above floor.

Note: Some unusual inspection tasks may require up to 1000 foot-candles of light.

As a guide in determining illumination requirements, the use of a steel scale with 1/64-in. divisions requires 180 foot-candles of light for optimum visibility.

Use explosion-proof lamps near fuels or other explosion or fire hazards.

ILLUMINATION FOR SPECIAL MILITARY FACILITIES

Task/Area	Illum. Level	Lighting Equipment
Dim-out, reading CRT's	2 ft-c maximum	Rheostat controlled with 2 ft-c level marked
Film viewing rooms	5 ft-c minimum	Rheostat controlled with 5 ft-c level marked
Hallways, stairways, stock rooms, washrooms, storage areas, power plants, service-support areas	10 ft-c minimum	General fixed level
Ready rooms, Launch control facilities, general office/conference rooms, normal detail work	20-50 ft-c	General fixed level
Draftin, tele-type, class rooms, telemetry readout areas, crypto area, fine detail, fair contrast, speed not essential	50-100 ft-c	General lighting plus suplementary lighting where necessary
Data handling, computer areas, televising, small detail very difficult and prolonged visual tasks, low brightness contrast, high speed and accuracy essential	100 ft-c or more	General lighting(homogeneous diffuse) plus supplementary lighting as required

ILLUMINATION STANDARDS FOR VEHICLE INTERIOR/INSTRUMENTATION

CONDITION OF USE	LIGHTING SYSTEM	BRIGHTNESS	ADJUSTMENT
General interior illumination	White flood, indirect/dė-fused	Minimum - 15ftL	Fixed
Map reading	White flood, indirect/de-fused	15 to 50 ftL	Continuously adjustable
Instruments	White flood, diffused or back-lighted	0 to 100 ftL	Continuously adjustable
Labels, panel	White, back-lighted or transillum.	0 to 100 ftL	Continuously adjustable
Warning/Advisory indicator lights	RED - Warning AMBER _ OTHER Diffused back or integral light	150 ft L	Fixed

Notes: a. Light source (or reflection from) shall not be visible to the operator in his normal driving position.

b. Illumination shall be equally distributed across instrument face or label; brightness variation should not exceed 3;1.

c. Transilluminated markings shall be sharply defined and readable from any angle up to 60° from ERP.

d. Instrument cover glass shall be anti-glare coated.

	Visual Acuity	Percent Contrast	Threshold Background Luminosity Footlamberts	Speed of Vision Required Discriminations/Sec	Speed of Vision Factor Discriminations/Sec	Acceleration Force "G"	Acceleration Force Factor	% Accuracy Required	Accuracy Factor	Min. Luminosity Required Footlamberts	Approximate Illumination Required Footcandles
	A	B	C	D	E	F	G	H	I	J	K
Map and Chart Reading	0.25	90	0.004	30	20.0	4	3	1	50	12.0	20.0
Instrument Reading	0.25	150	0.003	50	50.0	4	3	1	50	22.5	30.0
Operate Radios	0.25	150	0.003	50	50.0	4	3	1	50	22.5	30.0
Operate Flight Controls	0.1	20	0.004	5	2.5	4	3	1	50	15.0	30.0
Perform Calculations	0.25	50	0.01	20	10.0	1	1	1	50	5.0	10.0
Prepare Reports	0.25	50	0.01	20	10.0	1	1	1	50	5.0	10.0
Clean Compartments	0.1	30	0.03	5	2.5	1	1	1	50	3.75	10.0
Scullery	0.25	20	0.1	20	10.0	1	1	1	50	50.0	60.0
Maneuver in Area	0.05	30	0.0001	5	2.5	1	1	1	50	0.0125	0.02
Enter and Leave Compartment	0.05	30	0.0001	5	2.5	1	1	1	50	0.0125	0.02
Reading for Pleasure	0.25	150	0.003	50	50.0	1	1	1	50	7.5	10.0
Playing Recreational Games	0.2	50	0.006	30	20.0	1	1	1	50	6.0	10.0
Preparing Food	0.25	90	0.004	30	20.0	1	1	1	50	4.0	5.0
Eating Food	0.25	30	0.035	5	2.5	1	1	1	50	4.375	10.0
Inventory Stores	0.25	90	0.004	20	10.0	1	1	1	50	2.0	5.0
Self Relief of Personnel	0.1	30	0.003	5	2.5	1	1	1	50	0.375	1.0
First Aid	0.5	50	0.1	15	7.0	1	1	1	50	35.0	60.0
Personal Cleanliness	0.5	50	0.1	5	2.5	1	1	1	50	12.5	20.0
Emergency Repair	0.25	30	0.035	10	4.5	1	1	1	50	6.875	10.0

$J = (C)(E)(G)(I)$ $\quad K = \dfrac{J}{\%\ \text{Reflection}}$

ILLUMINATION REQUIRED FOR VARIOUS TASKS IN A SPACE VEHICLE

NATURAL ILLUMINATION SOURCE BRIGHTNESS

Natural Illumination Sources	Ft. Lamberts
Sun, Apparent	4.086×10^{8} to 4.67×10^{8}
Moon	7.41×10^{2}
Moonless Sky – Clear Night	1.29×10^{-4}
Moonlight – Clear	4.70×10^{-4}
Blue Sky	1.81×10^{2}
Cumulus Sky	7.24×10^{-2}
Sky – Overcast	11.67
Sky – Light Clouds	1.837×10^{3}
Sky – Dark Clouds	94.26
Average Clear Sky	2.325×10^{3}
Sirius	4.30×10^{9}
Snow – In Sunlight	4.972×10^{2}
*Sunlight – Reflected from Cloud Cover	9.290×10^{-1} (10^{4})
*Sunlight – Reflected from Sky	9.29×10^{-1} (10^{-6})

REPRESENTATIVE REFLECTION VALUES FROM EARTH'S SURFACE

Surface	Sunlight Reflected (%)
Ocean	3 to 5
Dry Grass	3 to 6
Deciduous Forest	3 to 10
Ground	10 to 20
Rocks	30
Lush Grass	15 to 25
New Snow	70 to 86

*As seen from an orbiting vehicle.

RECOMMENDED REFLECTANCES	
Surface	**①Reflectance**
②Ceiling	80% (80-95%)
Walls	50% (40-60%)
Floors	30% (20-40%)
Furniture	35% (25-45%)
Office Machines and Equipment	35% (25-45%)
Chalkboards	③15% (15-20%)

① Number outside parentheses indicates the preferred value; numbers inside represent permissible tolerances. Diffuse non-glossy finishes are recommended throughout.

② Recommended reflectances are for finish only. Over-all average reflectance of acoustic materials may be somewhat lower. The upper walls (one to two feet below the ceiling) may be painted with the same paint as is used on the ceiling.

③ In-service "chalked" value. Reflectance of clean board should be at least 5% lower.

EFFECT OF COLORED LIGHT ON COLORED OBJECTS

Object Color	Red Light	Blue Light	Green Light	Yellow Light
White	Light Pink	Very Light Blue	Very Light Green	Very Light Yellow
Black	Reddish Black	Blue Black	Greenish Black	Orange Black
Red	Brilliant Red	Dark Bluish Red	Yellowish Red	Bright Red
Light Blue	Reddish Blue	Bright Blue	Greenish Blue	Light Reddish Blue
Dark Blue	Dark Reddish Purple	Brilliant Blue	Dark Greenish Blue	Light Reddish Purple
Green	Olive Green	Green Blue	Brilliant Green	Yellow Green
Yellow	Red Orange	Light Reddish Brown	Light Greenish Yellow	Brilliant Light Orange
Brown	Brown Red	Bluish Brown	Dark Olive Brown	Brownish Orange

Section 2

PHYSIOLOGICAL FACTORS

Section 2

PHYSIOLOGICAL FACTORS

This section contains information which relates to maintaining the human operator within physiological tolerance limits which assure safety and effective performance. Since materials were drawn from other sources there is an obvious overlap between this and other sections.

The following specific references are suggested for additional reading:

Benson, O. O. & Strughold, H. - Physics and Medicine of the Atmosphere and Space, John Wiley & Sons, N. Y., 1960.

Gauer, O. H. & Suidema, G. D. - Gravitational Stress in Aerospace Medicine, Little-Brown & Co., Boston, 1961.

Sell, S. B. & Berry, C. A. - Human Factors in Jet and Space Travel, The Ronald Press, Co., N. Y., 1961.

Roth, E. M. (ed) - Compendium of Human Responses to the Aerospace Environment, NASA CR-1205(vols. I, II & III)

Webb, P. (ed) - Bioastronautics Data Book, NASA SP-3006, Scientific & Technical Information Div., NASA, Washington, D. C., 1964.

AFSC DH 1-6 - System Safety, Air Force Systems Command/ NASA Design Handbook Series 1-0. Space & Missile Systems Command, Andrews AFB, Washington, D. C. 20331.

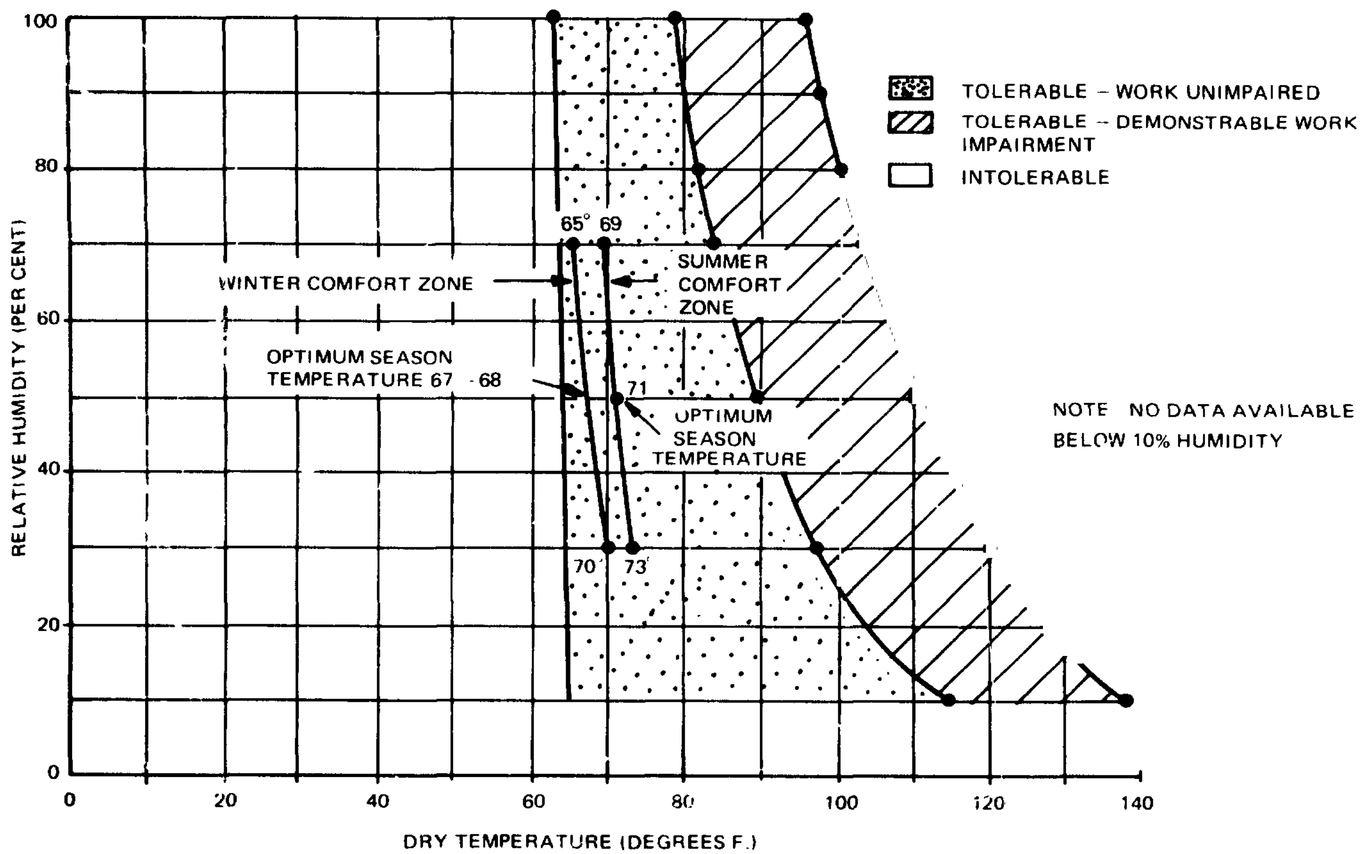
NASA CR-1205(III) - Compendium of Human Responses to the Aerospace Environment, (Sections 10-16) edited by E. M. Roth, M.D.

GENERAL PHYSIOLOGICAL CRITERIA FOR SYSTEM DESIGN

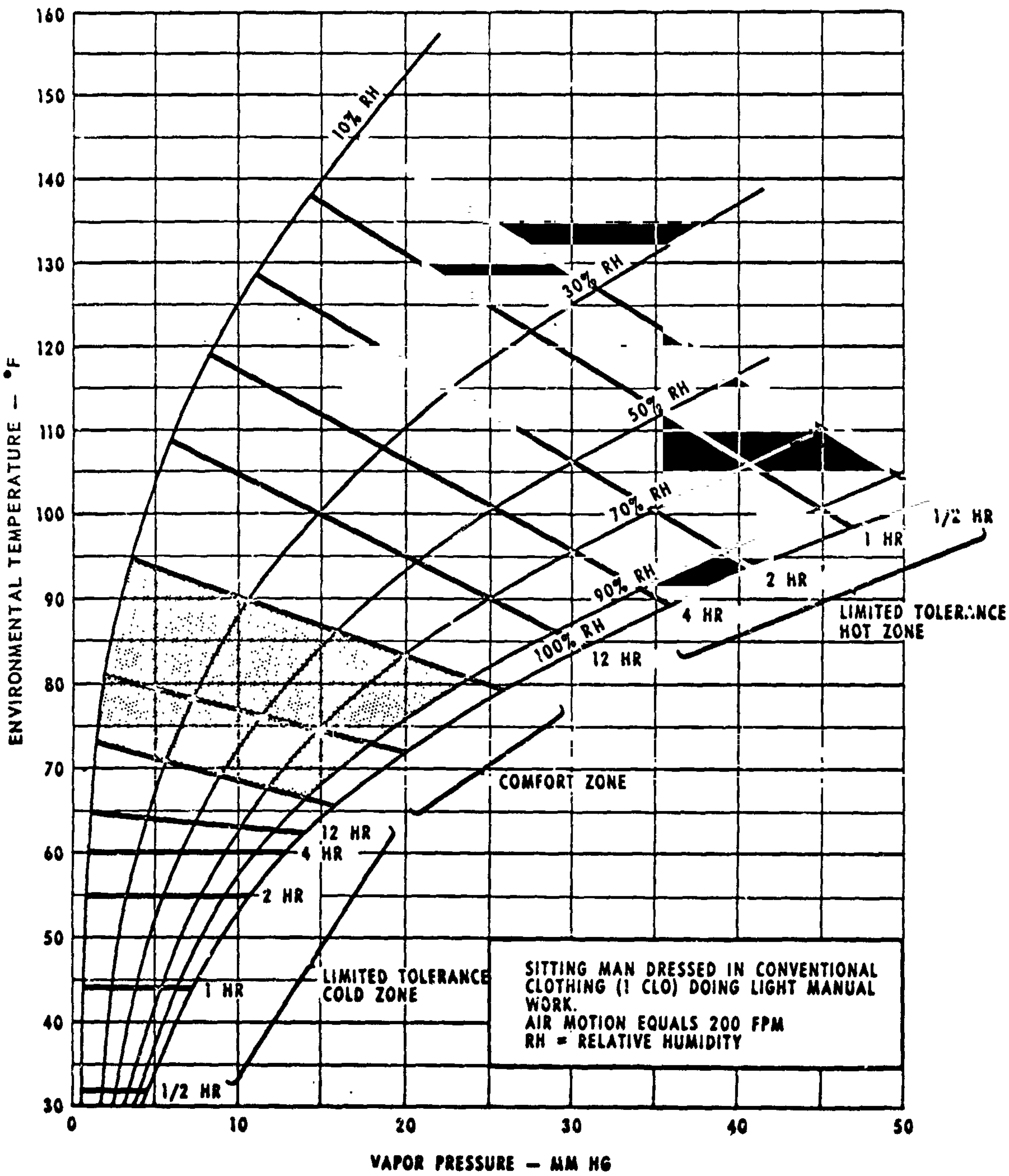
CONDITION	Optimum Value	Conventional Limits		Extreme Limits
		Min	Max	
Relative Humidity (%)	50	30	70	N/A
Effective Temperature (°F)	68	66-71	66-71	N/A
Dry Bulb Temperature (°F)	72	72-78	68-74	N/A
Atmosphere:				
Total cabin pressure (PSIA)	14.7	10.1	14.7	5.4-14.7
Standard Air 100% Oxygen (1)	N/A	3.5	5.0	2.7- 8.3
Oxygen partial pressure (mm Hg)				
in Standard air (21% O_2)	160	110	160	59-160
all oxygen (2)	N/A	180	260	141-430
Nitrogen partial pressure (mm Hg)	593	0	580	0-619
Water partial pressure (mm Hg)	9.6 (3)	5	15 (4)	N/A
CO_2 partial pressure (mm Hg)	0.3	0	8 (1)	0-23 (1)

(AFSC DH 1-6)

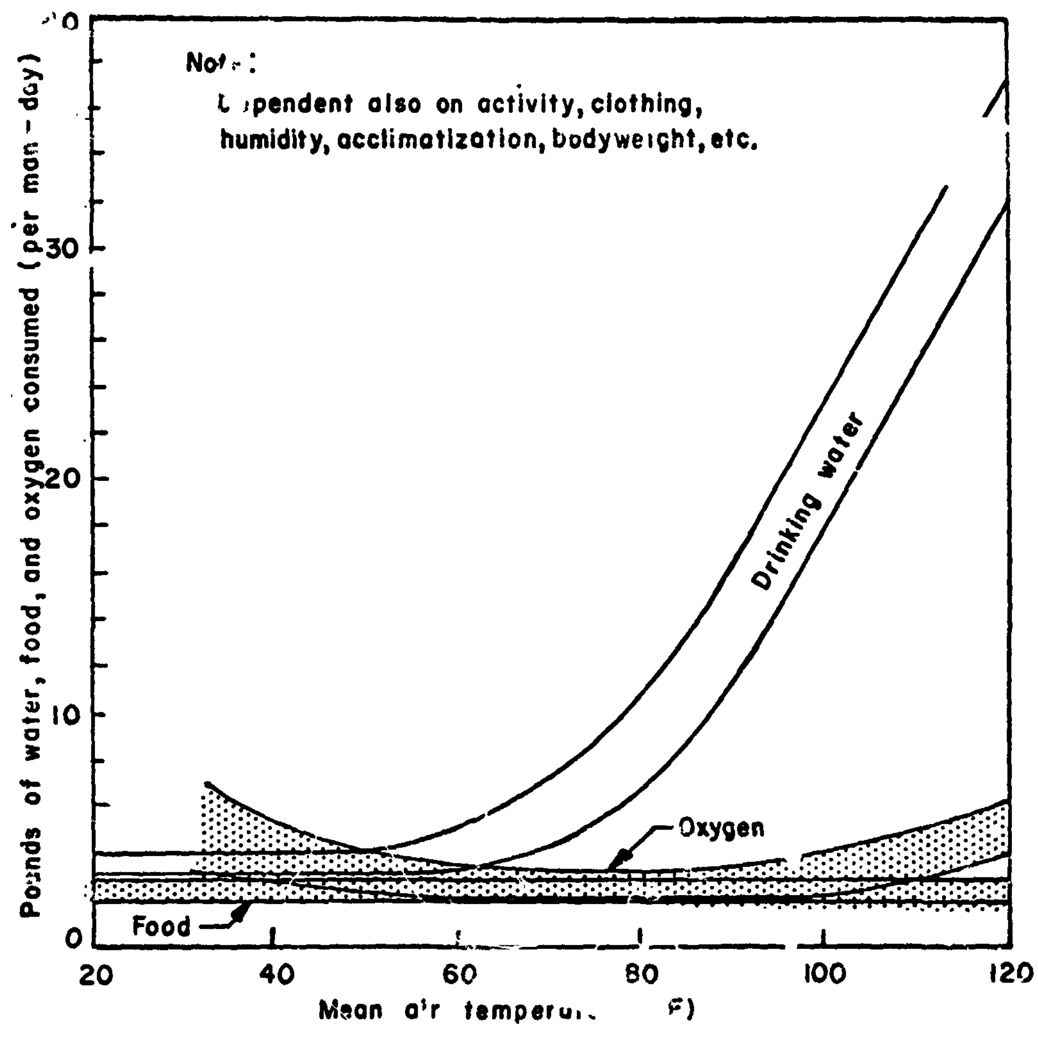
(1) Time dependent
(2) Same as total cabin pressure with 100% O_2
(3) At 74° F and 50% relative humidity
(4) At 74° F and 30 to 70 % relative humidity



TOLERABLE TEMPERATURE-HUMIDITY REQUIREMENTS (WITH CONVENTIONAL CLOTHING)

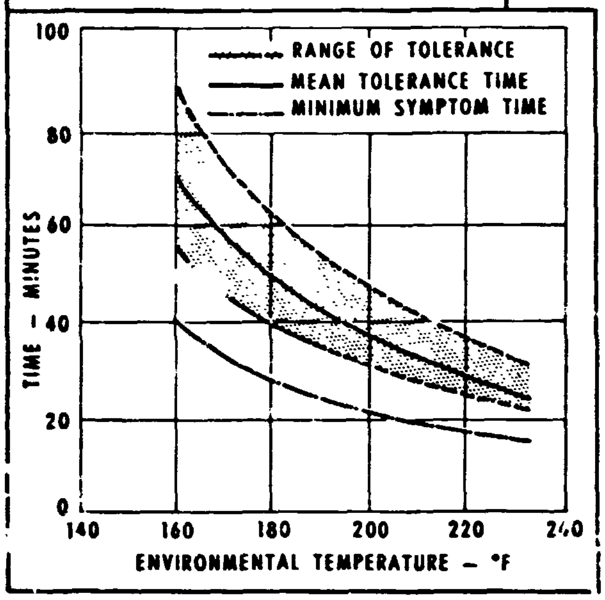


Tolerance-Comfort Limits, Temperature/Humidity

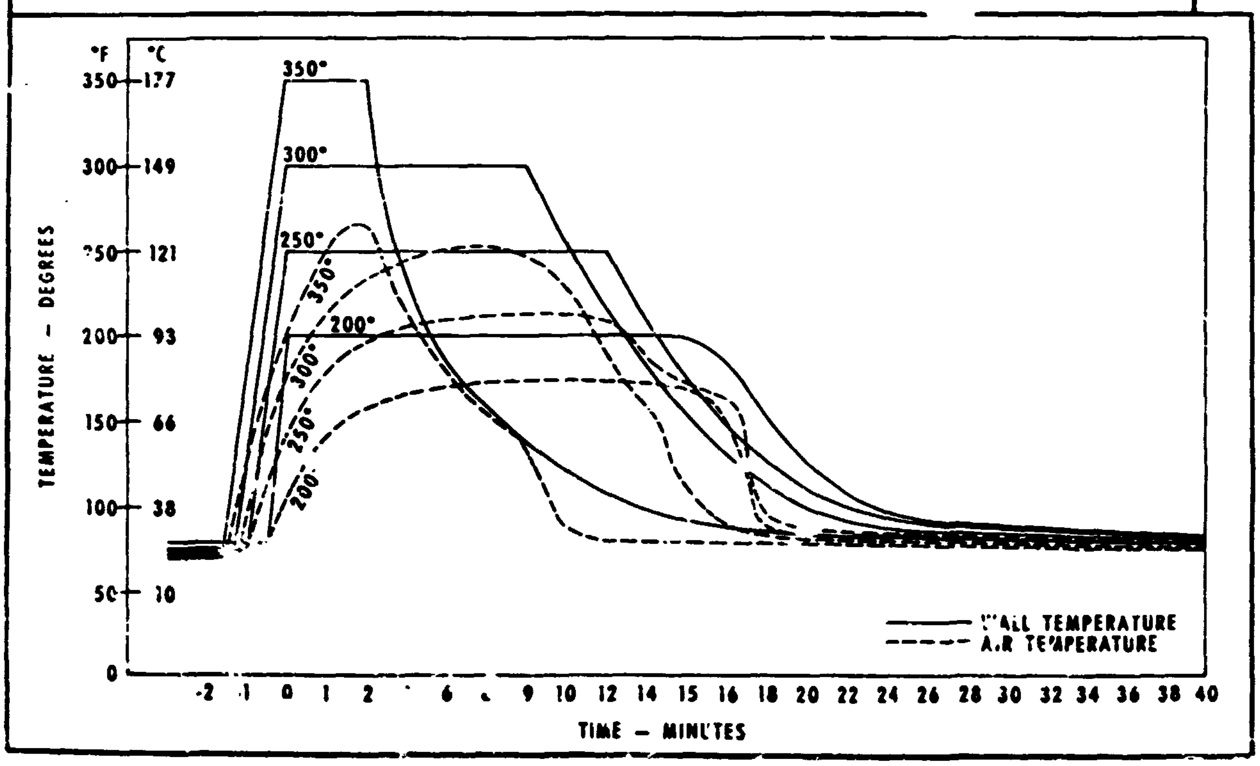


—EFFECT OF TEMPERATURE ON WATER, FOOD, AND OXYGEN REQUIREMENTS

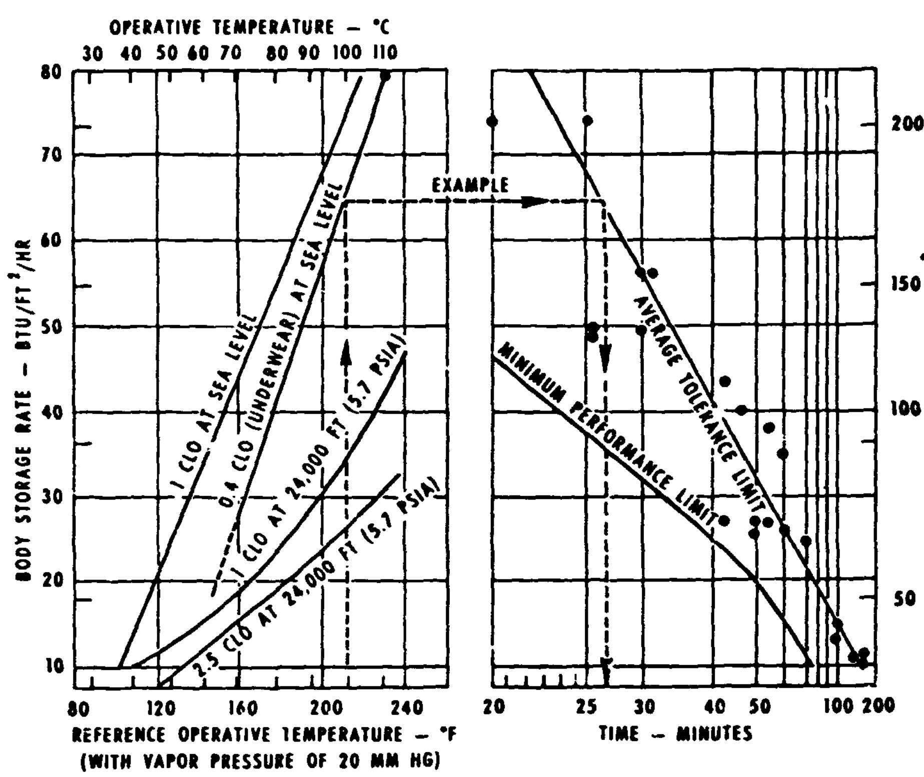
Mean and Range of Tolerance Time and Minimum Symptom Time for High Temperature



Time-Temperature Relationships for Heat Stress Exposure



Heat Storage and Tolerance



THIS CHART SHOWS THE RATE OF STORAGE OF BODY HEAT FOR SEVERAL CONDITIONS OF CLOTHING AND ALTITUDE. WHERE SEATED AND UNTRAINED MEN ARE EXPOSED TO NONCOMPENSABLE HEAT. ENTRY IS BY MEANS OF THE REFERENCE OPERATIVE TEMPERATURE, DEFINED AS THE TEMPERATURE OF AIR AND WALLS WHICH, IN COMBINATION WITH A VAPOR PRESSURE OF 20 MM HG, HAS EQUIVALENT EFFECTS TO SOME OTHER COMBINATION OF HUMIDITY AND TEMPERATURES. OPERATIVE TEMPERATURE IS THE WEIGHTED MEAN OF AIR AND WALL TEMPERATURE, WHERE THE WEIGHTING COEFFICIENTS ARE THE RESPECTIVE HEAT TRANSFER COEFFICIENTS FOR CONVECTION AND RADIATION.

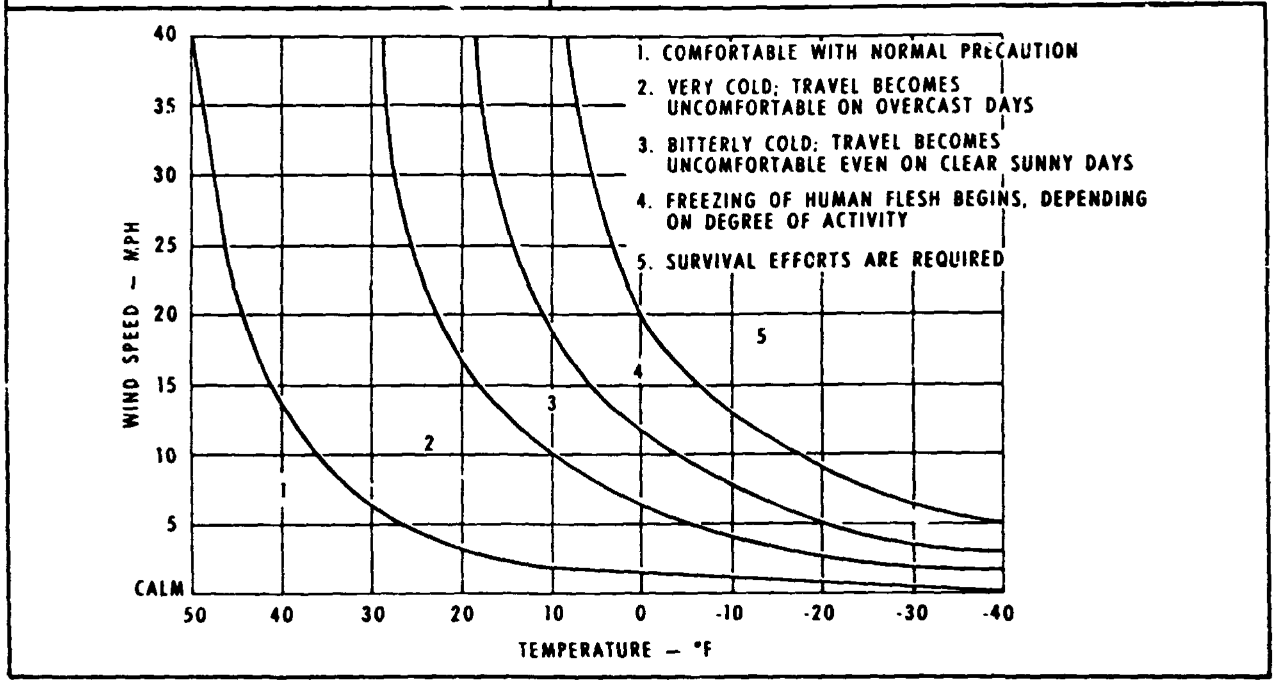
RANGE AND LEVEL OF SENSITIVITY TO HEAT EXCHANGE

Temperature (°F)	Temperature Difference (°F)*	Sensation or Effect	Rate of Heat Transfer (Btu/sec/sq in)**
212	121	2nd-degree burn on 15-sec contact	
180	89	2nd-degree burn on 30-sec contact	
160	69	2nd-degree burn on 60-sec contact	
140	49	pain; tissue damage (burns)	
120	29	pain "burning heat"	5.58×10^{-3}
109	18		
		warm	3.8×10^{-4}
91 ± 4	0	neutral; "physiological zero"	0
		cool	
54	−37		
		"cold heat"	
37	−54		
		pain	
32	−59	water freezes	
Below 32	−59	pain; tissue damage (freezing)	

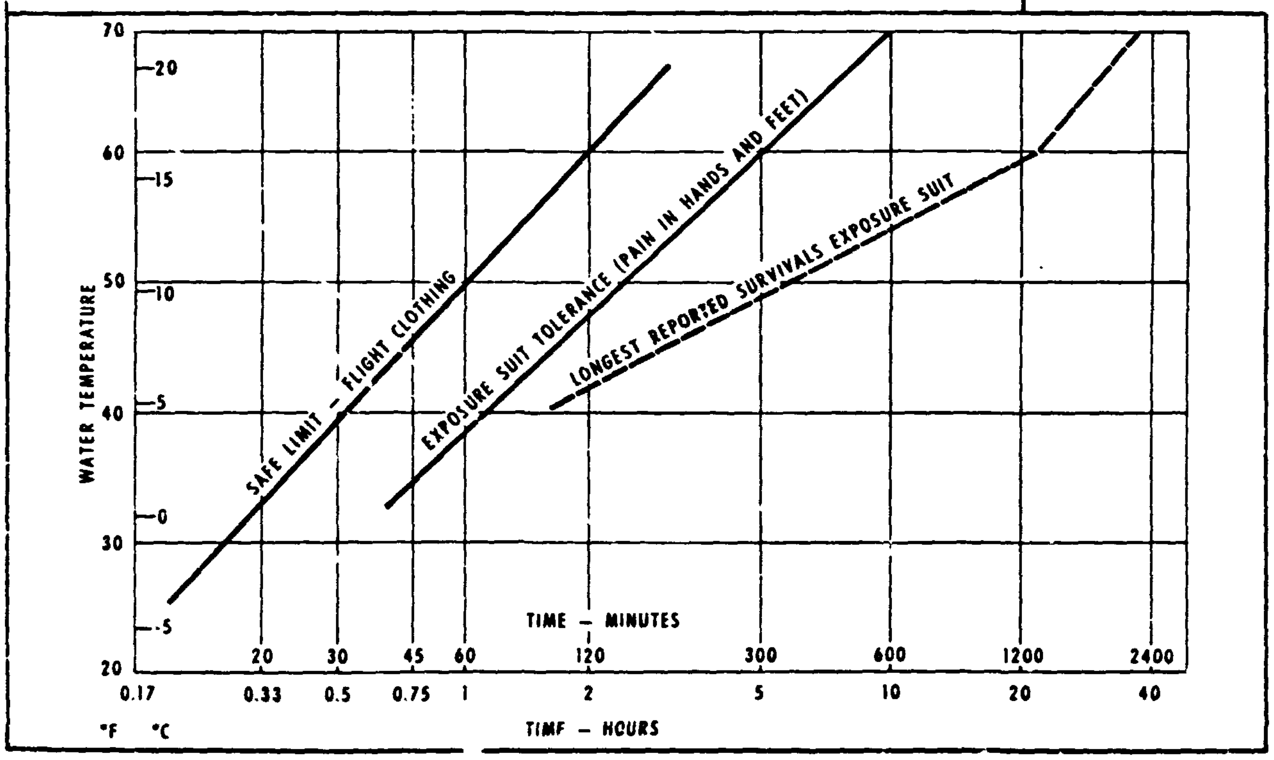
*Based on physiological zero (91°F).

**Rate indicated will produce a change in sensation in 3 sec (lower figure) or change the sensation from neutral to pain in 3 sec (higher figure).

