T79-11612
JSC-14581

NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
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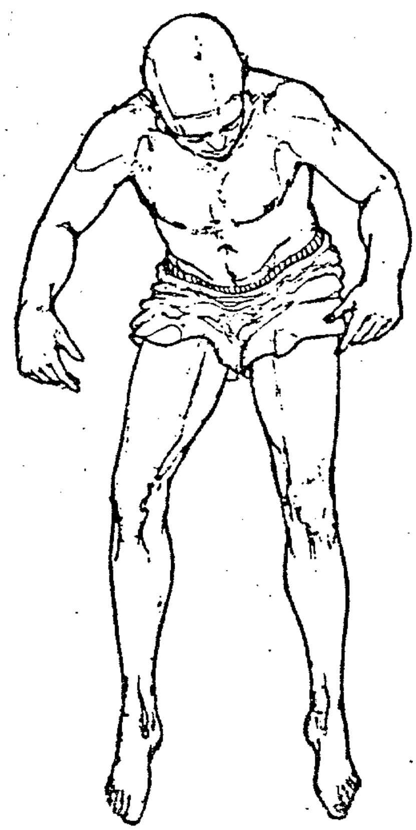
DESIGN GUIDE



The Influence of Zero-G and Acceleration on the Human Factors of Spacecraft Design

DESIGN GUIDE

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Prepared By

Brand Norman Griffin

August 1978

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ABSTRACT

Considering the duration of his existence on this planet, man has only most recently experienced accelerations other than one-g. So pervasive and enduring this force has been, it has played an instrumental role in his evolutionary development.

Each manned space flight experiences a range of acceleration including zero-g and accordingly transitions and adjustments must be made. Consequently, in order to provide the spacecraft designer with the human factors implications of acceleration, this document was prepared.

AUSPICES

This document is a result of a ten week NASA-ASEE Summer Faculty Fellowship grant. It was prepared in the Spacecraft Design Division at the Johnson Space Center with James L. Lewis as mentor.

INTENT

The principle intent of this investigation is to initiate work on human factors of acceleration as they influence spacecraft design.

SCOPE

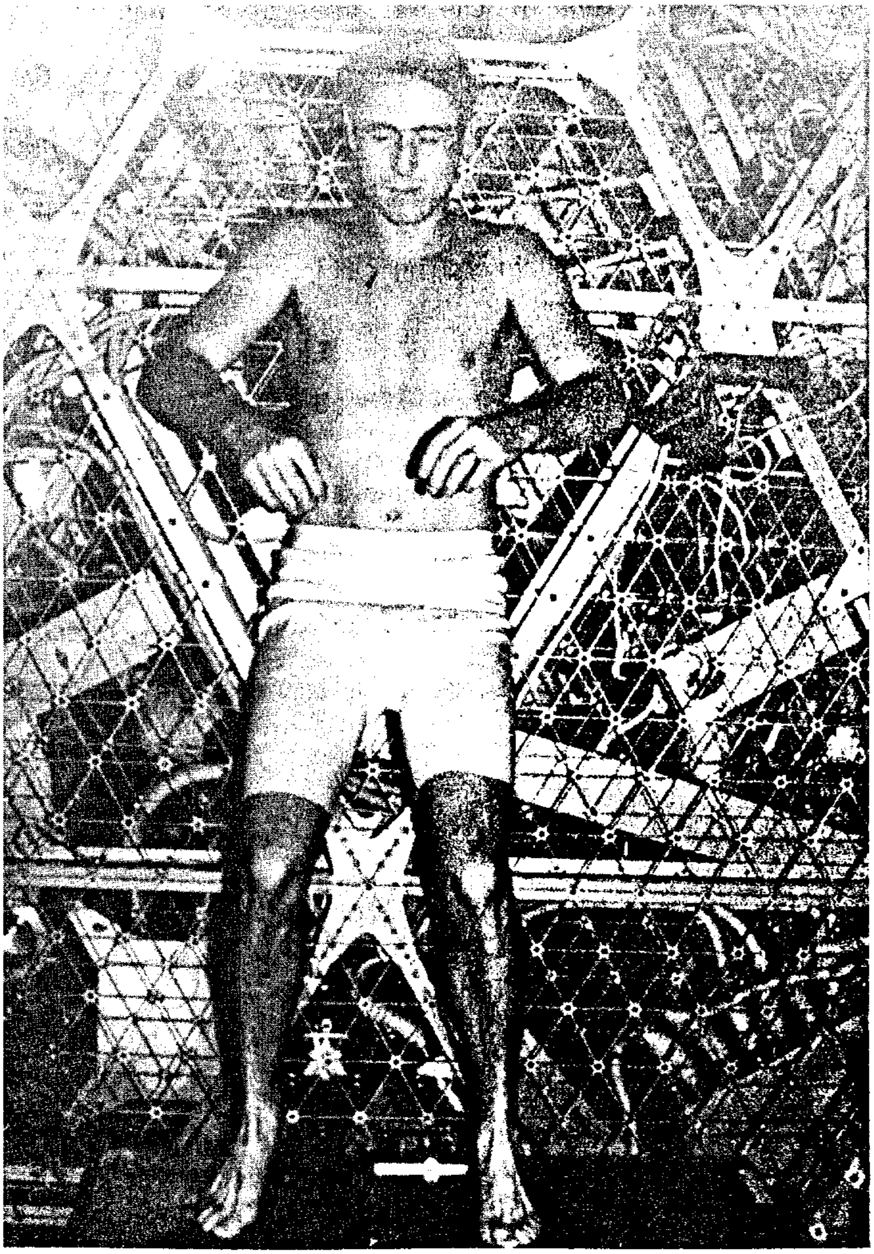
Major topic areas are discussed in varying degrees of detail. They include the presentation of both historical and acceleration contexts for comparative examination and reference, the anthropometric measures of both male and female which help define a neutral body envelope, and a classification of orientation conditions with respect to spaceflight.

VALIDITY

The emphasis of this investigation was to outline a spacecraft design guide. Certain information presented herein was derived by interpolation, extrapolation, observation and experience. This approach was taken so that yet untested study areas might be included, and later according to experiment data and expert opinion, be verified, adjusted or eliminated. In order not to color the credibility of the valid information, those areas lacking critical review will be noted. In general, the partial-g data and the greater-than-one-g data is estimated or extrapolated, and the female anthropometric data are extrapolated from the male data.

TERMS

In order to establish a common understanding several terms used within the text should be explained. Since gravity is a form of acceleration these terms are used interchangeably. This is also the case with zero-g and weightlessness. The single letter "G" refers to a unit of measure of acceleration where one-g equals the gravity on earth. Zero-g is a balance of forces in which an object can be assumed to be in a constant state of free fall. Muscles in their natural relaxed position characterize neutral body posture which is the form that the body assumes in zero-g.



Zero-g Posture

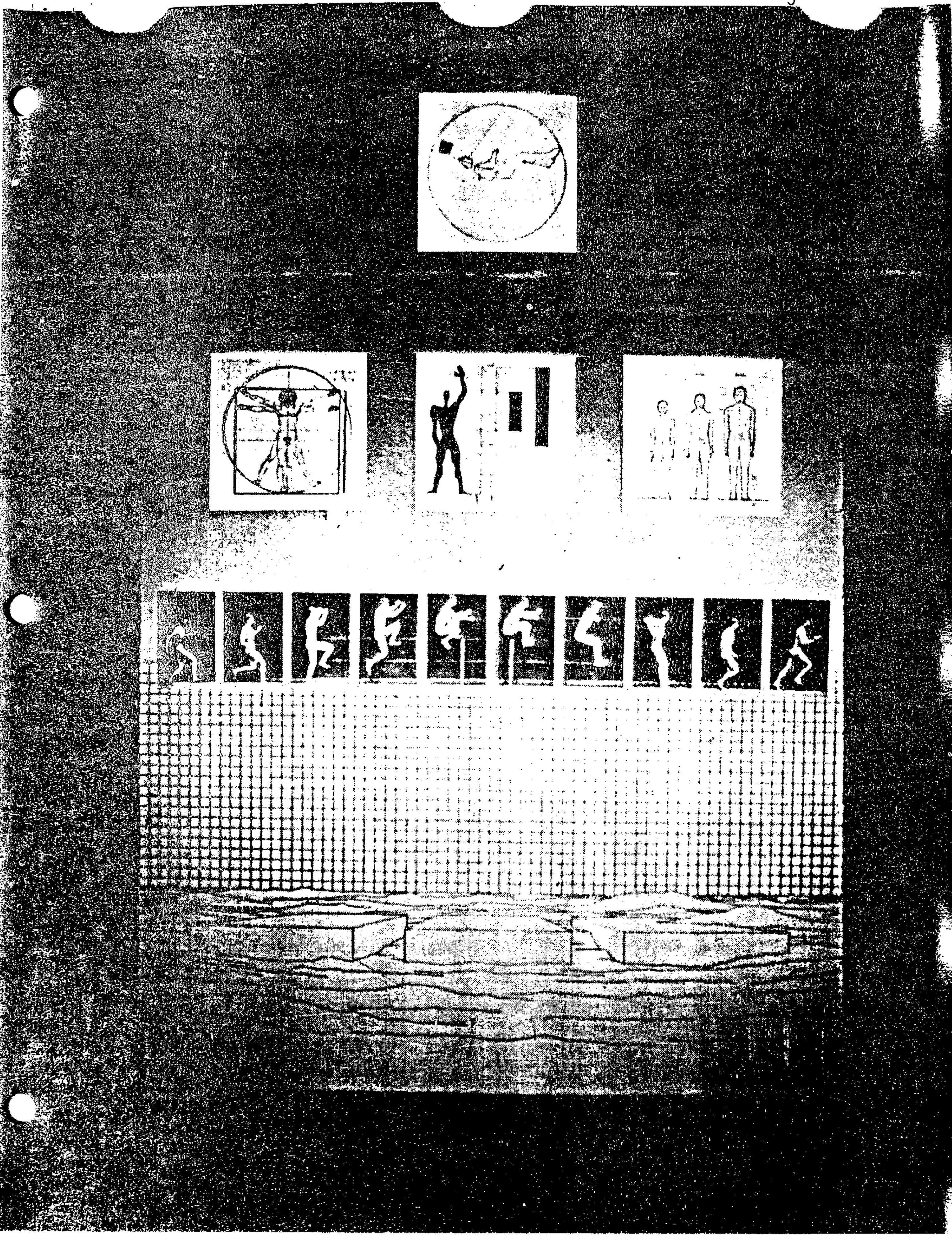
HISTORICAL CONTEXT

The purpose of the following drawing is to demonstrate the relevance of neutral body posture within its proper historical context. The images are all milestone interpretations of the measures of man and represent two fundamental concepts for an anthropomorphic design source. One concept is conveyed by the zero-g figure and the other by the remaining images. Leonardo de Vinci's Vitruvian Man, Le Corbusier's La Modular, and Henry Dreyfuss' Measured Man chronologically trace differences in interpretation of a static one-g man, while Muybridge's Man in Motion incrementally displays the dynamics of motion against one-g acceleration.

Within their environment, these gravity bound concepts are useful and necessary for responsive man-machine design. They are, however, invalid outside of that gravity state. For those situations, a modified figure, borne from extant physical conditions, must be the designer's reference.

Properties associated with the ambient environment (i.e., dynamics of liquids and gases) not only influence posture, but directly determine anatomical, physiological and kinesiological characteristics.

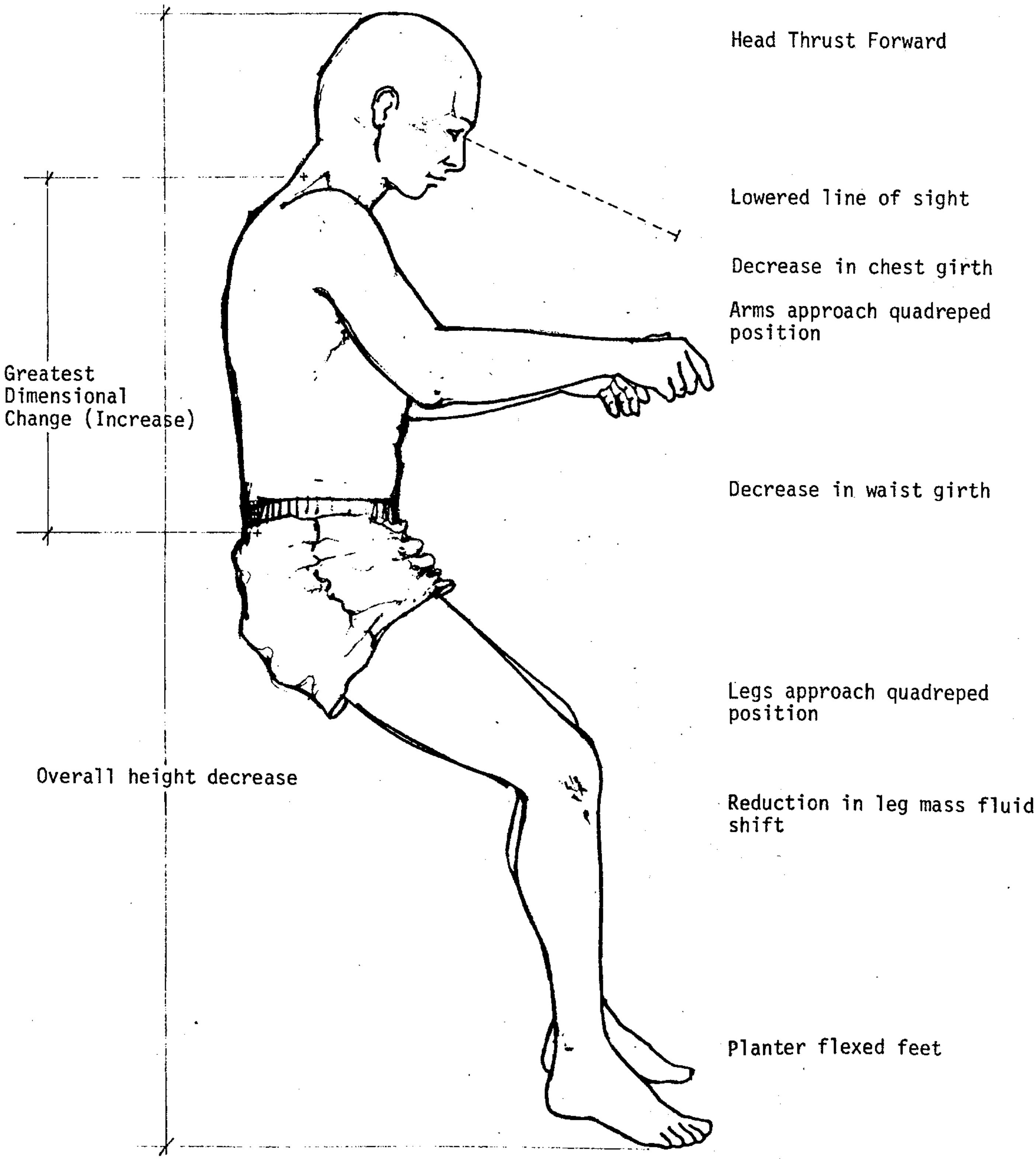
More interesting, perhaps is that from another vantage point, the zero-g environment represents a truly universal constant with planetary and solar gravities as variables. Consequently, for manned spaceflight the significance of what the neutral body posture figure symbolizes cannot be overstressed.



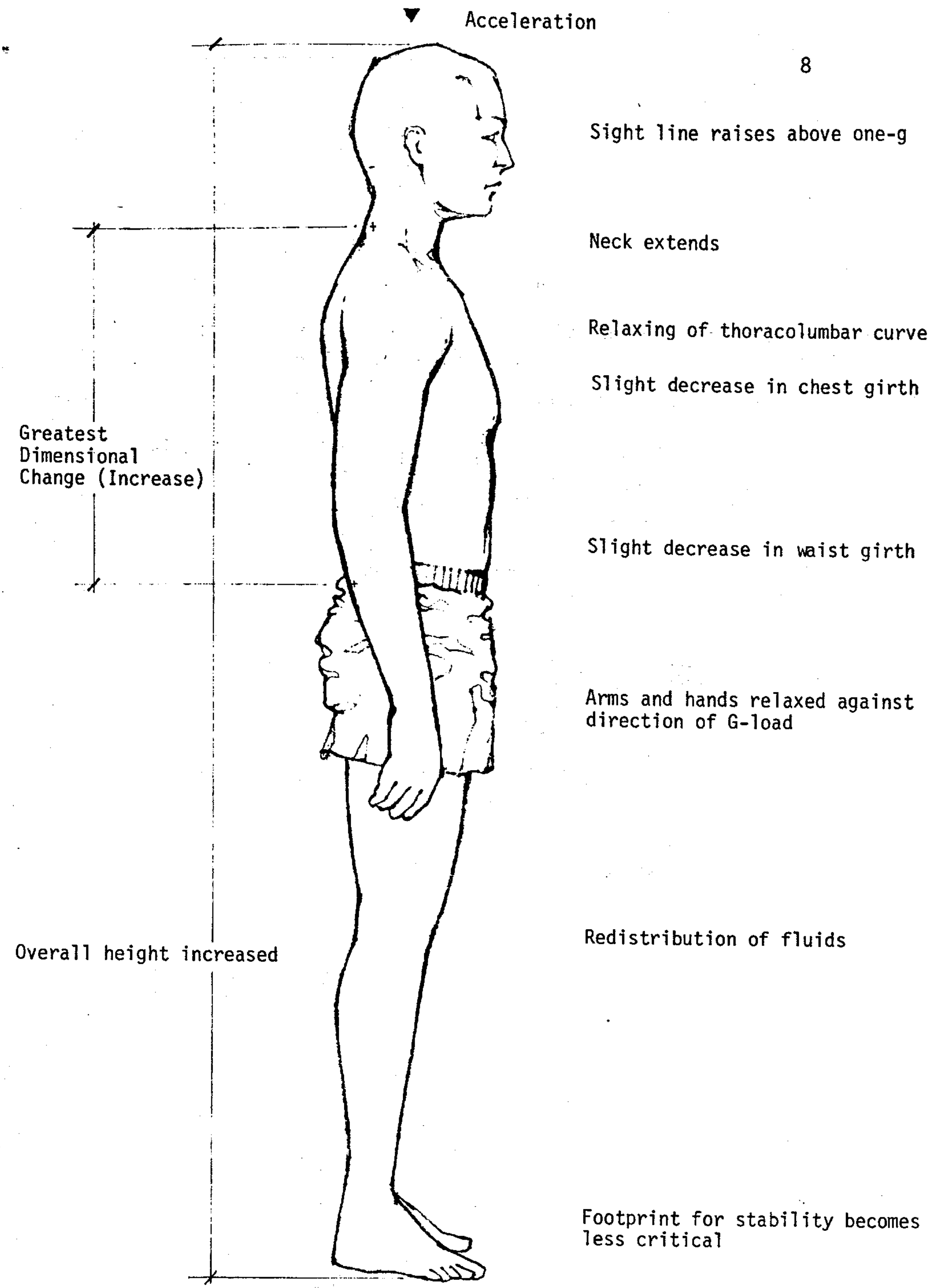
ACCELERATION

The acceleration profile of spaceflight from lift-off to touchdown necessarily experiences a variance of g-loads. Though regime and direction with respect to posture may vary, this exposure is inevitable. Anatomical and physiological characteristics are different under these loads and do effect crew capabilities and performance. Accordingly, the understanding of these characteristics should be considered extremely important for location and design of spacecraft elements.