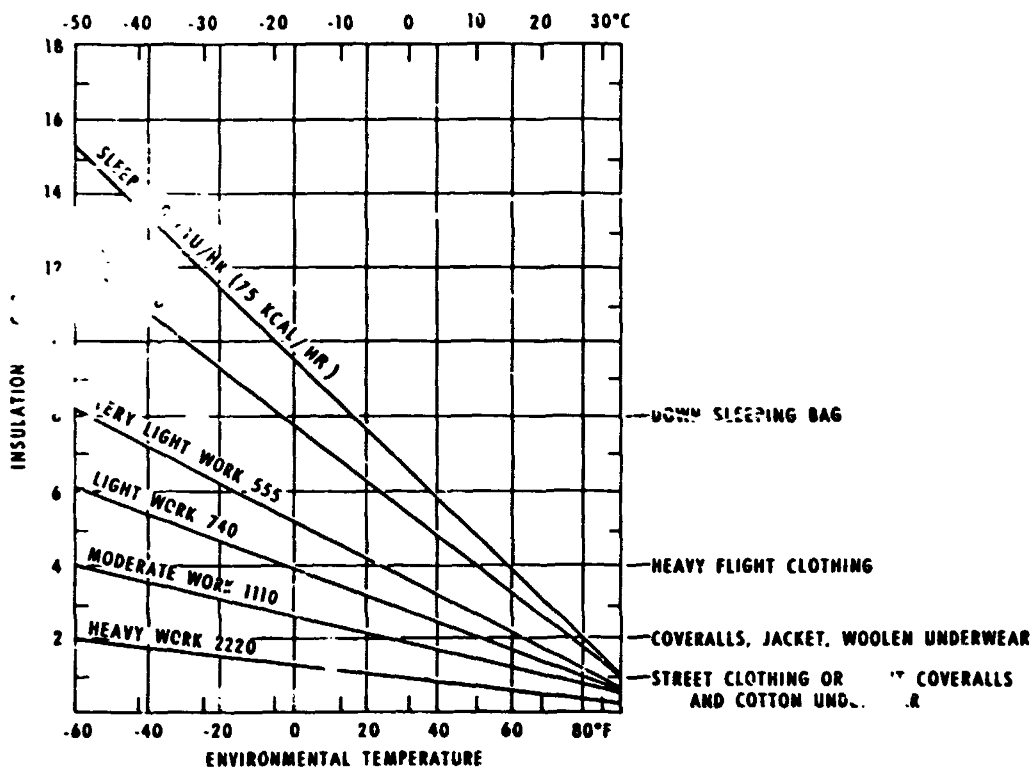
Chill Index



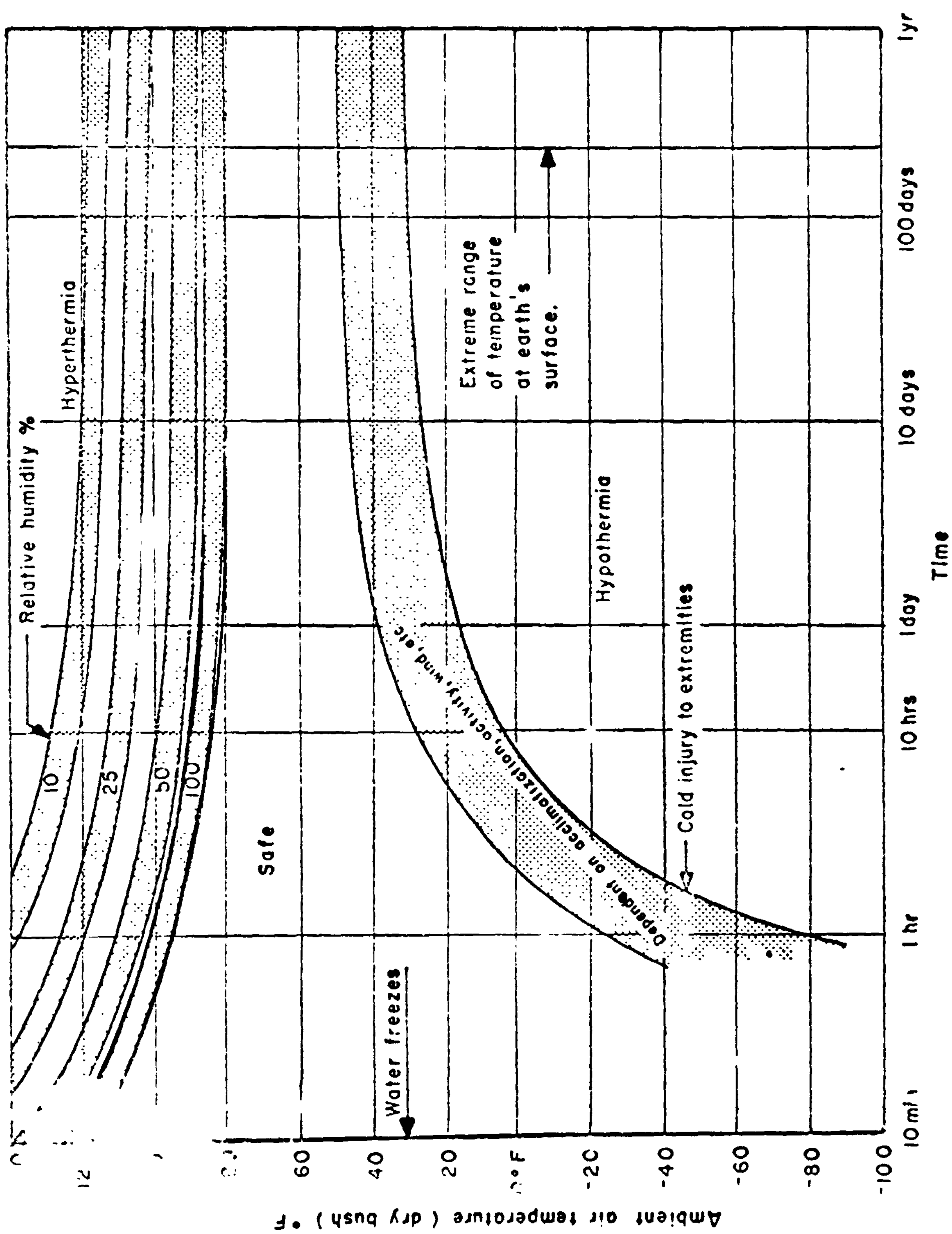
Tolerance Limits for Cold Water Immersion Based on Experience and Laboratory Studies



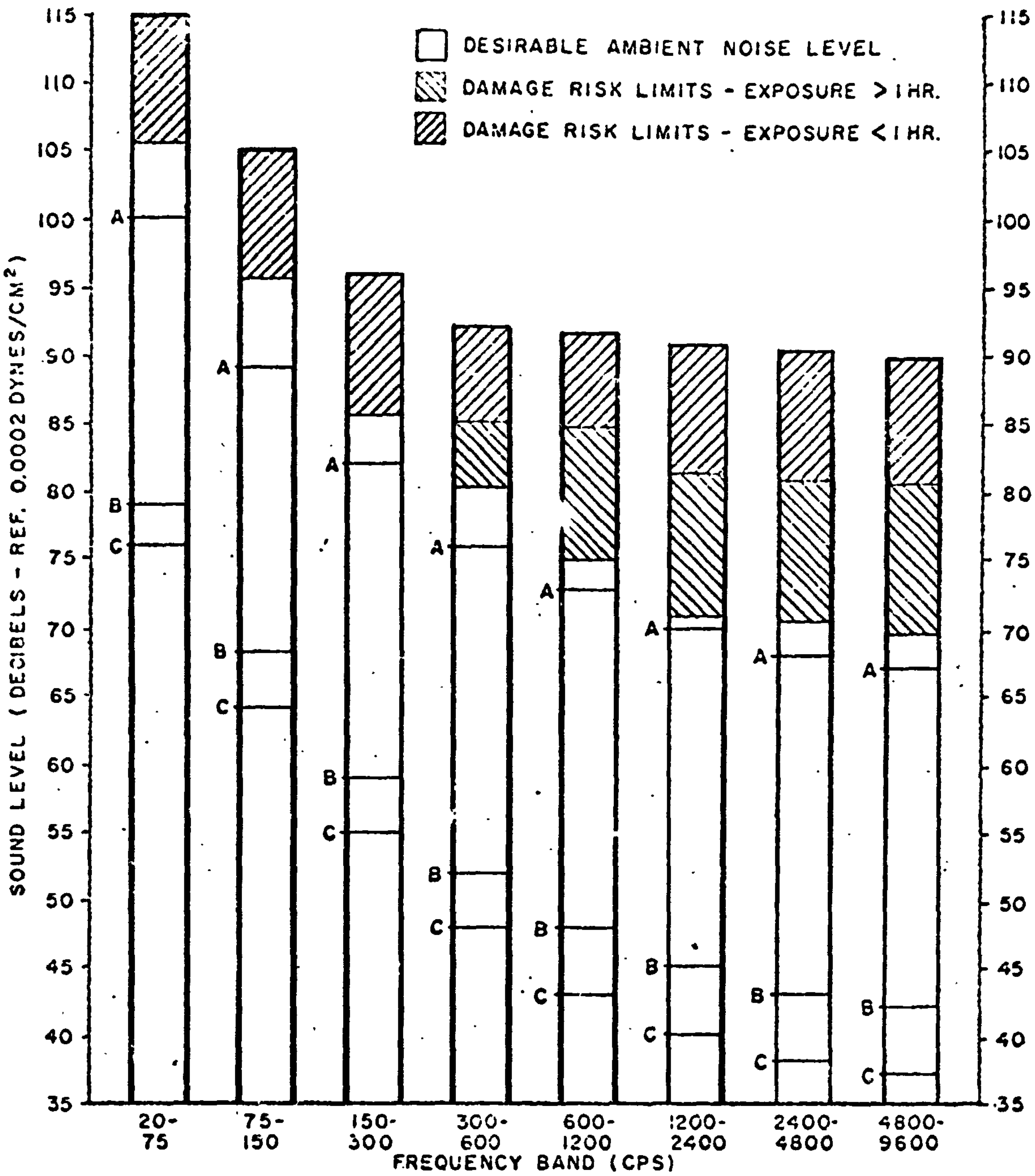
Clothing Insulation Requirements for Cold Environments at Various Levels of Activity



BASED ON AVERAGE MAN – AREA = $1.8 m^2$



—APPROXIMATE HUMAN TIME - TOLERANCES; TEMPERATURE
OPTIMUM CLOTHING



RECOMMENDED MAXIMUMS:

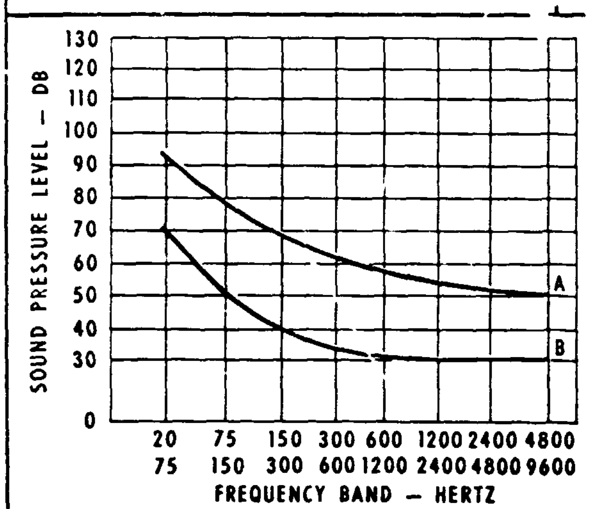
A. PERSONNEL REQUIRED TO BE CONTINUOUSLY PRESENT, VOICE COMMUNICATION IS MINIMAL. (TELETYPE, COMPUTER, COMMAND TRANSMITTER ROOMS)

B. EQUIPMENT USED REGULARLY IN OPERATIONAL SITUATIONS. (E.G.: TELEMETRY, RADAR, TT&C ROOMS)

C. EQUIPMENT USED IN EXECUTIVE OFFICES AND CONTROL, VIEWING, CONFERENCE ROOMS.

RECOMMENDED AND TOLERABLE LIMITS FOR OPERATIONAL NOISE LEVELS

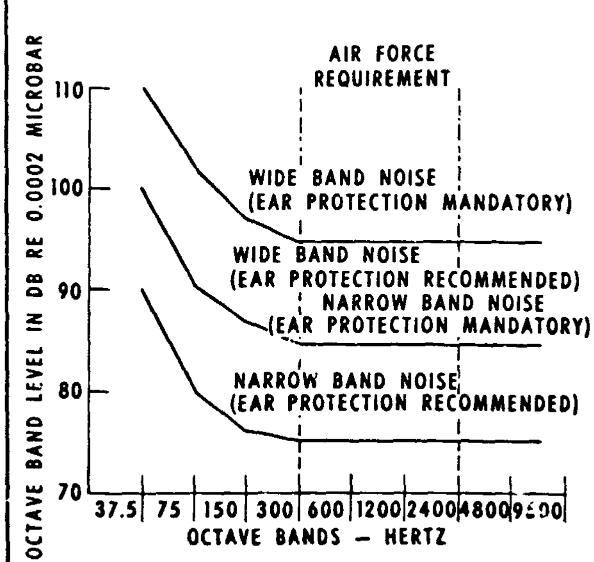
Tolerance Criteria for Noise in Manned Spacecraft*



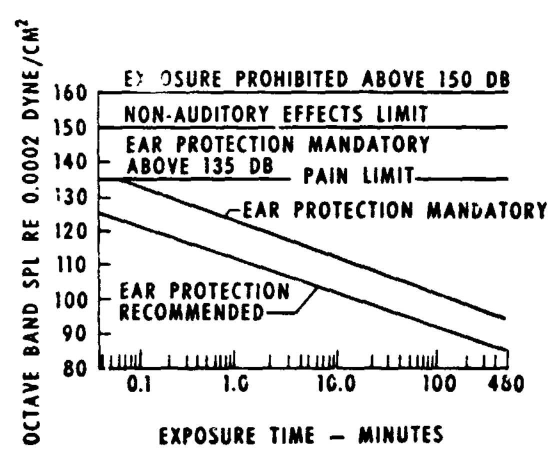
A. MAXIMUM TOTAL NOISE LEVEL
B. DESIRABLE TOTAL NOISE LEVEL FOR SLEEP AND REST

*Extracted from Ref 1(C).

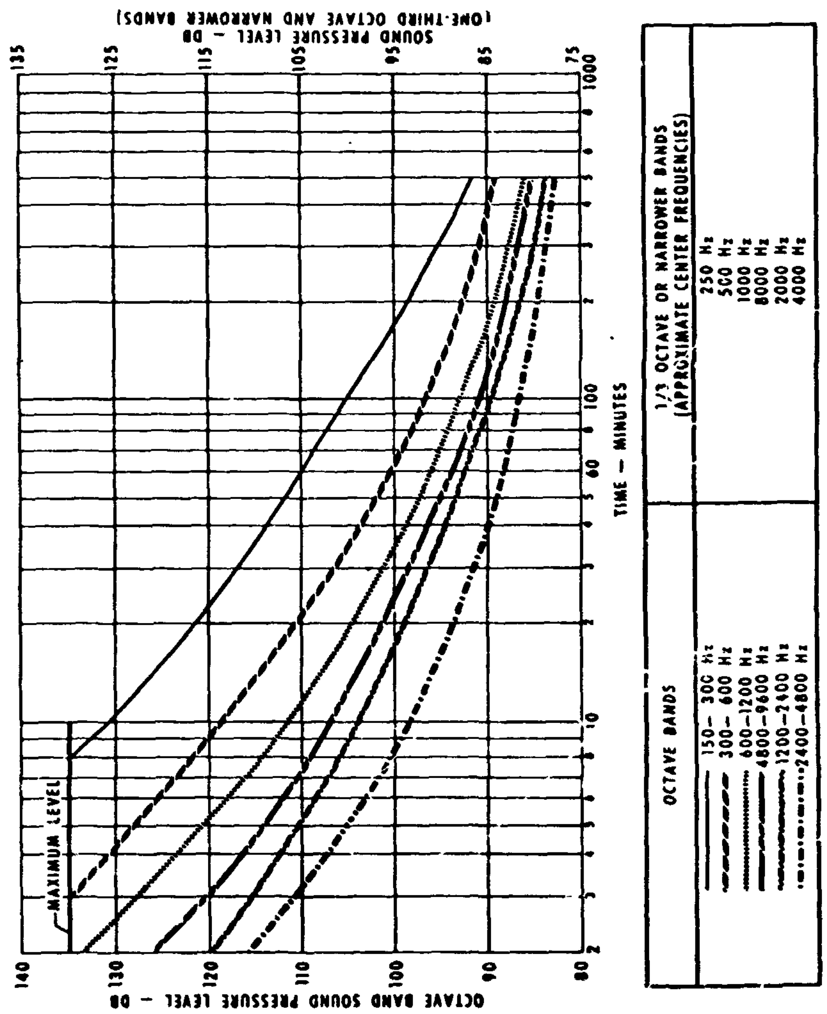
Long Term (8 Hr) Damage Risk Criteria



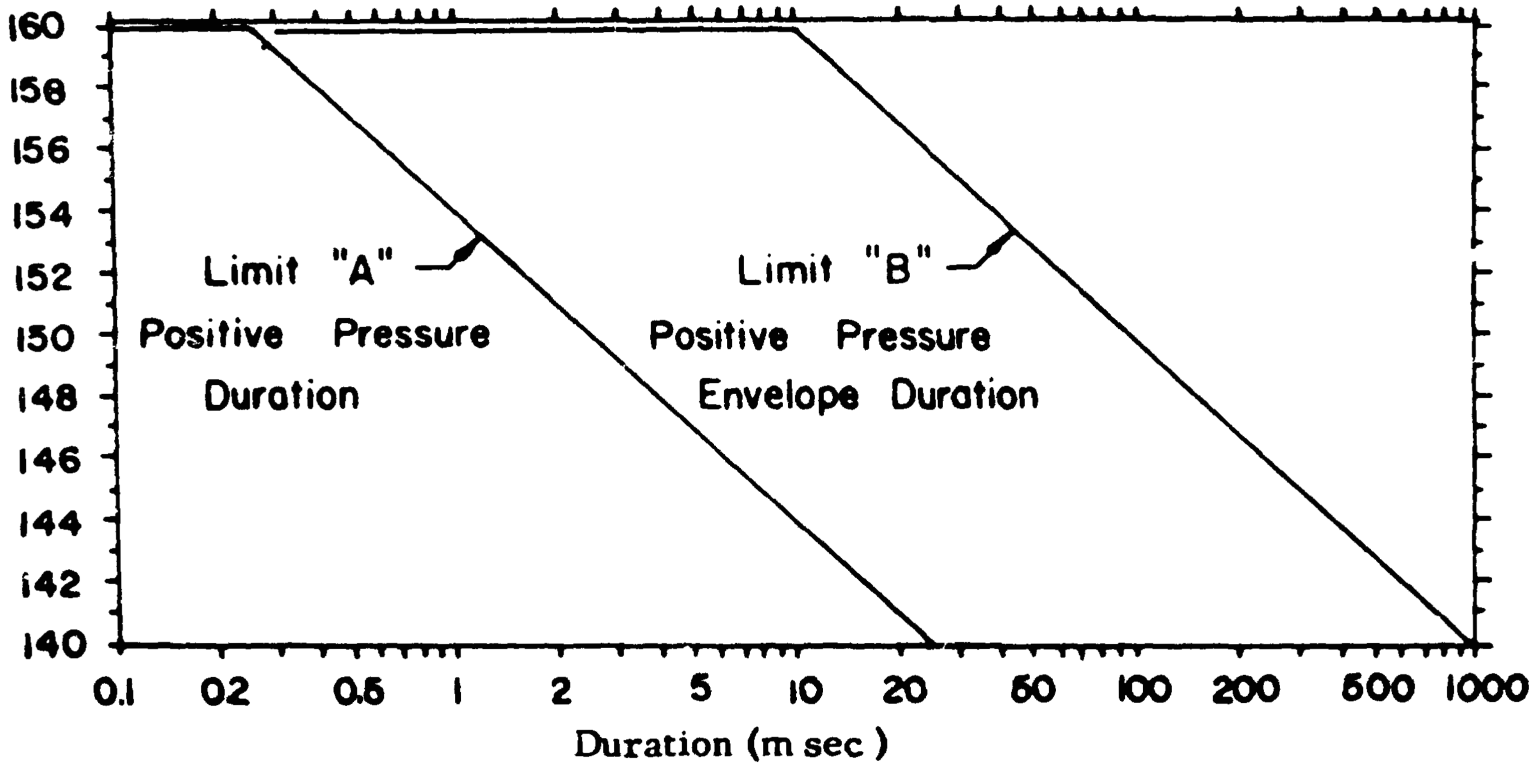
Short Term Damage Risk Criteria (Wide Bank Noise)



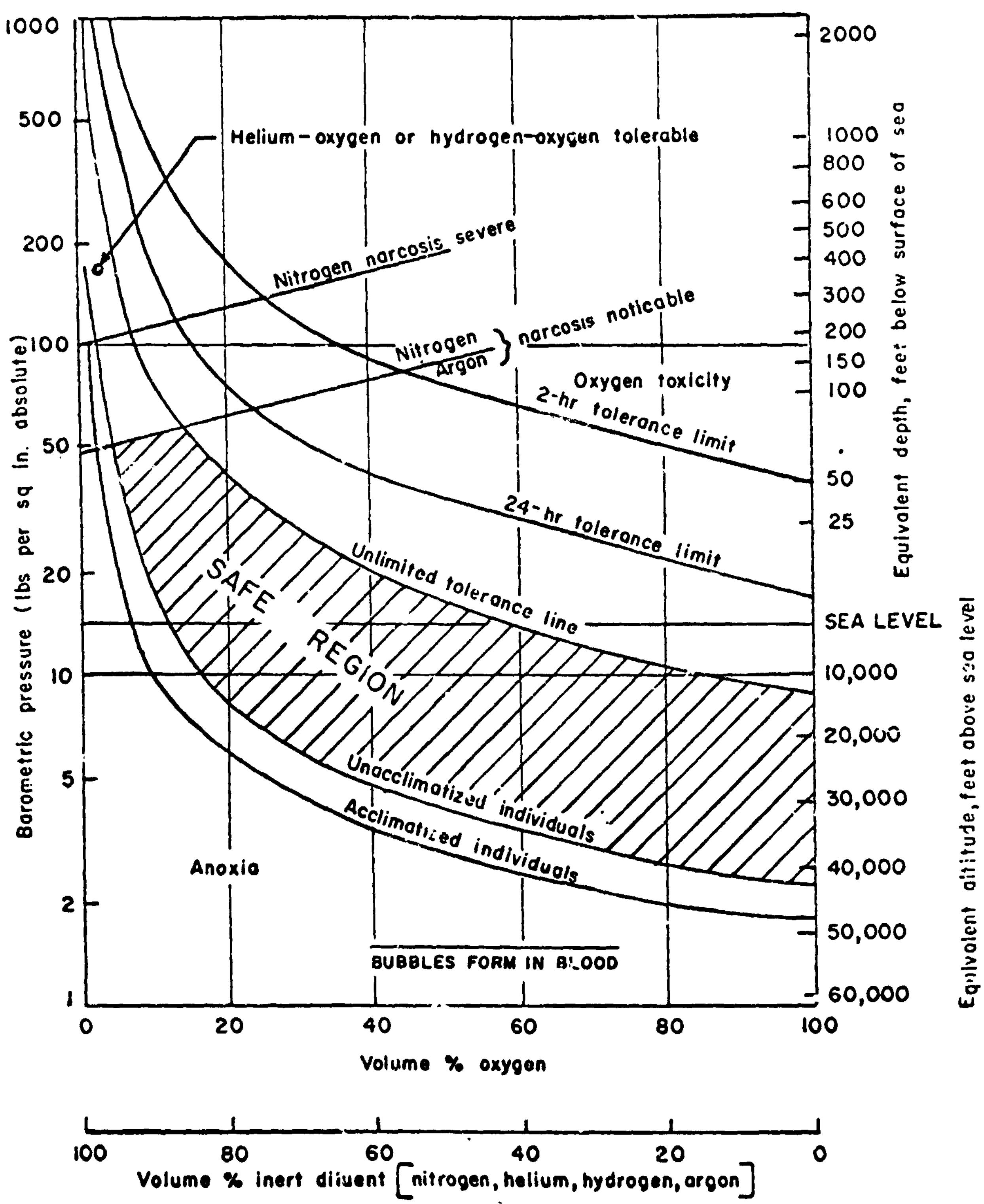
Damage Risk Contours



DAMAGE RISK CONTOURS FOR ONE EXPOSURE PER DAY TO CERTAIN OCTAVE (LEFT-HAND ORDINATE) AND CERTAIN ONE-THIRD OCTAVE OR NARROWER (RIGHT-HAND ORDINATE) BANDS OF NOISE. THIS DESIGN NOTE CAN BE APPLIED TO INDIVIDUAL BAND LEVELS PRESENT IN BROAD BAND NOISE.

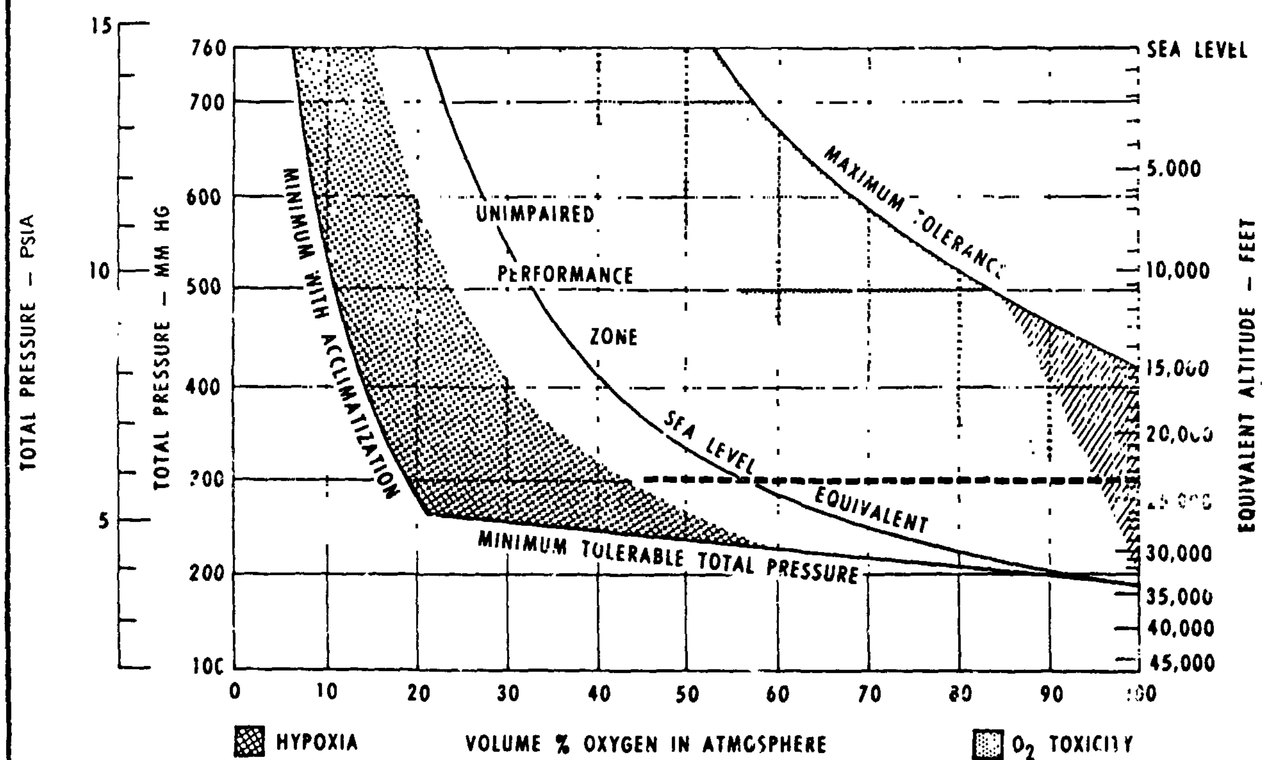


MAXIMUM ACCEPTABLE IMPULSE NOISE PARAMETERS
FOR ARMY MATERIEL COMMAND SMALL ARMS



HUMAN TOLERANCES - ATMOSPHERIC COMPOSITION AND PRESSURE

Oxygen-Pressure Effects



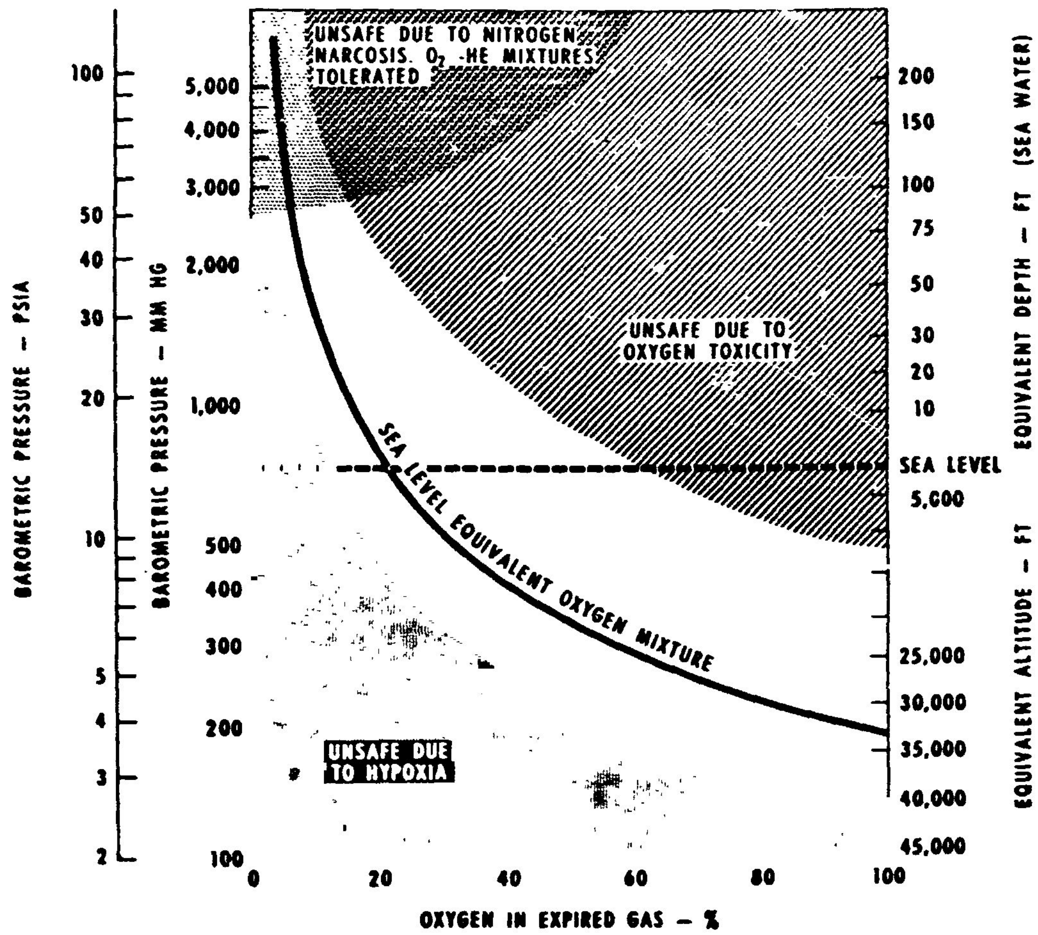
THE PHYSIOLOGICAL RELATIONS BETWEEN THE PERCENTAGE OF OXYGEN IN THE ATMOSPHERE OF AN AEROSPACE VEHICLE AND THE TOTAL PRESSURE OF THAT ATMOSPHERE SHOWN HERE ARE BASED ON CONTINUOUS EXPOSURE FOR ONE WEEK OR MORE. ATMOSPHERIC AIR CONTAINS 21% OXYGEN BY VOLUME. AT SEA LEVEL, THIS LEADS TO A BLOOD SATURATION OF 95%. TO MAINTAIN THE SAME DEGREE OF OXYGEN IN THE BLOOD AT LOWER PRESSURE, THE PERCENTAGE OF OXYGEN IN THE ATMOSPHERE MUST INCREASE AS SHOWN BY THE "SEA LEVEL EQUIVALENT" CURVE. THE UNIMPAIRED PERFORMANCE ZONE, BOUNDED BY THE HEAVY LINE, INDICATES THE RANGE OF VARIATION THAT CAN BE TOLERATED WITHOUT PERFORMANCE DECREMENT.

THE MAXIMUM OXYGEN TOLERANCE (DEFINITE PATHOLOGY) FOR LONG PERIODS IS CURRENTLY UNDER INVESTIGATION. THE ROLE OF NITROGEN AND TRACE CONTAMINANTS ON THE SYMPTOMS OF OXYGEN TOXICITY IN THE 90–100% OXYGEN RANGE IS STILL OPEN TO QUESTION, AS SHOWN BY THE HATCHED AREA.

PROLONGED EXPOSURE TO LOW OXYGEN LEVELS LYING TO THE LEFT OF THE UNIMPAIRED PERFORMANCE ZONE REQUIRES ACCLIMATIZATION. ACCLIMATIZATION IS ACCOMPLISHED BY CONTINUOUS EXPOSURE TO SUCCESSIVELY LOWER PRESSURES WITH NO INTERMEDIATE RETURN TO HIGHER PRESSURES. ACCLIMATIZATION TO 25,000 FT REQUIRED 4–6 WEEKS. AS SHOWN, PERFORMANCE IS STILL IMPAIRED.

THE MINIMUM TOLERABLE TOTAL PRESSURE IS BASED UPON THE EFFECTIVE PARTIAL PRESSURE OF OXYGEN, DISREGARDING AEROEMBOLISM, WHICH MAY OCCUR BELOW 300 MM HG TOTAL PRESSURE IN THE ABSENCE OF ADEQUATE DENITROGENATION. THIS AEROEMBOLISM LIMITATION IS SHOWN BY THE INTERRUPTED HORIZONTAL LINE.

Barometric Pressure Limits



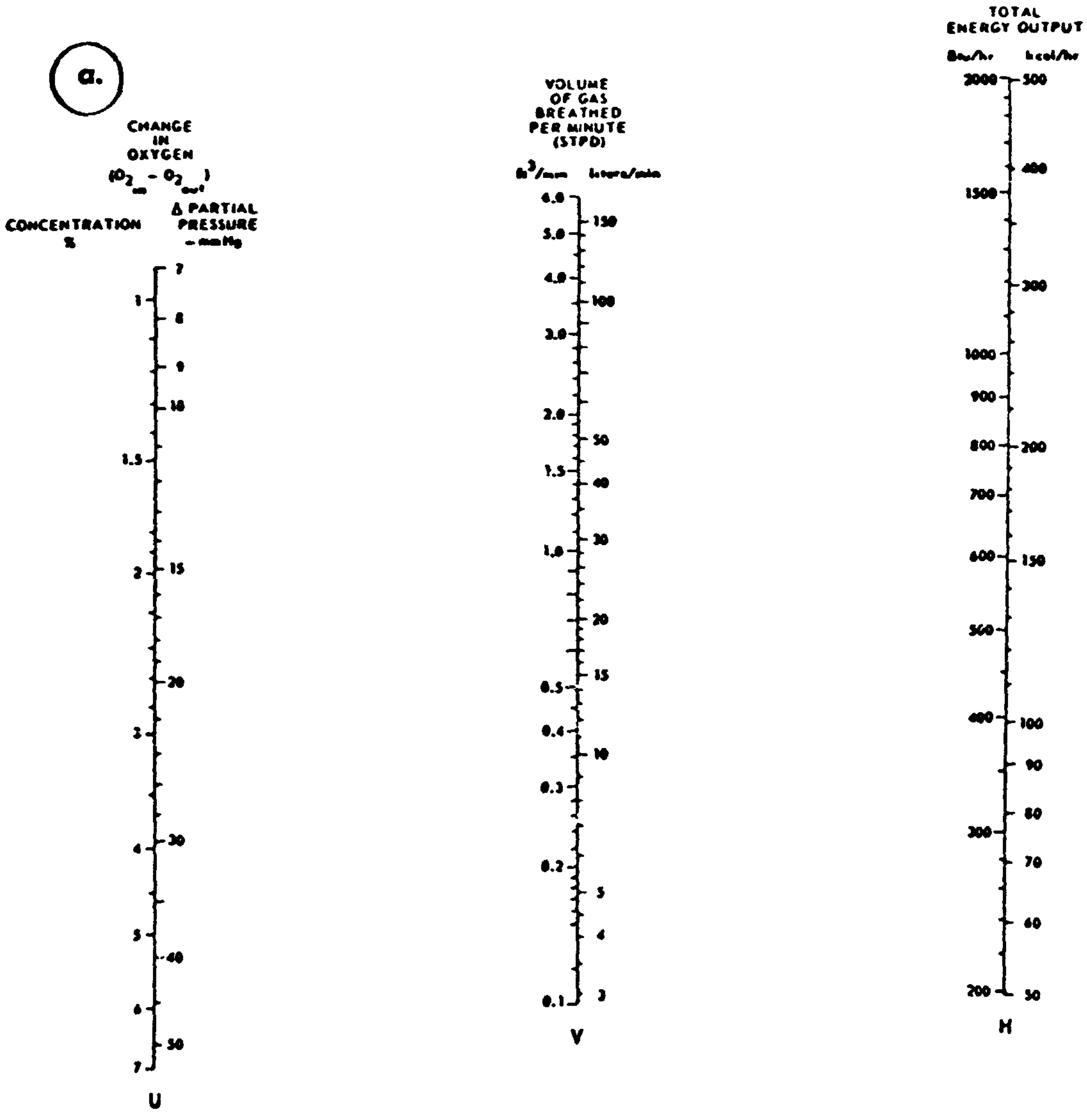
SHOWN HERE IS THE APPROXIMATE RANGE OF BAROMETRIC PRESSURES ABOVE AND BELOW ONE ATMOSPHERE (MEAN SEA LEVEL PRESSURE, 14.7 PSIA OR 760 MM HG) THAT CAN BE TOLERATED BY A HUMAN BEING BREATHING GAS MIXTURES CONTAINING THE INDICATED PROPORTIONS OF OXYGEN. THE HEAVY LINE INDICATES THE GAS MIXTURE THAT WILL MAINTAIN A SEA-LEVEL EQUIVALENT OXYGEN PARTIAL PRESSURE IN THE LUNGS AT VARIOUS BAROMETRIC PRESSURES.