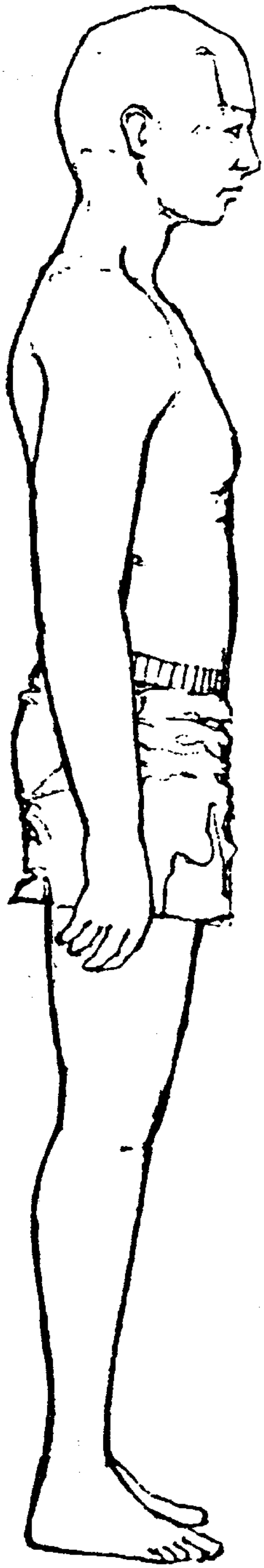
An incremental progression of posture as influenced by acceleration provides the reference base upon which independent variables are superimposed, e.g., vision, fluid pooling, etc. In this series the one-g figure serves as the datum allowing deviation to be measured from that standard. In addition to the graphic description of acceleration impact on each variable, a list of implications indicates potential design application.



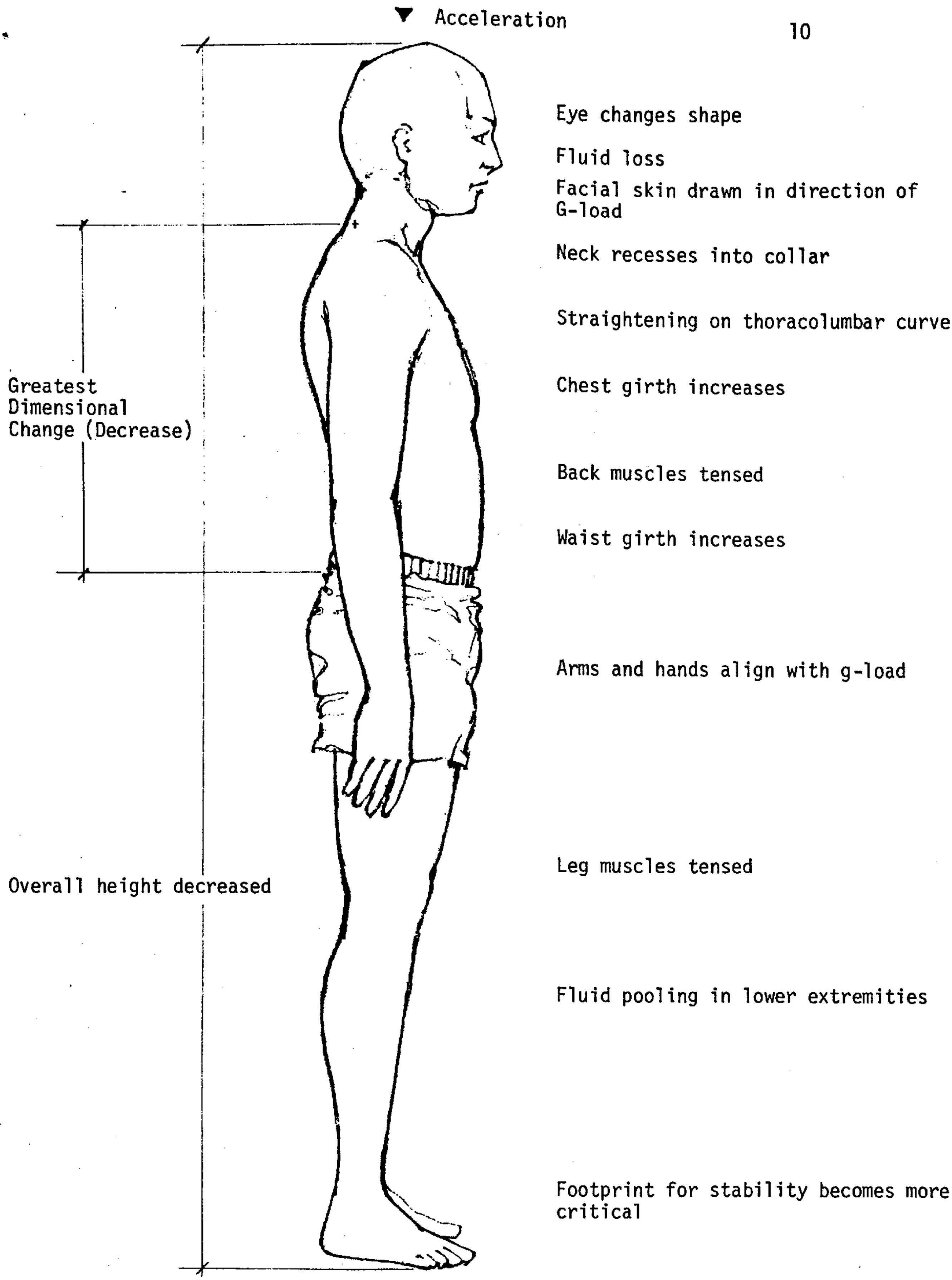
Zero-G Posture



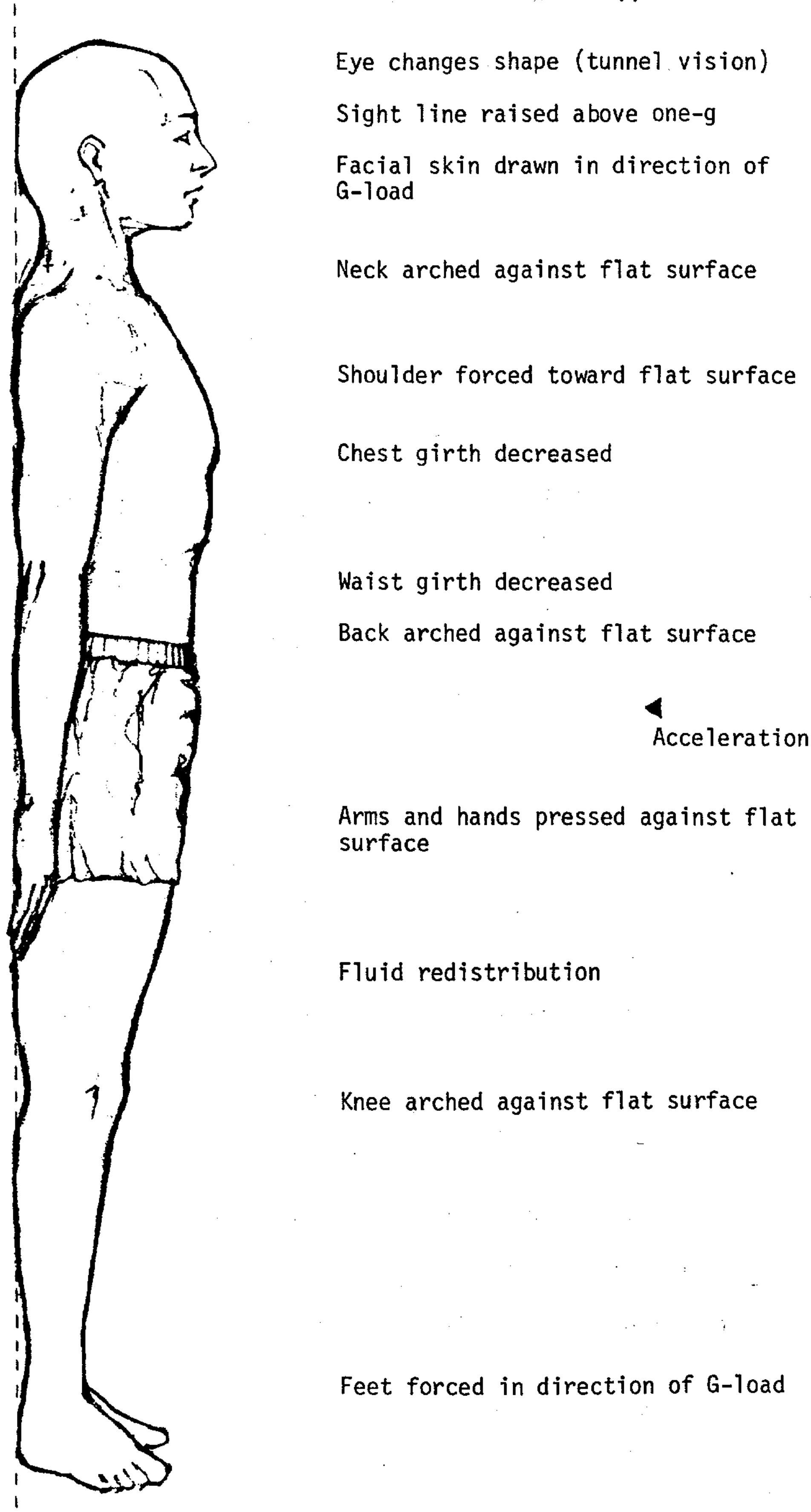
Partial G Posture
(Assumed)



One-G Posture



One - Two G Posture

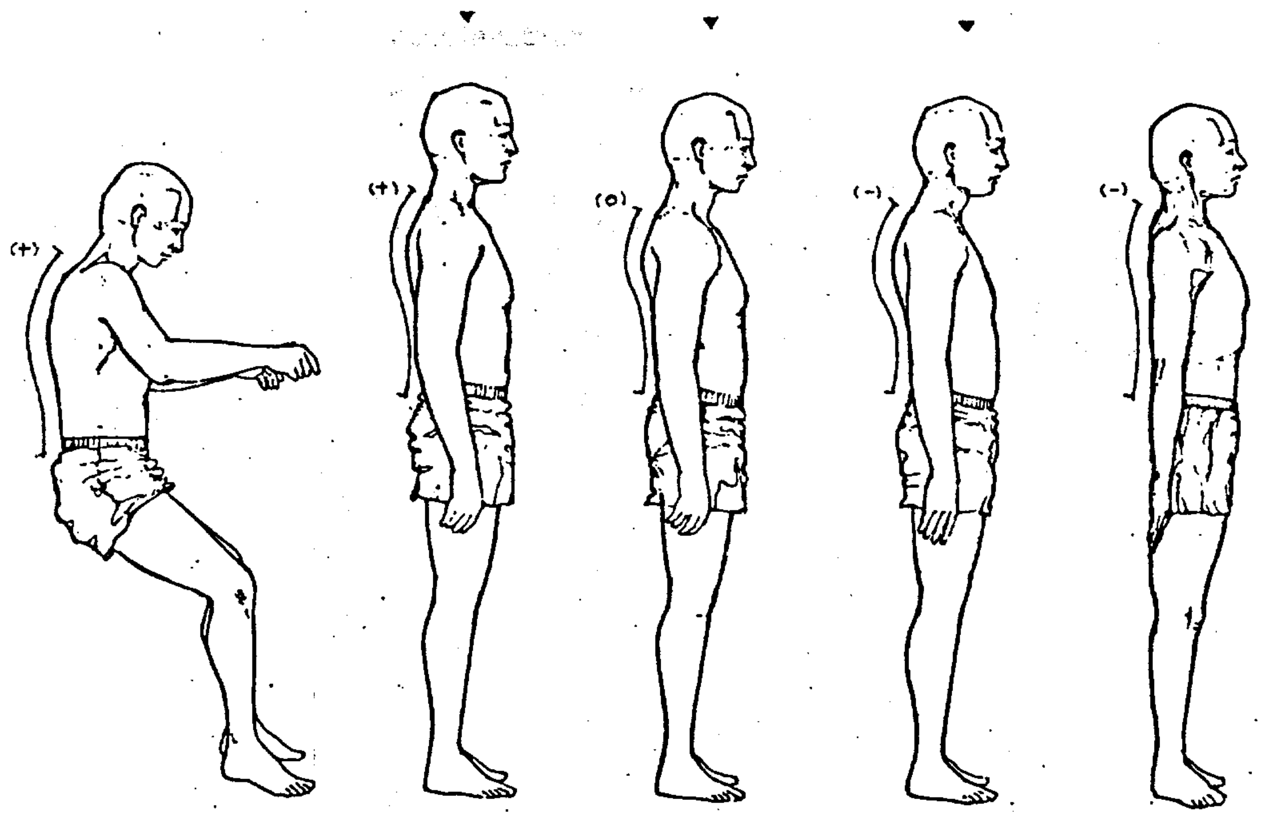


Over Two G Posture

ACCELERATION GRADIENT

Variable: Intervertebral Extension/Compression

Acceleration



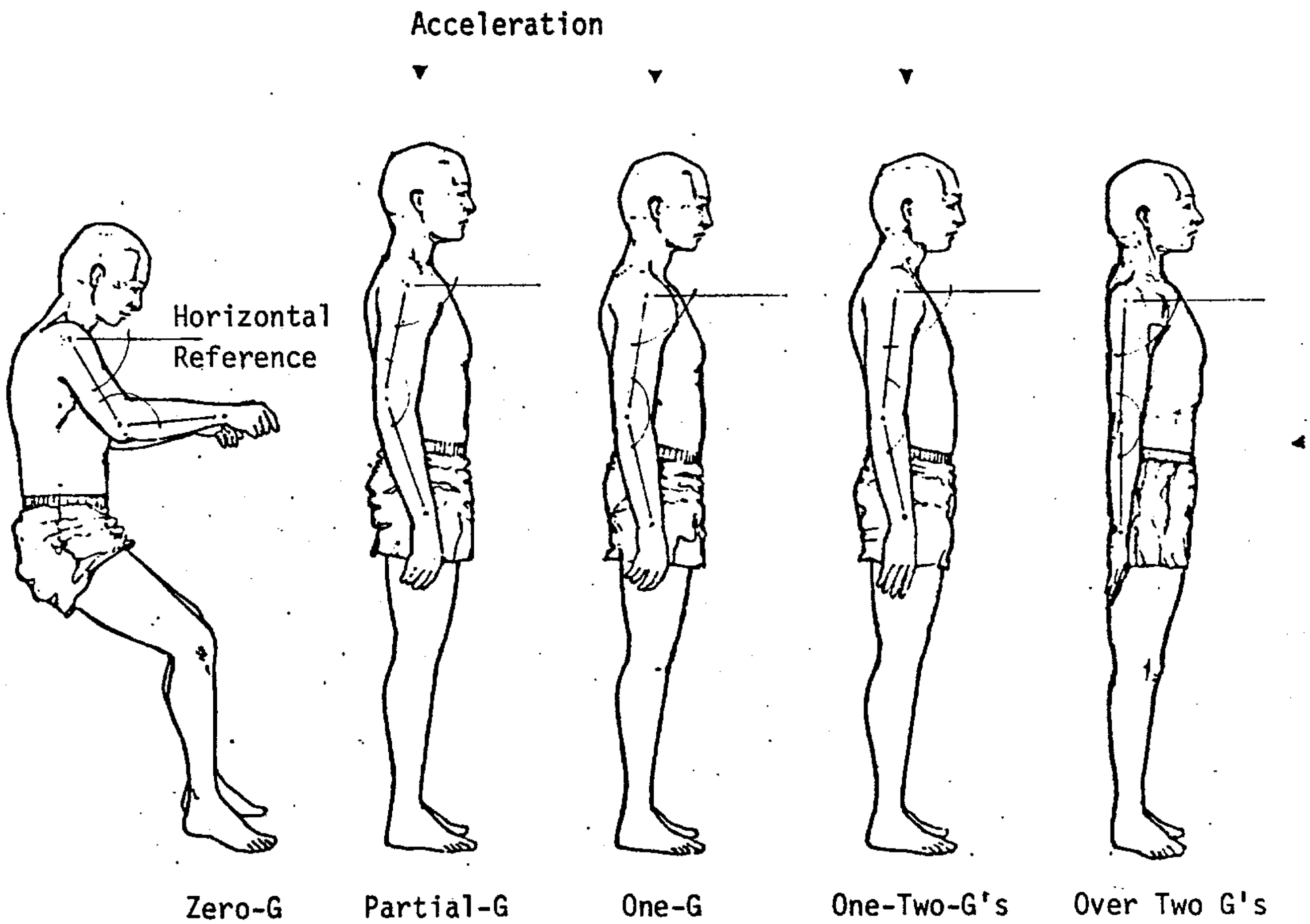
Zero-G Partial-G One-G One-Two-G's Over Two G's

Implications:

1. Intravehicular and extravehicular garment fit.
2. Restraint, seat or couch body support.
3. Height of work surfaces.

ACCELERATION GRADIENT

Variable: Rotation About the Shoulder Joint

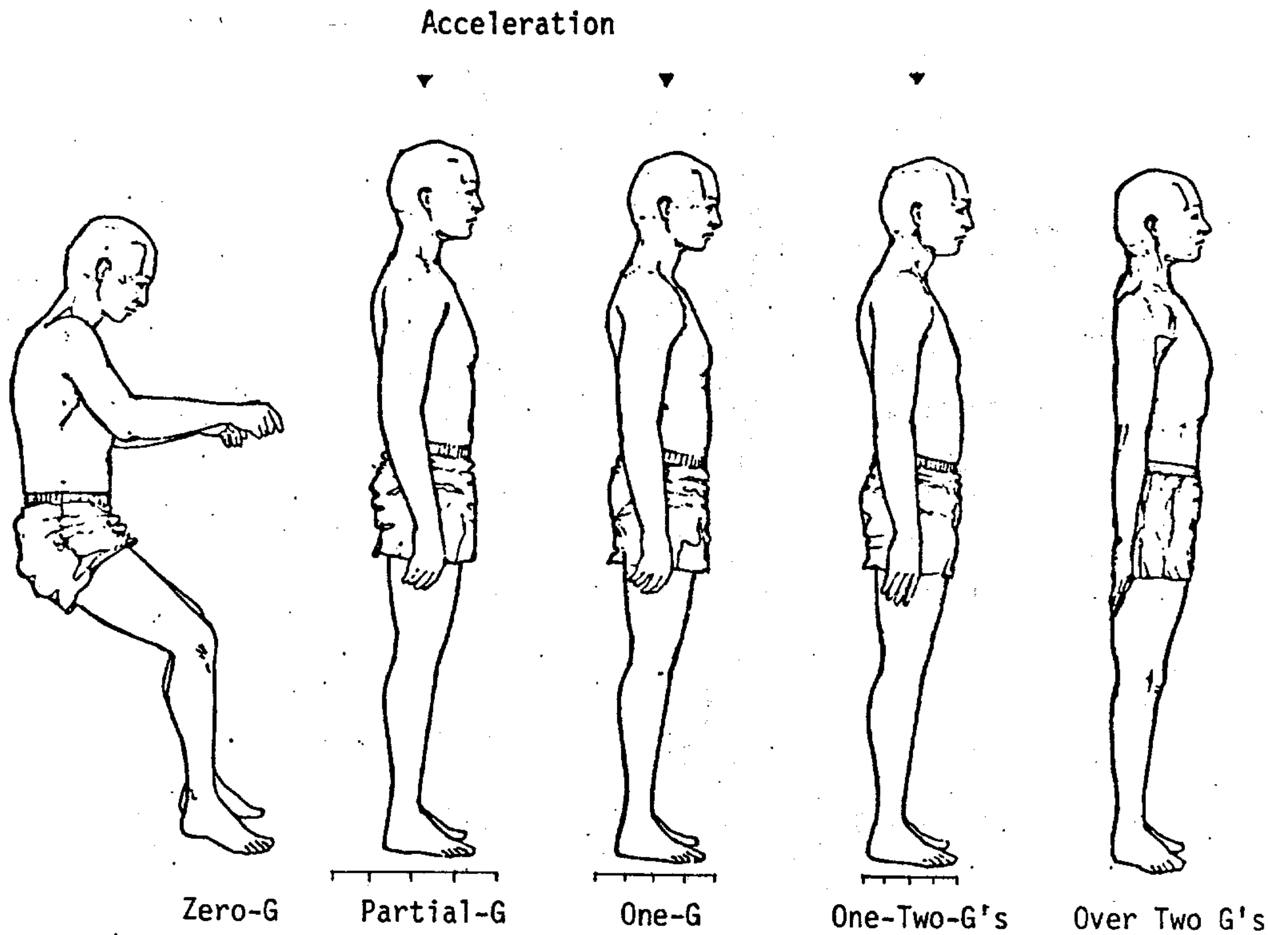


Implications:

1. Intravehicular and extravehicular garment fit.
2. Location of controls.
3. Location of work surfaces.

ACCELERATION GRADIENT

Variable: Balance

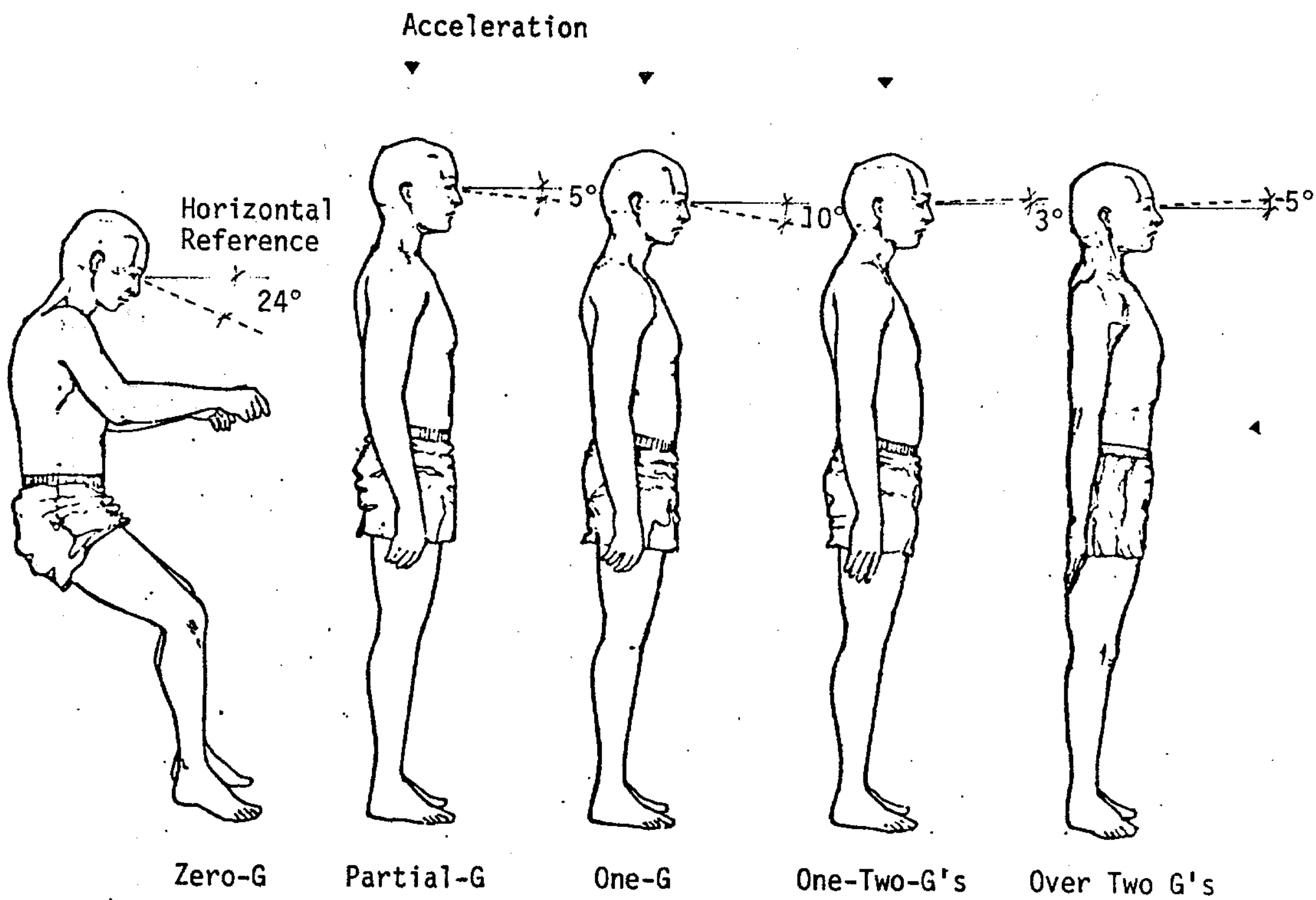


Implications:

1. Balance becomes increasingly more critical as the G-load increases.
2. Type of operations to be performed under each G-condition.
3. Posture (standing, seated, reclined, etc.) under each G-condition.

ACCELERATION GRADIENT

Variable: Line of Sight

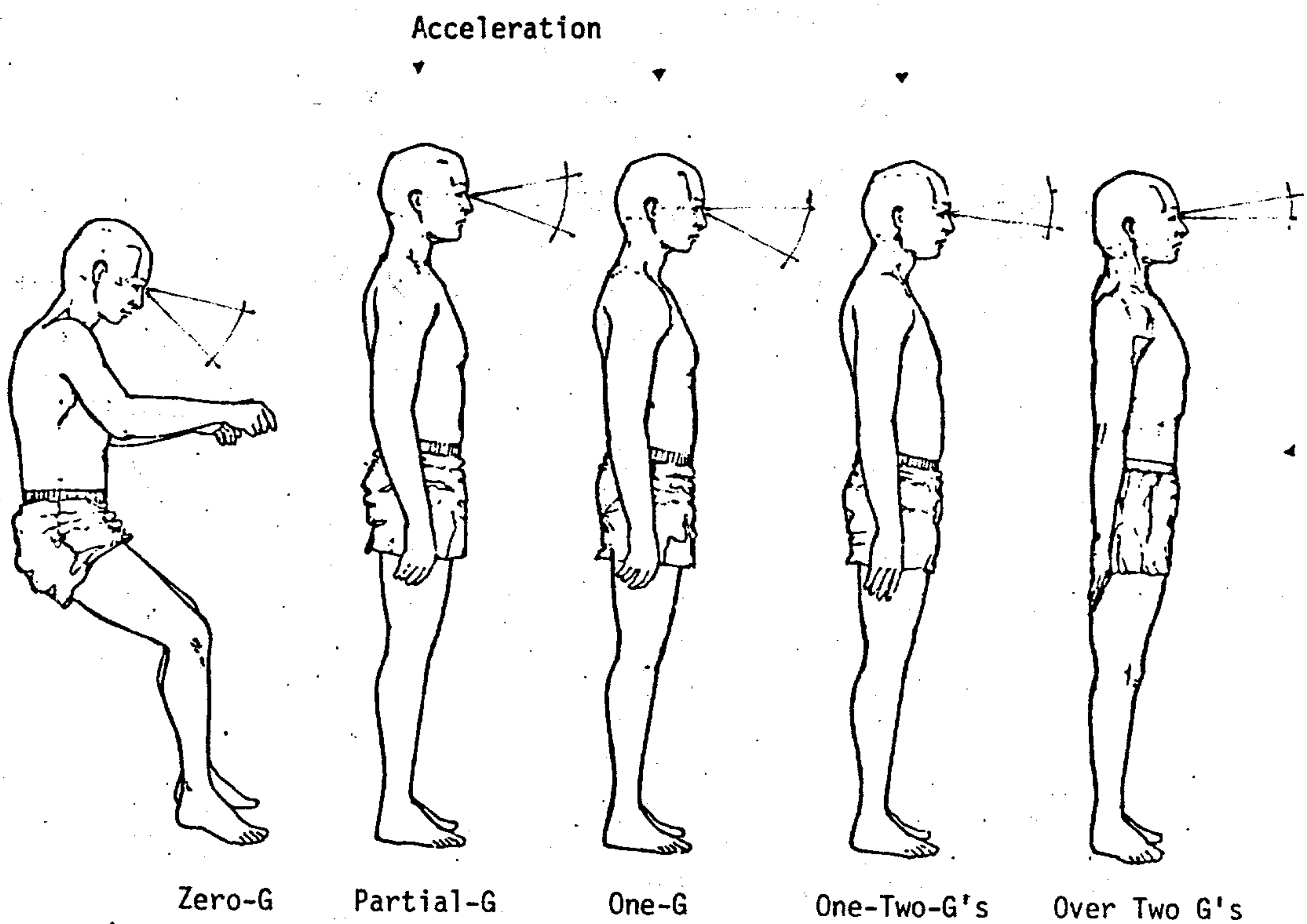


Implications:

1. Location of displays.
2. Neck/head support.
3. Instrument scan.

ACCELERATION GRADIENT

Variable: Cone of Vision



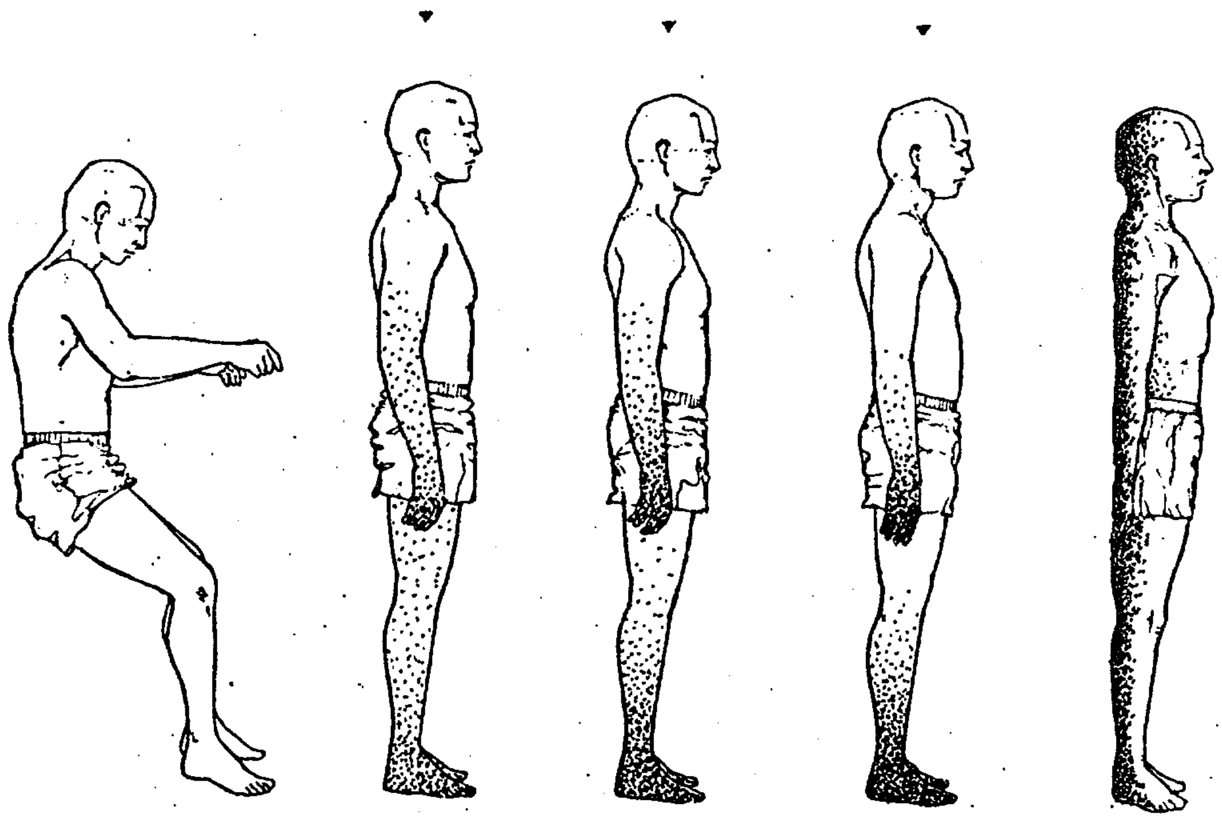
Implications:

1. Location of essential display.
2. Location of eye-pieces.
3. Helmet optics.

ACCELERATION GRADIENT

Variable: Fluid Pooling

Acceleration



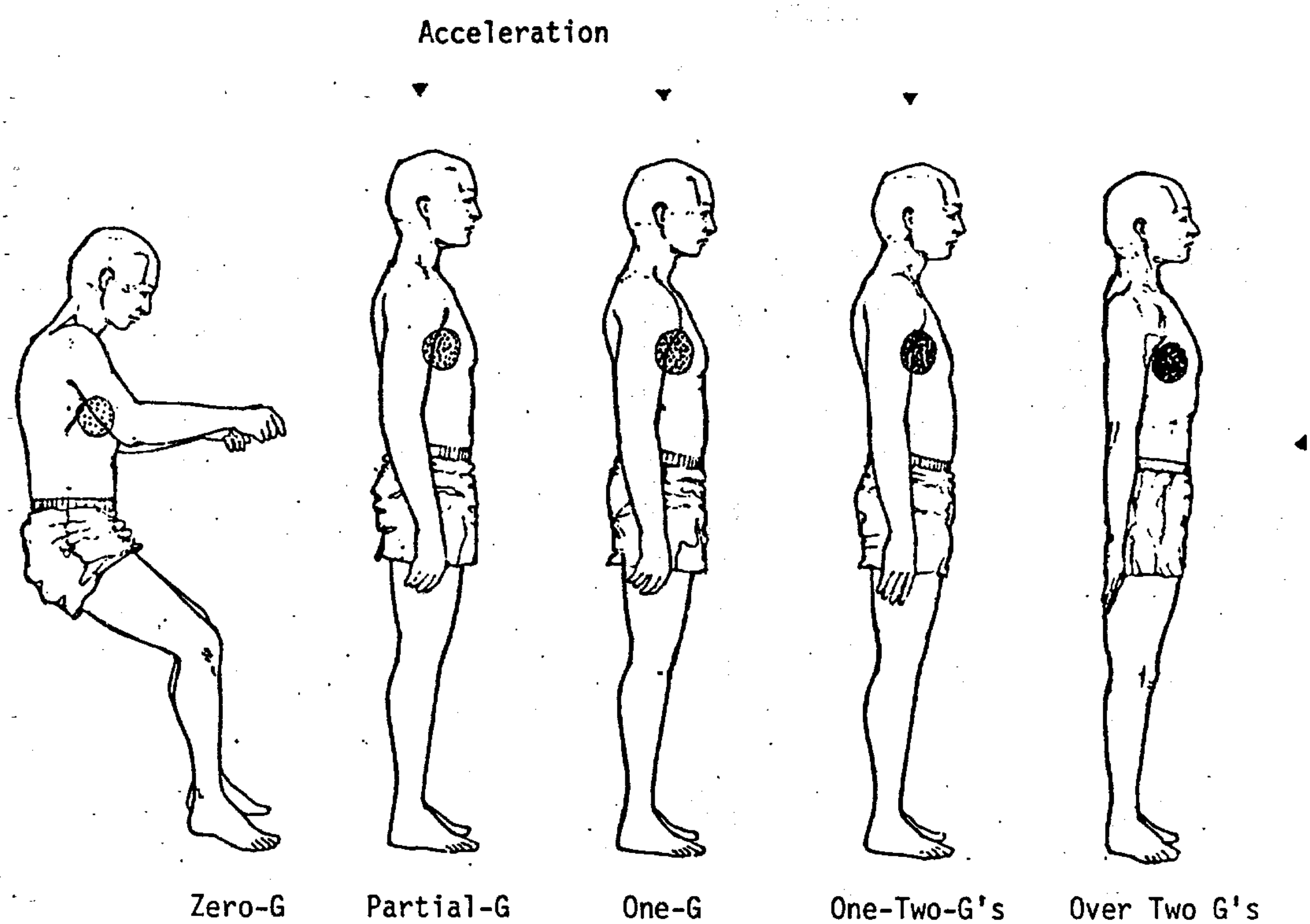
Zero-G Partial-G One-G One-Two-G's Over Two G's

Implications:

1. G-suit tolerances.
2. Direction and duration of G-load.
3. Posture and hemodynamics.
4. Support and pressure points.

ACCELERATION GRADIENT

Variable: Cardiovascular Work

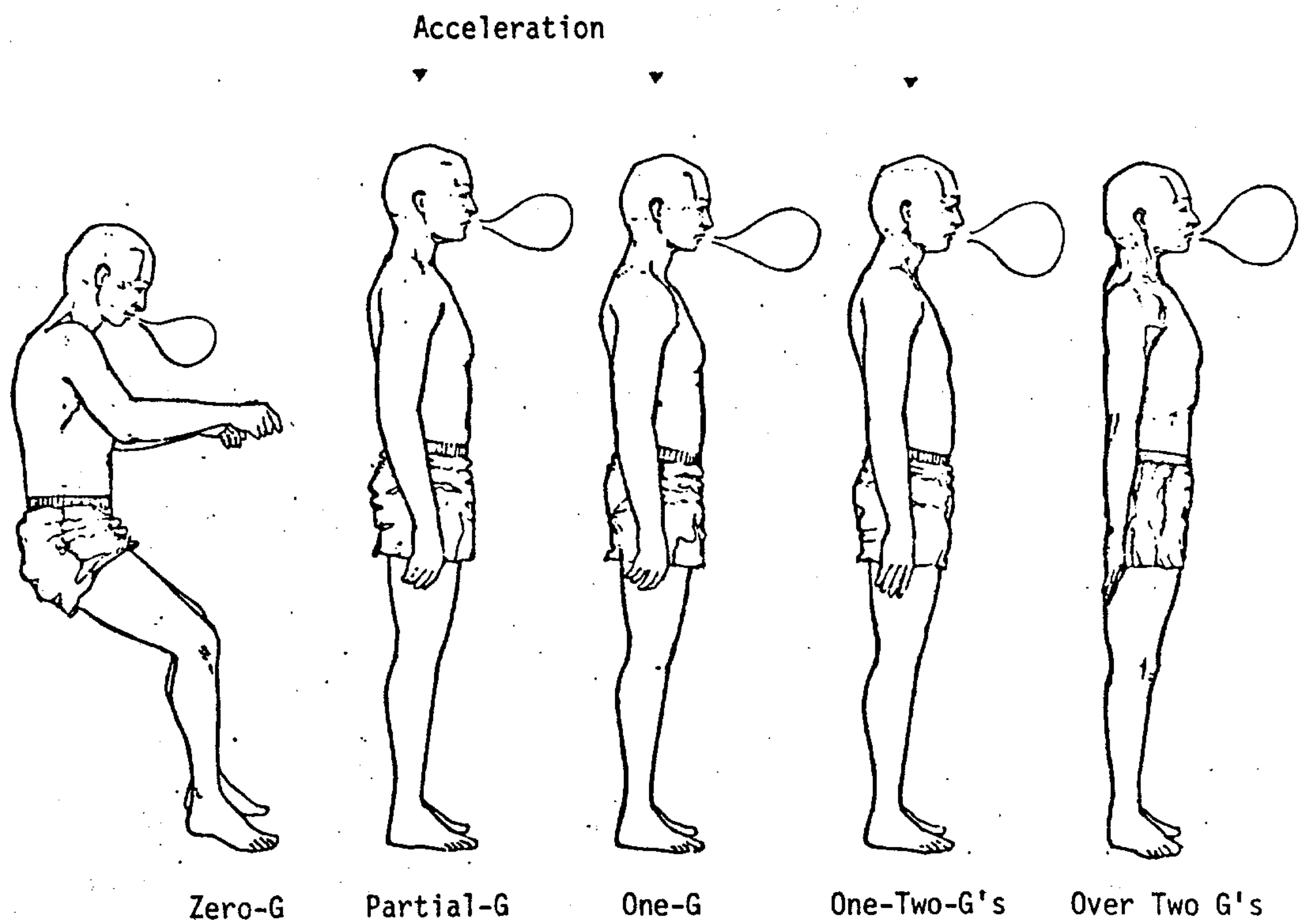


Implications:

1. Reach and translation envelope/circulation.
2. Recovery time.
3. Fatigue cost.

ACCELERATION GRADIENT

Variable: Gas Exchange

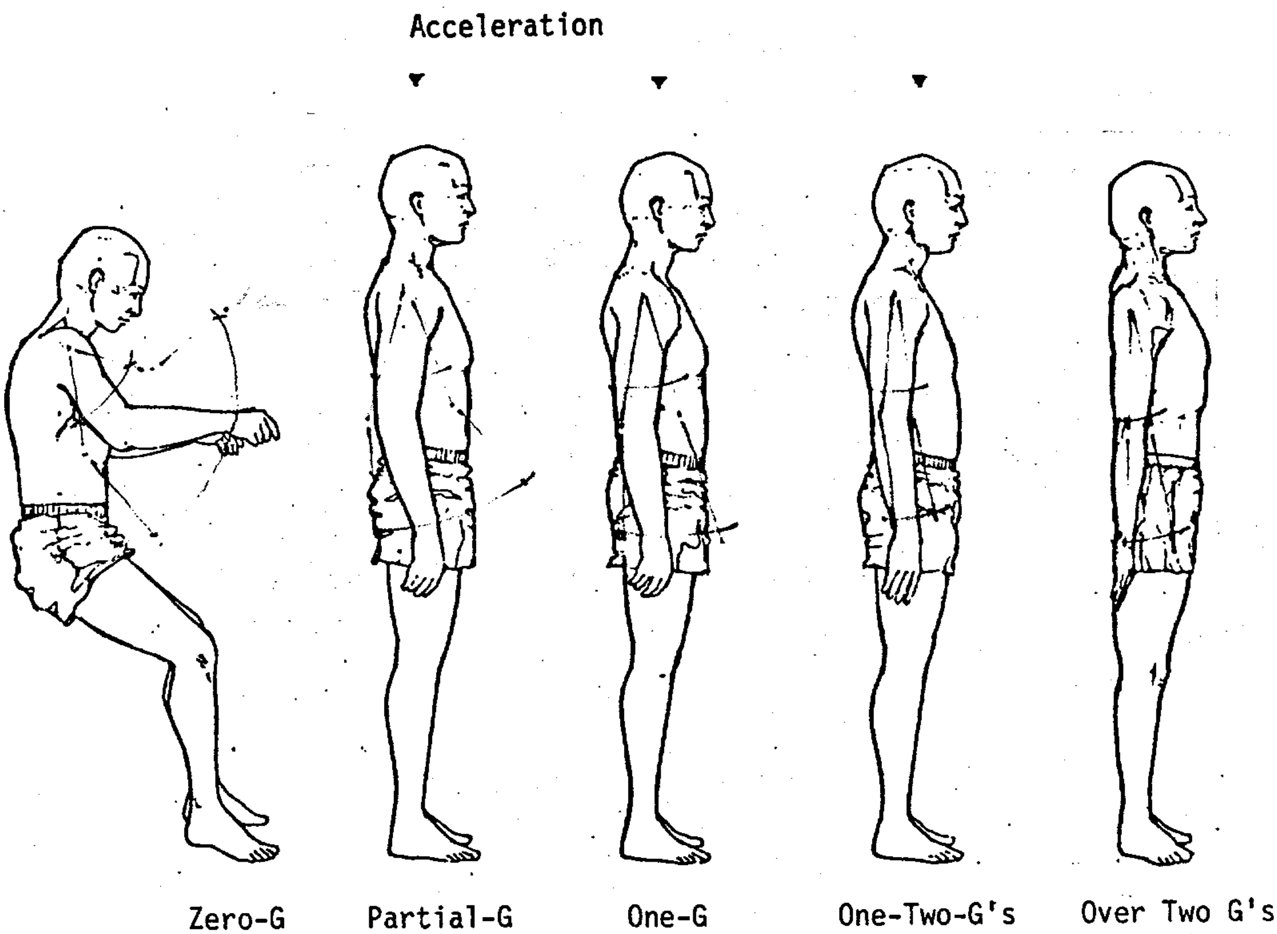


Implications:

1. Effort in breathing - lung capacity.
2. O_2 consumption increases with acceleration.
3. Hemodynamics and gas exchange in lungs.
4. Gravity state and convection - convection in zero-g to accelerated action in higher g-states.

ACCELERATION GRADIENT

Variable: Anthropometric Envelope (Nominal)



Implications:

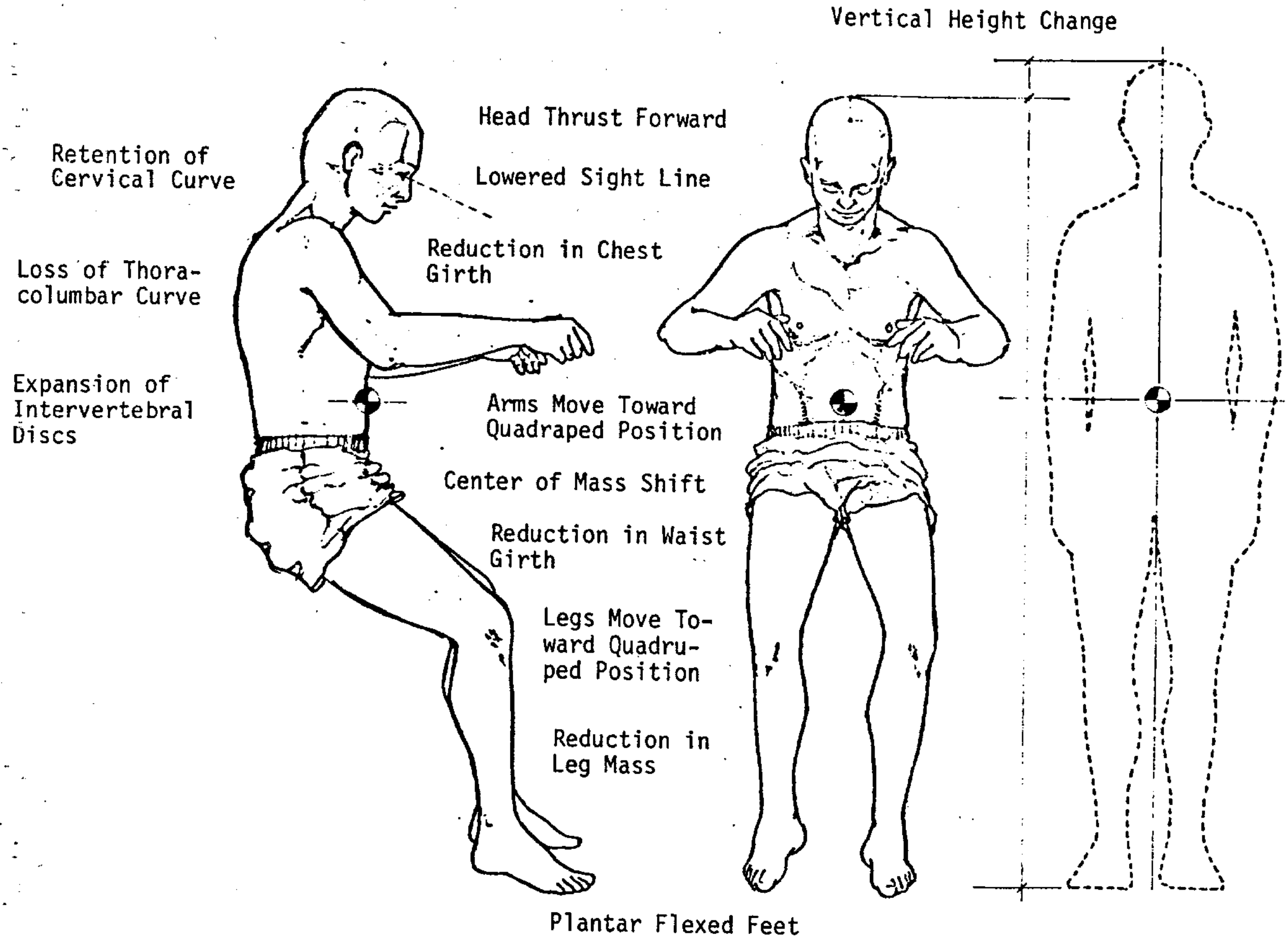
1. Location of controls.
2. Intravehicular and extravehicular garment fit.
3. Angular speed of limbs.

ANTHROPOMETRICS

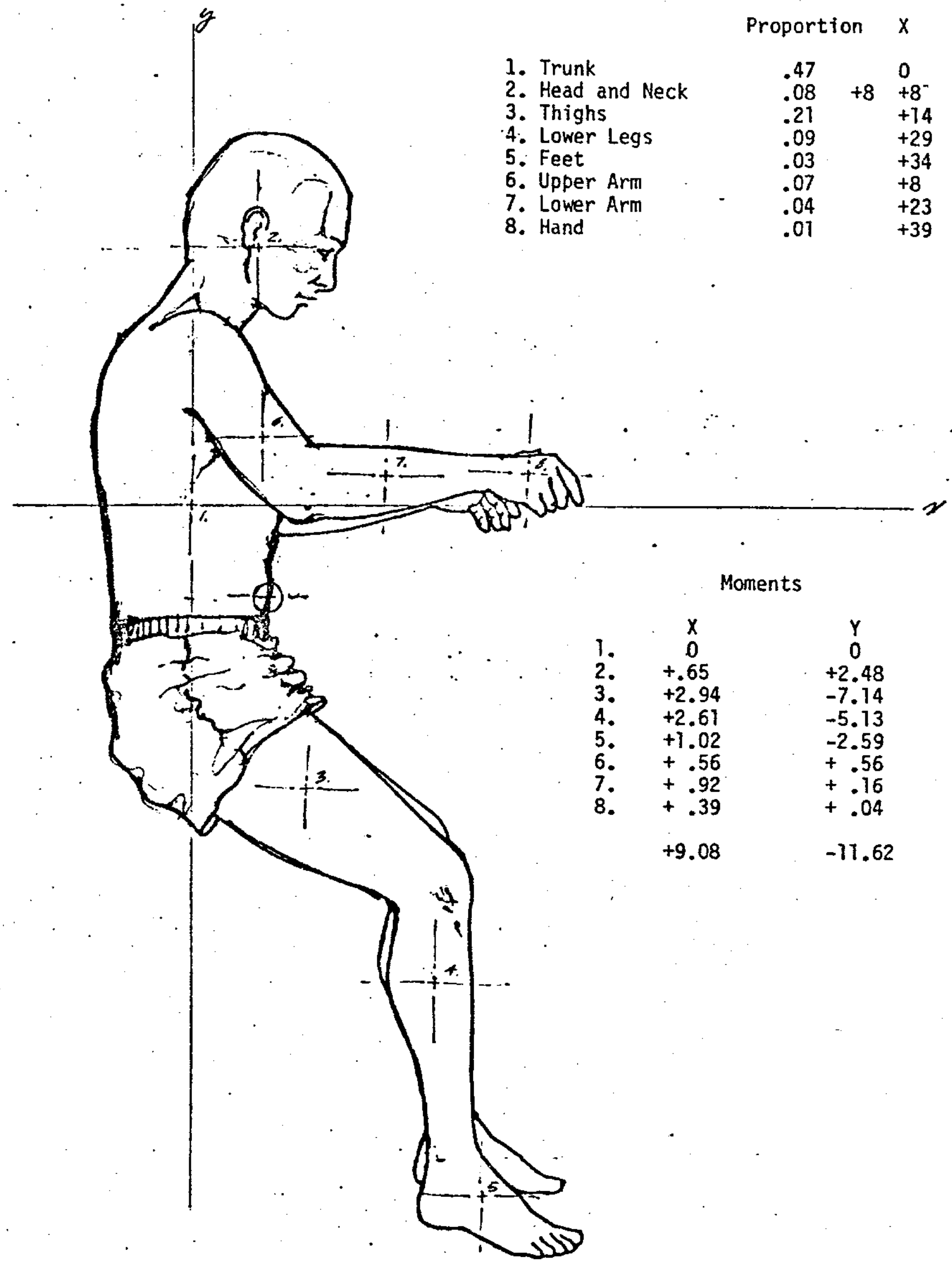
Speculation of a zero-g body posture preceded the Skylab mission, however, analysis of photography from SL-4 provided the requisite data essential for a giant leap in confidence. Further definition of this condition was added by inflight crew comments and post flight debriefings.

The following section describes neutral body posture by various measures. Drawings detail, by gender, dimensions, angular tolerances and percentiles for both static and dynamic states.

Some of the drawings are more postulates than axioms. They suggest a relationship or condition which may exist, yet require further in situ observation and a larger sampling to insure certainty. For example, since no data is currently available, this is obviously the case for the female projections.