ALTHOUGH PHYSIOLOGICAL STUDIES OF PRESSURE EFFECTS HAVE BEEN CONDUCTED FOR MANY DECADES, MANY FACETS OF THE PROBLEM HAVE NOT BEEN ADEQUATELY EXPLORED. IT IS KNOWN THAT IF MAN IS SUPPLIED WITH AN APPROPRIATE GAS MIXTURE, HE CAN SURVIVE CONSIDERABLE PERIODS OF EXPOSURE TO A WIDE RANGE OF BAROMETRIC PRESSURES. MAN'S ULTIMATE TOLERANCE LIMITS FOR HIGH AND LOW BAROMETRIC PRESSURES ARE NOT YET KNOWN. LIKEWISE IT IS NOT KNOWN WHETHER THE NECESSARY GAS MIXTURES FOR SUCH EXPOSURES ARE IN THEMSELVES TOXIC. THIS IS PARTICULARLY IMPORTANT WHEN MAN IS REQUIRED TO BREATH 100% OXYGEN FOR CONSIDERABLE PERIODS.

O

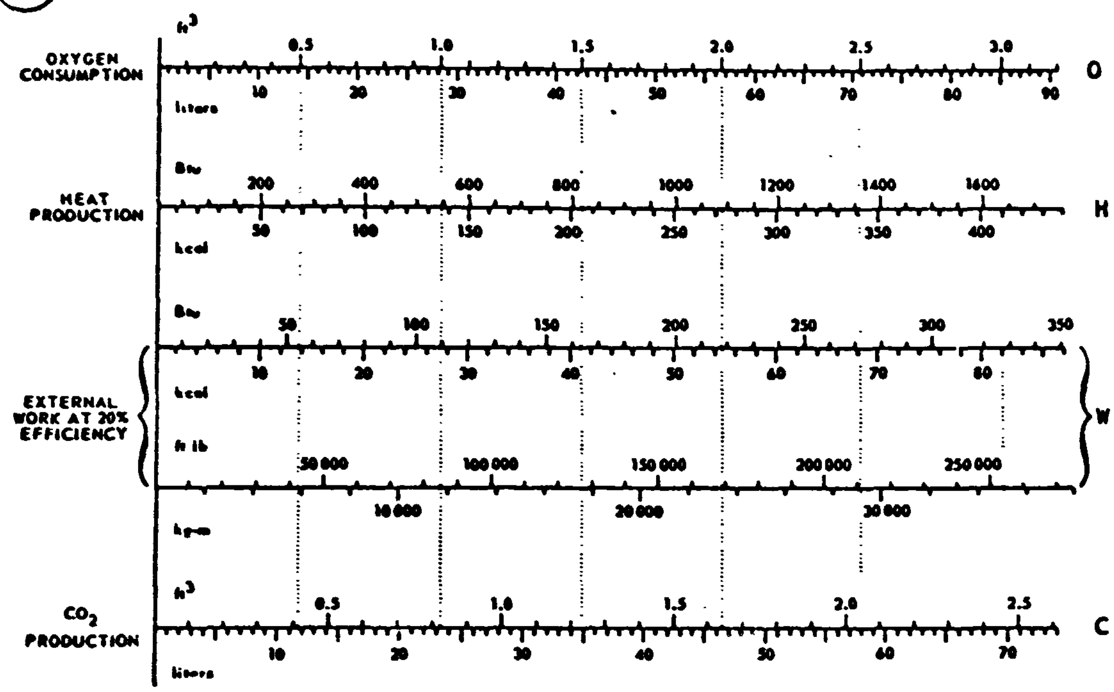
Oxygen Costs - Nomograms

Heat output is determined from respiratory data in the following way. First, the oxygen consumption is calculated from the respiratory ventilation volume of the subject and the difference in oxygen concentration between the inspired and expired air. Second, the volume is corrected to 0°C, 760 mm Hg, dry (STPD); this is particularly important at reduced atmospheric pressures. Third, the heat output corresponding to each unit volume of oxygen is selected, either by approximation or from a knowledge of the subject's diet or from his measured respiratory quotient. For simplicity in calculation, the following two nomograms have been constructed.

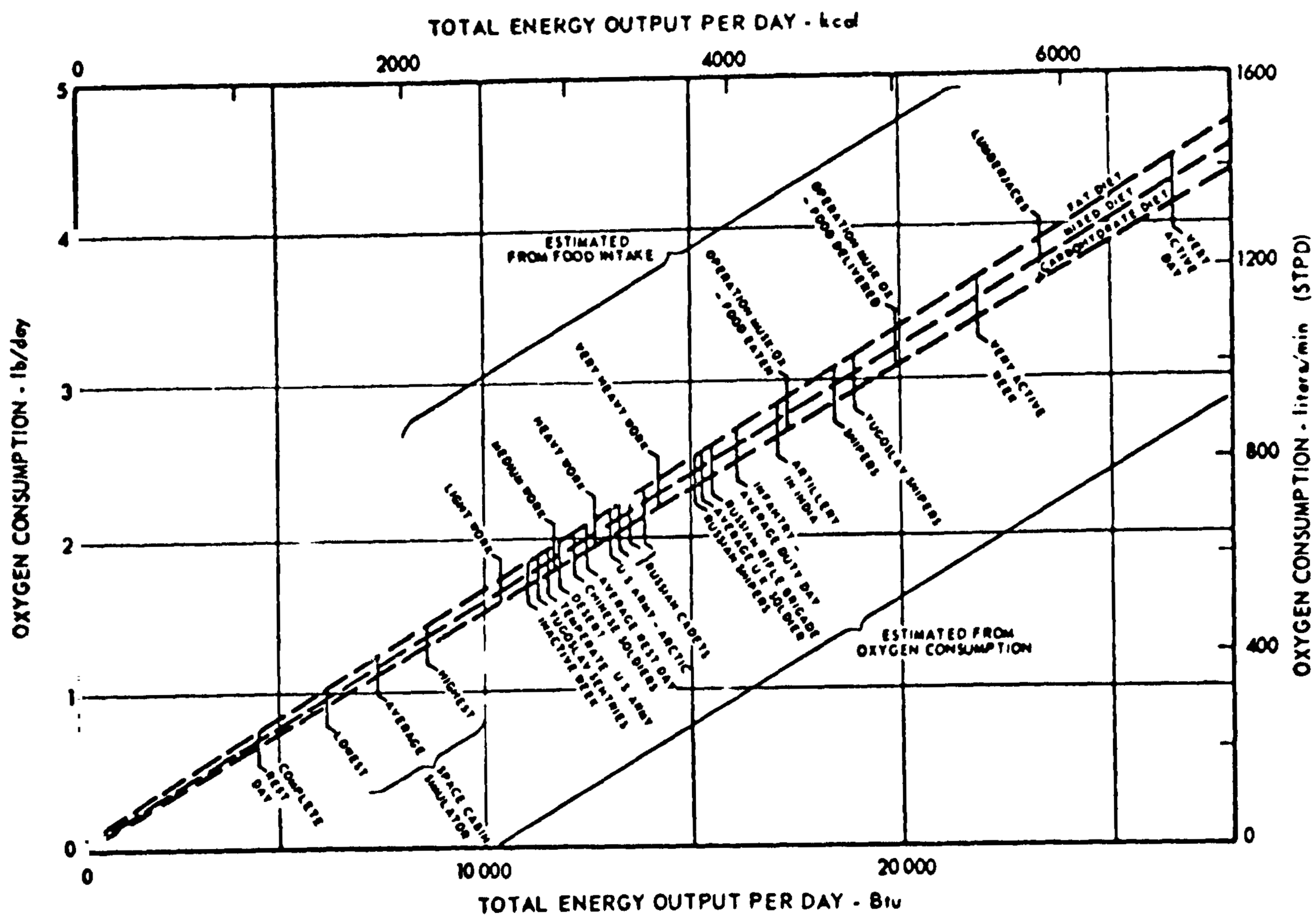


Nomogram a uses the standard values: RQ = 1.00 and 1 liter of oxygen is equivalent to 5.0 kcal. It permits direction calculation of heat output (H) in Btu/hr from oxygen uptake (U) and ventilation rate (V). Alternatively, U can be calculated from H and V, or V from U and H.

b.



Nomogram b uses the standard values: RQ = 0.82 and 1 liter of oxygen is equivalent to 4.825 kcal. This nomogram allows one to interrelate, by drawing straight vertical lines, the values for oxygen consumption (O), heat output (H), external work output (W), and carbon dioxide production (C), at typical conversion rates. Note that H may be as much as 3% lower or 5% higher than the quoted value at any specific oxygen consumption, depending on the RQ, which equals 0.7 for a pure fat diet and 1.00 for a pure carbohydrate diet. Values given in the third and fourth lines have to be modified if the efficiency changes. Typical ranges are 5 to 25%, average 20%, so that the listed work output may increase by three-quarters if the task is one that can be performed at high efficiency (e.g., bicycling). Conversely, the true value may be reduced by three-quarters if the function is inefficiently performed, e.g., high speed walking.



This chart contains data on the total daily energy exchanges of adults. Vertical axes give total oxygen consumption. Horizontal axes give total energy output.

Classification of Physical Work by its Severity

	lb O_2/hr	kcal/min	Btu/hr
Very Light work	below 0.10	below 2.5	below 595
Light work	0.10 - 0.18	2.5 - 5.0	595 - 1190
Moderate work	0.18 - 0.28	5.0 - 7.5	1190 - 1785
Heavy work	0.28 - 0.38	7.5 - 10.0	1785 - 2380
Very heavy work	0.38 - 0.47	10.0 - 12.5	2380 - 2975
Unduly heavy work	over 0.47	over 12.5	over 2975

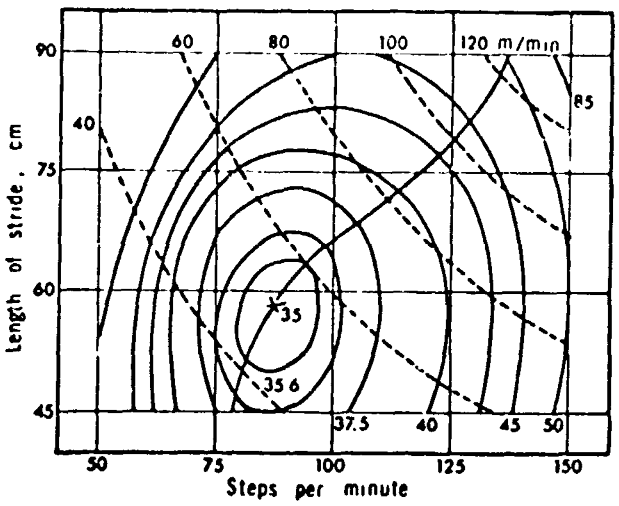
Oxygen Costs of Special Activities

SPECIAL ACTIVITIES

		Typical values for		
Engineering tasks		lb O_2/hr	kcal/min	Btu/hr
Medium assembly work		0.11	2.9	680
Welding		0.12	3.0	720
Sheet metal work		0.12	3.1	760
Machining		0.13	3.3	800
Punching		0.14	3.5	840
Machine fitting		0.17	4.5	1060
Heavy assembly work--noncontinuous		0.20	5.1	1210
Driving vehicles and piloting aircraft				
Driving a car in light traffic		0.05	1.3	300
Night flying--DC-3		0.06	1.6	380
Piloting DC-3 in level flight		0.07	1.7	400
Instrument landing--DC-4		0.10	2.5	590
Piloting light aircraft in rough air		0.11	2.7	640
Taxi-ing--DC-3		0.11	2.9	680
Piloting bomber aircraft in combat		0.12	2.9	700
Driving car in heavy traffic		0.12	3.2	760
Driving truck		0.13	3.3	790
Driving motorcycle		0.14	3.5	840
Moving over rough terrain on foot				
Flat firm road	2.5 mph	0.11-0.19	2.8-4.9	660-1140
Grass path	2.5	0.13-0.20	3.2-5.1	760-1240
Stubble field	2.5	0.16-0.23	4.0-6.1	960-1440
Deeply plowed field	2.0	0.19-0.27	4.9-6.9	1160-1640
Steep 45° slope	1.5	0.19-0.27	4.9-6.9	1160-1640
Plowed field	3.3	0.30	7.8	1850
Soft snow, with 44 lb load	2.5	0.79	21.0	4880

SPECIAL ACTIVITIES (continued)

			Typical values for		
			$lb\ O_2/hr$	kcal/min	Btu/hr
Load carrying					
Walking on level with 58 lb load, trained men	2.1 mph		0.07	1.9	45.
	2.7		0.11	2.9	690
	3.4		0.18	4.6	1100
	4.1		0.32	8.3	1980
Walking on level with 67 lb load, trained men	2.1		0.09	2.3	550
	2.7		0.11	2.9	690
	3.4		0.20	5.1	1210
	4.1		0.33	8.4	2000
Walking on level with 75 lb load, trained men	2.1		0.10	2.5	600
	2.7		0.13	3.4	810
	3.4		0.20	5.2	1240
	4.1		0.34	8.6	2100
Walking up 36% grade with 43 lb load, sedentary men	0.5		0.26	6.7	1590
	1.0		0.47	12.3	2910
	1.5		0.62	16.0	3800
Swimming on surface					
Breast stroke	1 mph		0.27	7.0	1650
	2		1.13	29.0	6900
	3		3.78	97.0	23100
Crawl	1		0.35	9.0	2150
	2		0.70	18.0	4200
	3		1.87	48.0	11400
Butterfly	1		0.47	12.0	2900
	2		1.13	29.0	6900
	3		2.92	75.0	17850
Walking under water					
Walking in tank	minimal rate		0.11	2.9	700
Walking on muddy bottom	minimal rate		0.21	5.5	1300
Walking in tank	maximal rate		0.28	7.2	1700
Walking on muddy bottom	maximal rate		0.33	8.4	2000
Movement in snow					
Skiing in loose snow	2.6 mph		0.32	8.1	1930
Sled pulling--low drag, hard snow	2.2		0.34	8.6	2020
Snowshoeing--bearpaw type	2.5		0.34	8.7	2070
Skiing on level	3.0		0.35	9.0	2140
Sled pulling--low drag, medium snow	2.0		0.38	9.7	2310
Snowshoeing--trail type	2.5		0.40	10.3	2460
Walking, 12-18" snow, breakable crust	2.5		0.50	12.7	3010
Skiing on loose snow	5.2		0.52	14.6	3800
Snowshoeing--trail type	3.5		0.59	14.8	4200
Skiing on loose snow	8.1		0.80	20.6	4900
Measured work at different altitudes					
Bicycle ergometer	430 kg-m/min	720 mm Hg	0.20	5.1	1230
	430	620	0.19	4.9	1170
	430	520	0.21	5.4	1290
Mountain climbing	880-1037 kg-m/min	610 mm Hg	0.36-0.43	9.2-11.0	2200-2640
	566- 786	425	0.30-0.37	7.7- 9.5	1840-2260
	393- 580	370	0.25-0.41	6.4-10.5	1530-2520



Caloric Consumption as a Function of Length of Stride and Cadence

Dashed lines represent speeds in m/min; thin solid lines (contour lines), caloric consumption; heavy solid line, optimal combinations of cadence and length of stride for various speeds *

Energy Cost and Strain of Walking with Loads on Sand Dunes (1G)

Activity	Mean kcal/m²/hr for —			
	No load	25 lb	30 lb	40 lb
Treadmill	131	144	–	150
Level sand surface	212.2	242.6	248.5	269.6
Level hard surface	145.2	155.7	161.4	166.2
Up sand-dune slopes (2.0-2.5 mph)	282.9	333.2	320.2	346.1
Down sand-dune slopes	186.2	205.0	216.0	231.5

a. Energy Cost of Walking and Carrying Pack Loads

(Speed = 2.5 mph; figures are average of four trials on each of four subjects.)

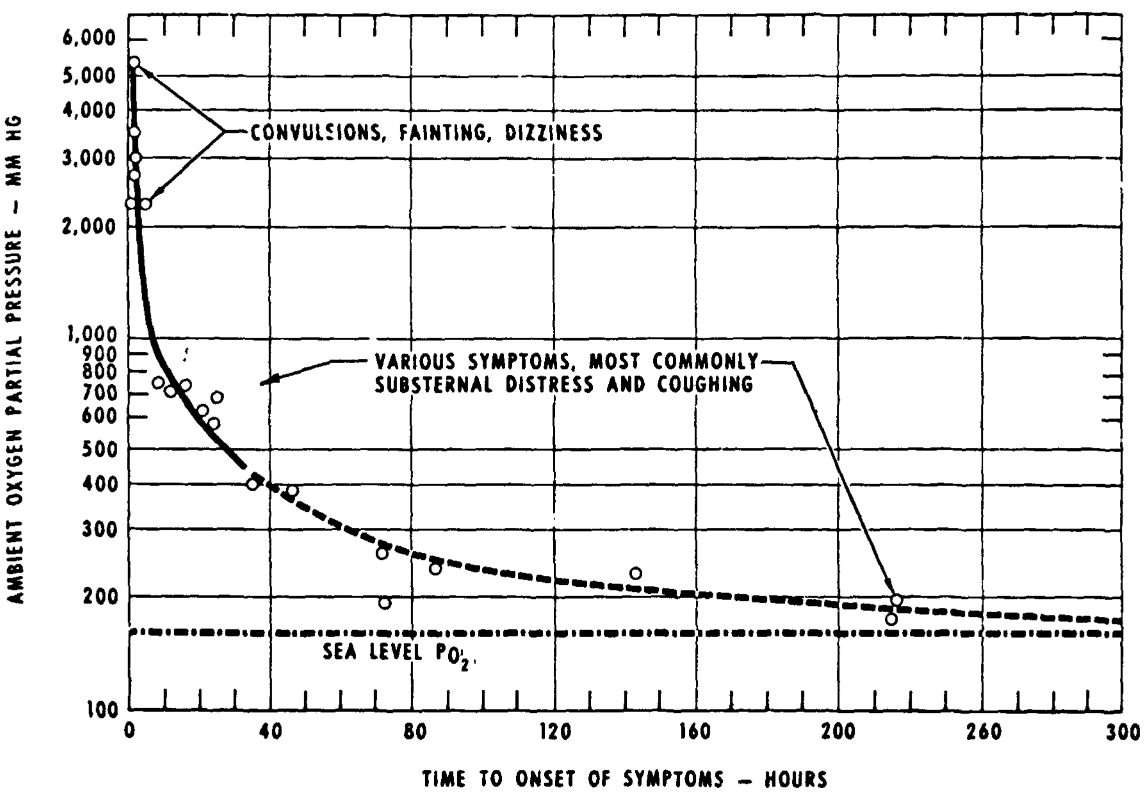
Activity	Mean kcal/m²/200 yd for—			
	No load	25 lb	30 lb	40 lb
Level sand	9.13	10 58	10 83	11 34
Up sand dunes (11-12% grade)	13 30	15 74	17.00	16 44

b. Comparative Energy Expenditure While Walking on Level Sand and Climbing Sand Dunes, Carrying Various Packboard Loads

Load	Mean final rectal temp., °F		Mean final pulse rate, beats/min	
	Level sand surface	Level hard surface	Level sand surface	Level hard surface
No load	100.8	100.0	126.9	101.4
25 lb	101.1	100.1	139.2	107.7
30 lb	101.3	100.2	146.3	113.3
40 lb	101.6	100.3	160.4	128.7

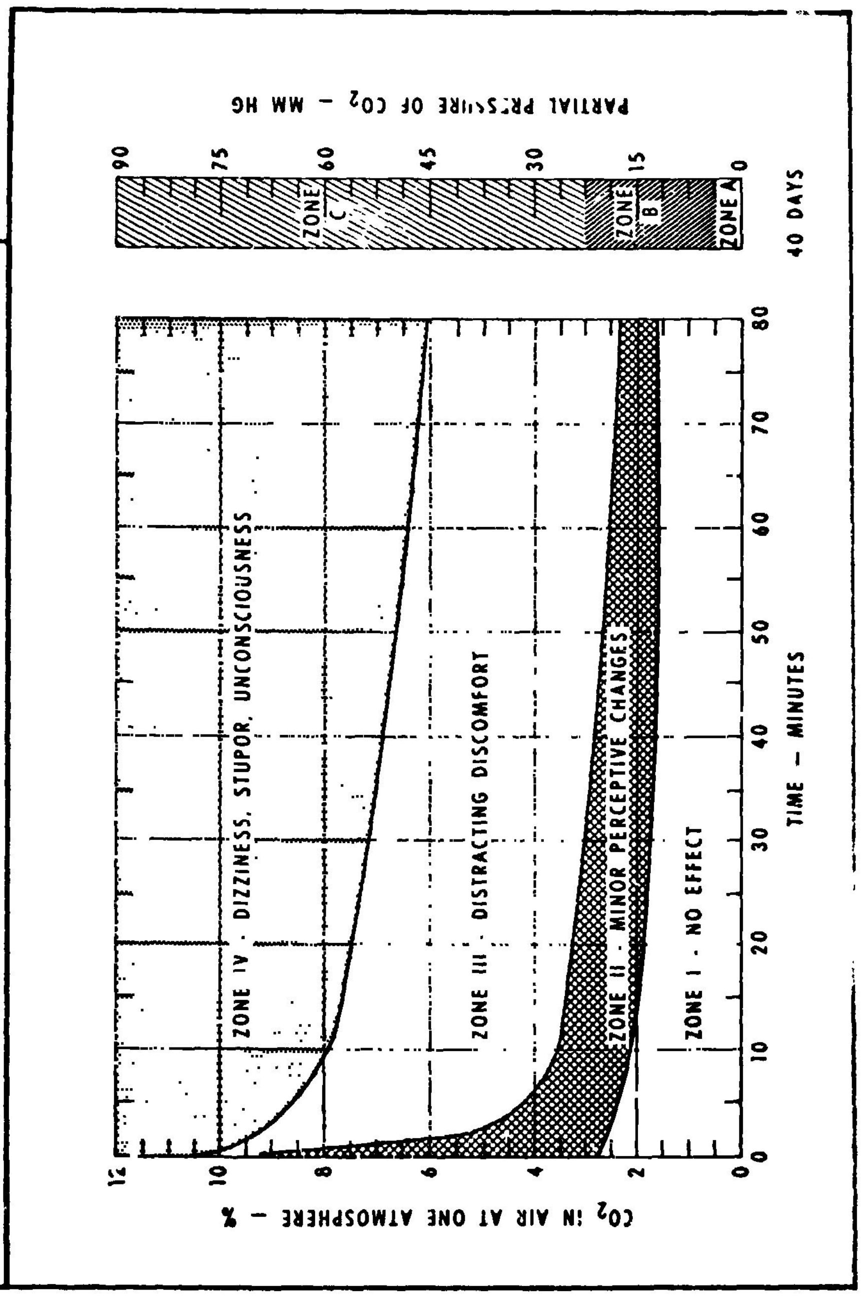
c. Strain of Walking on Sand with Various Packloads

Oxygen Toxicity



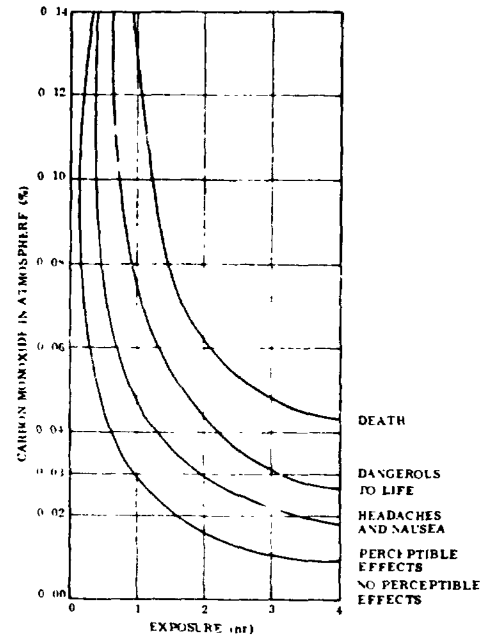
THE CURVE REPRESENTS THE APPROXIMATE TIME OF APPEARANCE OF TOXIC SIGNS AND SYMPTOMS. THESE VARY WITH THE PARTIAL PRESSURES OF O_2 (PO_2) WHICH CAUSE THEM. ABOVE 760 MM HG, THE CENTRAL NERVOUS SYSTEM IS THE PRIMARY SITE OF DEFECT WITH SYMPTOMS SUCH AS NAUSEA, DIZZINESS, CONVULSIONS, AND SYNCOPE. IN THE RANGE OF 400 TO 760 MM HG, RESPIRATORY AND NERVOUS SYSTEM SYMPTOMS PREDOMINATE. THESE ARE SUBSTERNAL DISTRESS (BRONCHITIS AND PROBABLY ATELECTASIS), PARESTHESIA, AND NAUSEA. IN THE RANGE OF 200–400 MM HG, REPORTED SYMPTOMS ARE RESPIRATORY AND POSSIBLY HEMATOLOGICAL AND RENAL: SUBSTERNAL DISTRESS, PROTEIN, AND CYLINDRICAL CASTS IN THE URINE. WHETHER OR NOT THERE IS REALLY "TOXICITY" IN THE LOW LEVEL, LONG TIME EXPOSURE IS BEING DEBATED. STUDIES IN PROGRESS MAY CLARIFY THE EXACT CAUSE OF SYMPTOMS AND LABORATORY FINDINGS IN THIS LOWER RANGE. THE ROLE OF CONTAMINATING GASES (N_2) AND TRACE VAPOR CONTAMINANTS IN THE OXYGEN IS STILL UNKNOWN.

Carbon Dioxide Effects



Effects of Various Concentrations of Carbon Monoxide in Air at Sea Level

PERCENT OF CO IN AIR	EFFECTS
1.28	Immediate effect, unconsciousness and danger of death in 1–3 min
0.64	Headache and dizziness in 1–2 min; unconsciousness and danger of death in 10–15 min
0.32	Headache and dizziness in 5–10 min; unconsciousness and danger of death in 30 min
0.16	Headache, dizziness and nausea in 20 min; collapse, unconsciousness, possibly death in 2 hr
0.08	Headache, dizziness and nausea in 3/4 hr; collapse possibly unconsciousness in 2 hr
0.04	Frontal headache and nausea after 1–2 hr; occipital after 2-1/2 to 3-1/2 hr
0.02	Possible mild frontal headache in 2–3 hr



EFFECTS OF CARBON MONOXIDE FOR A GIVEN TIME ON MAN

Common Sources and Maximum Allowable Concentrations of Some Toxic Agents

COMMON SOURCE	TOXIC AGENT	MAXIMUM ALLOWABLE CONCEN-TRATION (PPM)
FUELS AND PROPELLANTS	AMMONIA	100
	ANILINE	5
	ETHYL ALCOHOL	1,000
	GASOLINE	250
	KEROSENE	500
	METHYL ALCOHOL	200
	NITROGEN TETROXIDE	5
ENGINE EXHAUSTS (INCLUDING ROCKET ENGINES)	ALDEHYDES:	
	ACETALDEHYDE	200
	ACROLEIN	0.5
	FORMALDEHYDE	5
	FURFURAL	5
	CARBON DIOXIDE	5,000
	CARBON MONOXIDE	100
	BROMINE	1
	NITROGEN DIOXIDE	5
	SULFUR DIOXIDE	5
HYDRAULIC FLUIDS	BUTYL CELLOSOLVE	50
	DIACETONE	50
	ARYL PHOSPHATES	0.06
	DIOXANE ALCOHOL	100
FIRE EXTINGUISHANTS	CARBON DIOXIDE	5,000
	CARBON TETRACHLORIDE	25
	CHLOROBROMETHANE	400
	METHYL BROMIDE	20
OIL SPRAYS AND FUMES	ALDEHYDES: (SEE ABOVE)	
REFRIGERANTS	CARBON DIOXIDE	5,000
	FREON	1,000
	METHYL BROMIDE	20
	SULFUR DIOXIDE	5
SMOKE	PHOSGENE (PLUS SAME AS FOR ENGINE EXHAUSTS)	1

Gas-Off Products of Cabin Materials

TYPE OF MATERIAL	NUMBER OF GAS-OFF PRODUCTS SEPARATED	HIGHEST CONCENTRATION*
Urethane Foam	3	7.5
Thermoplastic (Unidentified)	4	32.0
Teflon Bar	5	21.0
Nylon Tying Cord	7	100.0
Thermosetting Plastic Diallyl Phthalate	4	102.0
Thermosetting Plastic Phenolic	4	46.0
Fluorinated Rubber	7	100.0
Felt	2	45.0
Primer Coating Gray Vinyl	15	1650.0
Electrical Paper Tape	10	1620.0
Teflon Tubing	2	40.0
Orlon	7	4.0
Gray Enamel, Wrinkle	14	63.0
Magnet Wire	5	25.0
Cellulose Acetate	6	20.0
Plexiglass	2	9.0
Anti-seize Compound	5	Off scale
Screening Ink	16	2200.0
Fairprene Rubber-Buna	7	41.0
Fairprene Rubber-Viton	5	59.0
Thermoplastic Polyester Film	2	10.0
Silver Print Conductive Coating	6	620.0
Epoxy Potting and Sealing Compound	9	33.0
Epoxy Amine Urethane Potting Compound	9	[illegible]1.0
Plexiglass, acrylic	11	37.0
Sealing Compound, silicon rubber	7	3700.0
Epoxy Amine Adhesive	5	7.0
Tygon Tubing	14	Off scale
Lubricant (Unidentified)	12	130.0
Thermosetting Diallyl phthalate	7	7040.0
Adhesive Conductive Epoxy	2	55.0
Enamel Brown Epoxy 2-compound atmosphere	13	4200.0
Enamel Brown Epoxy 1-compound atmosphere	9	3800.0
Buna-U-Rubber	13	2300.0
Heat Exchanger (Unidentified)	6	290.0
Thermoplastic (Unidentified)	7	43.0
Thermoplastic Poly-Fluoro-chloro	4	3.0
Thermoplastic Polystyrene	8	110.0
Fiberglass Shredded	[illegible]	67.0
Resin (Unidentified)	20	600.0
Resin Polycarbamate	7	Off scale
Silicone Cement	5	

Concentrations expressed in equivalent area under [illegible]

Chemical Contaminants in Sealed Atmospheres

Acetaldehyde*	n-Hexane*
Acetone*	Hydrocarbons
Acetylene***	(Other than methane)**
Acrolein**	Hydrogen**
Ammonia**	HCl**
Arsine**	HF**
Benzene*	Mercury**
n-Butane*	Methane**
Butene-1*	Methylalcohol***
Cis-butene-1*	Methylchloroform*
Trans-butene-2*	Methylene chloride*
n-Butyl alcohol*	Methylethylketone*
CO_2***	3-methylpentane*
CO**	Methylisopropylketone*
Chlorine**	Monoethanolamine**
Cyclohexane*	NO_2**
2,2-dimethylbutane*	NO**
1,4-dioxane*	O_3**
Dioxene*	Phosgene**
Ethylacetate*	Isopentane*
Ethyl alcohol*	n-Pentane*
Ethylene***	Propane*
Ethylene dichloride*	n-Propylalcohol*
Freon-11*	Propylene*
Freon-12***	SO_2**
Freon-22*	Stibine**
Freon-23*	Toluene*
Freon-114*	Triarylphosphate**
Freon-114,unsym*	Trichloroethylene*
Freon-125*	Vinylchloride*
Hexamethylcyclotrisiloxane*	Vinylidene chloride*
	n-Xylene*
Hexane*	o-Xylene*
Formaldehyde***	

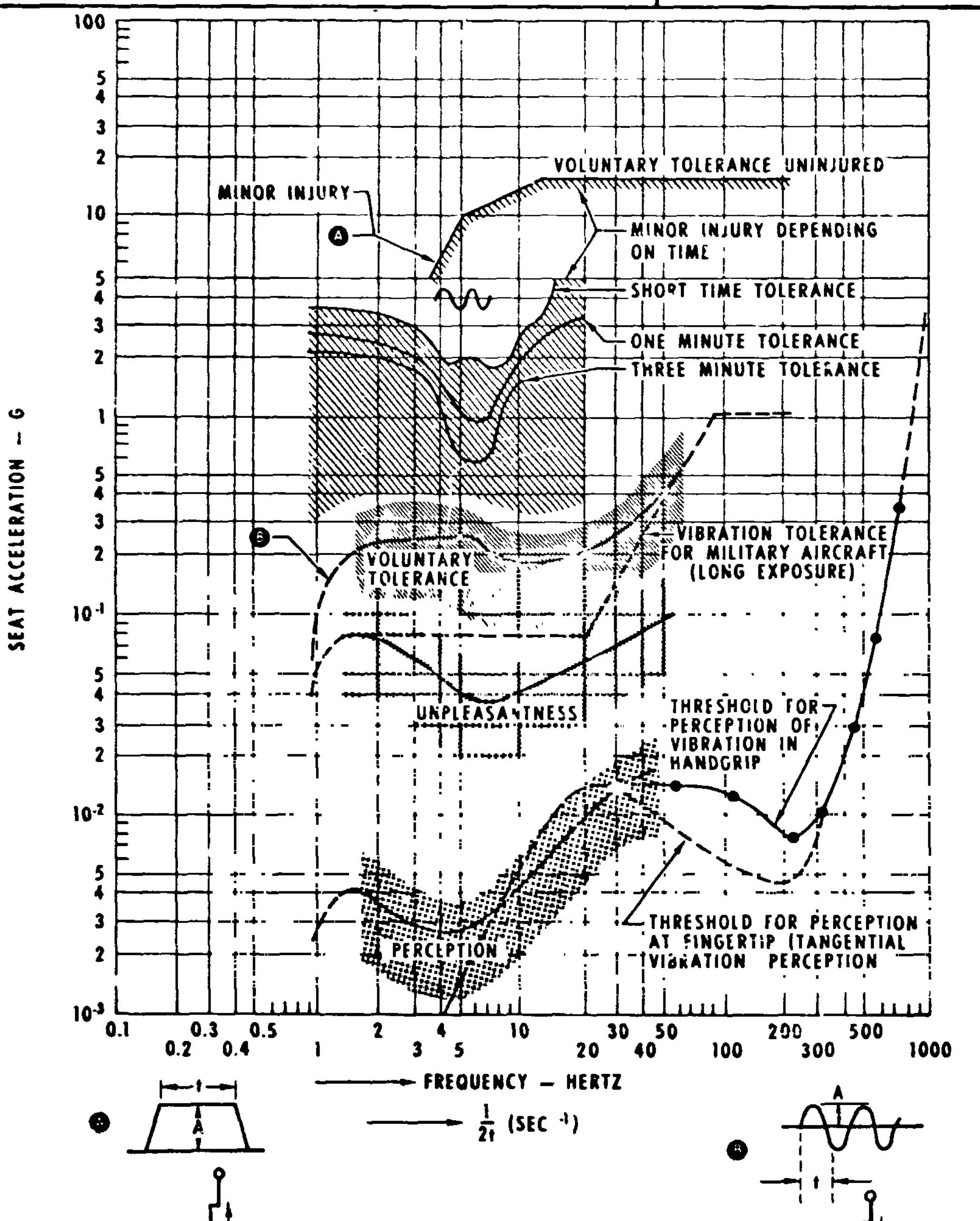
* Mercury spacecraft
** Nuclear submarines
*** Both

90-Day Continuous Tolerance Limits

90-day continuous tolerance limits for submarine atmospheres on the following contaminants have been proposed by the Advisory Center on Toxicology, National Academy of Sciences:

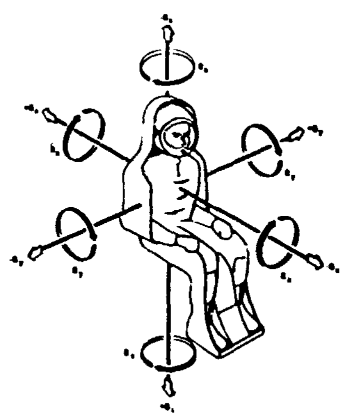
Acetylene	Chlorine	Mercury	Ozone
Arsine	Freon 12	Methane	Phosgene
Ammonia	Hydrogen	Methyl alcohol	Triarylphosphate
Carbon dioxide	Hydrochloric acid	Monoethanolamine	
Carbon monoxide	Hydrofluoric acid	Nitrogen dioxide	

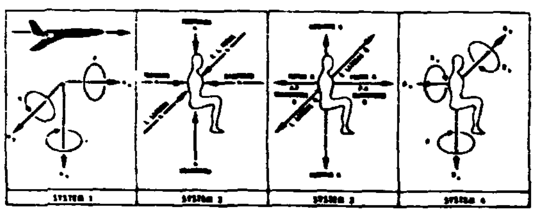
Criteria for Vibration Tolerance



THE FOUR SHADED ZONES REPRESENT: THRESHOLD FOR PERCEPTION; THE UNPLEASANT AREA OF VIBRATION; THE LIMITS OF VOLUNTARY EXPOSURE, UNPROTECTED, FOR 5–20 MINUTES; AND THE VOLUNTARY TOLERANCE LIMITS FOR SUBJECTS WITH LAP BELT AND SHOULDER HARNESS FOR THREE MINUTES, ONE MINUTE, AND LESS THAN ONE MINUTE. ABOVE THIS, MINOR INJURIES OCCUR, DEPENDING ON TIME. AT THE TOP OF THE CHART IS PLOTTED THE LARGE MAGNITUDE. THE CONVENTIONAL WAY OF MEASURING DURATIONS (t) AND AMPLITUDES (A) IS SHOWN IN THE SMALL DIAGRAMS AT THE BOTTOM.