Vertical Height Change
Head Thrust Forward
Retention of Cervical Curve
Lowered Sight Line
Reduction in Chest Girth
Loss of Thora-columbar Curve
Expansion of Intervertebral Discs
Arms Move Toward Quadraped Position
Center of Mass Shift
Reduction in Waist Girth
Legs Move Toward Quadruped Position
Reduction in Leg Mass
Plantar Flexed Feet

CENTER OF MASS (SEGMENTAL METHOD)



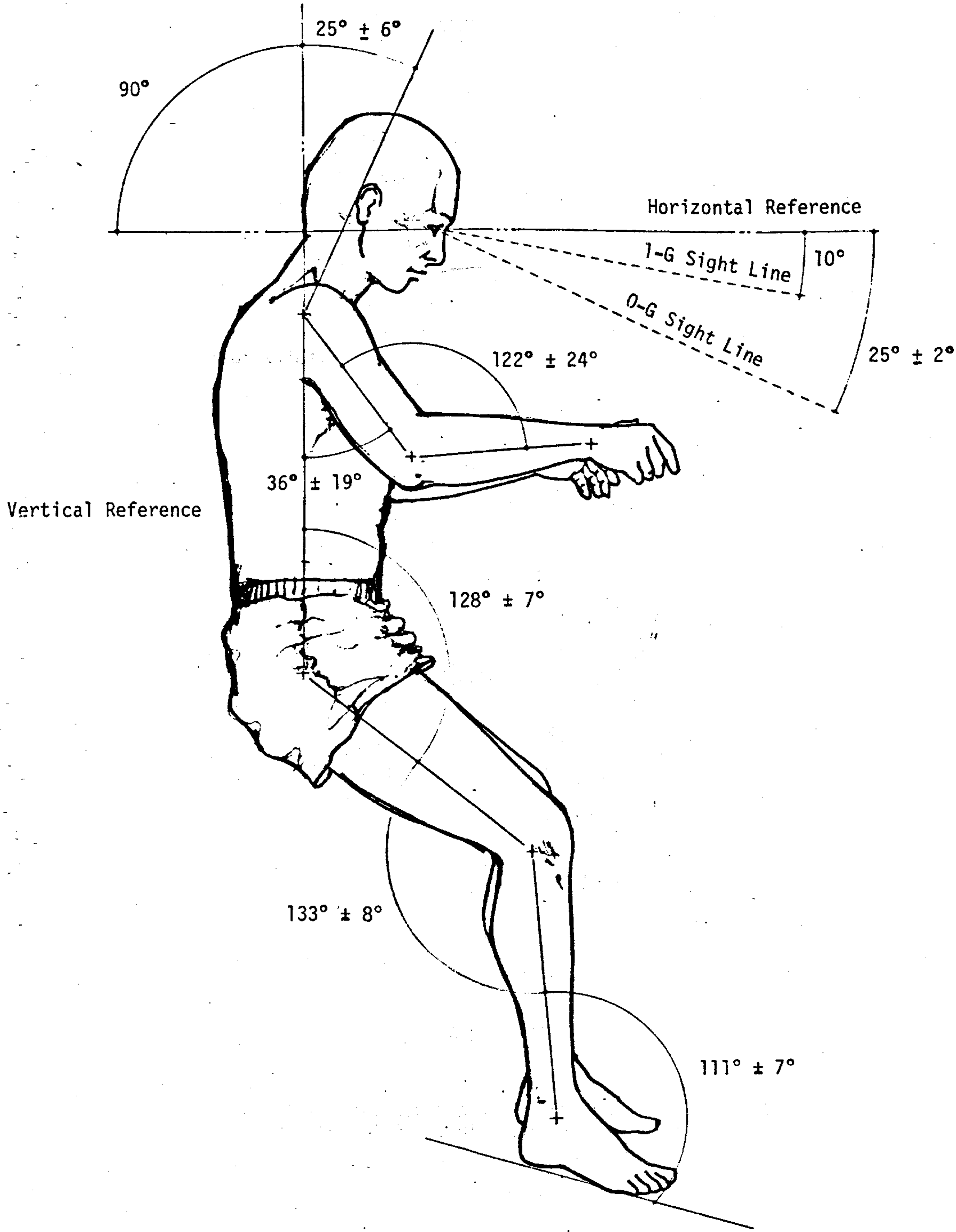
	Proportion		X	Y
1. Trunk	.47		0	0
2. Head and Neck	.08	+8	+8	+31
3. Thighs	.21		+14	-34
4. Lower Legs	.09		+29	-57
5. Feet	.03		+34	-83
6. Upper Arm	.07		+8	+8
7. Lower Arm	.04		+23	+4
8. Hand	.01		+39	+4

Moments

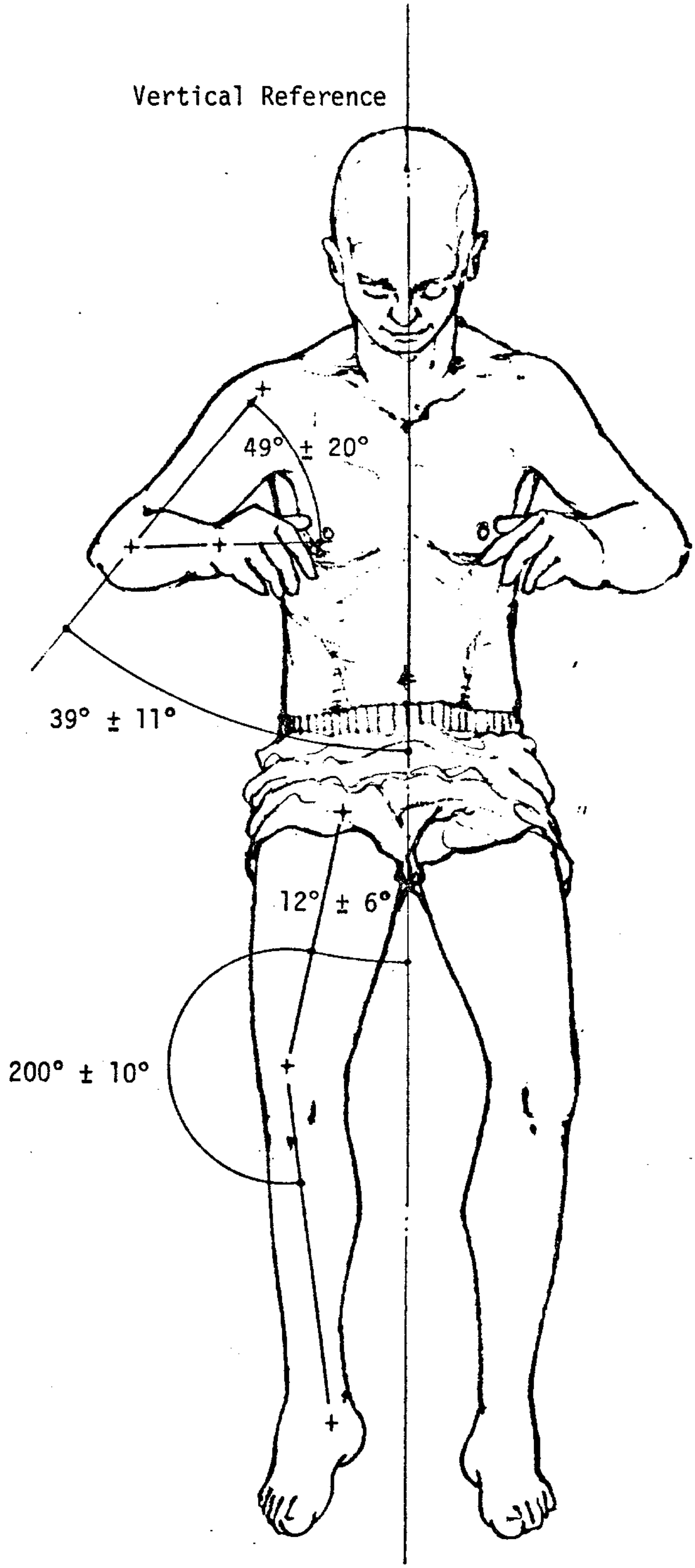
	X	Y
1.	0	0
2.	+.65	+2.48
3.	+2.94	-7.14
4.	+2.61	-5.13
5.	+1.02	-2.59
6.	+ .56	+ .56
7.	+ .92	+ .16
8.	+ .39	+ .04
	+9.08	-11.62

NOTE: Proportional to fluid shift and duration of exposure to zero-g, the c.g. will move in the +y direction.

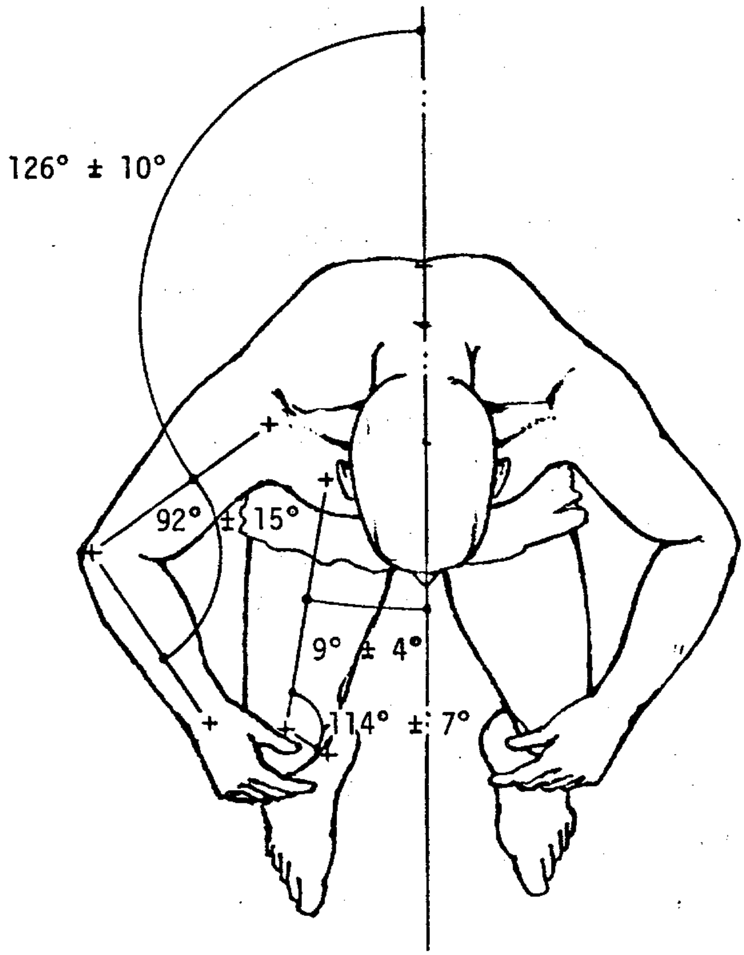
MALE ANGULAR RELATIONSHIPS
PROFILE VIEW



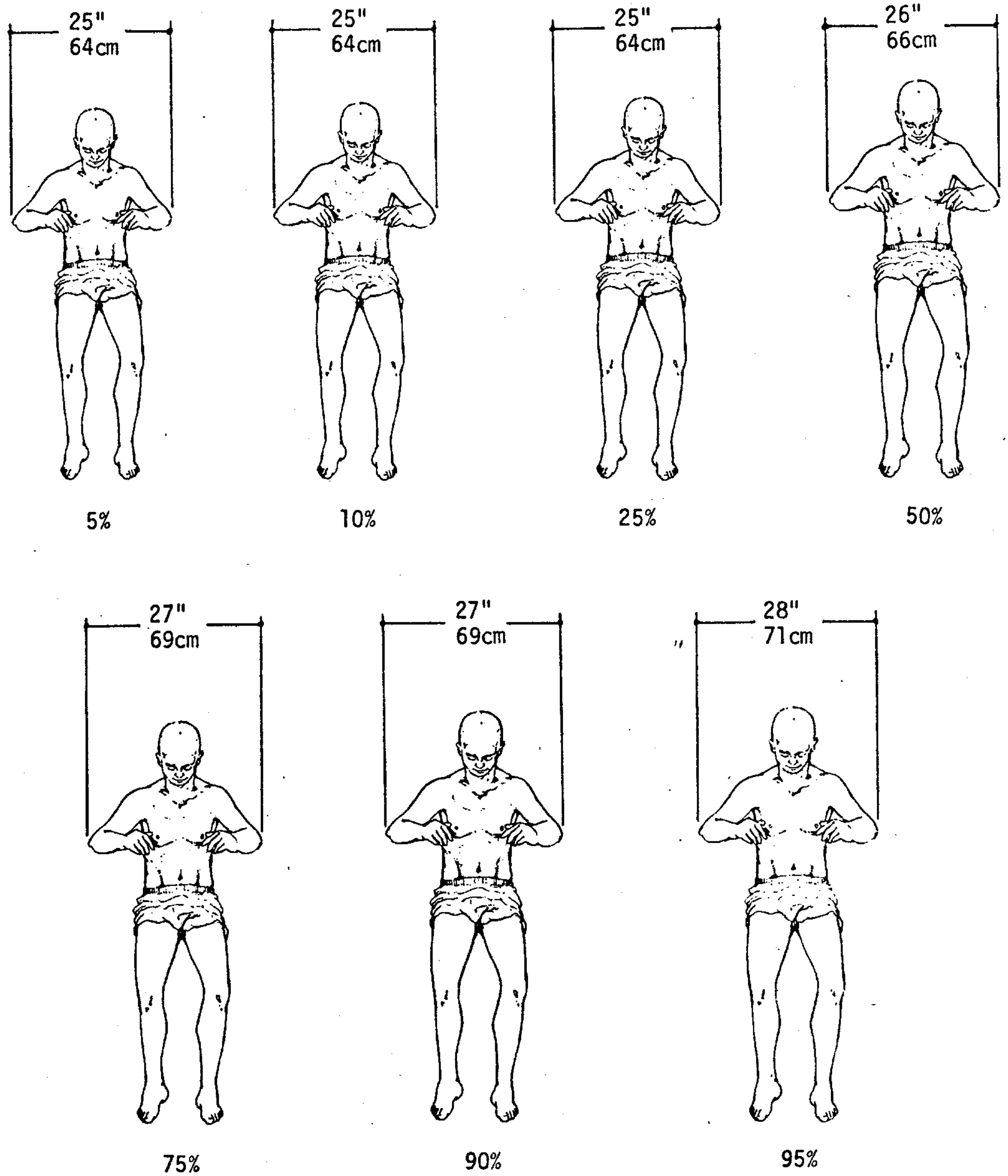
MALE ANGULAR RELATIONSHIPS
VENTRAL VIEW



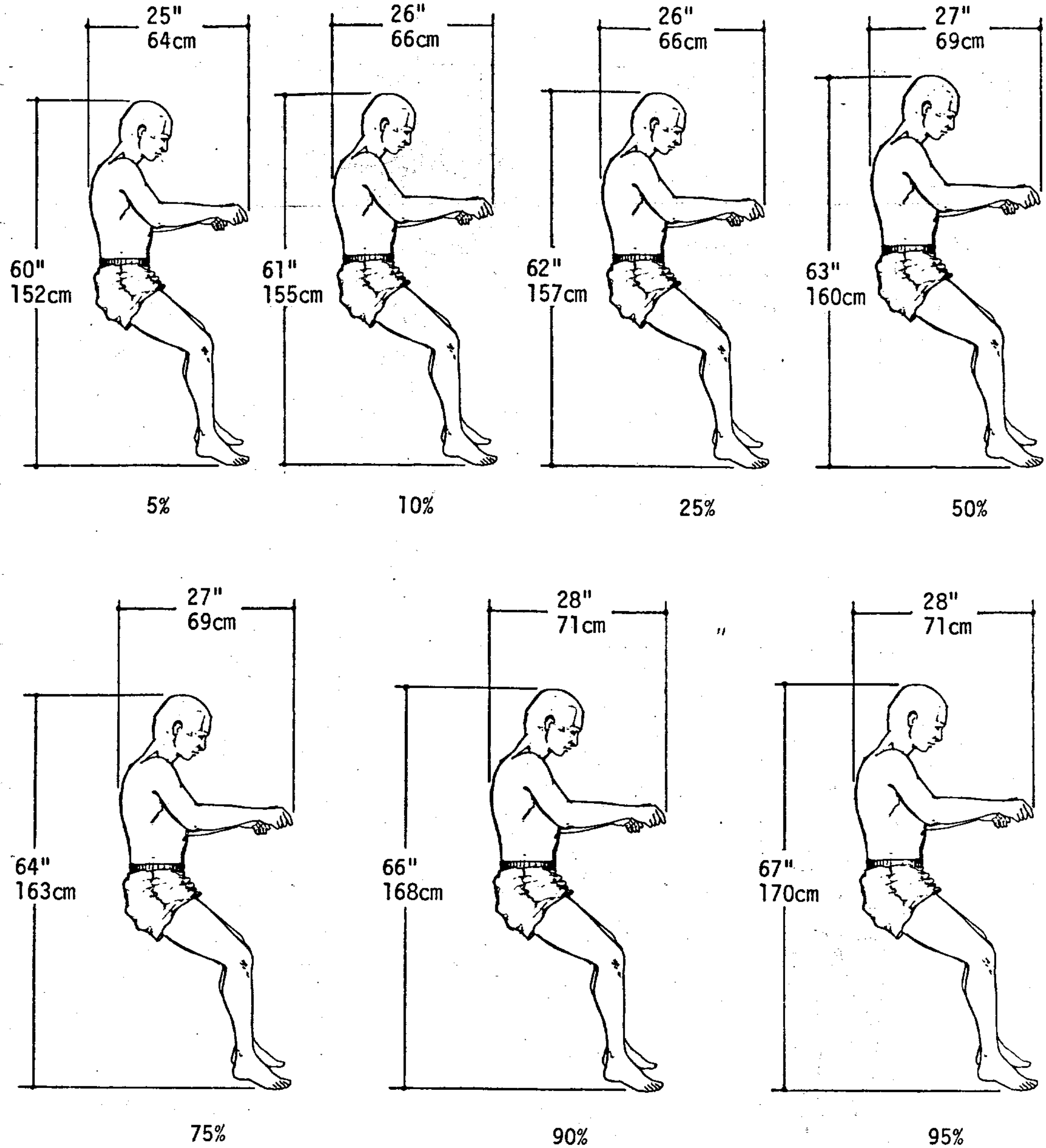
MALE ANGULAR RELATIONSHIPS
ANTERIOR VIEW