Body Acceleration Comparative Table of Equivalents



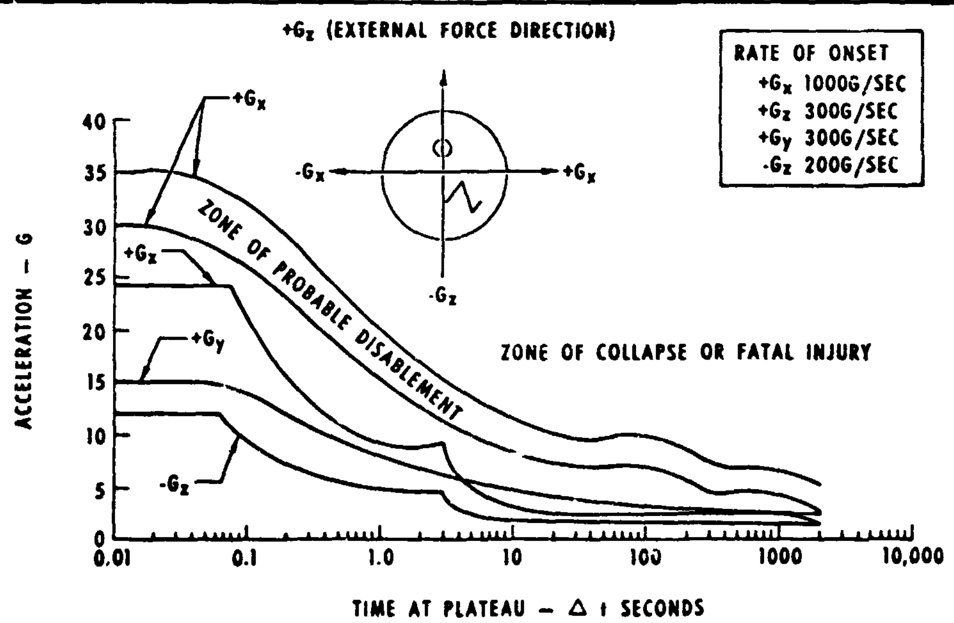


SYMBOLS AND VECTORS USED ARE BASED ON THE DIRECTION A BODY ORGAN (E.G. THE HEART) WOULD BE DISPLACED BY ACCELERATION. TABLE II – AND IN PARTICULAR SYSTEM 4 WHICH IS BASED ON DISPLACEMENT OF BODY FLUIDS – EXPLAINS THE MOST COMMONLY EMPLOYED TERMS

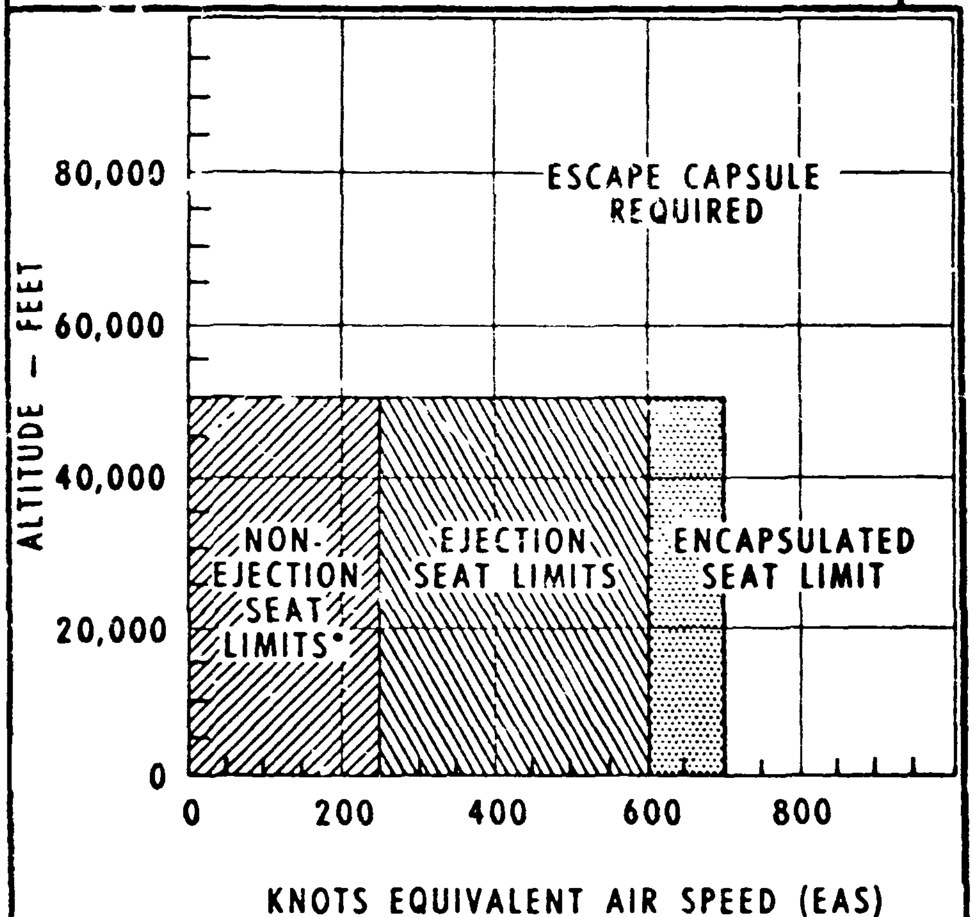
	TABLE I DIRECTION OF ACCELERATION		TABLE II INERTIAL RESULTANT OF BODY ACCELERATION		
	AIRCRAFT VECTOR (SYSTEM 1)	ACCELERATION DESCRIPTIVE (SYSTEM 2)	PHYSIOLOGICAL DESCRIPTIVE (SYSTEM 3)	PHYSIOLOGICAL DISPLACEMENT (SYSTEM 4)	VERNACULAR DESCRIPTIVE SYSTEM 5
LINEAR MOTION					
FORWARD	A_x	FORWARD ACCEL	TRANSVERSE A-P G* SUPINE G CHEST TO BACK G	G_x	EYEBALLS IN
BACKWARD	$-A_x$	BACKWARD ACCEL	TRANSVERSE P-A G PRONE G BACK TO CHEST G	G_x	EYEBALLS OUT
UPWARD	$-A_z$	HEADWARD ACCEL	POSITIVE G	G_z	EYEBALLS DOWN
DOWNWARD	A_z	FOOTWARD ACCEL (TAILWARD)	NEGATIVE G	G_z	EYEBALLS UP
TO RIGHT	A_y	R. LATERAL ACCEL (RIGHTWARD)	LEFT LATERAL G	G_y	EYEBALLS LEFT
TO LEFT	$-A_y$	L. LATERAL ACCEL (LEFTWARD)	RIGHT LATERAL G	G_y	EYEBALLS RIGHT
ANGULAR MOTION					
ROLL RIGHT	[illegible]	CARTWHEEL	ROLL	R_x	
ROLL LEFT	[illegible]	CARTWHEEL		R_x	
PITCH UP	[illegible]	SOMERSAULT	PITCH	$-R_y$	
PITCH DOWN	[illegible]	SOMERSAULT		R_y	
YAW RIGHT	[illegible]	PIROUETTE	YAW	R_z	
YAW LEFT	[illegible]	PIROUETTE		$-R_z$	

* A-P AND P-A REFER TO ANTERIOR-POSTERIOR AND POSTERIOR-ANTERIOR

Acceleration Limits of Human Tolerance



Escape Provision Requirements



*SPECIAL PURPOSE VEHICLES WITH A SPEED LESS THAN 260 EAS BUT WITH AN INHERENTLY HAZARDOUS MISSION PROFILE (STOL, VSTOL, ETC.) MAY REQUIRE AN ASSISTED ESCAPE CAPABILITY. THE DESIGNER MUST GIVE CAREFUL CONSIDERATION TO BOTH SPEED AND MISSION REQUIREMENTS BEFORE SELECTING MANUAL OVER ASSISTED ESCAPE SYSTEMS.

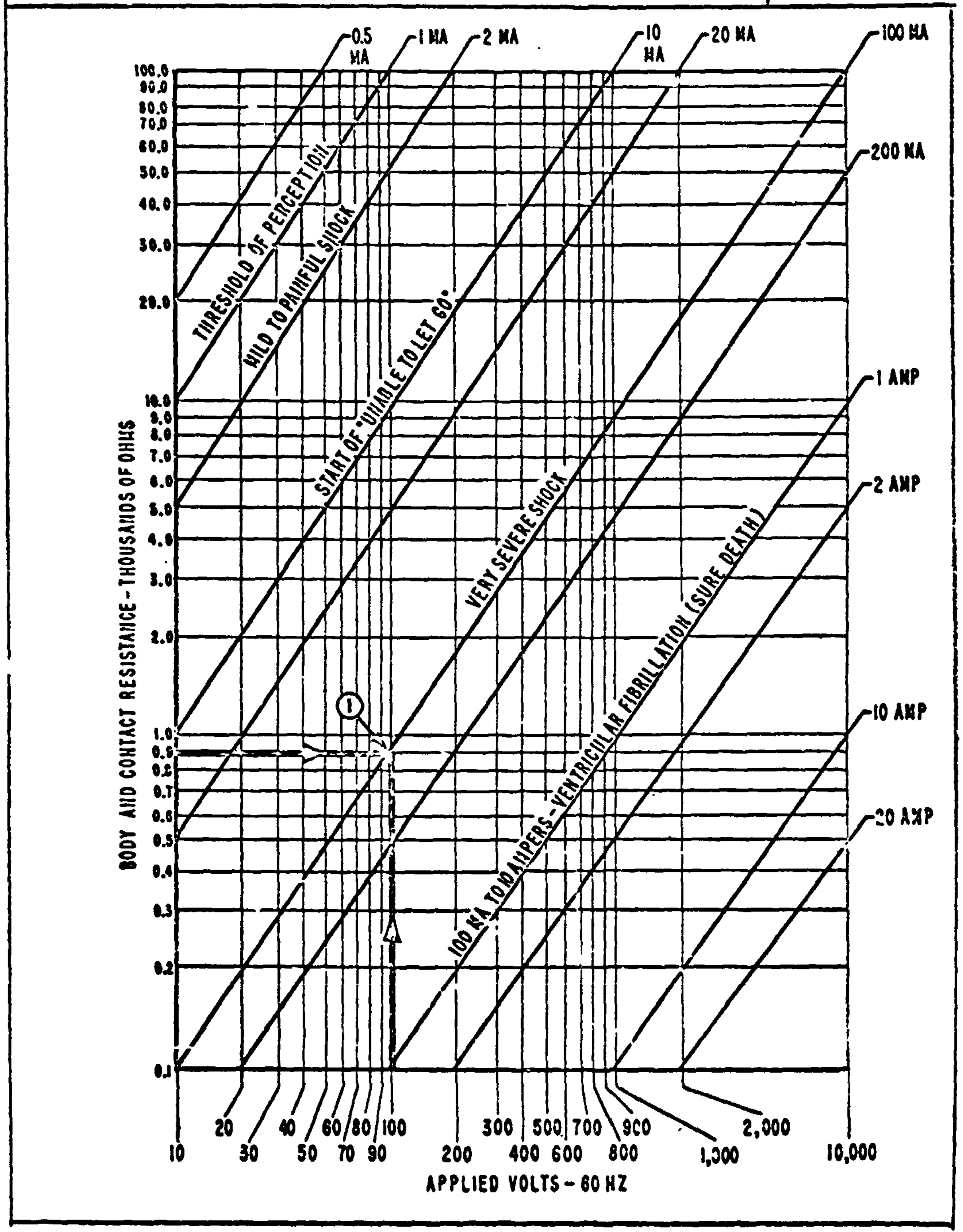
EFFECTS OF ELECTRICAL CURRENT ON THE HUMAN BODY

Current (milliamp)	Effect
Less than 1	Causes no sensation—not felt.
1-8	Sensation of shock; not painful; individual can let go at will because muscular control is not lost.
8-15	Painful shock; individual can let go at will because muscular control is not lost.
15-20	Painful shock; individual cannot let go because muscular control of adjacent muscles is lost.
20-50	Painful, severe muscular contractions; breathing is difficult.
50-100 (possible) 100-200 (certain)	Ventricular fibrillation (a heart condition that results in instant death—no known remedy).
200 and over	Severe burns; muscular contractions so severe that chest muscles clamp and stop heart during duration of shock (which prevents ventricular fibrillation).

The primary human detectors of electricity are all types of nerve endings in the skin.

Body resistance varies over a wide range. Thus dangerous potentials cannot be uniquely defined. Hand-to-hand resistance varies from 1,000 to 4,000 ohms with good contacts (brine wet hands). Hand-to-foot resistance is slightly smaller. With dry skin, similar measurements may yield resistances as high as 250,000 ohms. Under ordinary working conditions with sweaty hands, 5,000 ohms is commonly measured. Safety calculations recommend 1,000 ohms as the highest resistance which should be used.

Electrical Shock Hazard to Adult Males*



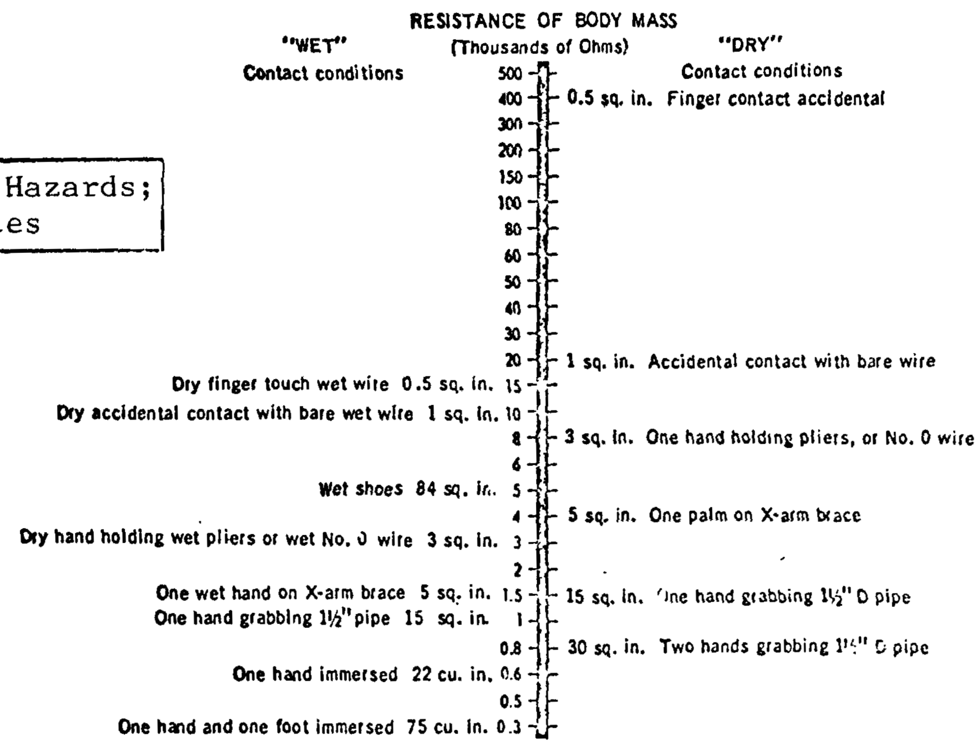
(See explanatory notes next page)

Electrical Shock Hazards; Explanatory Notes

(1) THIS SUB-NOTE SHOWS THE ELECTRICAL CURRENT HAZARD TO ADULT MALES AS A FUNCTION OF THE APPLIED 60 HZ VOLTAGE AND THE BODY AND CONTACT RESISTANCE (E.G., IF A PERSON WHOSE BODY AND SKIN CONTACT RESISTANCE IS 900 OHMS CONTACTS A VOLTAGE OF 100 VOLTS, 100 MILLIAMPERES OF CURRENT WOULD FLOW THROUGH HIM, ASSUMING A COMPLETE CIRCUIT).

(2) AN ELECTRIC CURRENT OF A GIVEN AMOUNT AFFECTS THE BODY IN MANY DIFFERENT WAYS DEPENDING ON THE PATH OF THE CURRENT. CURRENT PATHS INCLUDING THE HEAD OR TRUNK RESULT IN MORE SERIOUS INJURY THAN THOSE CONFINED TO ONE EXTREMITY. CURRENT PATHS THROUGH OR NEAR THE HEART OR RESPIRATORY SYSTEM MUSCLES OR THROUGH THE BRAIN ARE THE MOST CRITICAL.

(3) ELECTRIC CURRENTS OF ONLY A FEW MILLIAMPERES ARE SUFFICIENT TO "FREEZE" A VICTIM TO AN ELECTRIC CURRENT. THE HAZARDS INHERENT IN ELECTRICAL EQUIPMENT MUST BE RECOGNIZED AND PRECAUTIONS TAKEN TO PREVENT ELECTRIC SHOCK MISHAPS.



TYPICAL BODY SURFACE CONTACT RESISTANCE

ULTRAVIOLET RADIATION

The primary human detector of near ultraviolet radiation is the retina of the eye. There is no primary human detection of far ultraviolet radiation.

Near (long-wavelength) ultraviolet (300 to 400 millimicrons) causes no difference to man in the rate of subsequent dark adaptation after exposure either to ultraviolet radiation or visible light when they are matched for brightness. The lens of the eye fluoresces between 300 and 400 millimicrons, reaching a maximum between 360 and 370 millimicrons; the cornea of the eye fluoresces weakly between 315 and 360 millimicrons. Objects illuminated by ultraviolet light are difficult to focus on, the normal eye being 10 diopters myopic at 313 millimicrons.

Ultraviolet radiation produces excitation; i.e., it raises electrons in atoms or molecules to higher energy levels. It may produce cataracts in the eye. It is greatly absorbed and rapidly attenuated in living tissue. The shorter wavelengths produce ionization which is more damaging physiologically since it causes electrons to be ejected from atoms. Long-wavelength ultraviolet radiation produces sun tan on the skin. Short-wavelength ultraviolet radiation produces tissue damage since some ionization is produced.

RADIO FREQUENCY (RF) RADIATION

Microwave radiation injury has been qualitatively demonstrated in animals, but has not been observed clinically in electronics personnel. Animals eyes, and particularly their testes, are especially vulnerable to the shorter wavelengths. Experimental injury appeared thermal in nature; i.e., temperatures induced in the affected regions were sufficiently higher to account for injury on a thermal basis.

As risk criteria, the USAF uses 0.01 watts/cm^2, based upon the average power level.

INFRARED RADIATION

The primary human detector of near infrared radiation is the retina of the eye; of all infrared radiation, warmth receptors in the skin over the entire surface of the body. The range and level of sensitivity are the lower level of visual sensation.

ATOMIC RADIATION

There is no primary human detector of atomic radiation. The Roentgen equivalent man (rem) is a unit of biological dosage of any nuclear radiation absorbed.

Total lifetime dosage from background = 10 to 12 roentgens, where roentgen = the exposure dose of gamma radiation or X-rays which will form 1.61×10^{12} ion pairs when absorbed in 1 gram of air, i.e., will release 87 ergs of energy per gram of air ($\sim$97 ergs per gram of soft tissue).

Dose in rems = RBE x dose in rads, where

RBE = relative biological effectiveness; ratio of absorbed dose in rads of gamma radiation of a specified energy, to that of the given radiation having the same biological effect.

rad = the *absorbed* dose of any nuclear radiation which is accompanied by the liberation of 100 ergs per gram of absorbing material.

Very little information is available on the long term effects of atomic radiation. The best information available was used by the National Academy of Sciences to make recommendation for the maximum permissible cumulative atomic radiation dosage over a lifetime. (The effects of atomic radiation are cumulative.)

ESTIMATED YEARLY DOSE FROM NATURAL BACKGROUND RADIATION

	Roentgens/yr Sea Level	Roentgens/yr 5000 ft
Potassium in body	0.020	0.020
Thorium, uranium, and radium in granite	0.055	0.055
Potassium in granite	0.035	0.035
Cosmic rays	0.035	0.050
	0.145	0.160

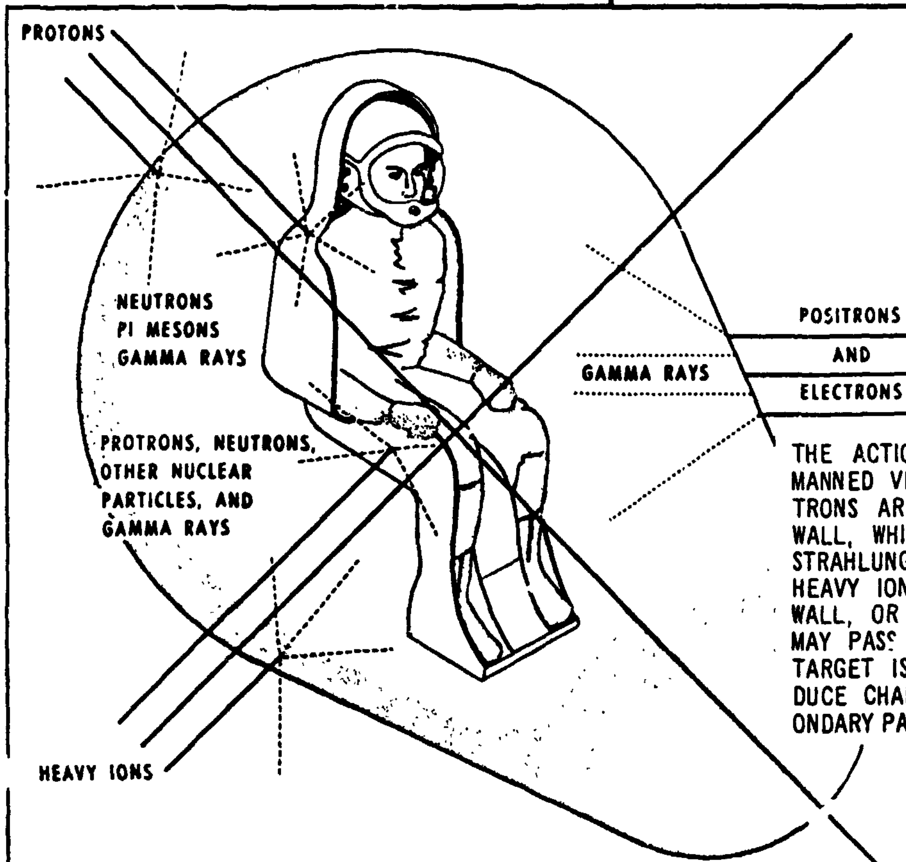
RELATIVE BIOLOGICAL EFFECTIVENESS OF DIFFERENT TYPES OF RADIATION

Type of Radiation	RBE
Gamma rays	1.0 (by definition)
Neutrons	$\sim$ 1.7
Alpha particles	$\sim$ 10
Beta particles	$\sim$ 1
X-rays	$\sim$ 1

Expected Short-Term Effects of Acute Whole-Body Radiation Doses

Acute Dose (roentgens)	Probable Short-Term Effect
0 to 50	No obvious effect, except possible minor blood changes.
80 to 120	Vomiting and nausea for about 1 day in 5 to 10% of exposed personnel. Fatigue but no serious disability.
130 to 170	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25% of personnel. No deaths anticipated.
180 to 220	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 50% of personnel. No deaths anticipated.
270 to 330	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness. About 20% deaths within 2 to 6 weeks after exposure; survivors convalescent for about 3 months.
400 to 500	Vomiting and nausea in all personnel on first day, followed by other symptoms of radiation sickness. About 50% deaths within 1 month; survivors convalescent for about 6 months.
550 to 750	Vomiting and nausea in all personnel within 4 hr from exposure, followed by other symptoms of radiation sickness. Up to 100% deaths; few survivors convalescent for about 6 months.
1000	Vomiting and nausea in all personnel within 1 to 2 hr. Probably no survivors from radiation sickness.
5000	Incapacitation almost immediately. All personnel will be fatalities within 1 week.

Space Radiation



THE ACTIONS OF PARTICLES MEETING A MANNED VEHICLE. ELECTRONS AND POSITRONS ARE STOPPED BY THE VEHICLE WALL, WHICH THEN EMITS THE BREHMSSTRAHLUNG (GAMMA RAYS). PROTONS AND HEAVY IONS MAY HIT A TARGET IN THE WALL, OR WITHIN THE CABIN, OR THEY MAY PASS RIGHT THROUGH. WHEREVER A TARGET IS HIT, THESE PARTICLES PRODUCE CHARACTERISTIC SHOWERS OF SECONDARY PARTICLES, AS SHOWN.

NATURE AND LOCATION OF ELECTROMAGNETIC AND PARTICULATE IONIZING RADIATIONS IN SPACE

NAME	NATURE OF RADIATION	CHARGE	MASS	WHERE FOUND
PHOTON	ELECTROMAGNETIC	0	0	RADIATION BELTS, SOLAR RADIATION (PRODUCED BY NUCLEAR REACTIONS AND BY STOPPING ELECTRONS) AND EVERYWHERE IN SPACE.
X RAY	ELECTROMAGNETIC	0	0	
GAMMA RAY	ELECTROMAGNETIC	0	0	
ELECTRON	PARTICLE	$-e$	1 m*	RADIATION BELT AND ELSEWHERE.
PROTON	PARTICLE	$+e$	1840 m* or 1 amu	PRIMARY COSMIC RAYS, RADIATION BELT, SOLAR FLARES.
NEUTRON	PARTICLE	0	1841 m*	SECONDARY PARTICLES PRODUCED BY NUCLEAR INTERACTIONS INVOLVING PRIMARY PARTICLE FLUX.
ALPHA PARTICLE	PARTICLE	$+2e$	4 amu	PRIMARY COSMIC RADIATION (NUCLEUS OF HELIUM ATOM)
HEAVY PRIMARY NUCLEI	PARTICLE	$\geq +3e$	≥ 6 amu	PRIMARY COSMIC RADIATION (NUCLEI OF HEAVIER ATOMS)

Maximum Ionization Radiation Exposure Limits

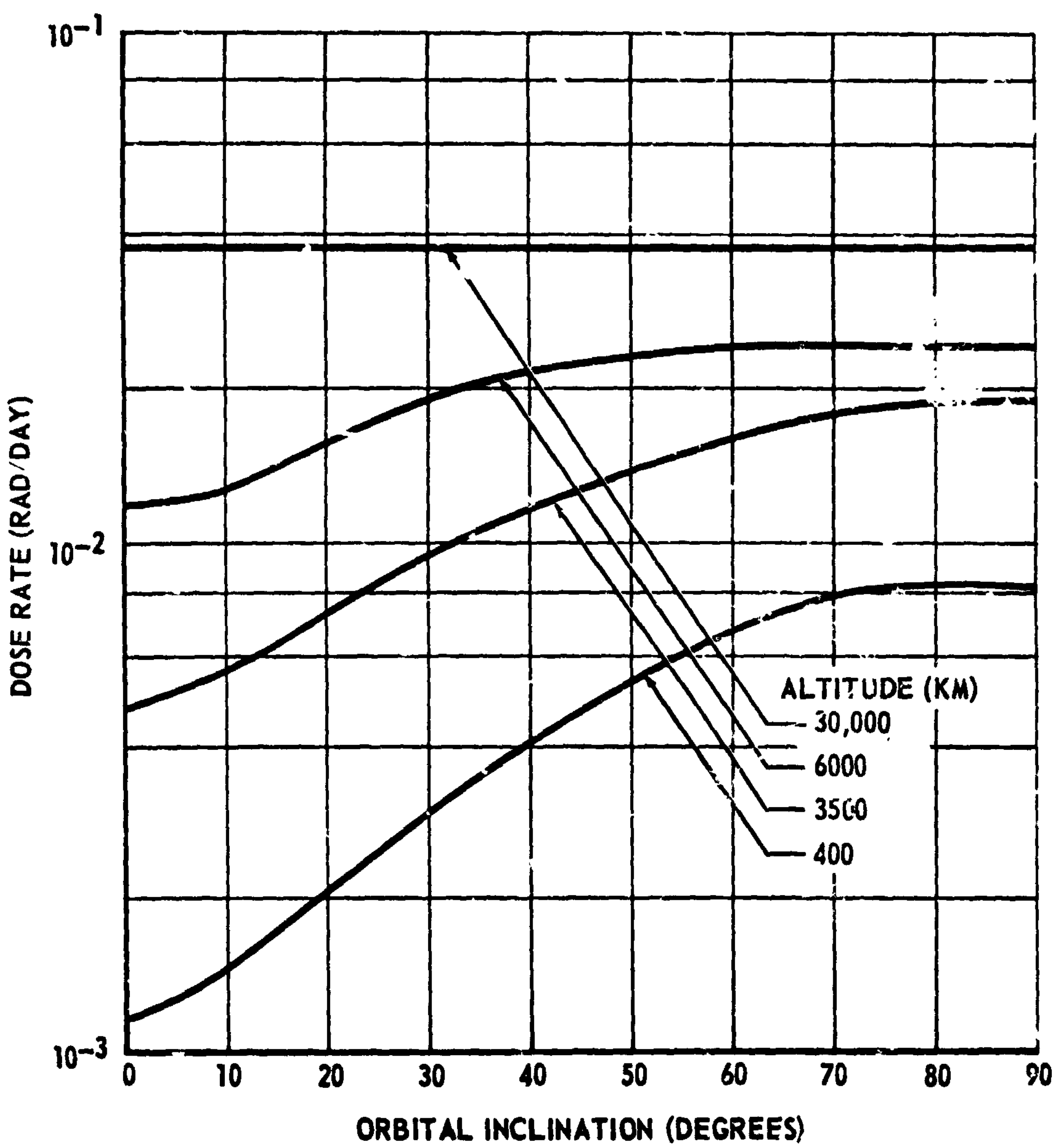
IONIZING RADIATION OF ANY TYPE OR COMBINATION OF TYPES	PERMISSIBLE REM* PER CALENDAR QUARTER (WITH COMPLETE MEDICAL HISTORY)**
Whole body	1.25
Head, trunk, blood-forming organs, eye-lens, and gonads	1.25
Body extremities	18.75
Skin	7.50
Acute accidental single exposure (either internal or external to the body)	25.0 (or more in extreme cases)

* REM = Roentgen Equivalent(s), Man

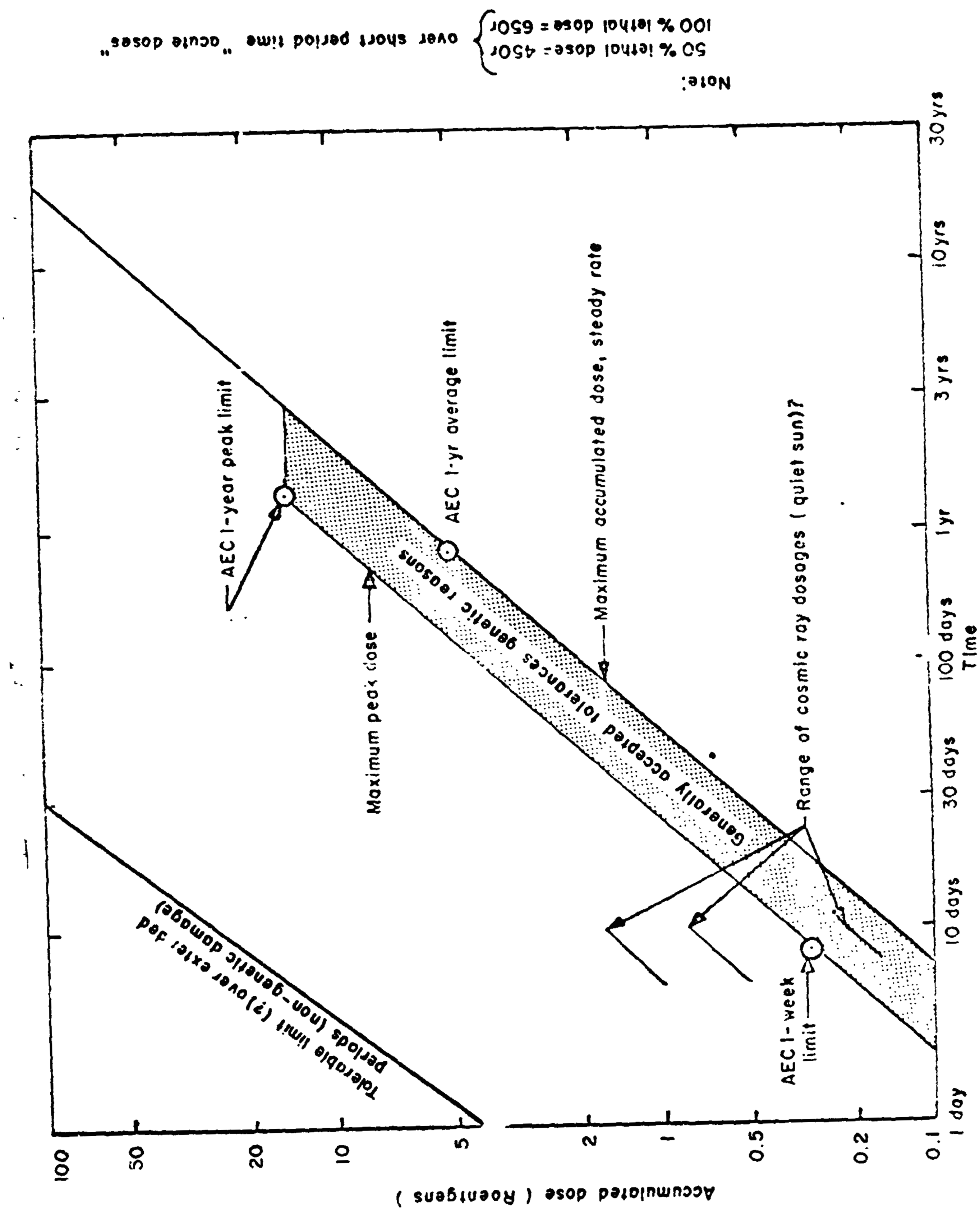
**If a medical record is available, a higher exposure (80% of the limit in effect) is permissible: 3/REM/quarter, provided no more than $5(n-18)$ REM total accumulated dosage has been met (where n is the age of the subject).

Shielding Recommendations for Ionization Radiation Protection

RADIATION TYPE	RANGE OF RAYS IN AIR	SHIELD MATERIAL	
		TYPE	THICKNESS
Alpha particles (4 million electron volts)	2.8 cm	Aluminum sheet Paper Ordinary clothing	1/64 inch 1/64 inch 1/64 inch
Beta particles (3 million electron volts)	13.0 m	Lead Aluminum Pyrex Lucite Water	1.4 mm 5.3 mm 6.6 mm 12.4 mm 14.8 mm
Gamma rays (4 million electron volts)	-	Shielding is accomplished by reducing intensity of incident gamma radiation by scattering interactions within a shield (probability of completely absorbing the nuclei of atoms in a shield is slight). Thickness of material required to reduce radiation to one-half is called the half-value layer. Half-value layers for typical materials are. Lead 0.3 inch Iron 0.5 inch Aluminum 2.7 inch Concrete 2.7 inch Water 8.3 inch	
Neutrons	-	Since gamma radiation is produced in the process of neutron attenuation, shielding against neutrons should also include shielding against gamma radiation. An effective material is cement mixed with iron shot. However, beryllium-lithium combinations are best for lightweight applications such as in aircraft, spacecraft, or remote handling equipment.	

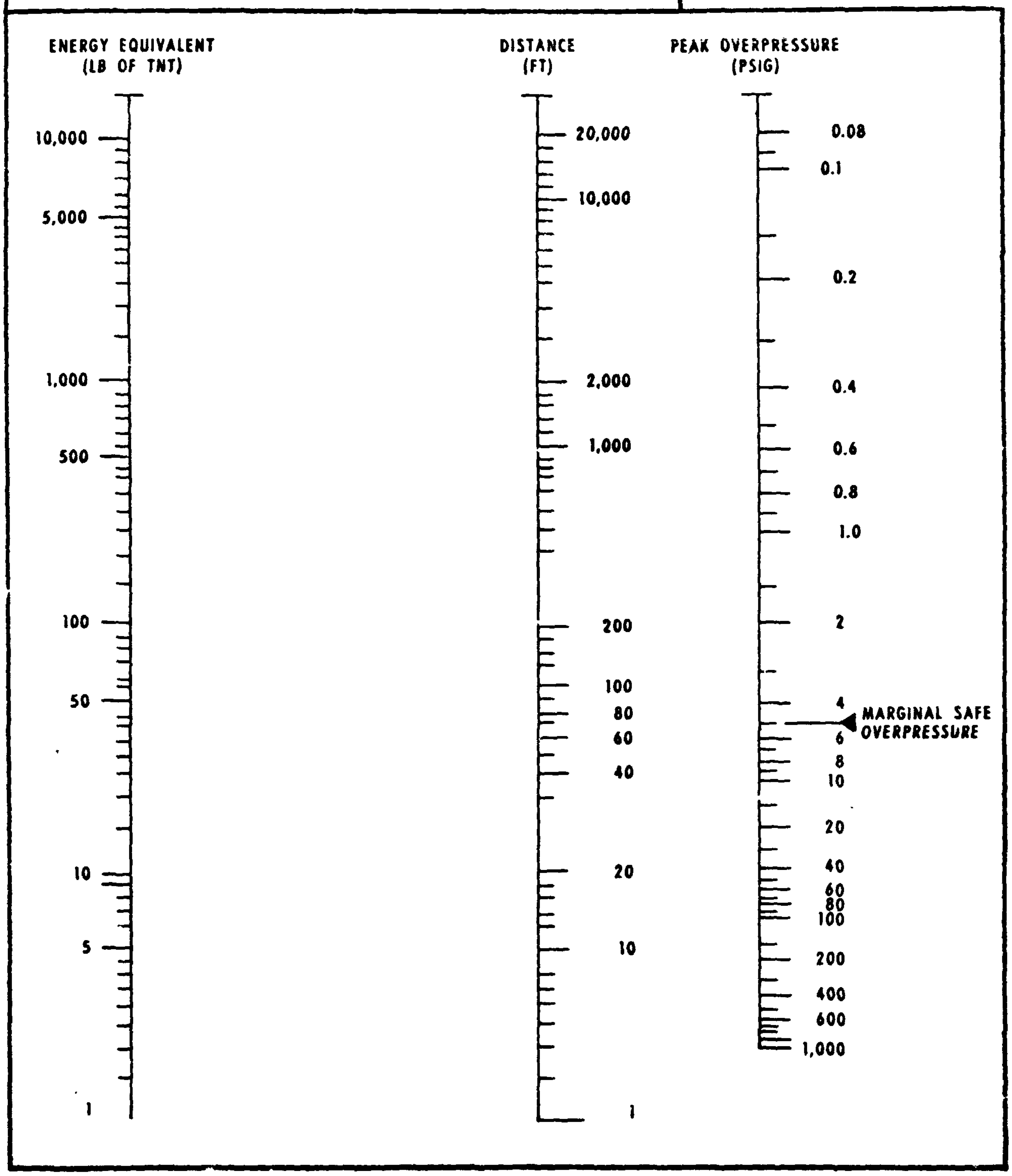


Average cosmic-ray dose rate at solar minimum as a function of circular orbital inclination for various altitudes.



—HUMAN TOLERANCES TO RADIATIC

Nomograph for Demonstrating Magnitude of Blast Hazard from Equivalent Weight of TNT



American Table of Distances

Blasting and Electric Blasting Caps		Other Explosives		Inhab'd Bldg Barri-caded* (Feet)	Public Railway Barri-caded* (Feet)	Public High'y Barri-caded* (Feet)
Number Over	Number Not Over	Pounds Over	Pounds Not Over			
1,000	5,000	—	—	15	10	5
5,000	10,000	—	—	30	20	10
10,000	20,000	—	—	60	35	18
20,000	25,000	—	50	73	45	23
25,000	50,000	50	100	120	70	35
50,000	100,000	100	200	180	110	55
100,000	150,000	200	300	260	155	75
150,000	200,000	300	400	320	190	95
200,000	250,000	400	500	360	215	110
250,000	300,000	500	600	400	240	120
300,000	350,000	600	700	430	260	130
350,000	400,000	700	800	460	275	140
400,000	450,000	800	900	490	295	150
450,000	500,000	900	1000	510	305	155
500,000	750,000	1000	1500	530	320	160
750,000	1,000,000	1500	2000	600	360	180
1,000,000	1,500,000	2000	3000	650	390	195
1,500,000	2,000,000	3000	4000	710	425	210
2,000,000	2,500,000	4000	5000	750	450	225
2,500,000	3,000,000	5000	6000	780	470	235
3,000,000	3,500,000	6000	7000	805	485	245
3,500,000	4,000,000	7000	8000	830	500	250
4,000,000	4,500,000	8000	9000	850	510	255
4,500,000	5,000,000	9000	10000	870	520	260
5,000,000	7,500,000	10000	15000	890	535	265
7,500,000	10,000,000	15000	20000	975	585	290

*Barricaded, as here used, signifies that the building containing explosives is screened from other buildings, railways, or from highways by either natural or artificial barriers. Where such barriers do not exist, the distances should be doubled.

NOTE: For larger quantities see the complete American Table of Distances, published by the Institute of Makers of Explosives.

Effects on Man from Blast Waves Produced by Conventional High Explosives*

Peak Static Overpressure (psig)**	Effect
0 to 2.5	Probably no effect on gross performance other than a momentary blinking, a possible transient in a control movement, and a possible slight decrease in auditory sensitivity.
2.5 to 7	Performance may deteriorate due to increased effects described above; greater than normal energy expenditure to perform a given task; nervous tension.
7 to 20	Ruptured eardrums; permanent hearing loss above 3,000 cps after repeated exposures; pain; mild feelings of lethargy and fatigue; inability to concentrate; general nervousness.
20 to 100 (especially $\geq$80)	Very much increased effects described above; damage to lungs, viscera and other organs, and to the brain; possible death.
Above 100 (especially >200 to 300)	Probable death, ordinarily due to the fact that air, forced into the ruptured blood vessels of the lungs, travels to the heart and brain (air embolism).

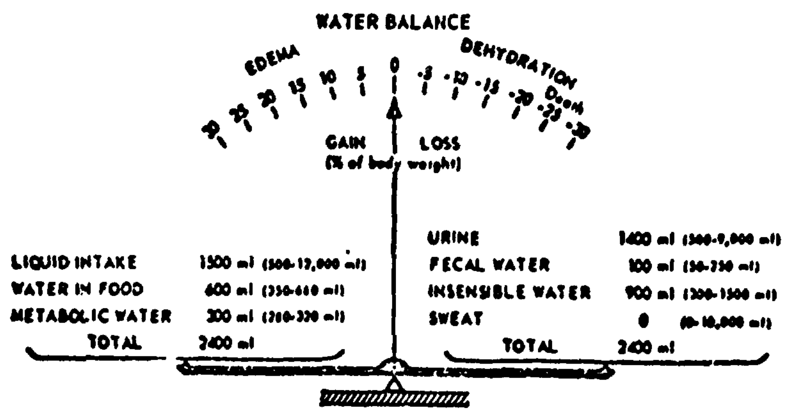
*Nuclear explosions, because of longer durations of blast waves (i.e., higher positive impulse) may produce these effects at the lower levels.

**Pounds per square inch gage, i.e., pressure above atmospheric pressure (14.7 psi).

TYPICAL CHARACTERISTICS OF A SHOCK WAVE TRAVELING IN FREE AIR

Peak Static Overpressure (psig)*	Peak Temperature (°F)	Time 0 to Peak (microsec)	Velocity (ft/sec)
2	3500	0.30	4400
5	6640	0.15	8200
10	8360	0.10	12200
15	9620	0.08	14400
20	10880	0.07	16500

*Pounds per square inch gage, i.e., pressure above atmospheric pressure (14.7 psi).



Conservative Estimates of Daily Water Requirement for Sanitation Purposes to Attain Hygiene and Comfort Equivalent to Earth Conditions

	Liquid wastes, kg/man-day		Solid wastes, kg/man-day	
	Minimum	Maximum	Minimum	Maximum
Food preparation	1.0	4.0	0.0:	0.040
Personal hygiene	1.5	4.5	.015	.045
Clothes washing	3.0	4.0	.030	.040
Cabin cleansing	1.0	5.0	.010	.050
Subtotal	6.5	17.5	.065	.175
Total	6.565 to 17.675			

Daily Human Metabolic Waste Production

	Reference					
	Liquid wastes, kg/man-day		Solid wastes, kg/man-day		Average metabolic wastes, kg/man-day	
	Minimum	Maximum	Minimum	Maximum		
CO_2	1.0	1.0	-----	-----	1.03	1 03
Perspiration and respiration	.80	3.48	-----	-----	1.0 to 3.5	1.00
Urine	1.2	1.5	0.060	0.075	1.5?	1.39
Feces	.053	.08	.017	.020	.182	.114
Total	3.13 to 6.155				3.732 to 6.232	3.534

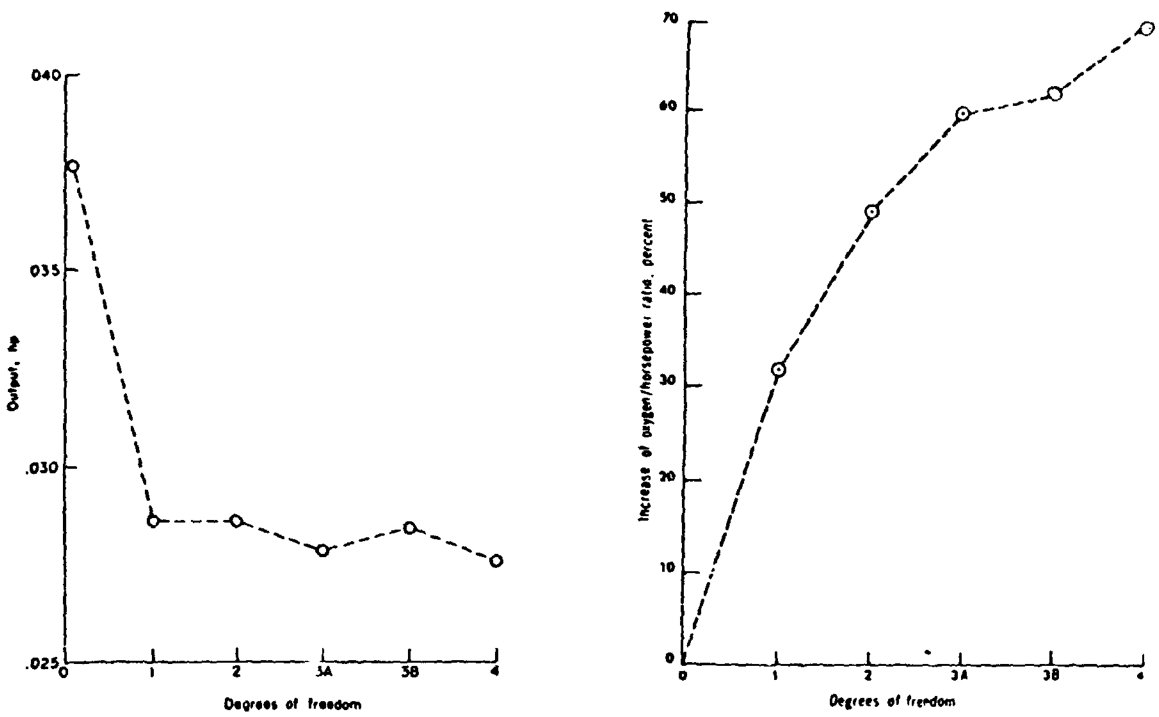
Weight, Volume, and Power for Several Types of Feeding Systems

Feeding System	Food		Environmental Conditions	Equipment			
	Weight	Volume		Type	Weight	Volume	Power
	(lb)	(ft^3)			(lb)	(ft^3)	(kilowatt hrs/day)
Minimal Acceptability: Foods compressed, freeze dehydrated, and limited in variety, no food service equipment available, temperature of water for food reconstitution 80-90°F.	1.0	0.06	Weightlessness	Water Storage Unit	1.5	0.4	0.01
Moderate Acceptability: A moderate variety of pre-cooked dehydrated foods, instant beverages, and bite-size pieces, approximately half the water at 40°F ± 5°, the remaining half at 180°F ± 10°, food service equipment limited to a water cooler and heater.	1.7	0.13	Weightlessness	Water Heater	5.0	0.6	0.30
				Thermo-Electric Water Cooler	5.5	0.7	0.45
High Level of Acceptability: A moderate variety of pre-cooked dehydrated foods, instant beverages, bite-size solids, and one pre-cooked frozen meal per day, approximately 4/5 of the water requirement for food preparation, the remaining 1/5 contained in frozen foods	2.5	0.15	Partial Gravity	Water Heater	5.0	0.6	0.30
				Thermo-Electric Water Cooler	5.5	0.7	0.45
				Thermo-Electric Freezer	158	12.0 capacity	15.00
				Oven	10.0	0.9	1.00

Metabolic Requirements for Spacecraft Cabins

Activity		cal/hr	Btu/hr
Sleep		70	280
Eating		1.5x basal	420
Exercise		2.5x basal	700
Rest and relaxation		1.5x basal	420
Work Program:			
Flight control		2.0x basal	560
Reconnaissance		2.5x basal	700
Scientific observation		2.5x basal	700
Repair		4.0x basal	1120
Suited(unpressurized) add increase as follows:			
Sleep	+10		
Eating	+50		
Exercise	+50		
Rest and relaxation	+50		
Work	+50		

Metabolic Costs of Work During Simulation of Weightlessness



a. Horsepower Output with Various Degrees of Freedom on Reciprocating Task; 15-Pound Load and 22-Inch Stroke

b. Pe..entage Increase of Oxygen/Horsepower ratio for a Reciprocating Task; 15-Pound Load and 22-Inch Stroke

Effect of degrees of freedom on power output and oxygen efficiency of output in a mechanical weightlessness simulator.

2 df - Subject free to translate horizontally in all directions.

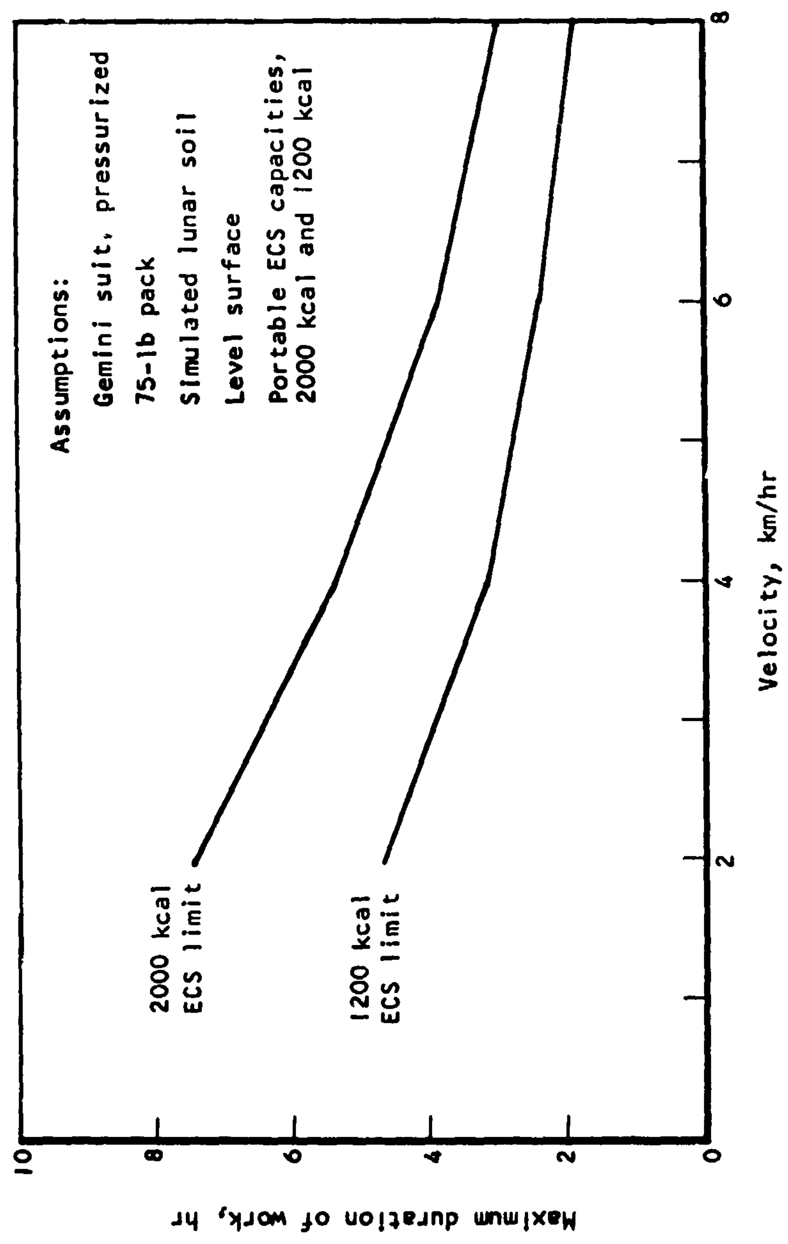
3 dfA - Subject free to translate horizontally in all directions and rotate in a vertical plane.

3 dfB - Subject free to translate horizontally in all directions and rotate in a horizontal plane.

4 df - Subject free to translate horizontally in all directions and to rotate about his own center of gravity in planes parallel and perpendicular to the floor.

c. Comparison of Metabolic Rates During Construction and Maintenance Work (Btu/hr)

Simulation	Rest	Maximum Measured
One-g	697	3243
Neutral buoyancy	1035	2170
Zero-g six-degree-of-freedom	478	3489



Duration of Lunar Walk as a Function of Velocity,
Assuming Two Protable ECS Capacities

Formulas for calculating energy cost and variance of walking on a level with load

For speeds between 2.0 and 4.5 mph, the following equations give predictions for the energy cost of marching and its variance:

$$E = K + Y$$

$$K = 0.0083\ (10 + W + L)\ e^{v/50}$$

$$Y = 0.56 \pm 0.0091\ W$$

$$\sigma^2 = 0.017\ e^{v/25}$$

where E = total energy expenditure in kilocalories per minute,

K = energy expenditure in kilocalories per minute above resting expenditure,

Y = resting energy expenditure in kilocalories per minute,

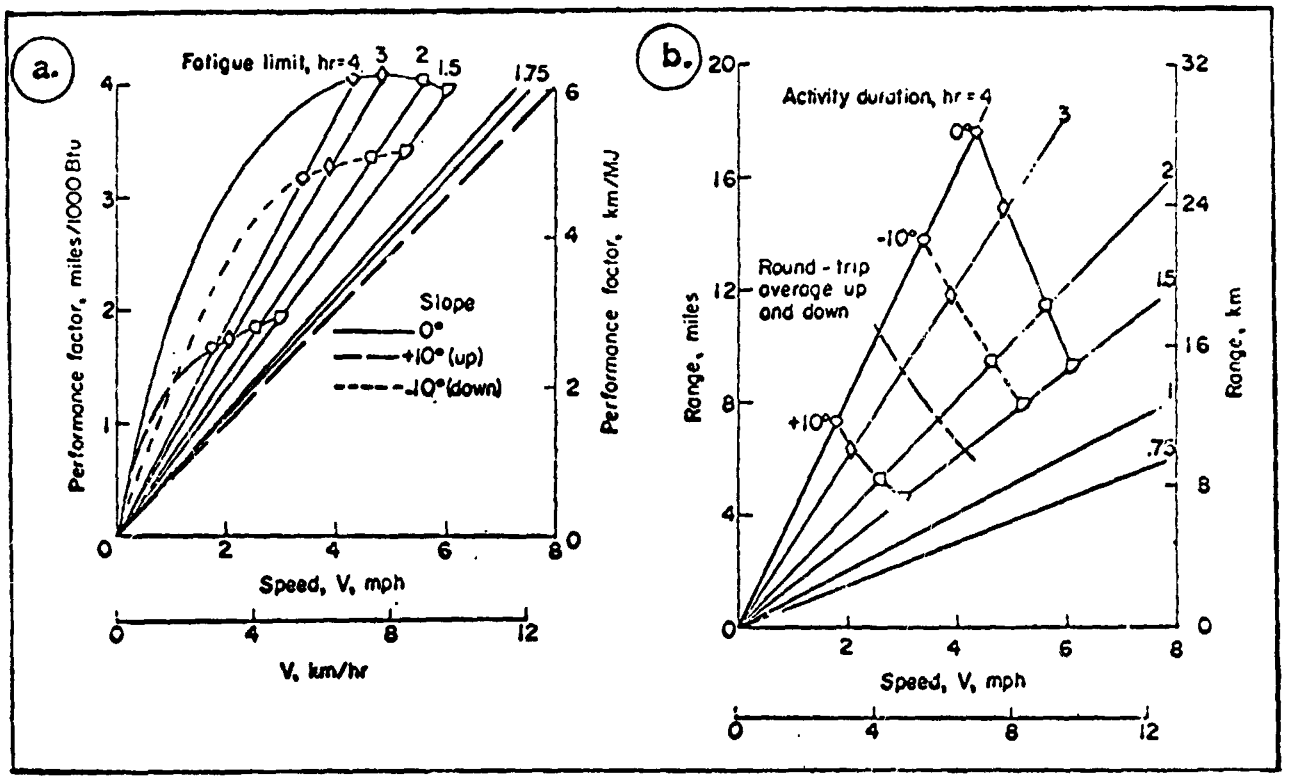
σ^2 = variance in K,

W = body weight in kilograms,

L = load carried in kilograms,

v = marching velocity in meters/min, and

e = exponential constant.



Effect of Surface Slope On Range Capability of Lunar Explorers (Estimated)

Section 3

BEHAVIORAL FACTORS

BEHAVIORAL FACTORS

This section contains information about human behavior and operator performance as an integral part of a man-machine system. Since materials were drawn from other sources there is an obvious overlap between this section and others such as equipment design and physiological factors. However, most of the data has been selected on the basis of operator performance effectiveness under various conditions - physical and environmental.

The following specific references are suggested for additional reading:

Fogel, L. J. - Biotechnology: Concepts and Applications, Prentice-Hall, Engelwood Cliffs, N. J., 1963.

Fitts, P. M. & Posner, M. I. - Human Performance - Basic Concepts in Psychology Series, Brooks-Cole Pub. Co., Belmont, Calif., 1968.

Meister, D. & Rabideau, G. F. - Human Factors Evaluation in System Development, John Wiley & Sons, N. Y., 1965.

McCormick, E. J. - Human Factors Engineering, McGraw-Hill Book Co., N. Y., 1964.

Morgan, C. T. et al - Human Engineering Guide to Equipment Design, McGraw-Hill Book Co., N. Y., 1963.

Woodson, W. E. & Conover, D. W. - Human Engineering Guide for Equipment Designers, Univ. Calif. Press, Berkeley, Calif., 1964.

Stevens, S. S. - Handbook of Experimental Psychology, John Wiley & Sons, N. Y., 1951.

NASA CR-1205(III) - Compendium of Human Responses to the Aerospace Environment, (Sections 10-16) prepared by E. M. Roth, M.D.

NASA CR-1370 - Predicting Human Performance in Space Environments, prepared by W. H. Teichner and Diane Olson, Harvard Univ.

COMPARISON OF HUMAN CAPABILITIES WITH MACHINE ALTERNATIVES

MAN	MACHINE
Man can recognize and use information redundance (pattern) in the real world to simplify complex situations.	Machines have limited perceptual constancy and are very expensive.
Man has high tolerance for ambiguity, uncertainty and vagueness.	Machines are highly limited by ambiguity and uncertainty in input.
Man can interpret an input signal even when subject to distraction, high noise or message gap.	Machines perform well only in a generally clean, noise-free environment.
Man is a selecting mechanism and can adjust to sense specific inputs.	Machines are fixed sensing mechanisms, operating only on that which has been programmed for them.
Man has very low absolute thresholds for sensing (e.g., vision, audition, tactile).	Machines, to have the same capability become extremely expensive.
Man has excellent long term memory for related events.	Machines, to have the same capability become extremely expensive.
Man can become highly flexible in terms of task performance.	Machines are relatively inflexible.

Man can improvise and exercise judgment based on long term memory and recall.	Machines cannot; they are best at routine, repetitive functions.
Man can perform under transient overload, his performance degrades gracefully.	Machines stop under overload; generally fail all at once.
Man can make inductive decisions in novel situations; can generalize.	Machines have little or no capability for induction or generalization.
Man can modify his performance as function of experience; he can learn "to learn".	Trial and error behavior is not characteristic of machines.
Man can override his own actions should the need arise.	Machines can only do what they are built to do.
Man is reasonably reliable; can add reliability to system performance by selection of alternatives.	Machines are reliable only at the expense of increased complexity and cost; then only for routine functions.
Man complements the machine in the sense that he can use it in spite of design failures, for a different task, or use it more efficiently than it was designed for.	Machines have no such capability.
Man complements the machine by aiding in sensing, extrapolating, decision making, goal setting, monitoring and evaluating.	Machines have no capacity for different performance than originally designed.

Man can acquire and report information incidental to the primary mission	Machines cannot do this.
Man can perform time contingency analyses and predict event in unusual situations.	Corresponding machines do very poorly.
Man is relatively inexpensive for corresponding complexity, is generally in good supply, but must be trained.	Machines are more limited in terms of complexity and supply by cost and time.
Man is light in weight and small in size for function achieved for most situations.	Machines with functional equivalence of man require more weight, power and cooling facilities.
Man is relatively easy to maintain; demands a minimum of "in task" extras.	Maintenance problems become disproportionately serious as complexity increases.

COMPARISON OF HUMAN LIMITATIONS WITH MACHINE ALTERNATIVES

MAN	MACHINE
Men are poor monitors of infrequent events or of events which occur frequently over a long period of time.	Machines can be constructed to detect reliably, infrequent events or events which occur frequently over a long period of time.
The human has a limited channel capacity.	Machines may have as much channel capacity as can be afforded.
Humans are subject to coriolis effects, motion sickness, disorientation, etc.	Machines are not subject to these effects.
Man has extremely limited short term memory for factual material.	Machines may have as much short-term (buffer) memory as can be afforded.
Man is not well suited to data coding, amplification or transformation tasks.	Machines are well suited to these kinds of tasks.
Human performance is degraded by fatigue and boredom.	Machine performance is degraded only by wearing out or by lack of calibration.
Human performance is degraded by long duty periods, repetitive tasks and cramped or unchanged positions.	Machines are less affected by long duty periods, perform repetitive tasks well; some may be restricted by position.

Man saturates quickly in terms of the number of things he can do and the duration of his effort.	Machines can do one thing at a time so fast that they seem to do many things at once, for a long period of time.
Man may introduce errors by mis-identification, redintegration or closure.	Machines do utilize these processes.
Expectation or cognitive set may lead an operator to "see what he expects, or wants to see".	Machines do not exercise these processes.
Much of human mobility is predicated and based on gravity relationships.	Machines may be built which perform independant of gravity.
Human are adversely affected by high g-forces.	Machines are unaffected by g-force.
Man can generate only relatively small forces, and cannot exert large forces for very long or very smoothly.	Machines can generate and exert forces as needed.
Man generally requires a review or rehearsal period before making decisions based on items in memory.	Machines go directly to stored information for decision.
When performing a tracking task, man requires frequent reprogramming; he does best when changes are under 3 radians/second.	Machines do not have such limitations.

Man has a built-in response latency of about 200 microseconds in a go/no-go situation.	Machines need have no response latency.
Man is not well adapted to high speed, accurate search of large volumes of information.	Computers are designed to do just this.
Man does not always follow an optimum strategy.	Machines will always follow the strategy designed into them.
Man has physiological, psyshological and ecological needs.	Machines have only ecological needs.
Men are subject to anxiety which may affect their performance efficiency.	Machines are not subject to this factor.
Man is dependent upon his social environment both present and remembered.	Machines have no social environment.
Man's diurnal cycle imposes cyclic degredation of behavior.	The machine cycle may be whatever is desired.
Interpersonal problems develop among humans.	There are no such problems among machines.
Unselected individuals differ greatly among themselves.	There are no unselected machines.

GENERAL POPULATION STEREOTYPE REACTIONS

- HANDLES USED FOR CONTROLLING LIQUIDS ARE EXPECTED TO TURN CLOCKWISE FOR OFF AND COUNTER-CLOCKWISE FOR ON.
- KNOBS ON ELECTRICAL EQUIPMENT ARE EXPECTED TO TURN CLOCKWISE FOR ON, TO INCREASE CURRENT, AND COUNTER-CLOCKWISE FOR OFF OR DECREASE IN CURRENT. (NOTE: THIS IS OPPOSITE TO THE STEREOTYPE FOR LIQUID.)
- CERTAIN COLORS ARE ASSOCIATED WITH TRAFFIC, OPERATION OF VEHICLES, AND SAFETY.
- FOR CONTROL OF VEHICLES IN WHICH THE OPERATOR IS RIDING, THE OPERATOR EXPECTS A CONTROL MOTION TO THE RIGHT OR CLOCKWISE TO RESULT IN A SIMILAR MOTION OF HIS VEHICLE, AND VICE VERSA.
- SKY-EARTH IMPRESSIONS CARRY OVER INTO COLORS AND SHADINGS: LIGHT SHADES AND BLUISH COLORS ARE RELATED TO THE SKY OR UP, WHEREAS DARK SHADES AND GREENISH OR BROWNISH COLORS ARE RELATED TO THE GROUND OR DOWN.
- THINGS WHICH ARE FURTHER AWAY ARE EXPECTED TO LOOK SMALLER.
- COOLNESS IS ASSOCIATED WITH BLUE AND BLUE-GREEN COLORS, WARMNESS WITH YELLOWS AND REDS.
- VERY LOUD SOUNDS OR SOUNDS REPEATED IN RAPID SUCCESSION, AND VISUAL DISPLAYS WHICH MOVE RAPIDLY OR ARE VERY BRIGHT, IMPLY URGENCY AND EXCITEMENT.
- VERY LARGE OBJECTS OR DARK OBJECTS IMPLY "HEAVINESS." SMALL OBJECTS OR LIGHT-COLORED ONES APPEAR LIGHT IN WEIGHT. LARGE, HEAVY OBJECTS ARE EXPECTED TO BE "AT THE BOTTOM." SMALL LIGHT OBJECTS ARE EXPECTED TO BE "AT THE TOP."
- PEOPLE EXPECT NORMAL SPEECH SOUNDS TO BE IN FRONT OF THEM AND AT APPROXIMATELY HEAD HEIGHT.
- SEAT HEIGHTS ARE EXPECTED TO BE AT A CERTAIN LEVEL WHEN A PERSON SITS DOWN!

HUMAN RELIABILITY

Human reliability has important implications not only in the way we design interfaces between man and machine, but also in deciding how to use man in a system. Quantification of human reliability is an extremely difficult and possibly impractical task. It is desirable, however, to consider human reliability from the standpoint of identifying relationships between human characteristics and certain factors which may degrade performance reliability. The primary consideration is to minimize human error potential through proper design.

Let us consider first the broad relationships between task characteristics and probability of error-free performance. Assuming that man can perform best under so-called normal conditions, we may classify types of performance according to their inherent reliability from best to worst.

1. Simple, discrete response to a single discrete signal.
2. Simple but varying response to single, successive signals.
3. Single discrete response to multivariant signals requiring sampling, judgment, and decision.
4. Successive, independent response to multivariant signals requiring sampling, judgment, and decision.
5. Complex concomitant responses to random-variant signals requiring extrapolation, interpretation, and decision.
6. Complex response to complex inputs including concurrence with another operator.

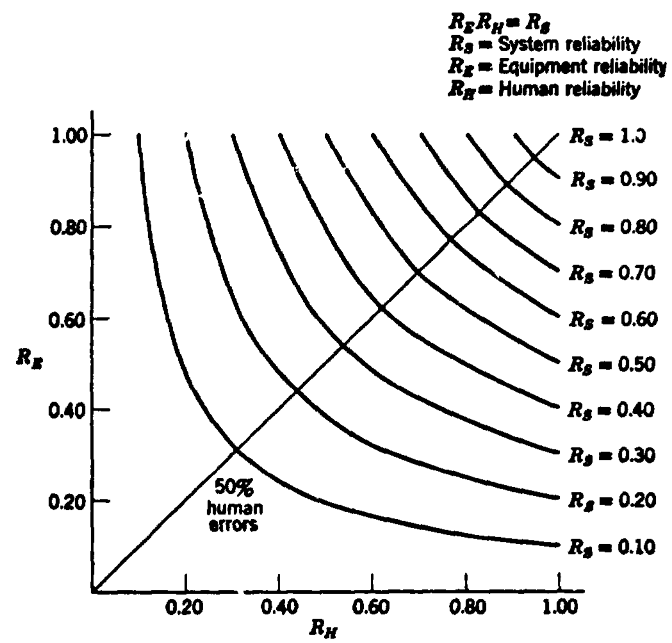


Figure 1-1 Effect of human and equipment reliability on system reliability, $R_E \times R_H = R_S$.