NOMINAL DIMENSIONS OF MALE NEUTRAL BODY
POSTURE ENVELOPE BY PERCENTILE GROUPS
VENTRAL VIEWS

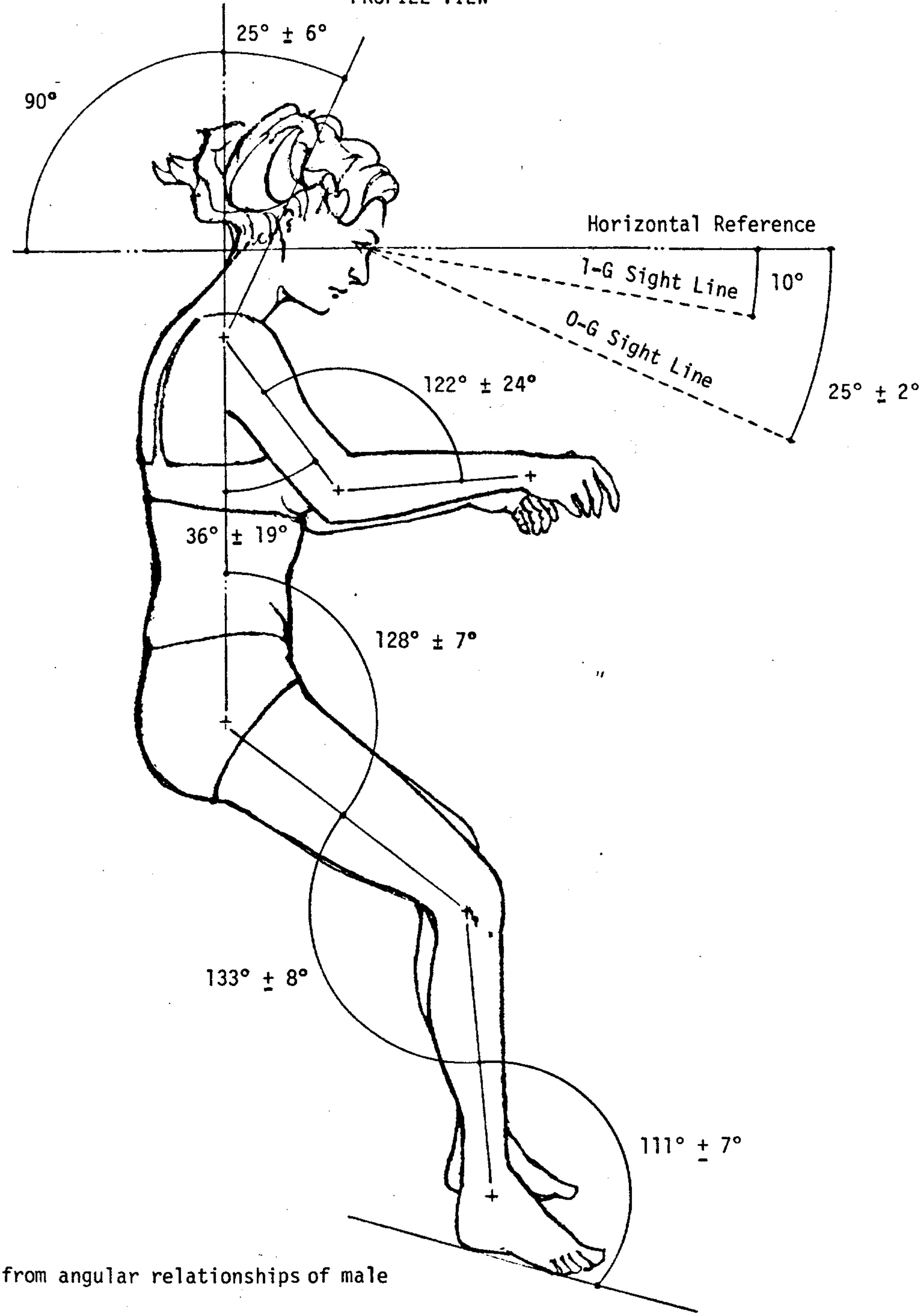


NOMINAL DIMENSIONS OF MALE NEUTRAL BODY POSTURE ENVELOPE BY PERCENTILE GROUPS PROFILE VIEWS



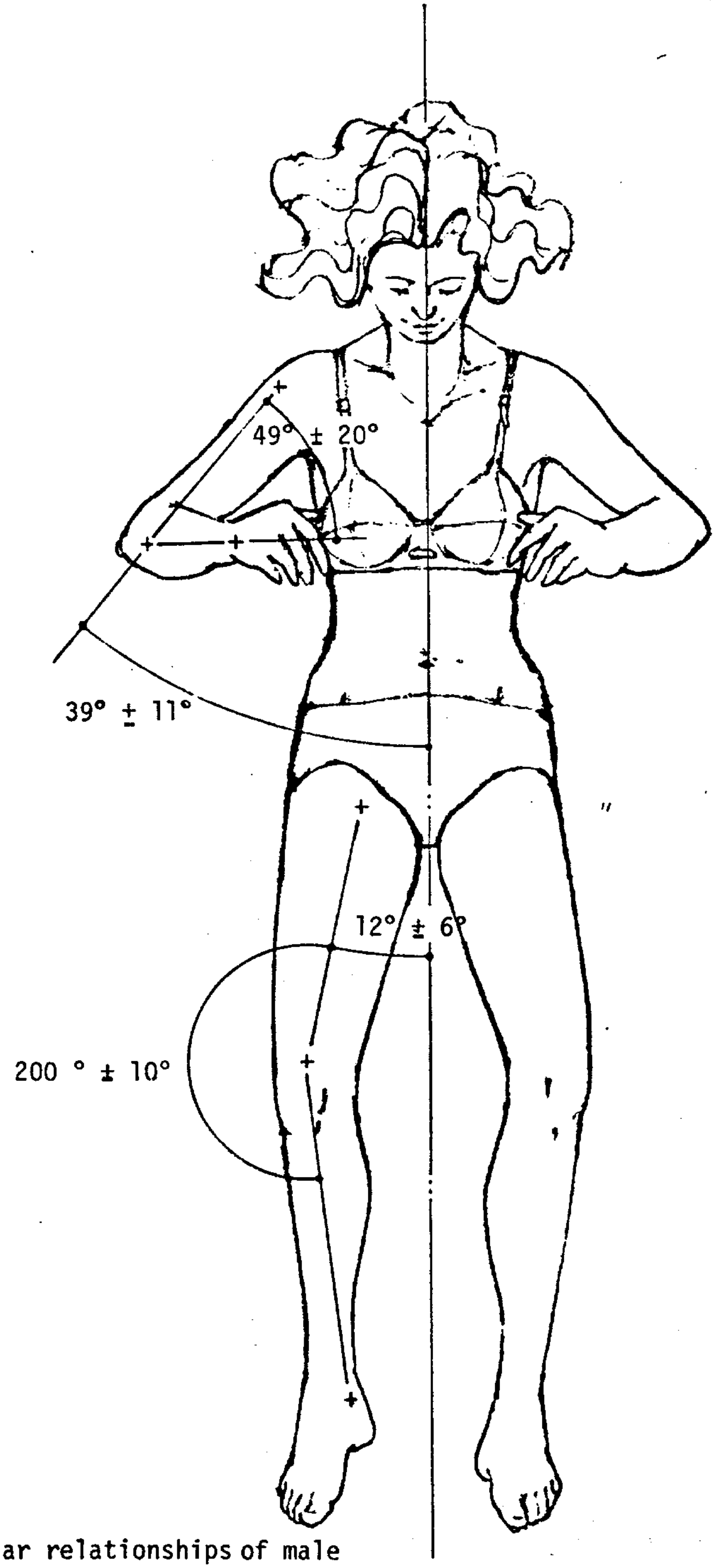
The following drawings depict an anticipated female neutral body posture. The nominal envelope is assumed to be the same as the male, however, owing to a generally greater degree of freedom, the range of movement for the female should be larger.

FEMALE ANGULAR RELATIONSHIPS (ANTICIPATED)*
PROFILE VIEW



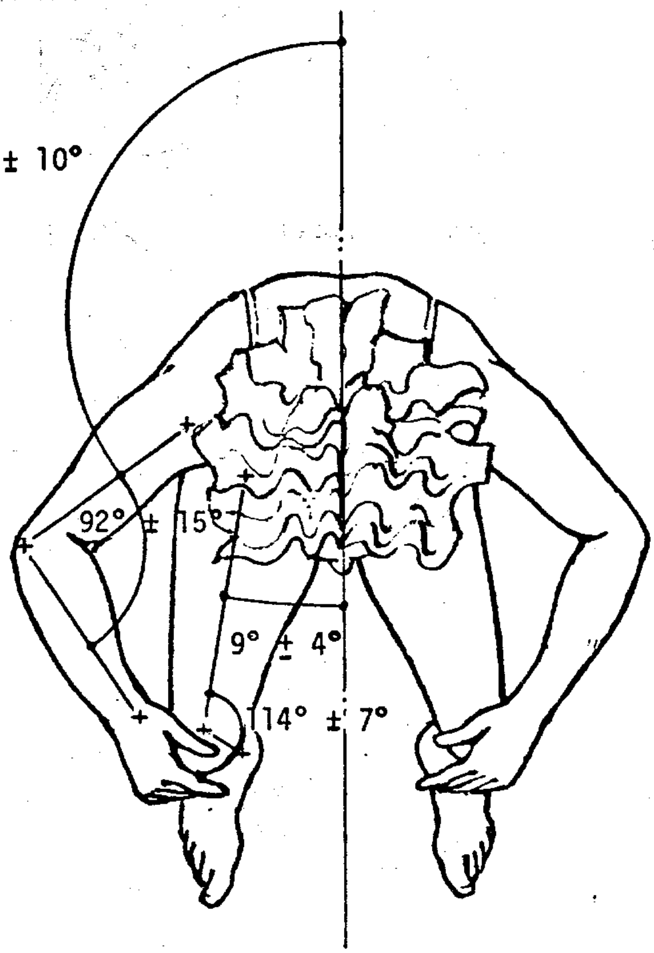
* Derived from angular relationships of male

FEMALE ANGULAR RELATIONSHIPS (ANTICIPATED)*
VENTRAL VIEW



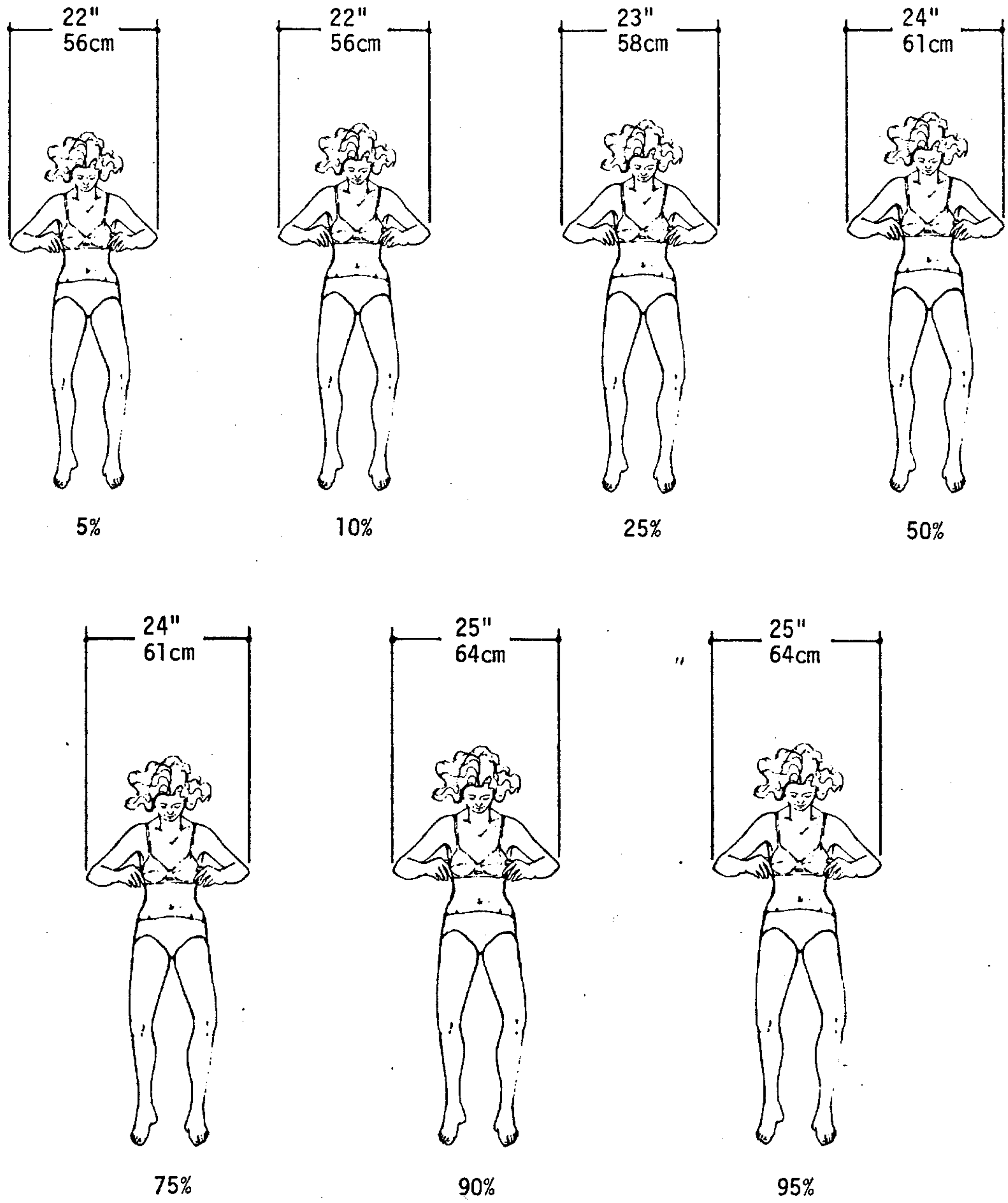
* Derived from angular relationships of male

FEMALE ANGULAR RELATIONSHIPS (ANTICIPATED)*
ANTERIOR VIEW

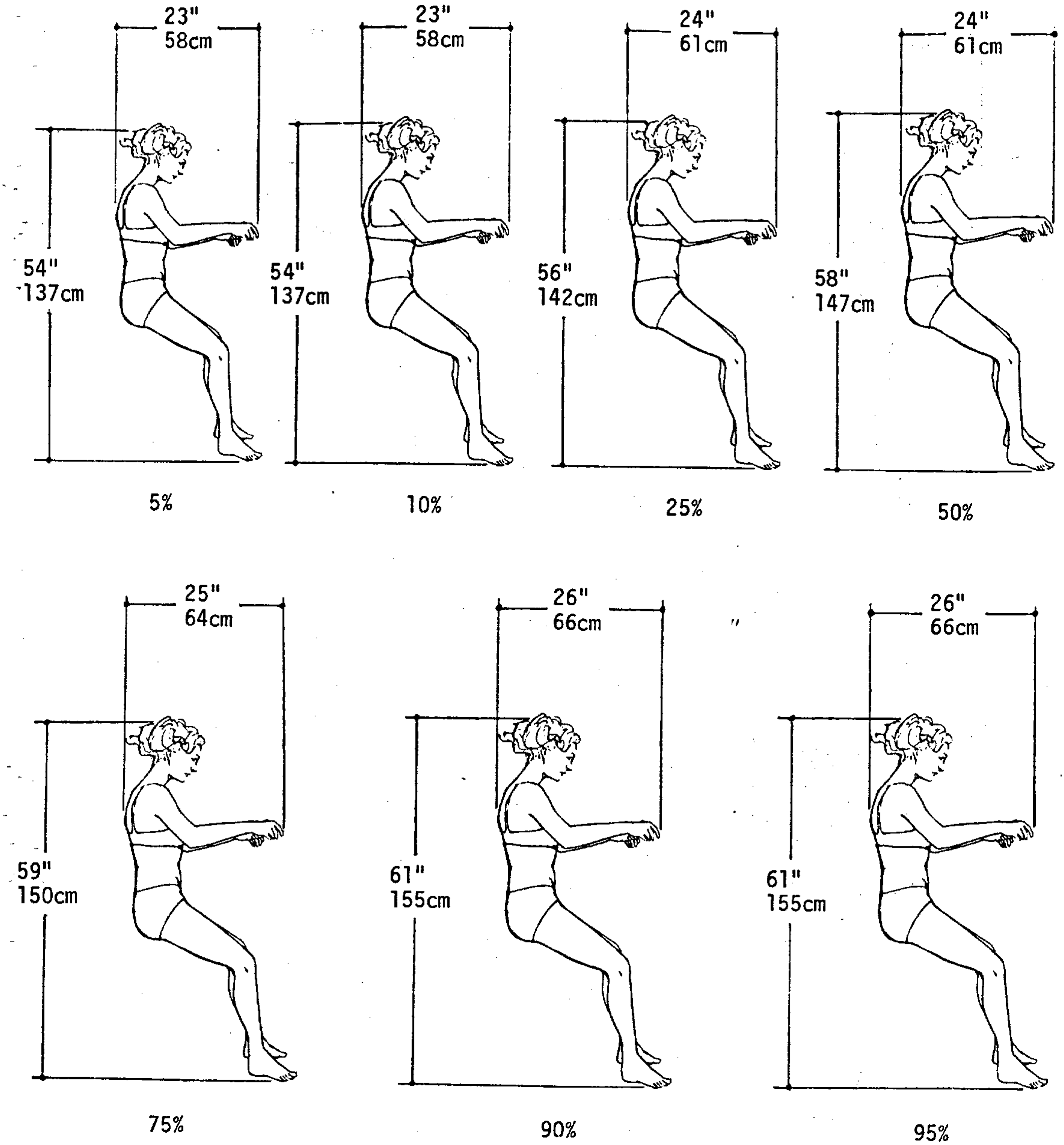


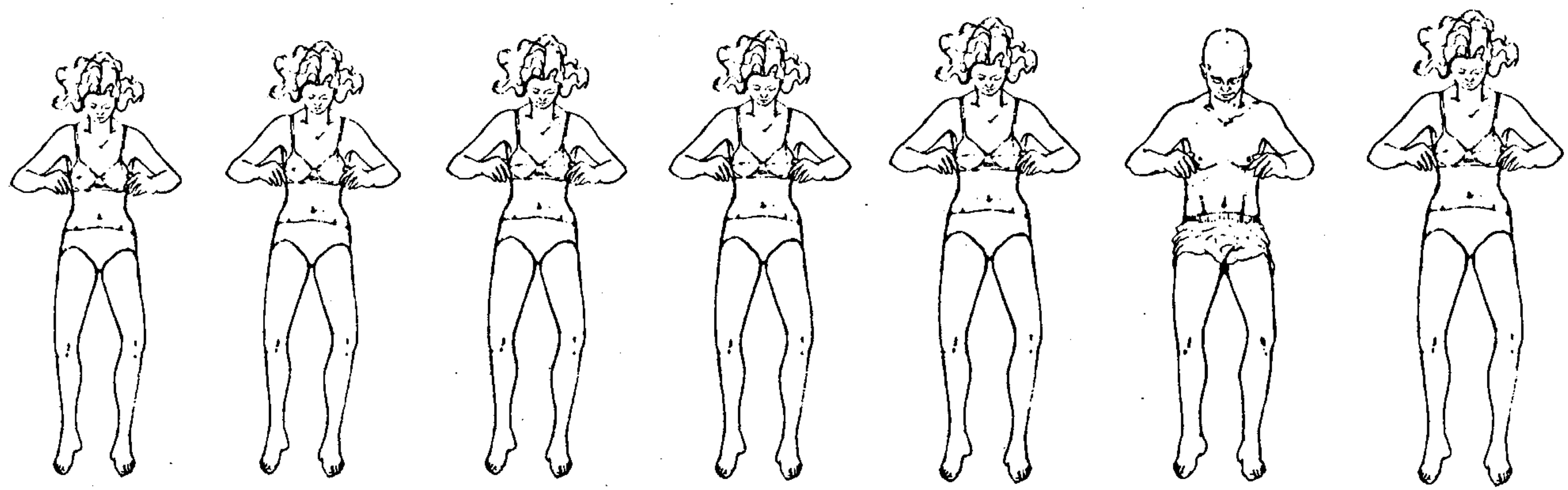
* Derived from angular relationships of male