Classification of Behaviors

Processes	*Activities*	*Specific Behaviors*
Perceptual Processes	Searching for and Receiving Information	Detects Inspects Observes Reads Receives Scans Surveys
	Identifying Objects, Actions, Events	Discriminates Identifies Locates
Mediational Processes	Information Processing	Categorizes Calculates Codes Computes Interpolates Itemizes Tabulates Translates
	Problem Solving and Decision Making	Analyzes Calculates Chooses Compares Computes Estimates Plans
Communication Processes		Advises Answers Communicates Directs Indicates Informs Instructs Requests Transmits
Motor Processes	Simple/Discrete	Activates Closes Connects Disconnects Joins Moves Presses Sets
	Complex/Continuous	Adjusts Aligns Regulates Synchronizes Tracks

MAXIMUM RATES OF INFORMATION TRANSFER IN VARIOUS DIMENSIONS OF SENSORY MODALITIES

MODALITY	DIMENSION	MAXIMUM RATE (BITS/STIMULUS)
Visual	Linear extent	3.25
	Area	2.7
	Direction of line	3.3
	Curvature of line	2.2
	Hue	3.1
	Brightness	3.3
Auditory	Loudness	2.3
	Pitch	2.5
Taste	Saltiness	1.9
Tactile	Intensity	2.0
	Duration	2.3
	Location on the chest	2.8
Smell	Intensity	1.53
	(MULTI-DIMENSIONAL MEASUREMENTS)	
Visual	Dot in a square	4.4
	Size, brightness, and hue (all correlated)	4.1
Auditory	Pitch and loudness	3.1
	Pitch, loudness, rate of interruption, on-time fraction, duration, spatial location	7.2
Taste	Saltiness and sweetness	2.3

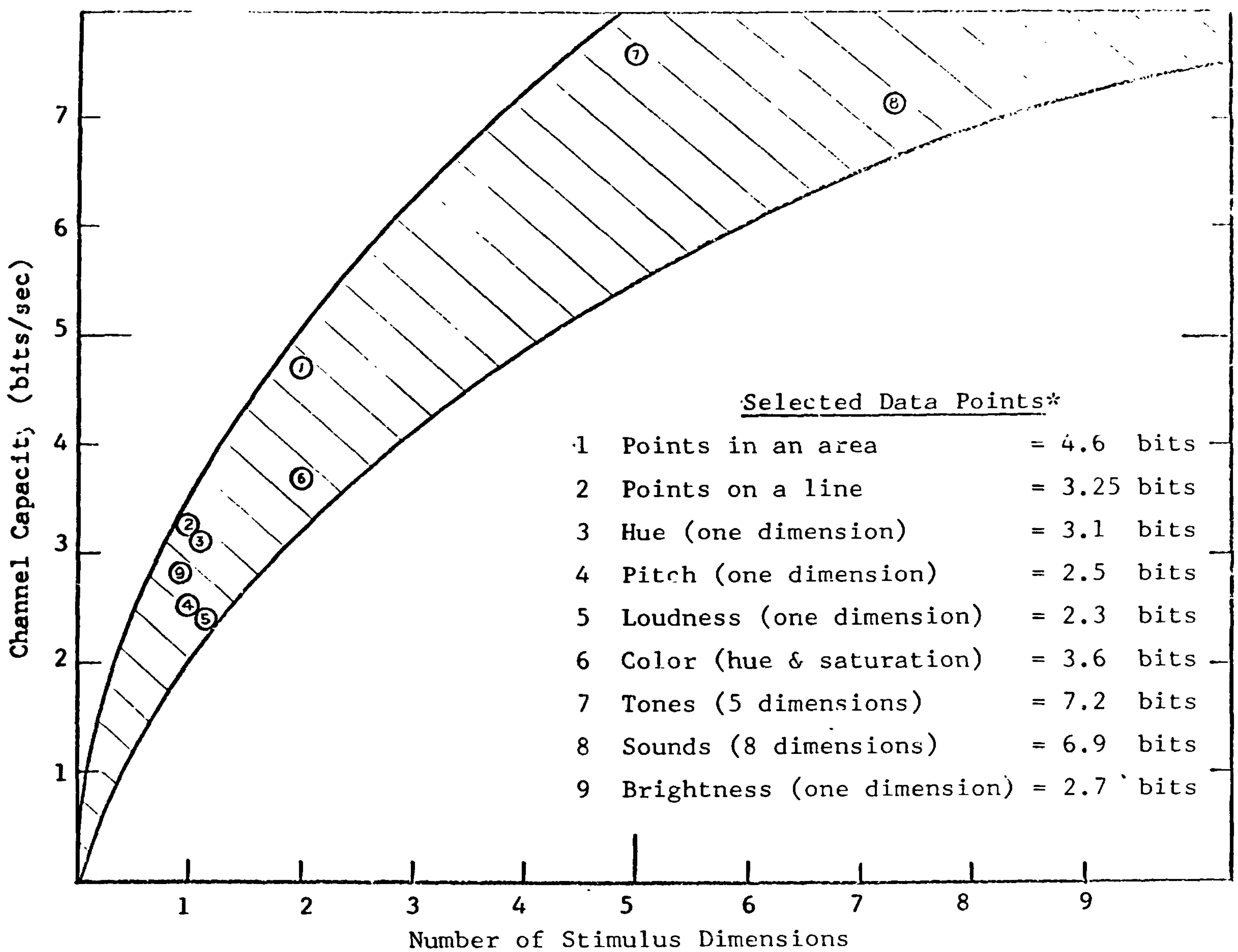
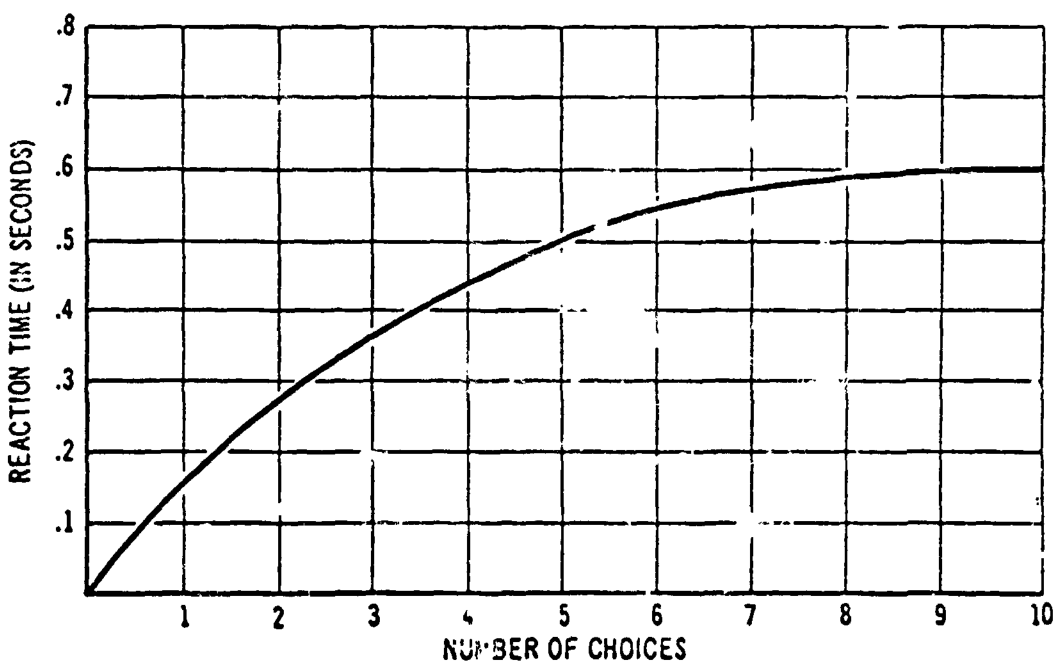


Figure - Human Sensory Channel Capacity - Visual & Auditory Modalities

Note* Recent studies suggest limited increase in channel capacity as function of number of stimulus dimensions - see 1, 7, and 8. Shaded area represents estimate of upper and lower bounds for increased capacity as function of stimulus dimensionality.

HUMAN REACTION TIME

a. By Sensory Mode:		
Pain	0.7	sec.
Odor	0.29	sec.
Warmth	0.22	sec.
Cold	0.2	sec.
Visual	0.19	sec.
Tactual	0.17	sec.
Auditory	0.215	sec. to
	0.125	min.
b. By Age:		
20 yrs.	0.2	sec.
30 yrs.	0.22	sec.
40 yrs.	0.25	sec.
c. Speed of Perception to Action:		
Neural transit	0.[illegible]	sec.
Brain recognition	0.4	sec.
Decision	5.0	sec.
Motor response	0.5	sec.
	6.0	sec. minimum



Operator reaction time versus number of choices

Comparison of the stimulus intensity ranges of the senses.

Sensation	Range of stimulation intensity: Smallest detectable	Range of stimulation intensity: Largest practical
Sight	$2.2\text{–}5.7 \times 10^{-10}$ ergs	$\sim 10^{9} \times$ threshold intensity
Hearing	1×10^{-9} erg/cm^2	$\sim 10^{14} \times$ threshold intensity
Mechanical vibration	0.00025 mm average amplitude at fingertip	$\sim$40 db above threshold
*Touch (pressure)	0.026 erg at ball of thumb	No data available
Smell	2×10^{-7} mg/m^3 of vanillin	No data available
Taste	4×10^{-7} molar concentration of quinine sulfate	No data available
Temperature	0.00015 gm-cal/cm^2/sec for 3-sec exposure of 200 cm^2 of skin	0.218 gm-cal/cm^3/sec for 3-sec exposure of 200 cm^2 of skin
Position and movement	0.2–0.7 deg at 10-deg/min for joint movements	No data available
Angular acceleration	0.12 deg/sec^2 for oculogyral illusion	Positive-g forces of 5–8g lasting 1 sec or more Negative-g forces of 3–4.5g
Linear acceleration	0.08g for deceleration	Same limitations as for angular acceleration for forces acting in direction of long axis of body

*Mowbray and Gebhard, 1958.

Comparison of the frequency-detectability range and frequency-discrimination abilities of some of the senses.

Stimulant or sensation	Frequency-detectability range		Frequency-discrimination ability	
	Lowest	Highest	Relative	Absolute
Color (hue)	300 mμ	1,050 mμ at extremely high intensities	~128 discriminable hues at medium intensitie	12 or 13 discriminable hues
Interrupted white light	One interruption	~50 interruptions/sec at moderate intensities and duty cycle of 0.5	375 discriminable interruption rates between 1–45 interruptions/sec at moderate intensities and duty cycle of 0.5	5 or 6 discriminable interruption rates
Pure tones	20 cps	20,000 cps	1,800 discriminable tone differences between 20 cps and 20,000 cps at 60 db loudness	4 or 5 discriminable tones
Interrupted white noise	One interruption	~2,000 interruptions/sec at moderate intensities and duty cycle of 0.5	460 discriminable interruption rates between 1–45 interruptions/sec at moderate intensities and duty cycle of 0.5	Unknown
Mechanical vibration	1 cps	10,000 cps at high intensities	180 discriminable frequency differences between 1 and 320 cps	Unknown

* Mowbray and Gebhard, 1958.

Comparison of the discrimination abilities of some of the senses.

Sensation	Discrimination ability	
	Relative	Absolute
Sight	~570 discriminable intensity differences with white light	3–5 discriminable intensities in wh light of 0.1–50 mL
Hearing	~325 discriminable intensity differences at 2,000 cps	~3–5 discriminable intensities with pure tones
Mechanical vibration	15 discriminable amplitudes in chest region using broad contact vibrator with 0.05–0.5 mm amplitude limits	3–5 discriminable amplitudes

* Mowbray and Gebhard, 1958.

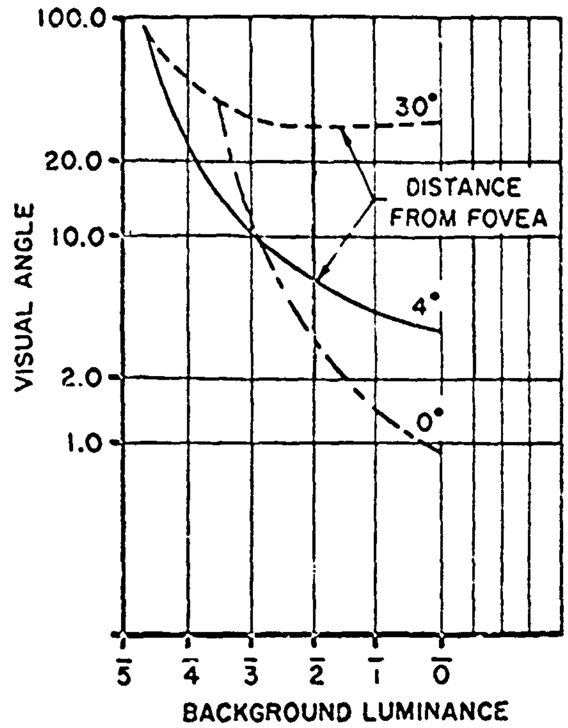
Characteristics of the senses.

Parameter	Vision	Audition	Touch	Taste and Smell	Vestibular
Sufficient stimulus	Light-radiated electromagnetic energy in the visible spectrum	Sound-vibratory energy, usually airborne	Tissue displacement by physical means	Particles of matter in solution (liquid or aerosol).	Accelerative forces
Spectral range	Wavelengths from 400 to 700 mu. (violet to red)	20 cps. to 20,000 cps.	>0 to <400 pulses per second	Taste—salt, sweet, sour, bitter. Smell—fragrant, acid, burnt, and caprylic	Linear and rotational accelerations.
Spectral resolution	120 to 160 steps in wavelength (hue) varying from 1 to 20 mu.	~3 cps. (20 to 1000 cps.) 0.3 percent (above 1000 cps.)	$\frac{\Delta pps}{pps} \cong 0.10$	—	—
Dynamic range	~90 db. (useful range) for rods = 0.00001 mL to 0.004 mL; cones = 0.004 mL to 10,000 mL	~140 db. 0 db = 0.0002 dyne/cm²	~30 db. .01 mm to 10 mm	Taste ≅ 50 db 3 × 10⁻⁸ to 3% concentration quinine sulphate. Smell = 100 db.	Absolute threshold ≅ 0.2°/sec/sec
Amplitude resolution $\frac{\Delta I}{I}$	contrast = $\frac{\Delta I}{I} = .015$	.5 db (1000 cps. at 20 db or above.)	~.15	Taste ≅ .20 Smell: .10 to 50	~.10 change in acceleration
Acuity	1' of visual angle	Temporal acuity (clicks) ≅ 0.001 sec.	Two point acuity = 0.1 mm (tongue) to 50 mm (back)	—	—
Response rate for successive stimuli	~0.1 sec.	~0.01 sec. (tone bursts)	Touches sensed as discreet to 20/sec.	Taste ~30 sec. Smell ~20 sec. to 60 sec.	~1 to 2 sec. nystagmus may persist to 2 min. after rapid changes in rotation.
Reaction time for simple muscular movement	~0.22 sec.	~0.19 sec.	~0.15 sec. (for finger motion, if finger is the one stimulated).	—	—
Best operating range	500 to 600μ (green-yellow) 10 to 200 foot-candles	300 to 6000 cps. 40 to 80 db	—	Taste: 0.1 to 10% concentration.	~1G acceleration directed head to foot.
Indications for use	1. Spatial orientation required. 2. Spatial scanning or search required. 3. Simultaneous comparisons required. 4. Multidimensional material presented. 5. High ambient noise levels. (Javitz, 1961)	1. Warning or emergency signals. 2. Interruption of attention required. 3. Small temporal relations important. 4. Poor ambient lighting 5. High vibration or G forces present. (Javitz, 1961)	1. Conditions unfavorable for both vision and audition. 2. Visual and auditory senses. (Javitz, 1961)	1. Parameter to be sensed has characteristic smell or taste. (i.e. burning insulation).	1. Gross sensing of acceleration information.
References	Baker and Grether, 1954 Chapanis, 1949 Woodson, 1954 Wulfeck, *et al.*, 1958	Licklider, 1951 Licklider and Miller, 1951 Rosenblith and Stevens, 1953 Stevens and Davis, 1938	Bekesy, 1961 Jenkins, 1951	Pfaffman, 1951	Wendt, 1951

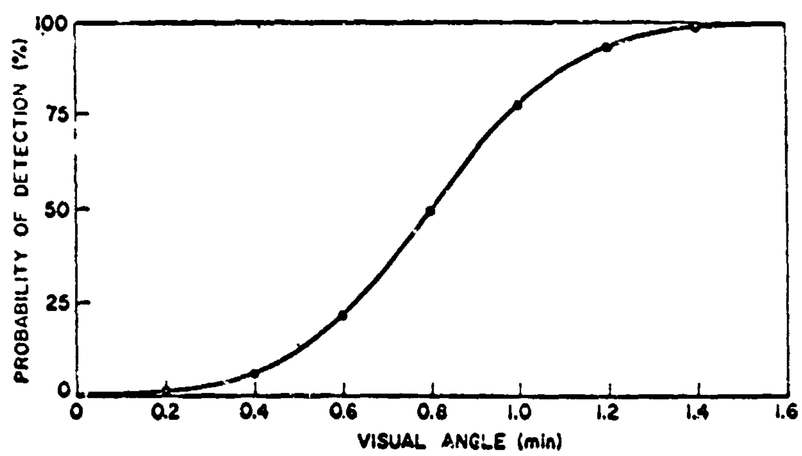
Variables which must be controlled when measuring some of the principal kinds of visual performance.

Type of Visual Performance	Variables to Be Controlled												
	Level of Illumination	Region of Retina Stimulated	Stimulus Size	Stimulus Color	Contrast between Test Object and Background	Adaptive State of Eye	Duration of Exposure	Distance at which Measured	Number of Cues Available	Movement	Other Objects in Field	Monocular vs. Binocular	Stimulus Shape
Visual acuity	X	X	(MV)[a]	X	X	X	X	X		X			X
Depth discrimination	X		X	X	X	X	X	X	X	X	X	X	
Movement discrimination	X	X	X	X	X	X	X	X	X	(MV)[a]	X		X
Flicker discrimination	X	X	X	X	X	X	X						
Brightness discrimination	X	X	X	X	(MV)[a]	X	X			X		X	X
Brightness sensitivity		X	X	X	(MV)[a]	X	X			X			X
Color discrimination	X	X	X	(MV)[a]	X	X	X	X	X		X		

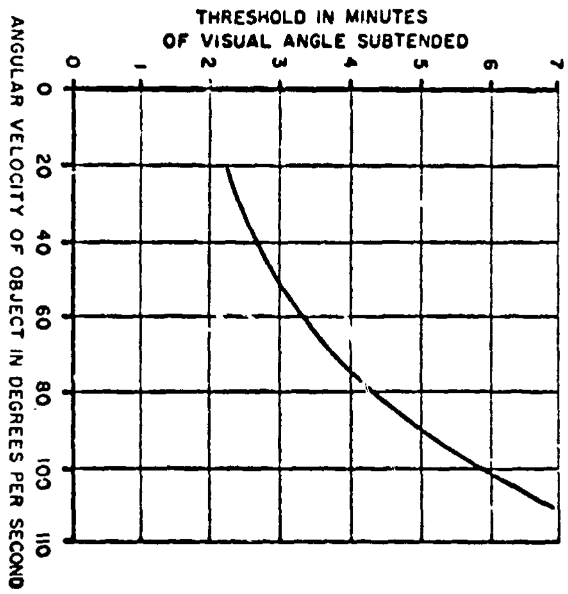
[a] Variable being measured
(From Wulfeck *et al.*, 1958)



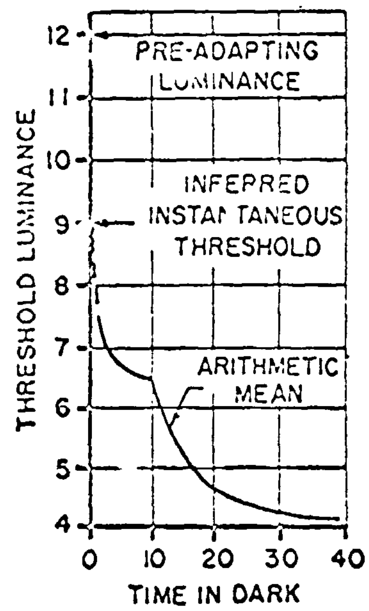
Visual angle of the smallest detail that can be discriminated as a function of background luminance.



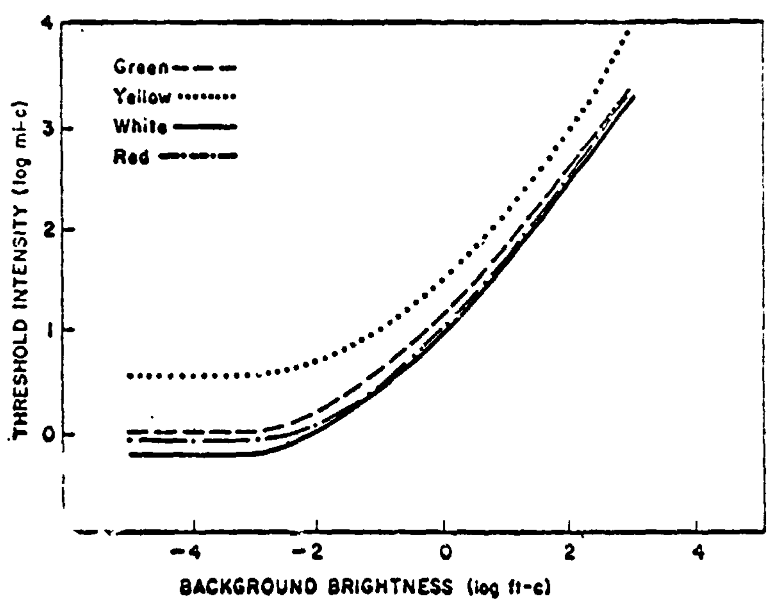
Probability of target detection as a function of target size (visual angle) when target is known.



Vis .l Acuity as a Function of ,elative Movement Between Observer and target.



Luminance that can just be seen as function of time in darkness.



[illegible] oint-source signal light of various colors when [illegible] against neutral background of various brightness.

DISPLAY, MOVING ELEMENT THRESHOLD DETECTION

Accurate tracking (control-display response) requires detection of movement of a displayed element. Very slow movement of the element tends to degrade the accuracy of tracking as well as detection of real vs noise targets. The following movement rates are required for effective operator response:

Threshold of Movement Detection: e.g., moving element viewed against a textured background:

1 to 2 min/sec

Moving element against uniform background:

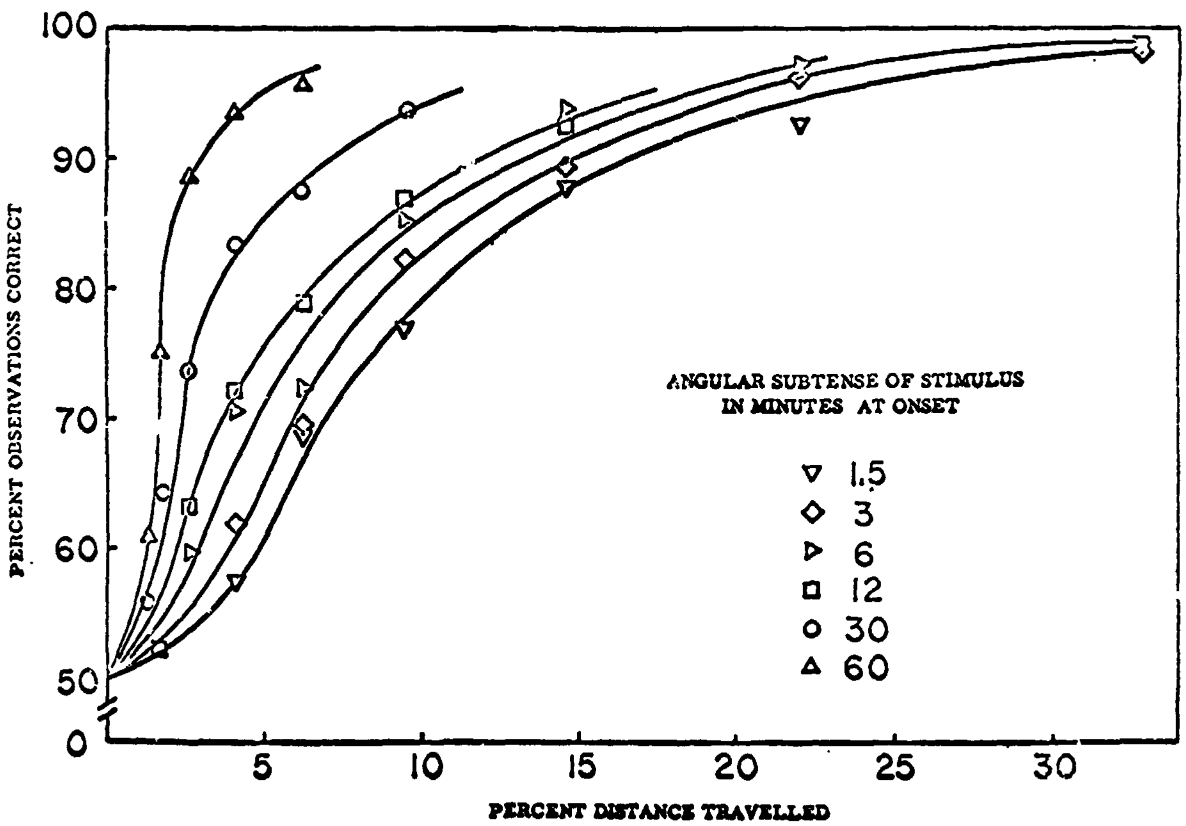
10 to 20 min/sec

Phi movement threshold:

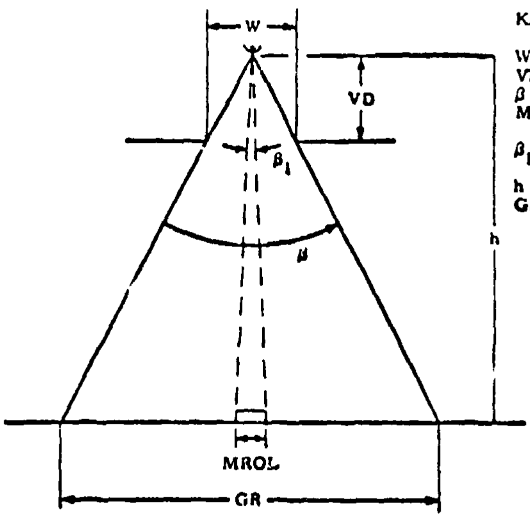
3° to 9°/sec

Blurring threshold:

12° to 30°/sec



Threshold Data for Visual Judgment of Target Motion During Rendezvous.



KEY

W	Window Size
VD	Viewing Distance
β	Viewing Angle
MROL	Minimum Resolvable Object Length
β_1	Angle Subtended at Eye by MRO
h	Orbital Altitude
GR	Ground Range, Naut Miles

Geometrical Relationships for Computing Optimum Direct Vision Capabilities.

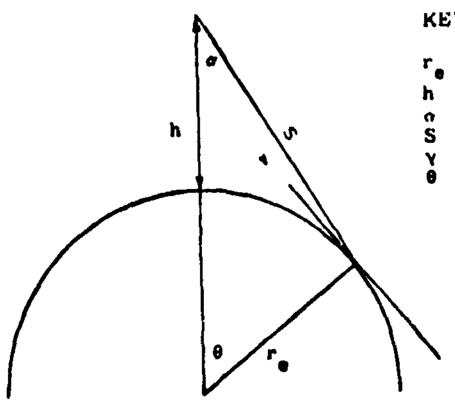
THEORETICAL CAPABILITIES OF DIRECT, UNAIDED VISION

Orbital altitude **h** *miles*	*Orbital velocity m.p.h.*	*Orbital period hrs–min.*	*Minimum resolvable object length* (MROL) *ft.*	*Ground range, nautical miles (By viewing distance to 7 in. vehicle window)* 12 in.	14 in.	16 in.
113	17,446	1:28	1730	66	56	49
505	16,663	1:41	7732	295	253	220
738	16,245	1:49	11,300	431	369	322
993	15,821	1:58	15,204	579	496	434
1485	15,089	2:16	22,738	866	742	649
2006	14,415	2:36	30,715	1170	1003	877
3542	12,854	3:40	54,325	2066	1771	1549
5059	11,723	4:50	77,643	2951	2529	2212
7585	10,362	7:00	116,141	4425	3742	3317
10,026	9414	9:20	153,518	5849	5013	4385
12,576	8658	12:00	192,563	7337	6283	5501
15,653	7950	15:30	239,678	9131	7826	6846
17,708	7563	18:00	271,144	10,330	8854	7745
20,053	7184	21:00	307,051	11,989	10,026	8771
22,289	6872	24:00	341,289	13,003	11,145	9749

TIME TO VIEW GROUND OBJECTS AS A FUNCTION OF ORBITAL ALTITUDE

(7 in. Window, 12 in. Viewing Distance)

Orbital altitude (miles)	*Time to view (min)*	*Orbital altitude (miles)*	*Time to view (min)*
113	0.422	7,585	121.5
505	1.48	10,026	248
738	2.37	12,576	489
993	3.45	15,653	1111
1485	5.87	17,708	2080
2006	9.47	20,053	5550
3542	24.20	22,289	∞
5059	49.70		



KEY

- r_e Earth Radius
- h Satellite Altitude
- α Look Angle from Satellite
- S Slant Range to Object
- γ Aspect Angle of Object
- θ Subtended Earth Central Angle

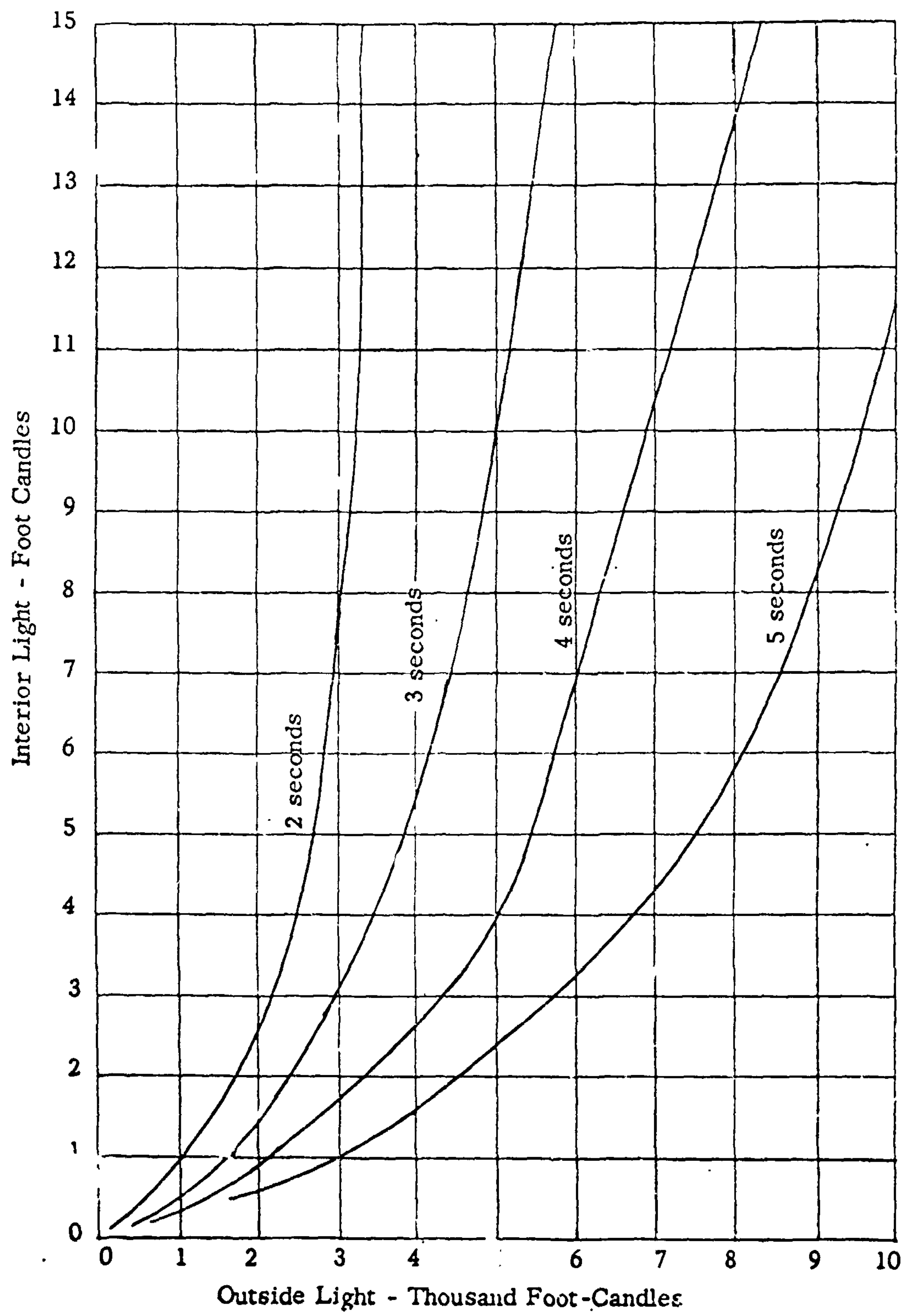
Simplified Geometrical Relationships for Forward Area Scan From Satellite

THEORETICAL CAPABILITIES OF DIRECT, UNAIDED VISION: FORWARD SCAN

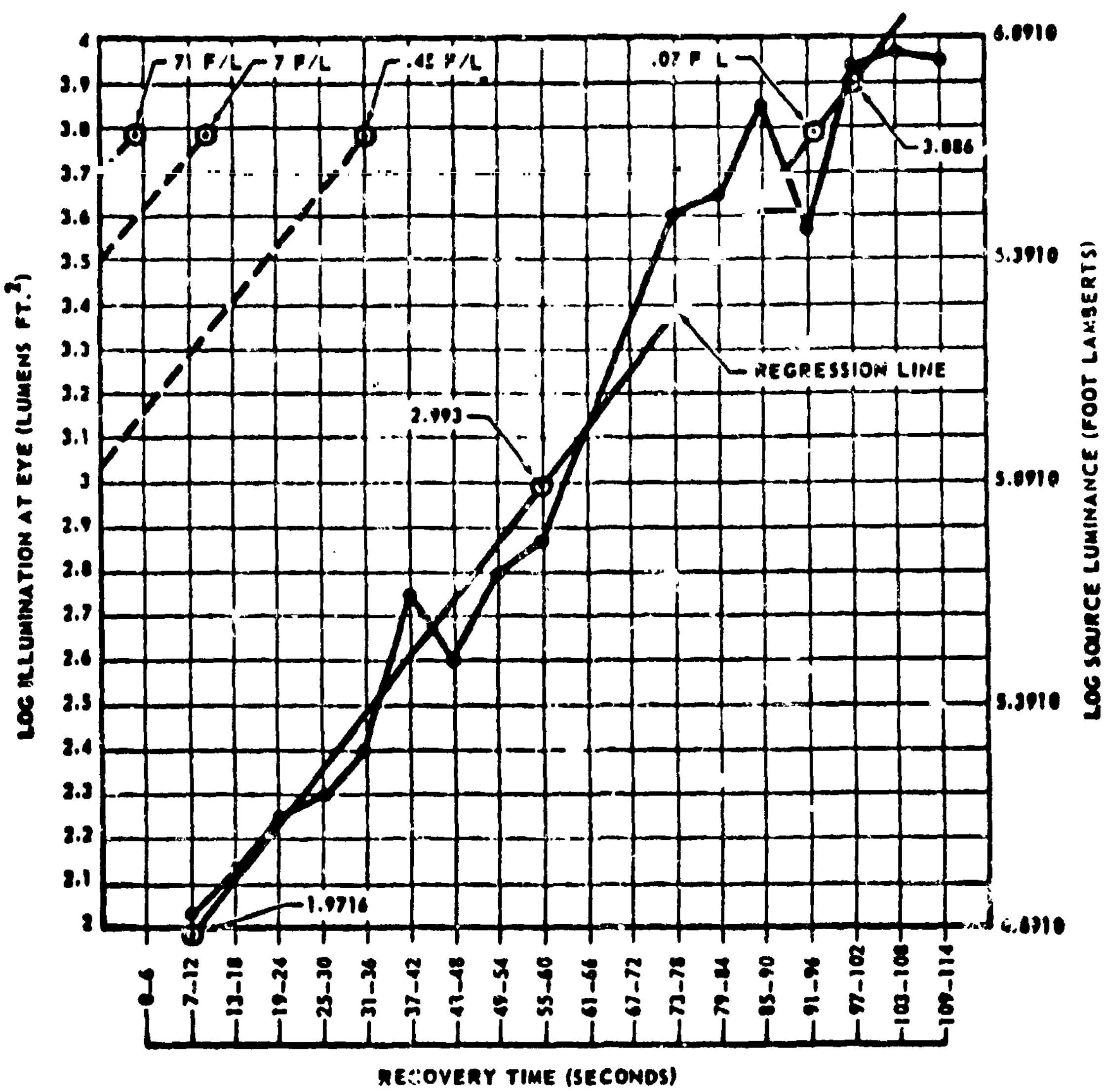
Orbital, altitude, nautical miles

Look angle	100			150			200			250			300		
	t	S	γ	t	S	γ	t	S	γ	t	S	γ	t	S	γ
0	0.0	100	90	0.0	150	90	0.0	200	90	0.0	250	90	0.0	300	90
5	2.1	100.3	84.9	3.3	151	84.8	4.4	202	84.7	5.6	252	84.6	7.01	303	84.5
10	4.4	102.7	79.7	6.6	152	79.6	9.0	204	79.4	11.4	254	79.3	14.0	306	79.1
20	8.8	105.3	69.4	13.6	160	69.1	18.7	214	68.8	23.9	267	68.5	29.2	321	68.2
30	14.2	116.5	59.0	21.9	175	58.5	29.7	233	58.1	38.0	292	57.6	43.2	352	57.3
40	20.7	131.7	48.6	31.9	198	47.9	43.8	267	47.1	57.6	344	46.4	69.2	405	45.7
50	29.8	159	38.0	46.2	241	36.9	63.5	325	35.8	82.2	411	34.7	101.8	500	33.6
60	44.5	210	27.0	69.8	323	25.3	98.0	443	23.6	129.3	572	21.7	164.5	712	19.7
70	77.0	335	14.7	130.5	554	11.3	212.5	878	6.1	—	—	—	—	—	—

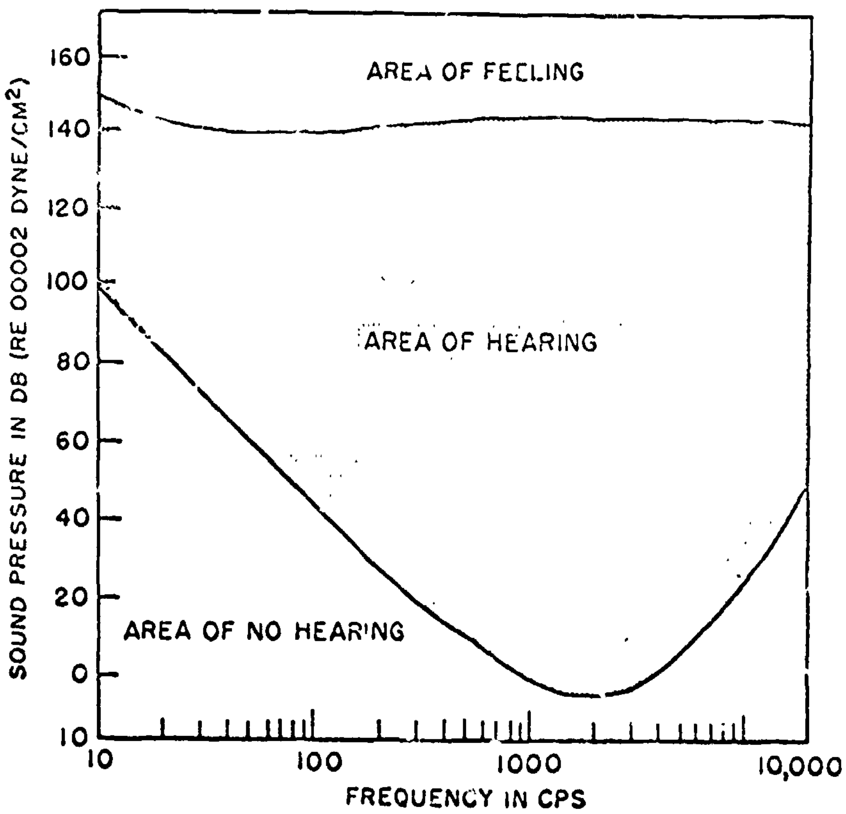
t = time to pass over object, seconds.
S = slant range to object, nautical miles.
γ = aspect angle of object.



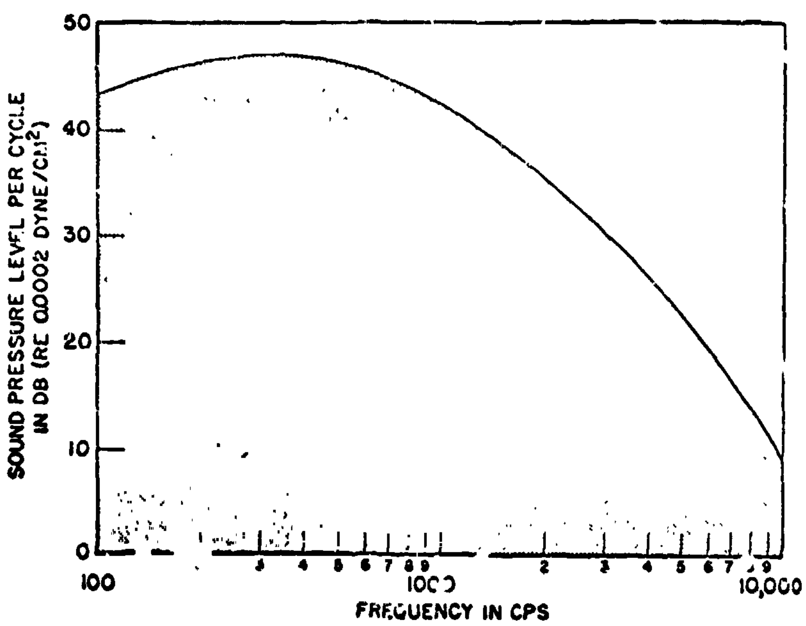
Glare Recovery Time Curves
for Map Reading After 5 Min. Exposure to Outside Light



Recovery time for visual task performance following brief (0.1 sec) exposure to various light intensities. The solid curve indicates visual task performance with object luminance of 0.07 ft-L and the dotted lines indicate performance with higher luminances. The flash intensity is indicated in the ordinates.



Threshold of audibility as a function of frequency.

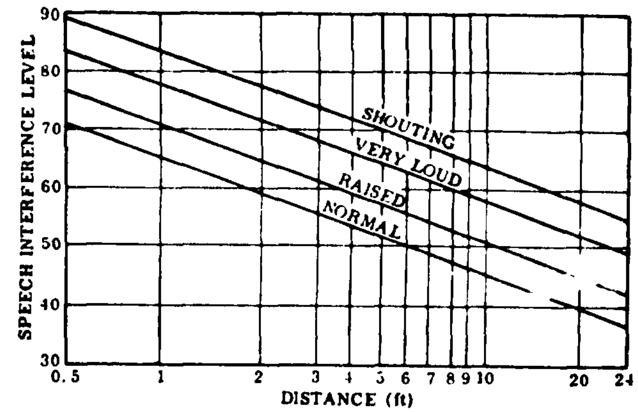


Average speech spectra.

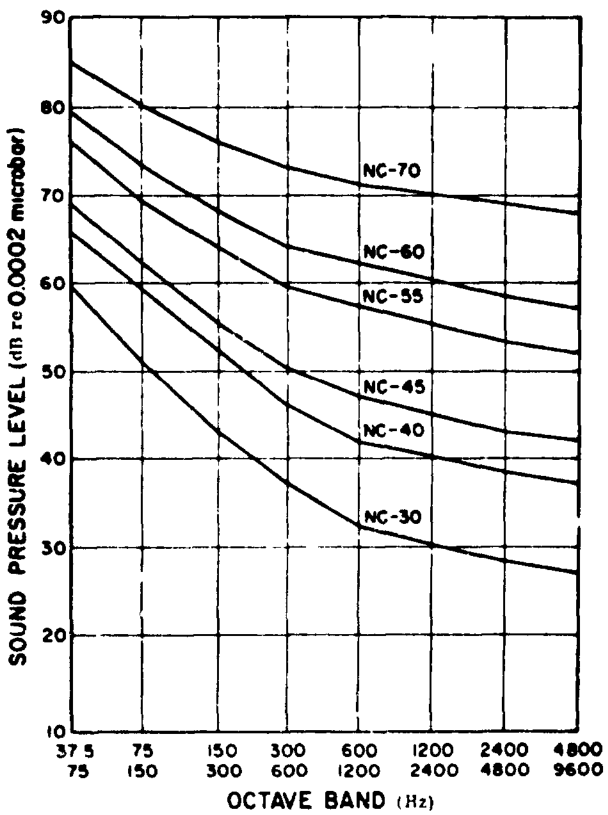
SPEECH COMMUNICATION (ARTICULATION INDEX)

Criticality of Communication for Proposed System	Articulation Index (minimum)
Sentence recognition is required	0.3
Isolated words are critical	0.5
Separate syllables must be intelligible	0.7

NOTE: If noise spectrum is relatively flat and steady, and communication requirements do not exceed an estimated AI of 0.5, acoustic acceptability may be based on the Speech Interference Level (Figure 42).



PERSON-TO-PERSON COMMUNICATIONS



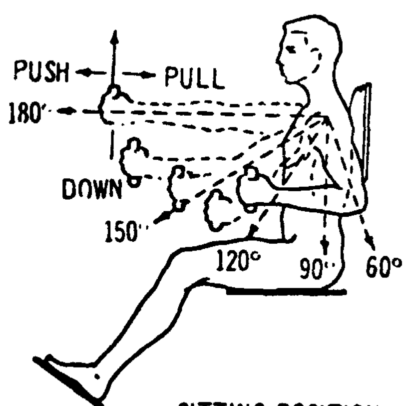
NOISE CRITERIA (NC) CURVES FOR SPEECH COMMUNICATION

NOISE CRITERIA FOR SPEECH COMMUNICATIONS

Area	Maximum Level
Maintenance areas	
Occasional nonelectrically aided voice communication	NC70
Intermittent direct communication and telephone conversation	NC60
Offices, shops and other areas where equipment used regularly	
Continuous direct communication	NC60
Frequent telephone communication	NC45
Aircraft	
Desirable for high intelligibility	NCA65
Maximum for high intelligibility	NCA70
Other areas	
General offices, command and control centers, drafting rooms and similar	NC40
Where extreme quiet is required	NC30

DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB) 5TH		50TH		95TH		S.D.	
		L	R	L	R	L	R	L	R
PUSH	60	22	34	79	92	164	150	31	38
	90	22	36	83	86	172	154	35	33
	120	26	36	99	103	180	172	42	43
	150	30	42	111	123	192	194	48	45
	180	42	50	126	138	196	210	47	49
PULL	60	26	24	64	63	110	74	23	23
	90	32	37	80	88	122	135	28	30
	120	34	42	94	104	152	154	34	31
	150	42	56	112	122	168	189	37	36
	180	50	52	116	120	172	171	37	37
LEFT	60	12	20	32	52	62	87	17	19
	90	10	18	33	50	72	97	19	23
	120	10	22	30	53	68	100	18	26
	150	8	20	29	54	66	104	20	25
	180	9	20	30	50	64	104	20	26
RIGHT	60	17	17	50	42	83	82	21	20
	90	16	16	48	37	87	68	22	18
	120	20	15	45	34	89	62	21	17
	150	15	15	47	33	113	64	27	18
	180	13	14	43	34	92	62	22	24
UP	60	15	20	44	49	82	82	18	18
	90	17	20	52	56	100	106	22	22
	120	17	24	54	60	102	124	25	24
	150	15	18	52	56	110	118	27	28
	180	9	14	41	43	83	88	23	22
DOWN	60	18	20	46	51	76	89	18	21
	90	21	26	49	53	92	88	20	20
	120	21	26	51	58	102	98	23	23
	150	18	20	41	47	74	80	16	18
	180	13	17	35	41	72	82	15	18

HUNSICKER, 1955.



Maximum force exerted in the sitting position on a vertical handgrip at various elbow angles (right hand) (left hand); male college students.

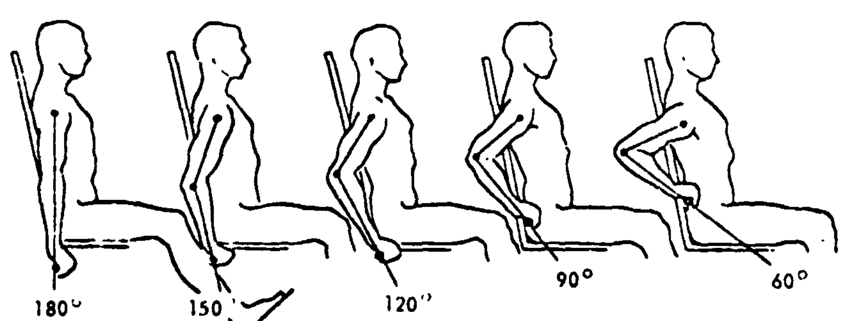
Maximum force exerted in the sitting position with the hand grasping (thumb away from body palm forward) at various elbow angles by the right and left arms of male college students

DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB) 5TH		50TH		95TH		S.D.	
		L	R	L	R	L	R		
PUSH	60	35	34	69	96	176	172	42	39
	90	25	25	59	65	104	117	27	24
	120	15	20	40	43	80	71	18	17
	150	13	17	38	36	69	59	30	14
	180	14	12	30	32	47	58	10	15
PULL	60	23	16	54	51	87	93	23	25
	90	13	13	42	43	68	74	21	19
	120	14	11	40	40	66	63	18	17
	150	16	11	40	37	62	66	15	17
	180	17	15	40	39	70	73	18	19
RIGHT	60	16	18	38	44	64	73	12	19
	90	12	16	32	39	46	72	12	24
	120	14	17	31	34	55	64	13	15
	150	12	[illegible]	32	32	62	60	15	14
	180	12	14	29	29	43	48	9	12
LEFT	60	17	13	42	36	81	70	20	17
	90	16	13	33	31	52	48	12	12
	120	14	12	28	30	45	46	8	11
	150	12	12	26	31	43	52	10	14
	180	8	10	27	28	44	44	10	10
UP	60	20	17	49	45	89	78	22	22
	90	24	21	75	63	131	107	29	27
	120	38	41	94	88	152	143	33	33
	150	44	37	104	103	164	161	36	40
	180	45	51	111	113	173	165	40	34
DOWN	60	20	20	58	59	138	132	41	35
	90	23	17	80	80	160	143	43	37
	120	35	29	84	92	136	148	33	13
	150	43	37	84	93	136	150	29	35
	180	36	44	78	87	124	135	28	32

HUNSICKER AND GREEY, 1957.

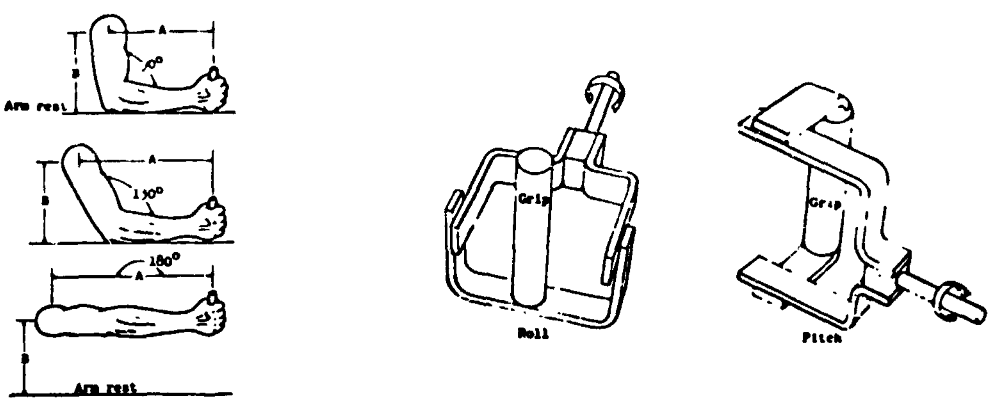
DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB) 5TH		50TH		95TH		S.D.	
		L	R	L	R	L	R	L	R
PUSH	60	33	40	86	94	138	156	35	36
	90	27	25	60	65	93	100	28	24
	120	17	23	43	46	71	70	17	15
	150	15	18	37	40	69	66	18	18
	180	12	17	32	32	59	59	13	12
PULL	60	20	13	39	37	64	50	18	16
	90	17	14	37	32	65	54	18	13
	120	12	13	30	26	56	43	14	10
	150	15	12	32	29	52	48	13	10
	180	16	11	34	28	61	48	15	12
RIGHT	60	20	19	42	41	66	72	15	19
	90	17	12	38	31	60	64	12	15
	120	17	9	34	26	53	53	8	13
	150	17	9	31	21	54	39	11	11
	180	15	10	28	19	41	34	8	7
LEFT	60	18	16	36	48	51	73	15	18
	90	11	16	27	39	54	59	11	15
	120	10	15	22	34	39	47	10	11
	150	9	18	23	32	53	45	16	7
	180	10	16	20	31	49	57	13	13
UP	60	22	23	57	49	100	79	22	20
	90	37	28	77	69	123	112	24	29
	120	45	41	91	91	145	138	30	30
	150	58	43	100	99	159	165	32	38
	180	47	35	101	95	171	156	11	35
DOWN	60	18	23	74	81	139	158	35	35
	90	23	22	75	83	136	142	34	35
	120	29	37	75	92	148	161	40	35
	150	39	40	79	90	136	154	29	34
	180	34	41	76	87	138	143	31	31

HUNSICKER AND GREEY, 1957.



SITTING POSITION

Maximum force exerted in the sitting position with the hand grasping (thumb toward body, palm rearward) at various elbow angles by the right and left arms of male college students.



Pilot	Distance A in.			Distance B, in.		Maximum controller angle (unconstrained), deg							
						Right Roll		Left Roll		Forward Pitch		Rearward Pitch	
	Measured at elbow angle of -												
	90°	130°	180°	90°	130°	90°	130°	90°	130°	90°	130°	90°	130°
1	15.00	19.00	26.25	13.00	12.50	105	105	80	75	45	35	30	40
2	11.50	18.00	25.ᴗ0	12.75	11.50	90	100	90	100	65	70	30	30
3	13.00	18.00	25.00	13.00	12.00	90	90	90	95	55	60	30	35
4	12.00	18.00	25.00	13.00	12.00	85	85	75	80	50	45	30	30
5	14.00	18.50	26.00	13.00	12.50	90	95	90	100	60	65	30	30
6	14.50	18.50	27.00	13.75	13.75	90	100	90	100	75	55	45	40
7	12.50	18.00	25.0ᴗ	12.75	11.50	90	90	105	105	70	75	30	30
8	13.50	18.50	27.00	13.25	13.00	100	95	100	100	80	75	30	30
9	13.30	18.50	27.00	13.25	13.00	90	90	105	105	45	45	40	40
10	13.00	17.50	27 50	13.75	13.50	90	100	90	105	75	65	55	55
11	14.50	18.75	28.50	13 25	13.75	90	105	90	105	60	75	30	30
Average	13.35	18.30	26 30	13.15	12.63	91.8	96	91.4	97.3	61.8	60.4	34.5	35.0

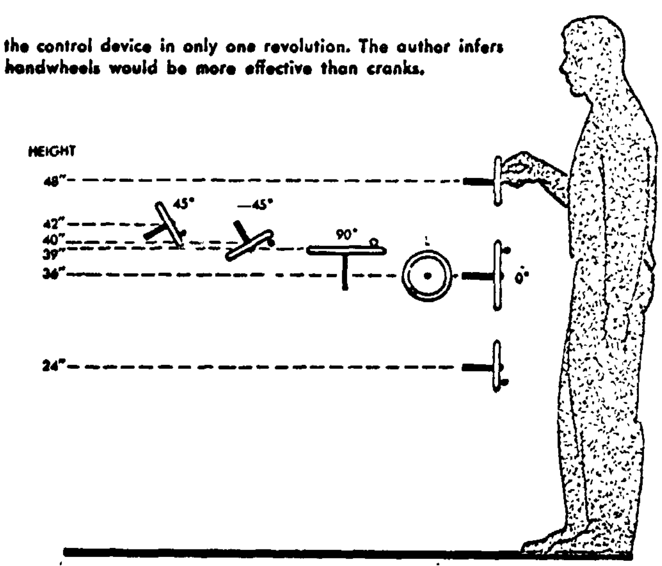
Measurements of the arms of pilots using a mockup of a side-arm controller, and of the unconstrained angular deflections they could achieve in roll and pitch with the controller. Data were taken with the arm straight or flexed as shown. The preferred neutral position for the controller was found to be 8° to the right and 15° forward of the vertical. The preferred arm position was a slight forward extension from 90°.

Force Capabilities Using Side-Arm Controller

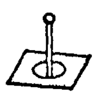
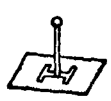
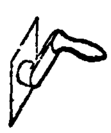
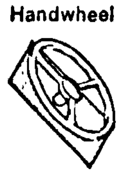
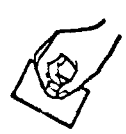
Handwheel/Crank Position, Diameter vs Force Requirements

HEIGHT (in.)	POSITION (deg.)	TYPE	SIZE Handwheel (W), Diameter in Inches; Crank (C), Radius in Inches — AT TORQUE OF 0 in. lb	40 in. lb	90 in. lb
24	0	W	3-6	10	16
36	0	W	3-8	10-16	16
	L	W	3-6	10	10
	0	C	1½-4½	4½-7½	4½-7½
39	90	W	3-10	10-16	16
	90	C	2½-4½	4½-7½	4½-7½
40	−45	W	3-6	6-16	10-16
	−45	C	2½-7½	4½-7½	4½-7½
42	45	W	3-6	10	10-16
	45	C	2½-4½	2½-4½	4½
48	0	W	3-6	8-16	10-16
	0	C	2½-4½	4½	4½-7½

These data were based on setting the control device in only one revolution. The author infers that for less than 90-degree turn, handwheels would be more effective than cranks.

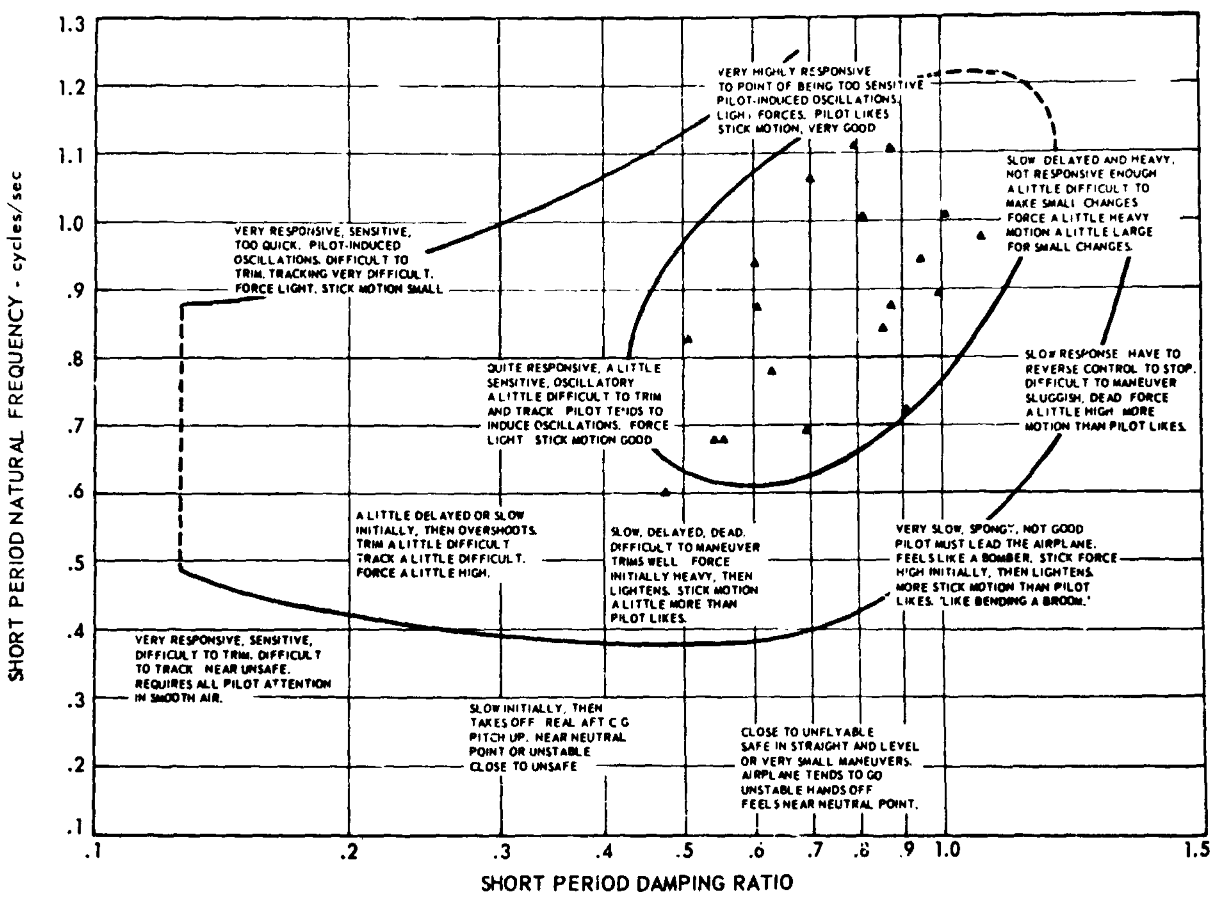


Guiding Principles for positioning Control Units

Type of control		Speed	Accuracy	Energy expenditure	Range	Load
Horizontal lever 		good	poor	poor	poor	up to ca. 9 kg
	Vertical lever	good	moderate	good	poor	up to ca. 13 kg
Joy-stick 	small	good	moderate	poor	poor	ca. 1 kg
	large	good	poor	good	poor	ca. 2 – 9 kg
Gear lever 		good	good	poor	very poor	up to ca. 9 kg
Crank 	small	good	poor	very poor	good	0·9 – 2·5 kg lever arm: up to 120 mm
	big	poor	very poor	good	good	over 3·5 kg lever arm: 150 – 220 mm
Handwheel 		poor	good	moderate	moderate	2 – 25 kg diameter 180 – 500 mm
Knob with continuous function 	small	poor	good	very poor	moderate	up to 450 cmg diameter 10 – 30 mm
	large	very poor	moderate	poor	moderate	up to 2500 cmg diameter 35 – 75 mm
Knob with step functions 		good	good	very poor	very poor	350 – 1500 g diameter 25 – 100 mm

Summary of the principal features of common control systems

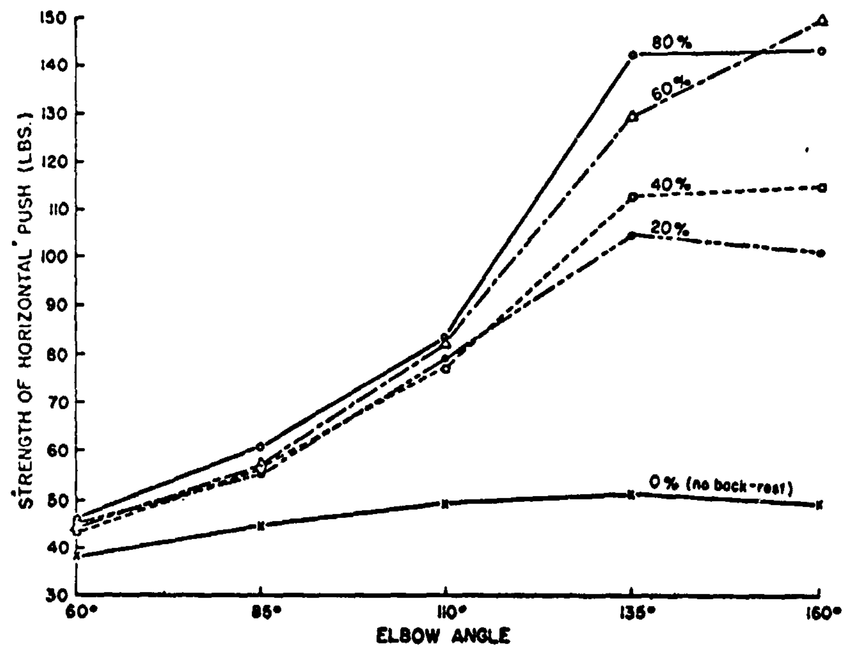
VEHICLE DYNAMIC RESPONSE VS. PILOT OPINION



The curves denote approximate boundaries of pilot opinion as measured on a five point opinion rating scale based on flight testing in a variable stability fighter-type aircraft. The rating scale is shown below. The inner curve bounds the acceptable region. The outer curve bounds the acceptable-poor and unacceptable regions. The data points show the "Best Tested" configurations. The comments are summaries of prevalent pilot remarks in various regions of natural frequency and damping.

Pilot Opinion Rating Scale

1. Optimum: This configuration is the best all around. It combines best precision of control with most comfortable control.
2. Acceptable, Good: Noticeably better than acceptable but still could be improved. For example, very comfortable to fly but not the best control precision.
3. Acceptable: In this configuration, the airplane's mission could be accomplished reasonably well, but with considerable pilot effort or attention required directly for flying the airplane.
4. Acceptable, Poor: Airplane safe to fly, but pilot effort or attention required is such as to reduce seriously the effectiveness of the airplane in accomplishing its mission.
5. Unacceptable: Pilot effort or attention required to the extent that the airplane's ability to accomplish its mission is doubtful. Or, airplane would be unsafe to fly if pilot's attention is required for navigation, radio, combat, etc.



Strength of arm extension (push) at five elbow angles with five conditions of back support.

Hand torque and hand flexion force which the human can apply with and without full pressure suit.

Means of Test Results

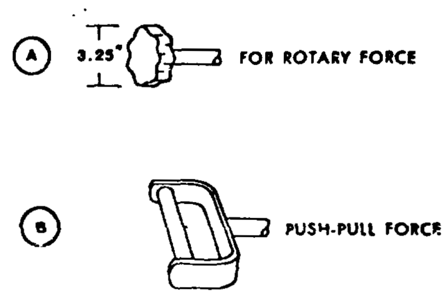
	Purdue Pegboard†				Hand Torque‡ Screwdriver		Hand Torque‡ Ball		Hand Torque‡ Knob		Hand Flexion§	
	Right	Left	Both	Assy.*	Pron.*	Sup.*	Pron.*	Sup.*	Pron.*	Sup.*	Right	Left
Without full-pressure suit	16.83	17.66	27.00	9.79	69.17	57.50	73.33	85.83	118.33	117.50	110.83	111.66
With full-pressure suit, unpressurized	8.16	8.16	12.66	3.63	62.50	45.83	70.00	74.16	118.66	140.83	78.33	80.00
With full-pressure suit, pressurized	6.00	6.83	6.16	2.00	51.66	48.66	56.66	60.83	105.50	105.83	60.00	60.83

* Abbreviations: Assy. = Assembly; Pron. = Pronation; Sup. = Supination.

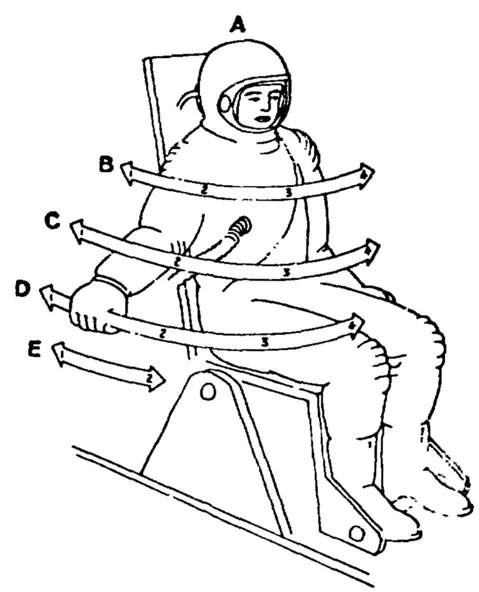
† Purdue pegboard measurements indicate number of pins placed in holes by right hand, left hand, and both hands in 30 sec, and the number of assemblies completed in 60 sec.

‡ Hand torque measurements in inch-pounds.

§ Hand flexion measurements in pounds.



(20th percentile subject
wearing Mark IV suit
pressurized at 3.5 psig)



MANUAL FORCES IN A PRESSURIZED SUIT

MEASUR-ING POINT	DISTANCE FROM SRP			STIRRUP (B)		KNOB (A)			
	Verti-cally	Later-ally	Longi-tudi-nally	Push	Pull	Clock-wise	Counter-clock-wise	Clock-wise	Counter-clock-wise
A-1	34	12	11	15	60	110	100	55	45
B-1	28	30	5	50	80	125	140	65	75
2	28	24	15	45	85	105	105	50	55
3	28	16	20	35	85	145	140	70	70
4	28	9	21	30	80	80	100	60	65
C-1	18	31	4	45	70	125	145	50	65
2	18	28	12	55	90	85	120	65	60
3	18	21	19	65	80	115	135	80	60
4	18	6	22	50	80	125	140	80	55
D-1	8	28	4	45	55	130	150	30	55
2	8	25	12	50	75	105	140	35	45
3	8	19	18	50	90	120	140	50	65
4	8	10	20	45	80	105	150	45	65
E-1	2	20	5	60	85	100	125	50	50
2	2	12	14	60	80	95	140	50	60

NOTE: Measuring points are in inches fro[illegible] [illegible]eat Reference Point (SRP). Push and pull figures are given in pounds, rotating forc[illegible] [illegible]ounds.

HUMAN WORK OUTPUT CYCLING (HORSEPOWER) LIMITS

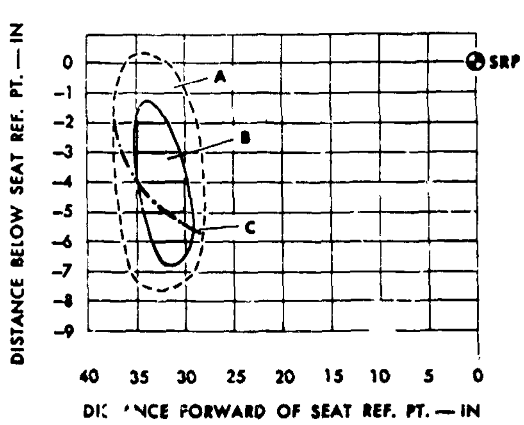
For about 1 second	6 horsepower
5 minutes	.5 to 2 horsepower
up to about 150 minutes	.4 to .5 horsepower
8 hours	.2 horsepower

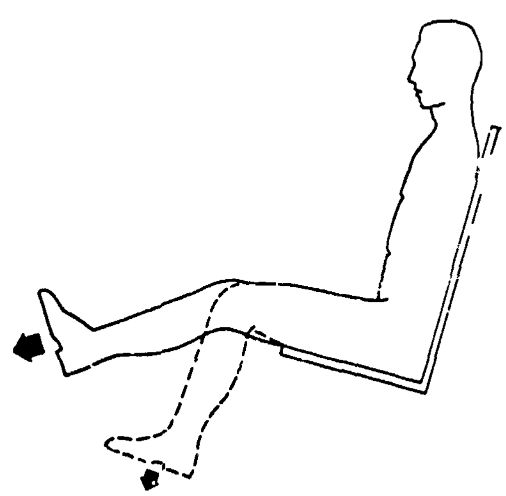
(Wilkie, D.R., Man as a Source of Mechanical Power, Ergonomics 3: 1-8, 1960)

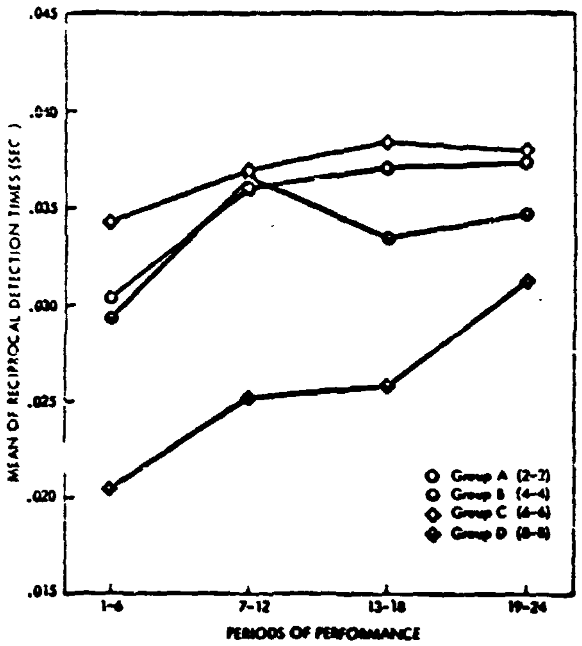
LEG STRENGTH

The following maximum forces can be applied to pedal controls by the average man assuming proper back support and optimum leg angle:

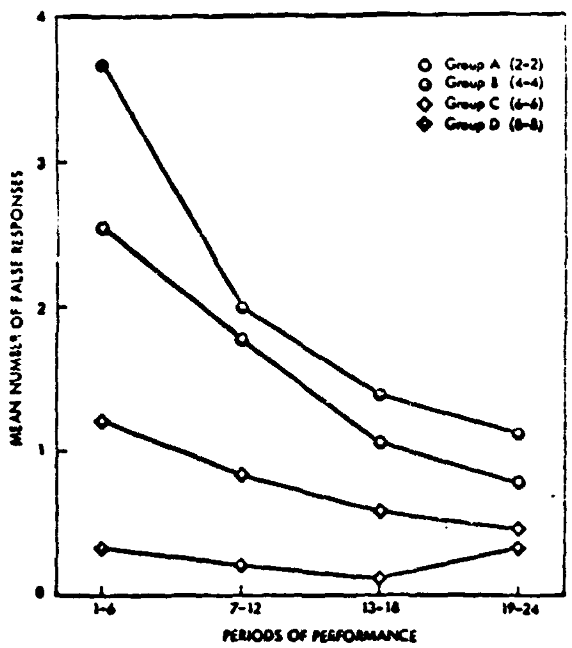
Up to 400 pounds of force can be applied by an average man in area A of the graph below, up to 600 pounds in area B. Line C represents a recommended optimum path of pedal travel where force application is considered a requirement.