NOMINAL DIMENSIONS OF FEMALE NEUTRAL BODY POSTURE
ENVELOPE BY PERCENTILE GROUPS (ANTICIPATED)
VENTRAL VIEW

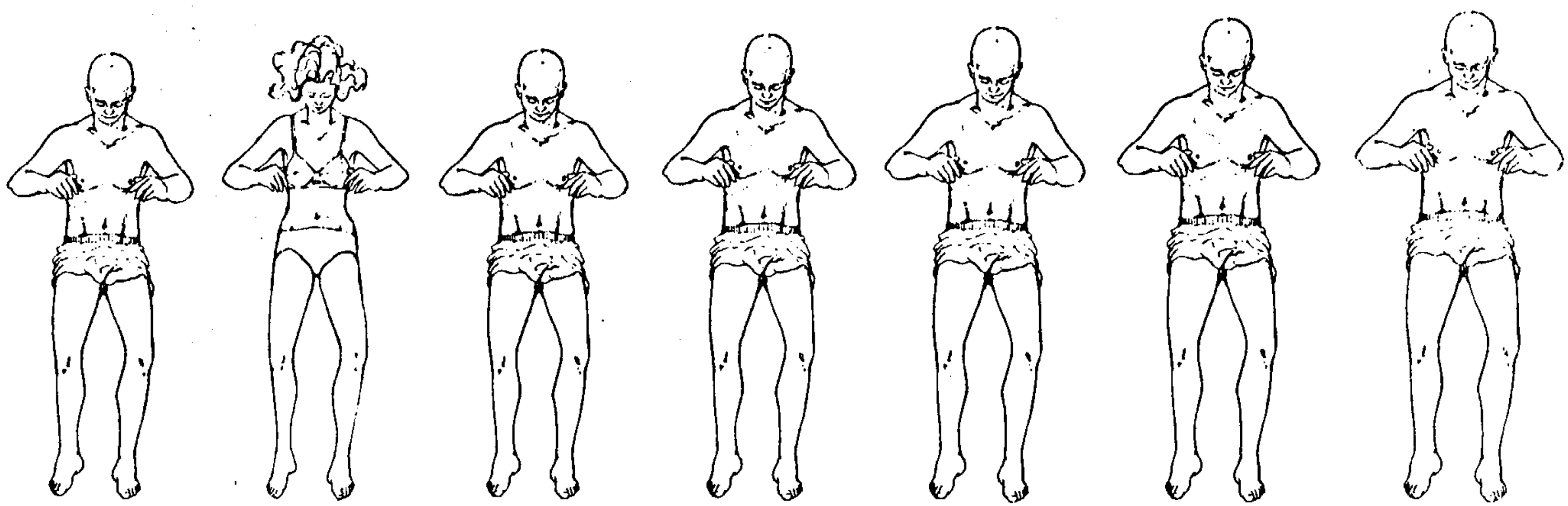


NOMINAL DIMENSIONS OF FEMALE NEUTRAL BODY POSTURE ENVELOPE BY PERCENTILE GROUPS (ANTICIPATED) PROFILE VIEW





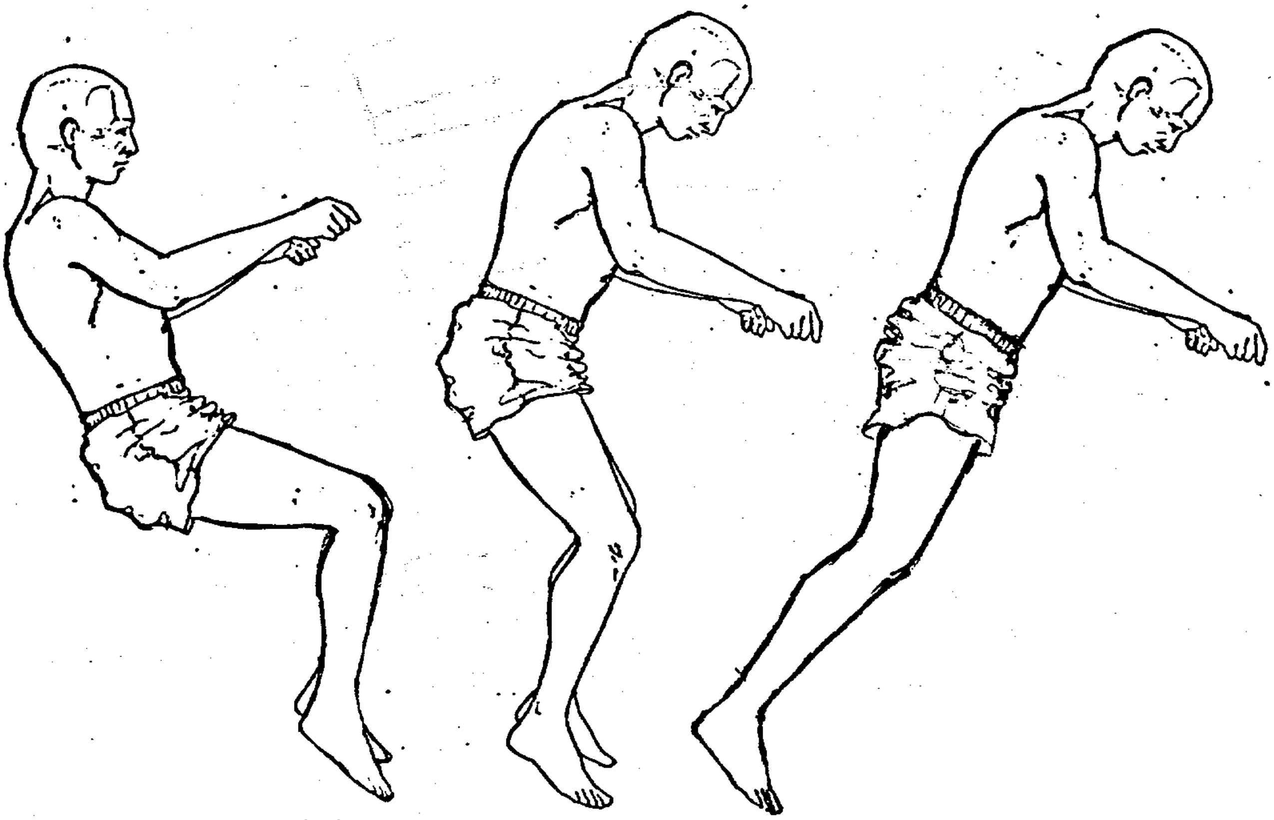
PERCENTILE	5%	10%	25%	50%	75%	5%	90%
N.B.P "	54	54	56	58	59	60	61
1-G "	60.0	60.8	62.5	64.1	65.8	66.2	67.2



PERCENTILE	10%	95%	25%	50%	75%	90%	95%
N.B.P	61	61	62	63	64	66	67
1-G	67.3	68	68.5	70.2	71.6	73.0	74.3

MALE AND FEMALE N.B.P. ARRANGED BY HEIGHT FROM PROJECTED ASTRONAUT POPULATIONS

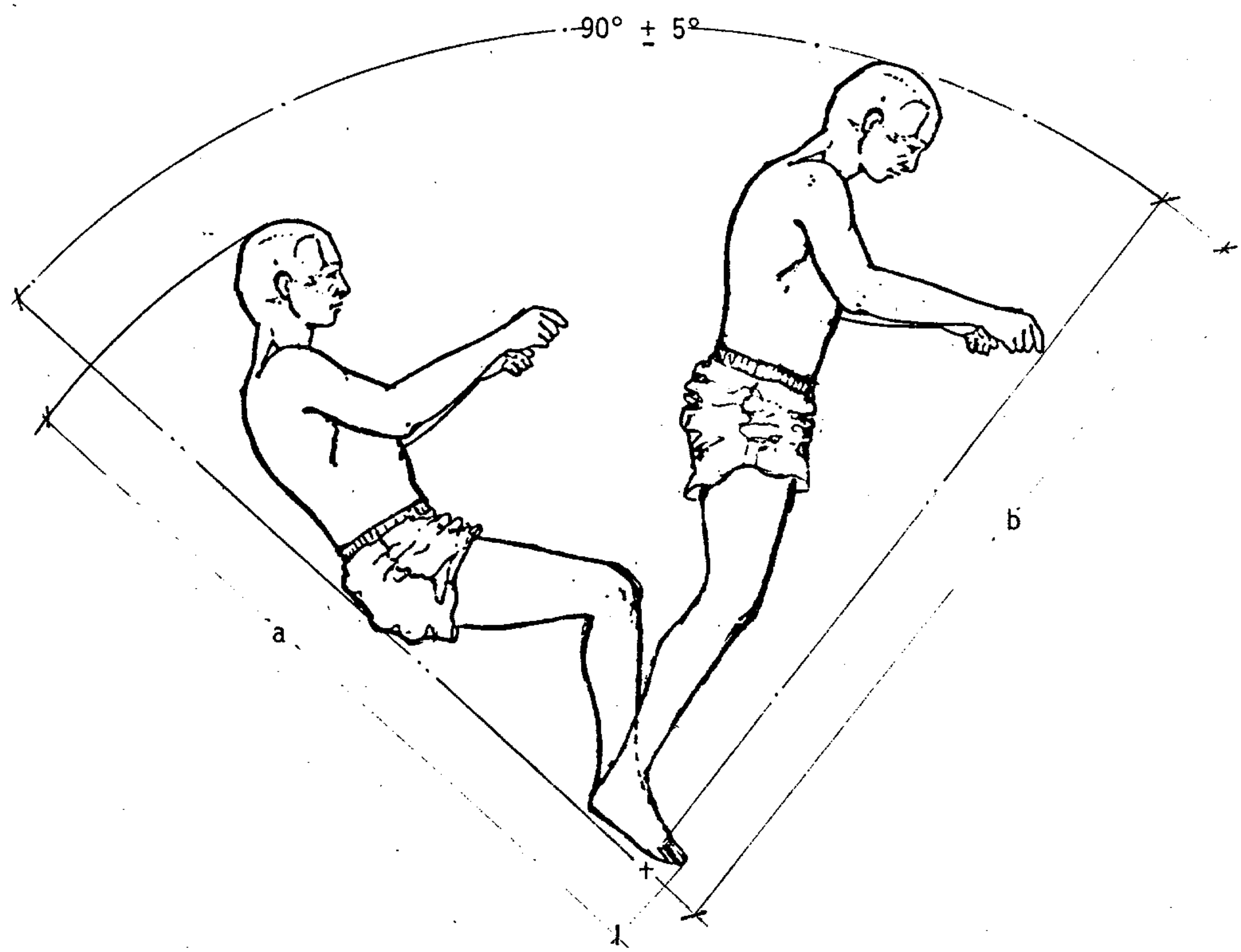
DYNAMIC ZERO-G INCREMENTS
(FEET RESTRAINED)



Aft Position N.B.P. Forward Position

NOTE: Owing to location of c.g. and freedom about knee joint, the aft position is easily assumed. The forward position, on the other hand, requires slight effort to achieve and maintain. These positions represent a nominal range and not the extremes.

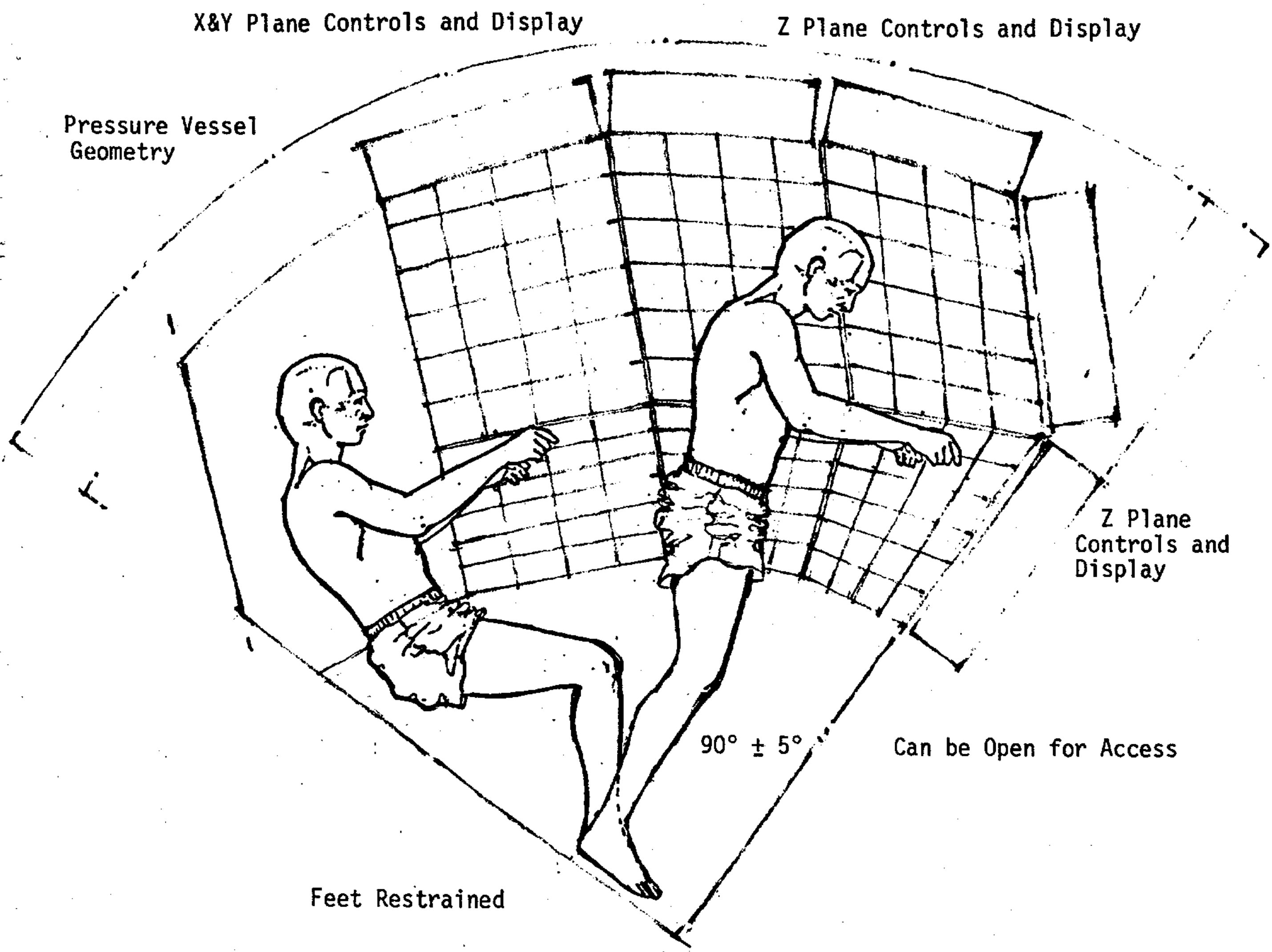
DYNAMIC ZERO-G ENVELOPE



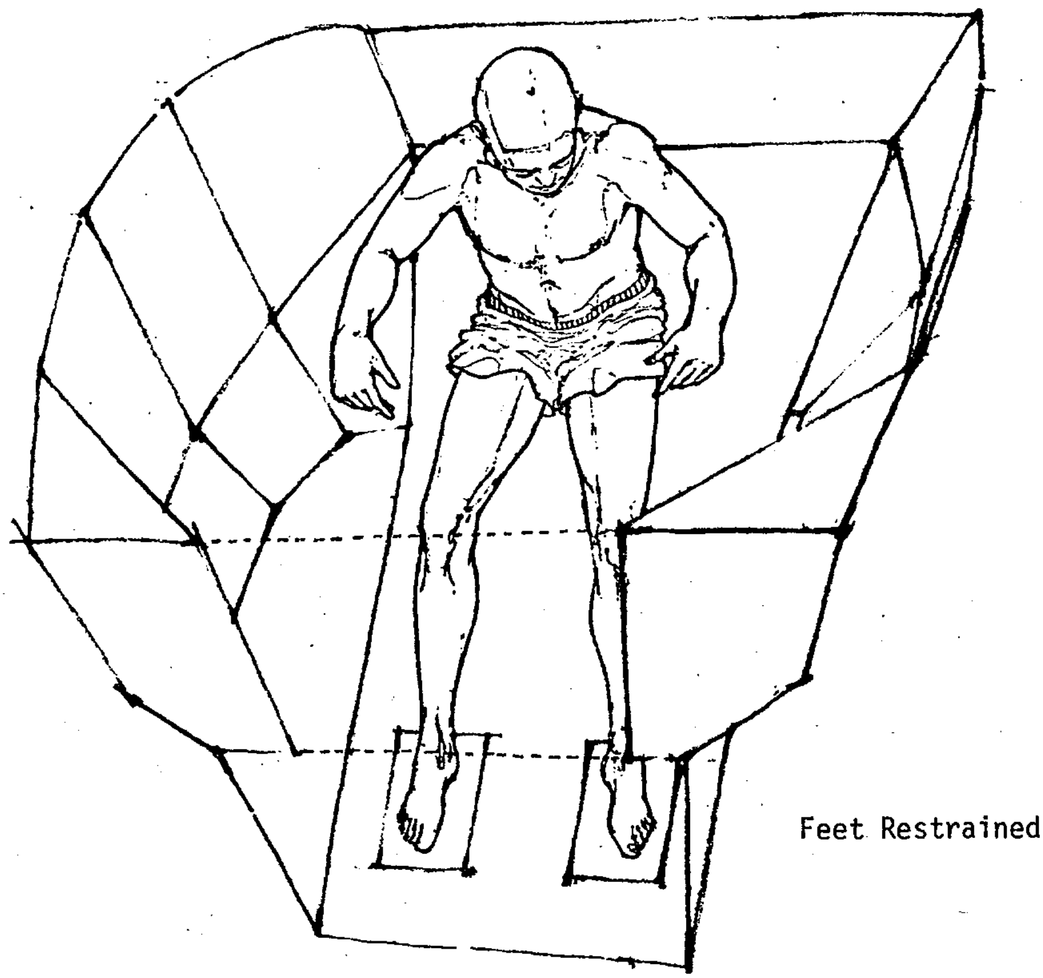
NOMINAL LIMITS OF MOVEMENT FROM
RESTRAINED FOOT POSITION

	MALE							FEMALE						
	5%	10%	25%	50%	75%	90%	95%	5%	10%	25%	50%	75%	90%	95%
a"	58	59	60	62	75	64	65	53	53	55	57	58	59	61
b"	65	66	67	69	70	71	72	59	59	61	63	64	66	67