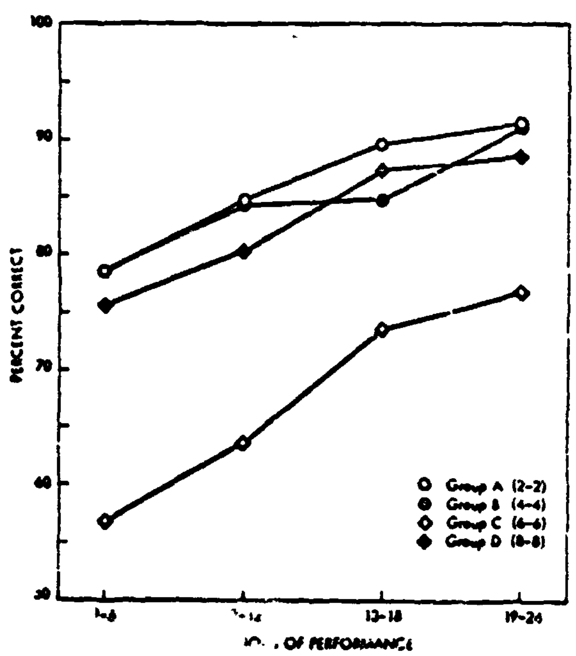


Detection Time



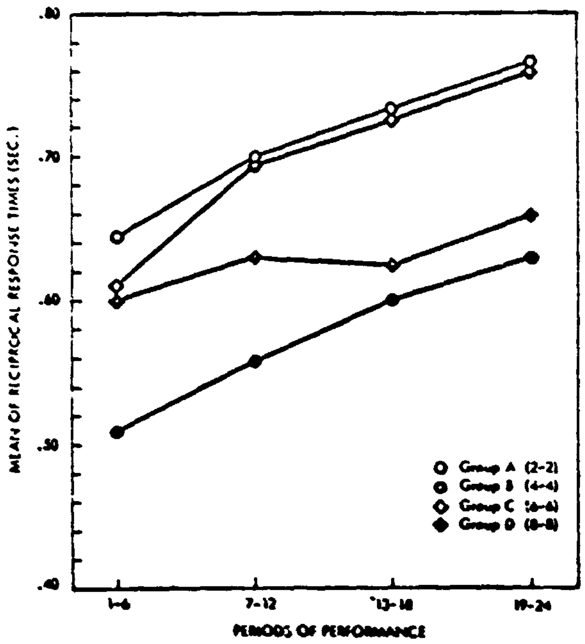
Probability of False Response

(2-2 = two hrs
on, two hrs off)

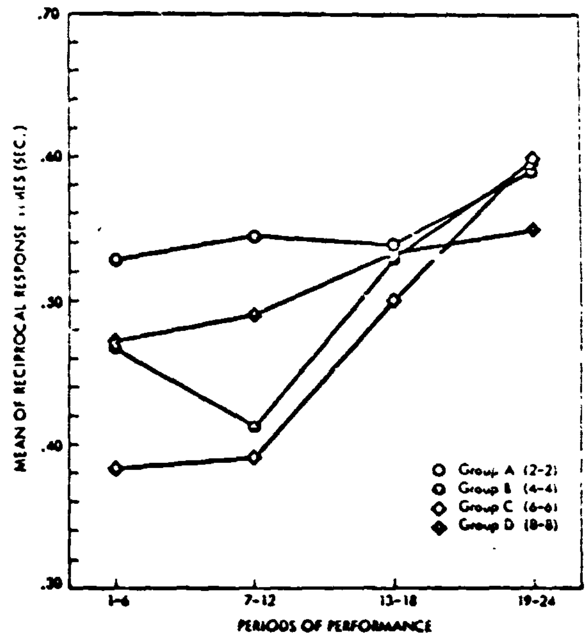


ɪtory Vigilance

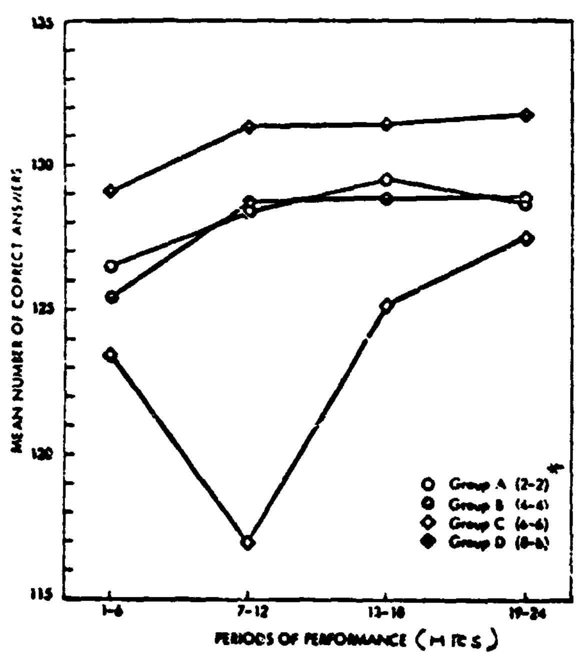
Performance Efficiency vs Work-Rest Cycle Configuration



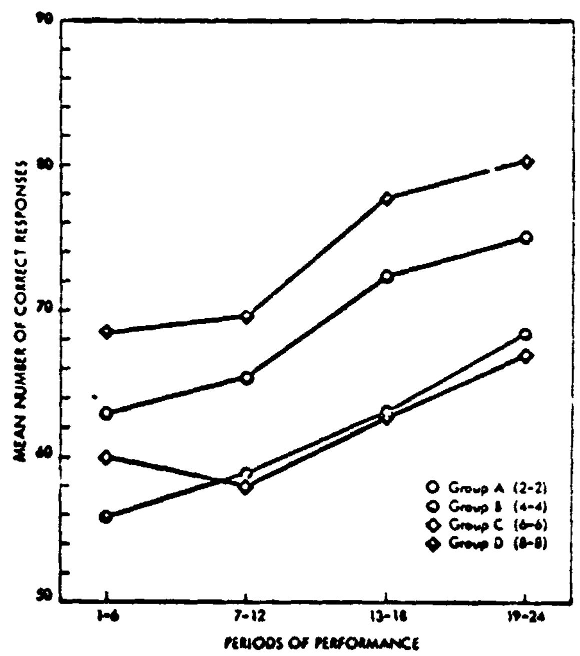
Probability Monitoring
(Response to Red Lights)



(Response to Green Lights)

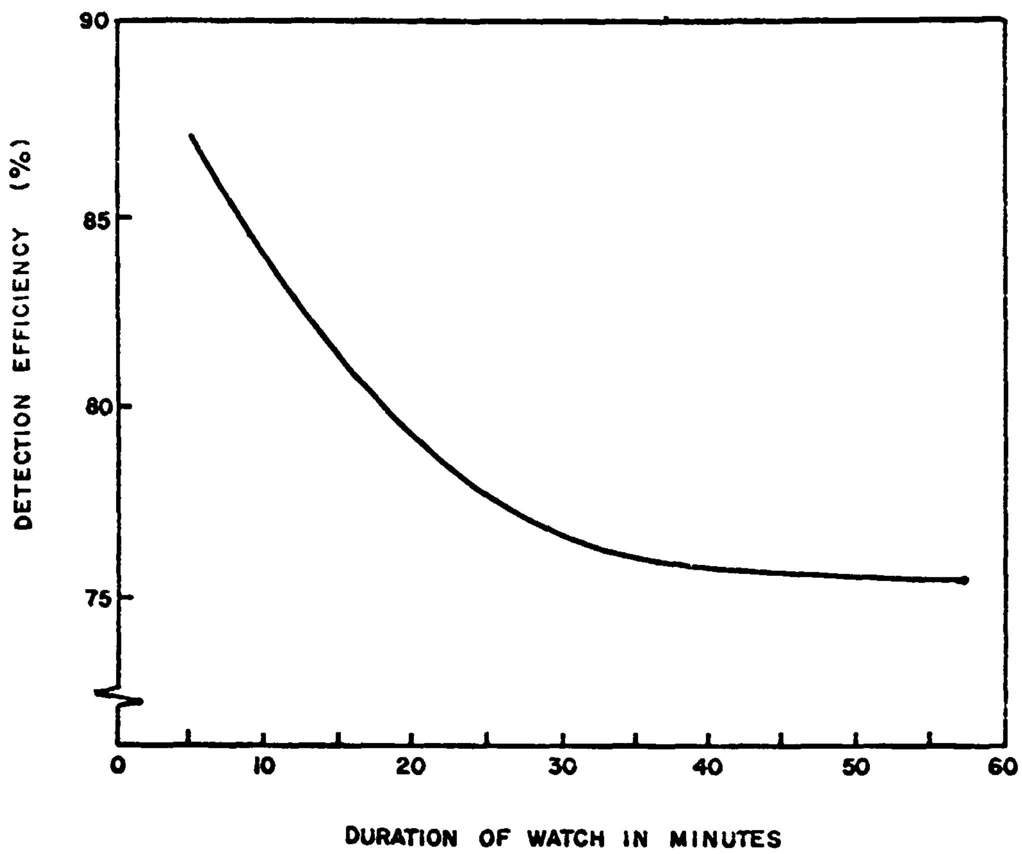


Arithmetic Computation



Pattern Discrimination

Performance Efficiency vs Work-Rest Cycle Configuration



Predicted event detection efficiency of group of radar operators in terms of alerted performance as a function of watch duration.

HUMAN BEHAVIORAL RESPONSE VS ENVIRONMENTS (GENERAL)

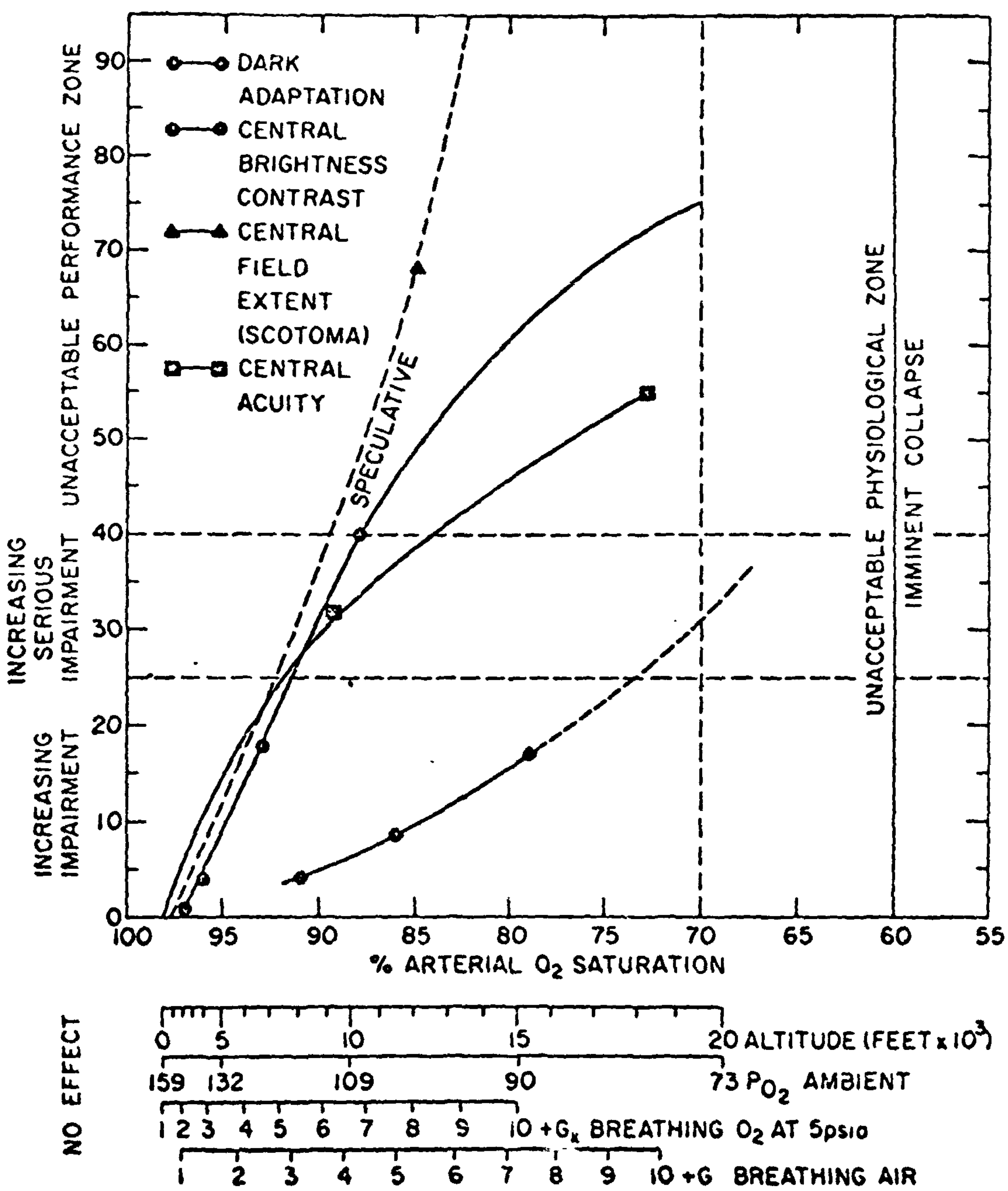
ENVIRONMENT	COMFORT ZONE	DISCOMFORT/ POSSIBLE DAMAGE
Acceleration	0 - 0.1 g	>1 g
Atmospheric Pressure	10 - 20 PSIA	8 PSIA
Atomic Radiation	0 - .2 Rem/yr	15 Rem/yr
Carbon Dioxide	0 - 1700 PPM	40,000 PPM
Carbon Monoxide	0 - 100 PPM	3,000 PPM
Electricity(60 cycle)	0 - 1 MA	10 MA
Heat Loss	330 - 1450 BTU/hr	>3,000 BTU/hr
Humidity	30 - 70 %	<10 - >90 %
Light	20 - 100 Ft-c	>10,000 Ft-c
Mechanical Vibration	0 - 1 cps 0 - .005 inches	10 cps .05 inches
Noise	0 - 85 db	>95 db
Oxygen	15 to 60 %	>60 %
Shock Waves	0 - 2.5 psig	>7 psig
Temperature	65 - 75°F	<30 - >100°F
Ventilation	13 - 20 cu ft/min	<5 - >50 cu ft/min

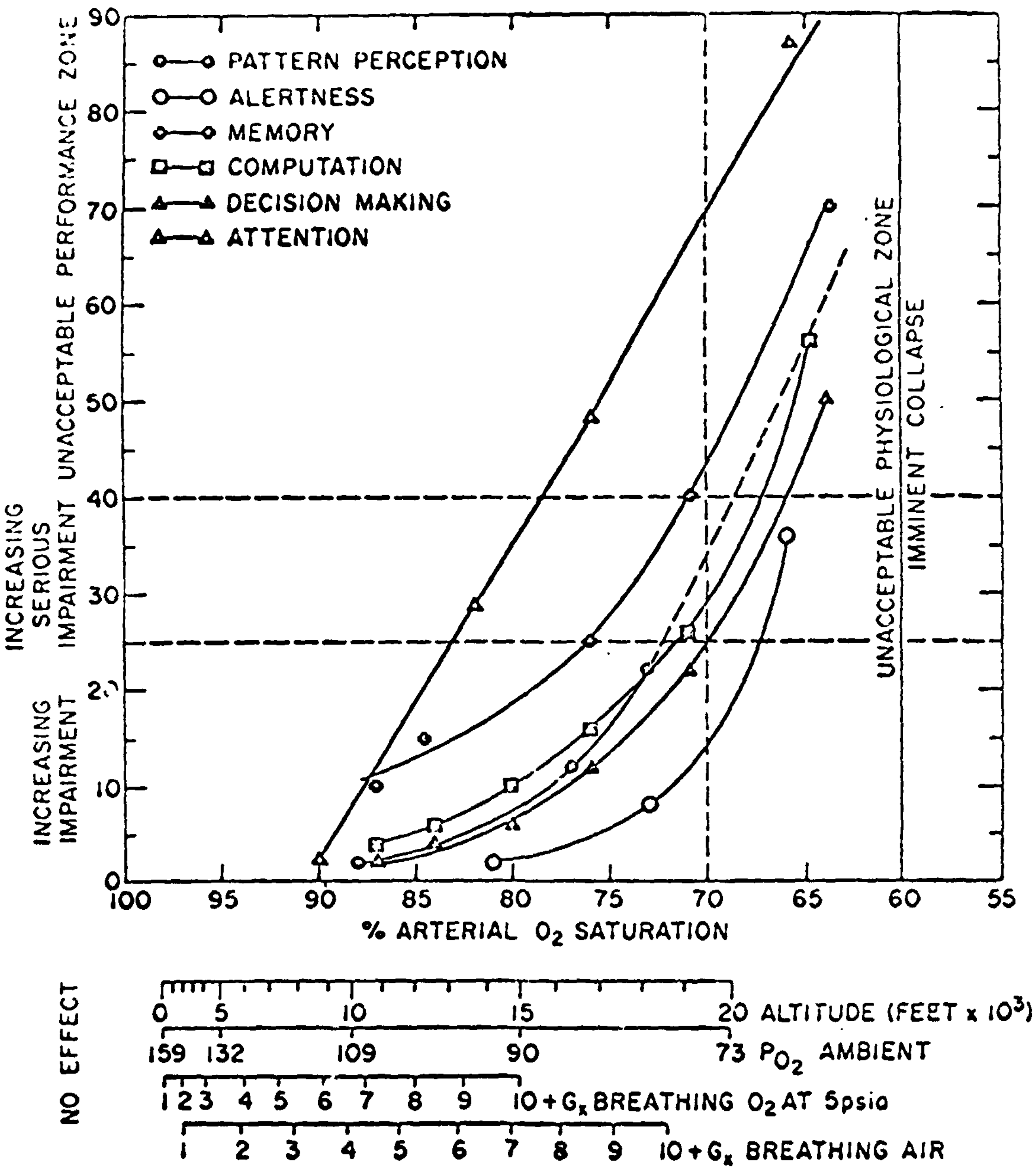
—Thresholds for +G: acceleration.

Criterion	Mean threshold, G	Standard deviation, G	Range, G
Loss of peripheral vision	4.1	± 0.7	2.2–7.1
Blackout	4.7	± 0.8	2.7–7.8
Unconsciousness	5.4	± 0.9	3.0–8.4

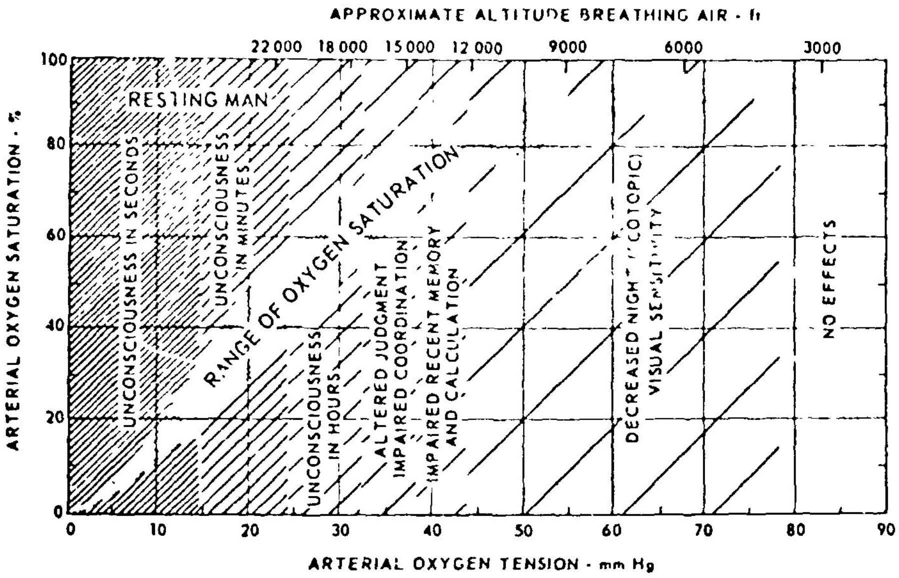
Effects of Hypoxemia and G_x Acceleration on Visual Performance

Response of Several Visual Functions to Hypoxemia



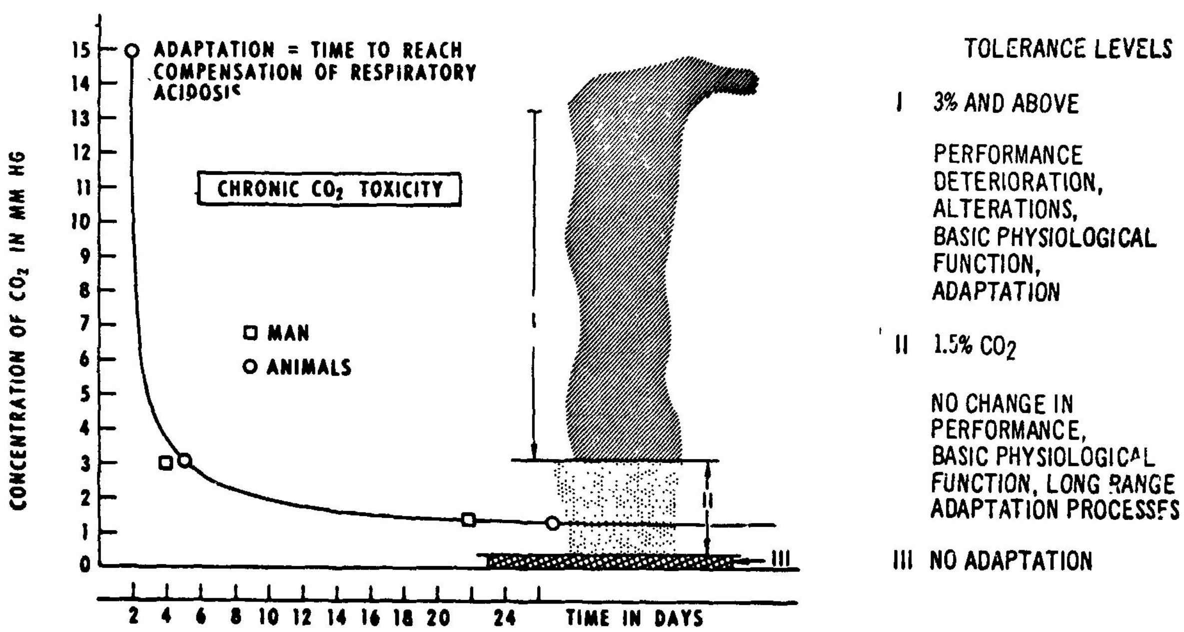


Effects of Hypoxemia on Some Intervening Mental Processes



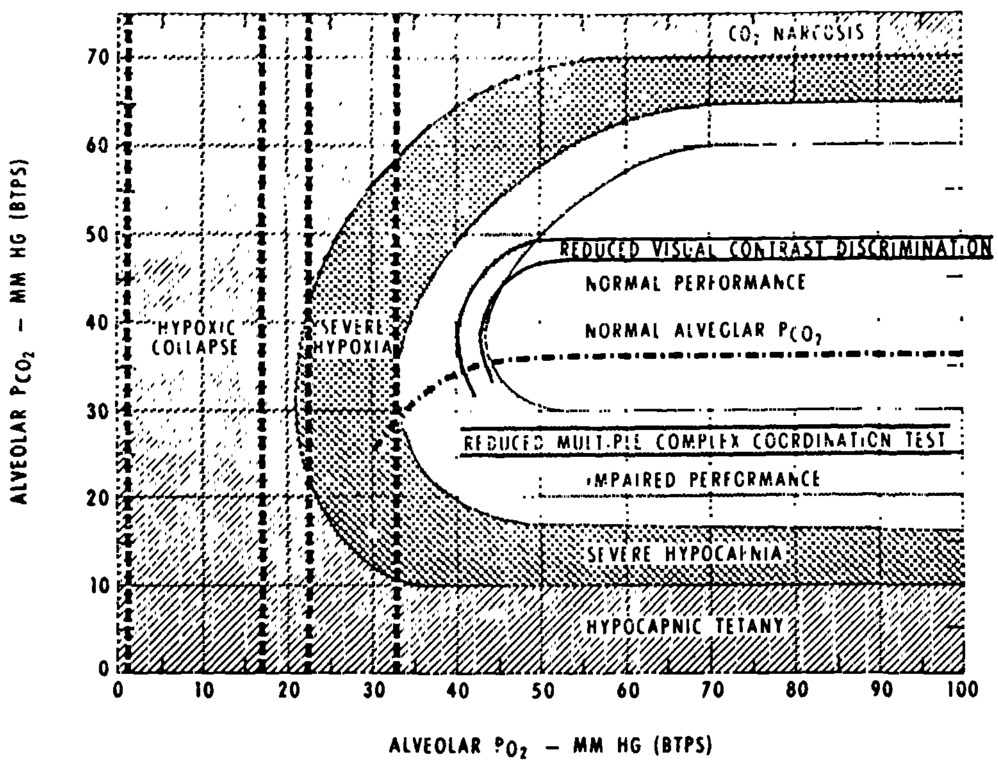
General Effect of Hypoxia on Arterial Saturation and Body Function

Time Concentration Curve for Adaptation to CO_2



TIME CONCENTRATION RELATIONSHIP IN ADAPTATION TO INCREASED CO_2 CONCENTRATION BASED ON EXPERIMENTS IN HUMANS AND ANIMALS AND TOLERANCE LIMITS FOR CHRONIC CO_2 TOXICITY BASED ON THREE DIFFERENT LEVELS OF ACTIVITY

Human Performance Under Abnormal O_2 and CO_2



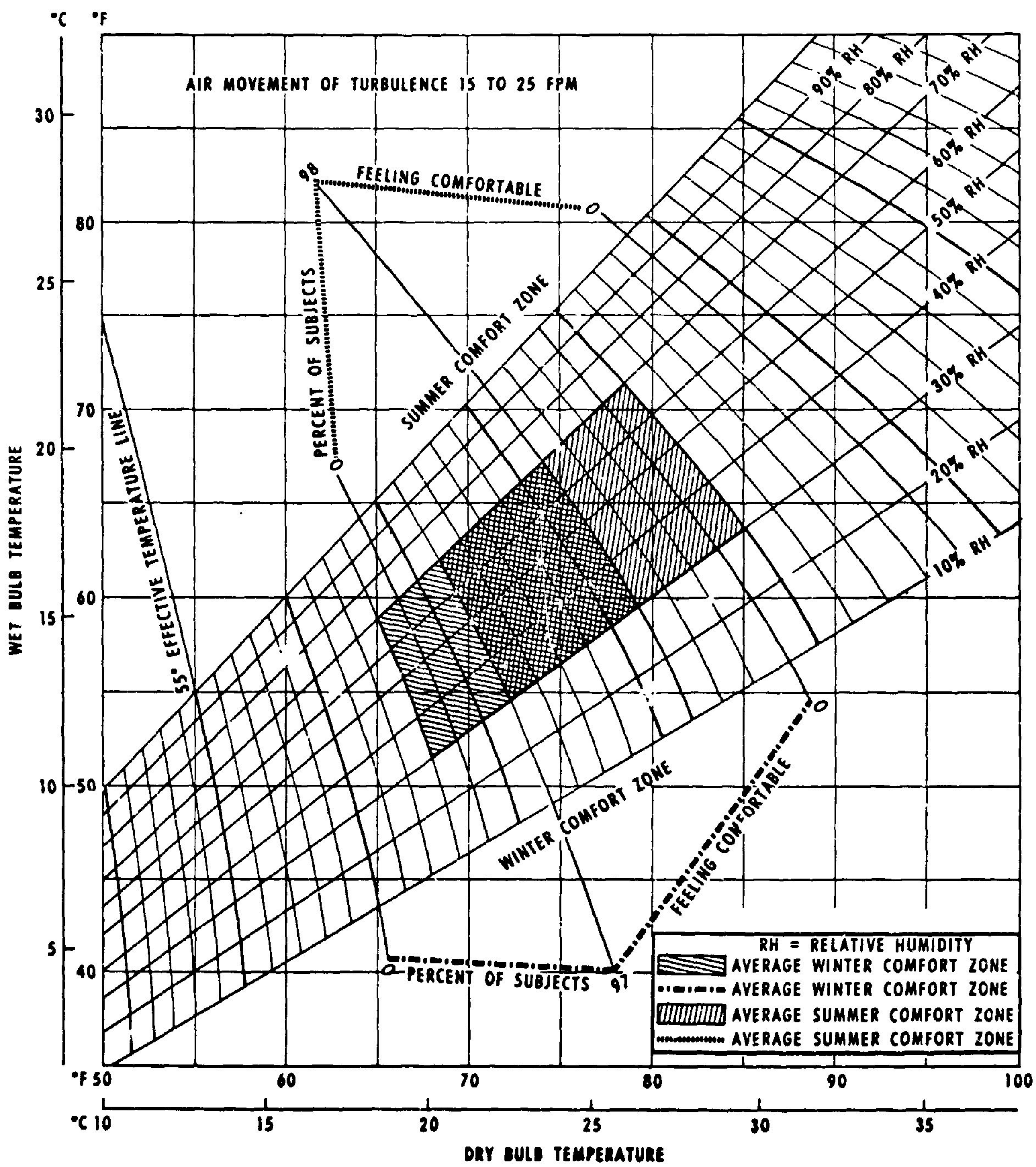
THIS GRAPH SHOWS THE RELATIONSHIP OF ALVEOLAR O_2 AND CO_2 COMPOSITION TO PERFORMANCE. THE SCALES ARE PARTIAL PRESSURES OF THE TWO GASES, AT BODY TEMPERATURE AND PRESSURE, SATURATED WITH WATER (BTPS). ABOVE THE DASHED LINE LABELED "NORMAL ALVEOLAR CO_2" ARE ZONES OF INCREASING HYPERCAPNIA, LIMITED BY THE ZONE OF CO_2 NARCOSIS. BELOW THE DASHED LINE, MARKED AS ZONES OF INCREASING HYPOCAPNIA, ARE LOWER LEVELS OF ALVEOLAR CO_2, WHICH ARE COMMONLY THE RESULT OF EXCESSIVE RESPIRATORY VENTILATION. THE LEFT SIDE OF THE GRAPH SHOWS LOW LEVELS OF ALVEOLAR PO_2, LABELED ZONES OF "SEVERE HYPOXIA" AND "HYPOXIC COLLAPSE," AND THESE HYPOXIC ZONES COMBINE WITH HYPER- OR HYPOCAPNIA TO AFFECT PERFORMANCE AS SHOWN.

NORMAL PERFORMANCE IS SEEN WHEN THE GAS TENSIONS FALL IN THE CLEAR AREA: IMPAIRED PERFORMANCE IN A HAND-STEADINESS TEST IS SHOWN BY SHADING, AND THE RESULTS OF TWO OTHER PERFORMANCE TESTS ARE PLOTTED ALSO TO INDICATE THE VARIATION TO BE EXPECTED WHEN "PERFORMANCE" IS VARIOUSLY MEASURED.

Typical Effects of Vibration on Human Beings

RESPONSE	EFFECT UPON PERFORMANCE	FREQUENCY (HZ)	DISPLACEMENT (IN)
Respiration	Decremental	3.5 to 6.0	0.75
Control	Decremental	4.0 to 8.0	0.14 to 0.61
Aiming	Decremental	15.0	0.07 to 0.12
	Decremental	25.0	0.035 to 0.055
	Decremental	35.0	0.03 to 0.05
Hand Coordination	Decremental	2.5 to 3.5	0.50
Foot Pressure Consistency	Decremental	2.5 to 3.5	0.50
Visual Acuity	Decremental	1.0 to 24.0	0.024 to 0.508
	Decremental	35.0	0.03 to 0.05
	Decremental	40.0	0.065
	Decremental	70.0	0.03
	Decremental	2.5 to 3.5	0.5
Tracking	Decremental	1.0 to 50.0	
	Decremental	2.5 to 3.5	
Attention	Decremental	2.5 to 3.5	0.5
	Decremental	30.0 to 300.0	0.02 to 0.2

Temperature for Comfort Requirements



TEMPERATURE VS PERFORMANCE

120° F	Tolerable for about 1-hour, but far above acceptable physical or mental activity range
85	Mental activity slows, errors begin
75	Physical fatigue appears
65	Optimum for physically active; sedentary requires about 70-72° to be comfortable*
50	Physical stiffness of extremities begins

Notes: Humidities between 30 and 70 % are considered comfortable by most people.

*Summer comfort zone = 65 - 75°F,
Winter comfort zone = 63 - 71°F.

HEATING, VENTILATION AND AIR CONDITIONING RECOMMENDATIONS

	Mobile Personnel Enclosures used for detailed work or occupied extended time	Permanent and semi permanent facilities	Operational and Maintenance ground vehicle cab compartments	
HEATING (maintain dry bulb temperature	Above 50°F	Approx 68°F	No arctic clothing, occupancy over 3 hrs; Approx 68°F	Cold environment (AR705-15) Arctic clothing worn; At reference temperature* of + 5° or above
TEMPERATURE uniformity	Floor-to-head level temperature difference = 10°F max.	Floor-to-head level temperature difference = 10°F max.	-	Around operator's body max. of 15°F above to 10°F below reference temperature

*Measured at a point 24-inches above the seat reference point.

HEATING, VENTILATION AND AIR CONDITIONING RECOMMENDATIONS (Cont.)

AIR CONDITIONING	Maintain effective temperature below 85°F	Maintain dry bulb temperature of approximately 68°F	-	-
VENTILATION	30 cfm/man min.	30 cfm/man min*	Normal 15 cfm/man min.	Hot climate (above 90°F) 150-200 cfm/man
AIRSP . past man	100 ft/min, 65 if possible	100 ft/min, 65 if possible	-	-
HUMIDITY	Approx. 45% at 70°F; decreasing with rising temperature; minimum = 15%	Approximately 45%	-	-

* Of which 2/3 should be outside air.

. Threshold Volume Requirements According to Duration of Mission

Duration (days)	Threshold of acceptable volume - Cubic Feet	Threshold of unacceptable volume - Cubic Feet
1	50	25
2	75	25
3	90	25
4	105	30
5	115	35
6	120	35
7	125	40
10	135	50
20	140	70
30	150	85
>60	?150	?150