WORKSTATION DIAGRAM
DYNAMIC ZERO-G ENVELOPE



WORKSTATION DIAGRAM FOR THE
DYNAMIC ZERO-G ENVELOPE



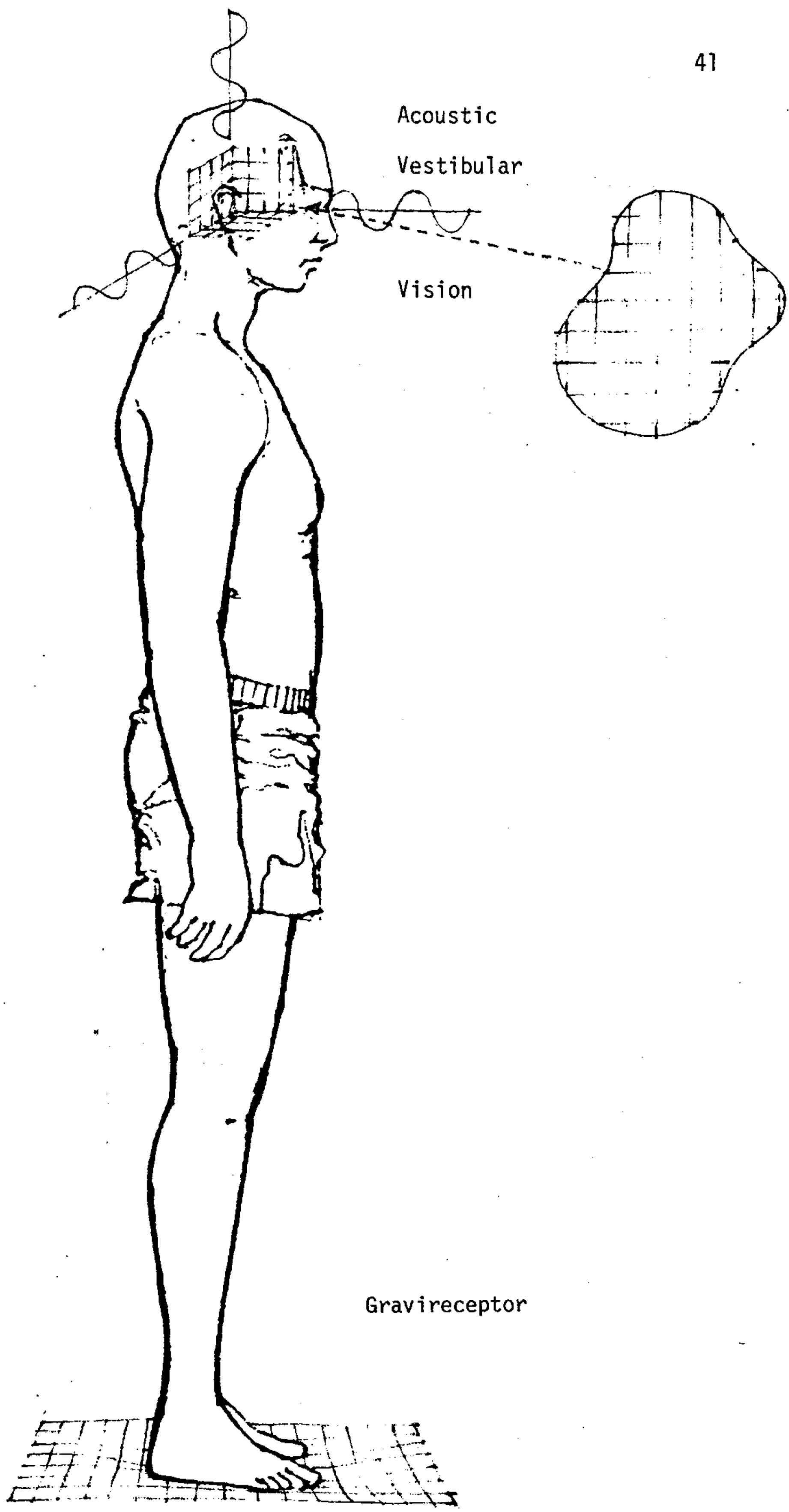
ORIENTATION

An on-going debate centers around orientation in zero-g. Few deny its significance, but the problem occurs with interpretation, individual variance and application. For example, evidence of a psychologist's concern for potential spatial disorientation was realized by an implied horizon painted on the interior of the Apollo VII capsule. This, however, was assessed by the astronauts not to be useful and discontinued.

One area where there appears to be unanimity is in a major USAF command where 100% of the pilots admitted experiencing spatial disorientation at least once and 14% of the fatal flying accidents were attributed to same.

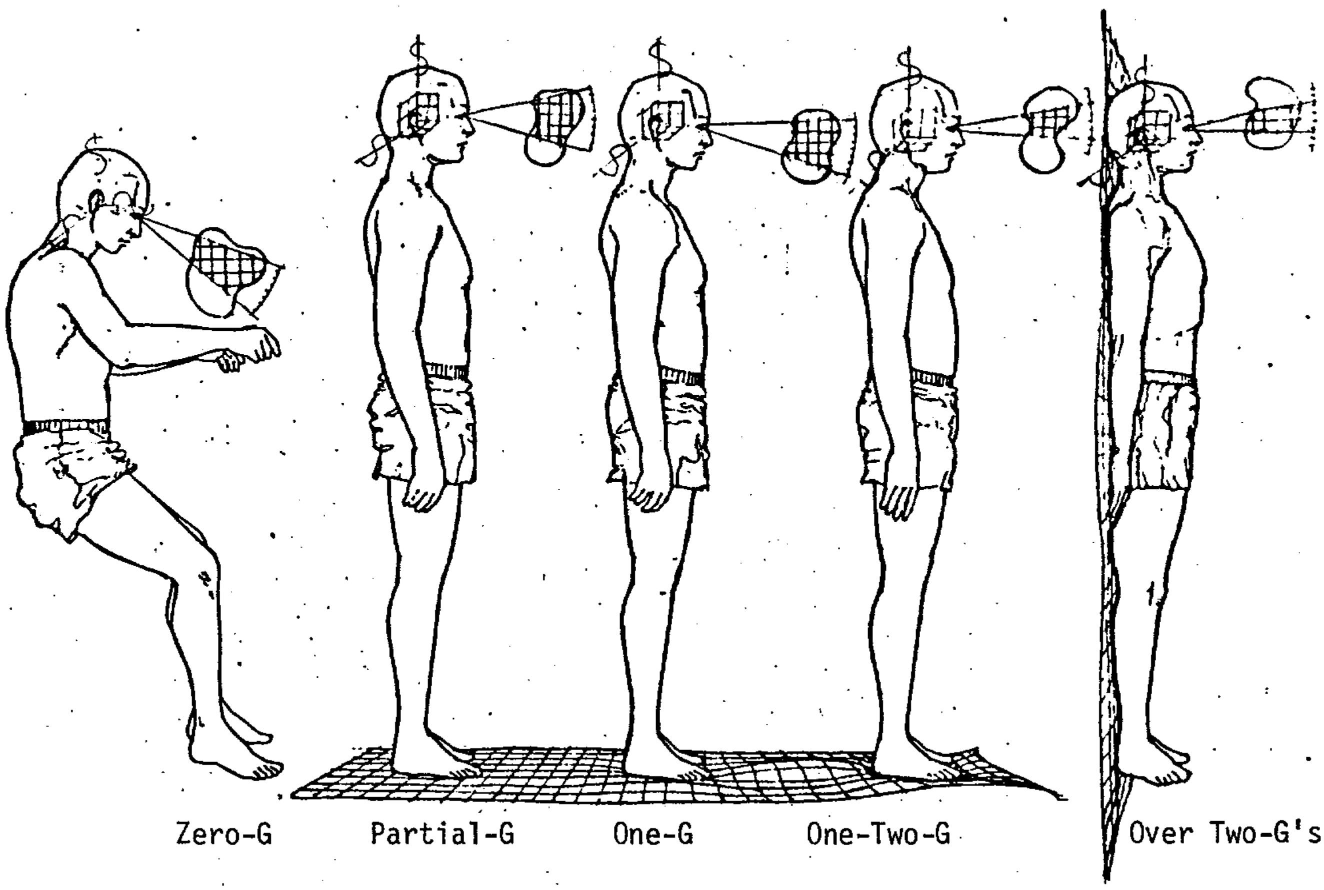
Contained within this section is a presentation of the major orientation analyzers. Considering the effect of acceleration on physiognomy, it is understandable that the performance of these sensors will be distributed under these conditions. Drawings of the analyzers and of the interaction of g-load and analyzers provide a simplified base for understanding isolated components of orientation.

Four categories of orientation germain to space flight suggest design applications that cover a range from spatial orientation to the natural conditioning of having grown up in a one-g environment.



MAJOR ORIENTATION ANALYZERS.

COMPARATIVE ORIENTATION ANALYZERS



Zero-G Partial-G One-G One-Two-G Over Two-G's

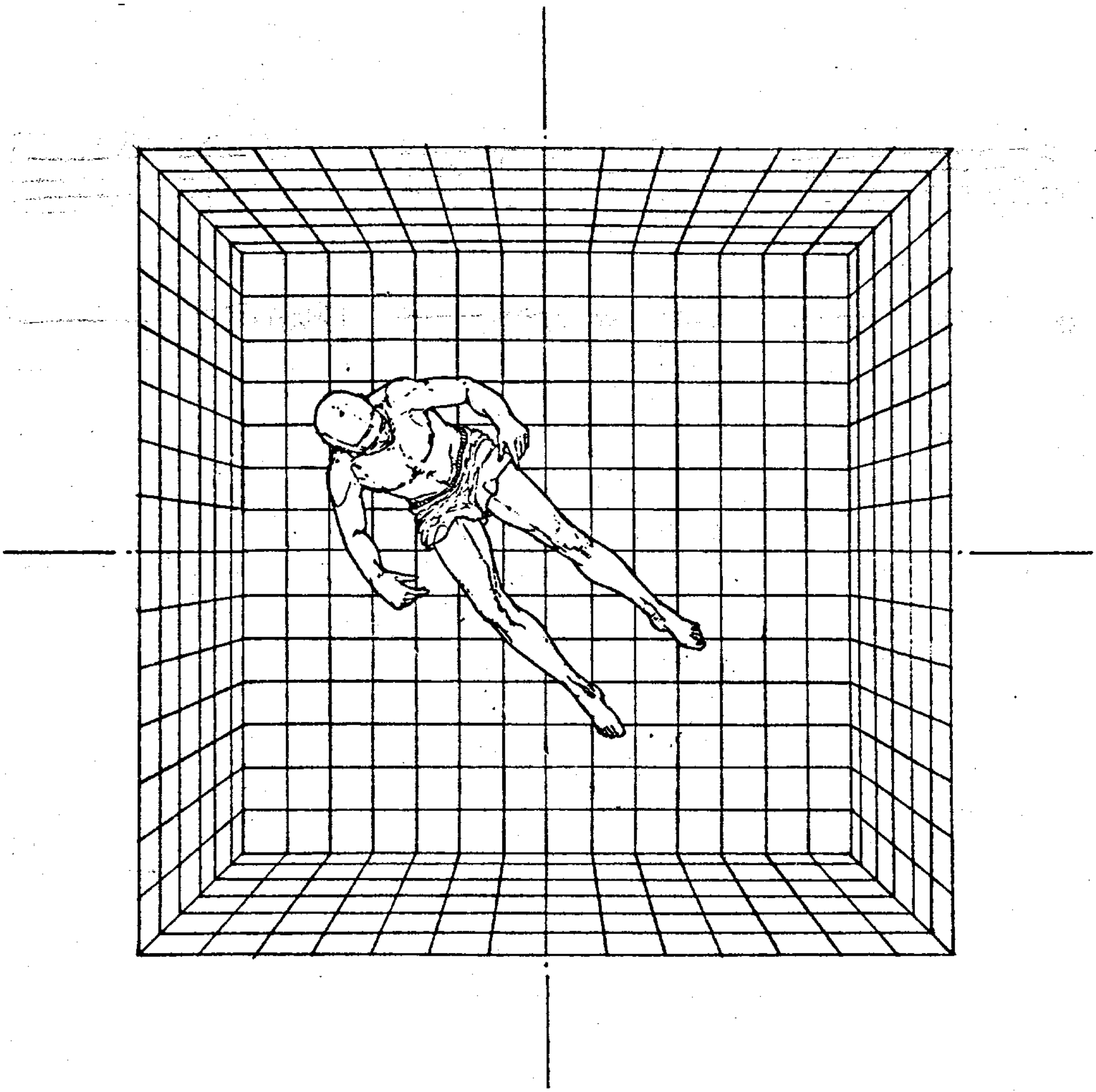
Reduction in number of afferent impulses used for orientation.

1. No otolith functions.

2. No cutaneous (propri-oceptive--must be imposed).

Tunnel Vision reduces field of sight.

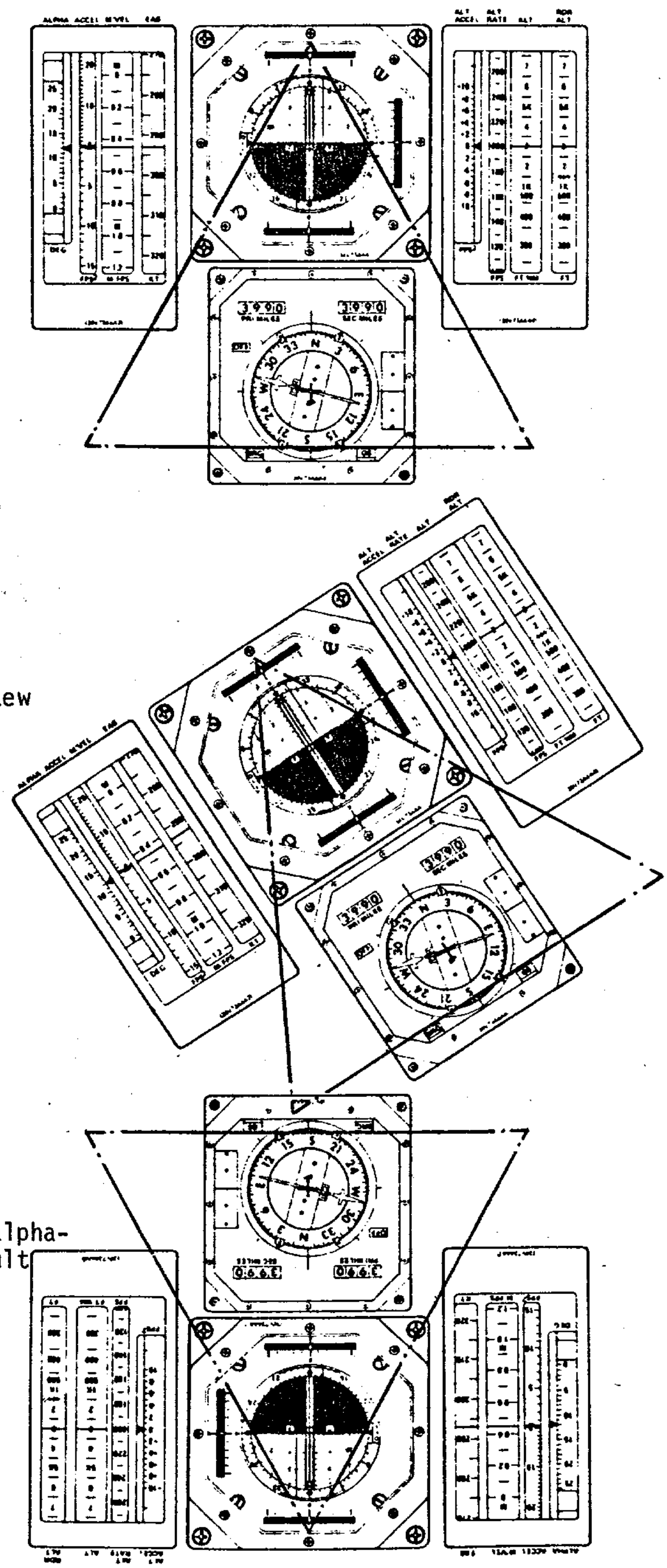
Four orientation conditions which influence spacecraft design are shown on the following pages.



Spatial Orientation

Ability to orient oneself either inside or outside of the spacecraft. Consider analyzers necessary and reference systems.

Reading



Designed Orientation

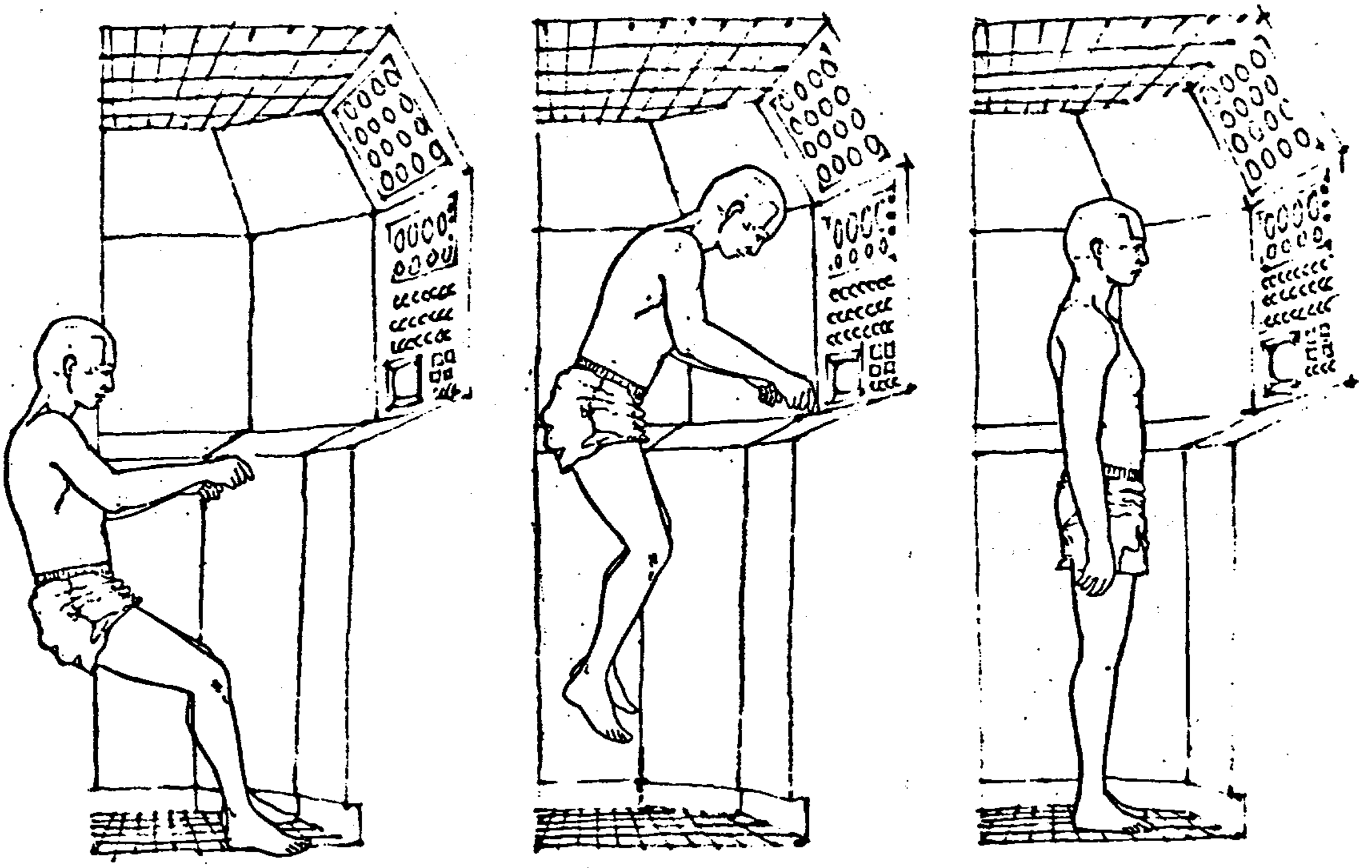
Axial Rotation ≈30°

1. Visual recollection askew (instrument scan)
2. Static and dynamic cognition retarded
3. Error prone

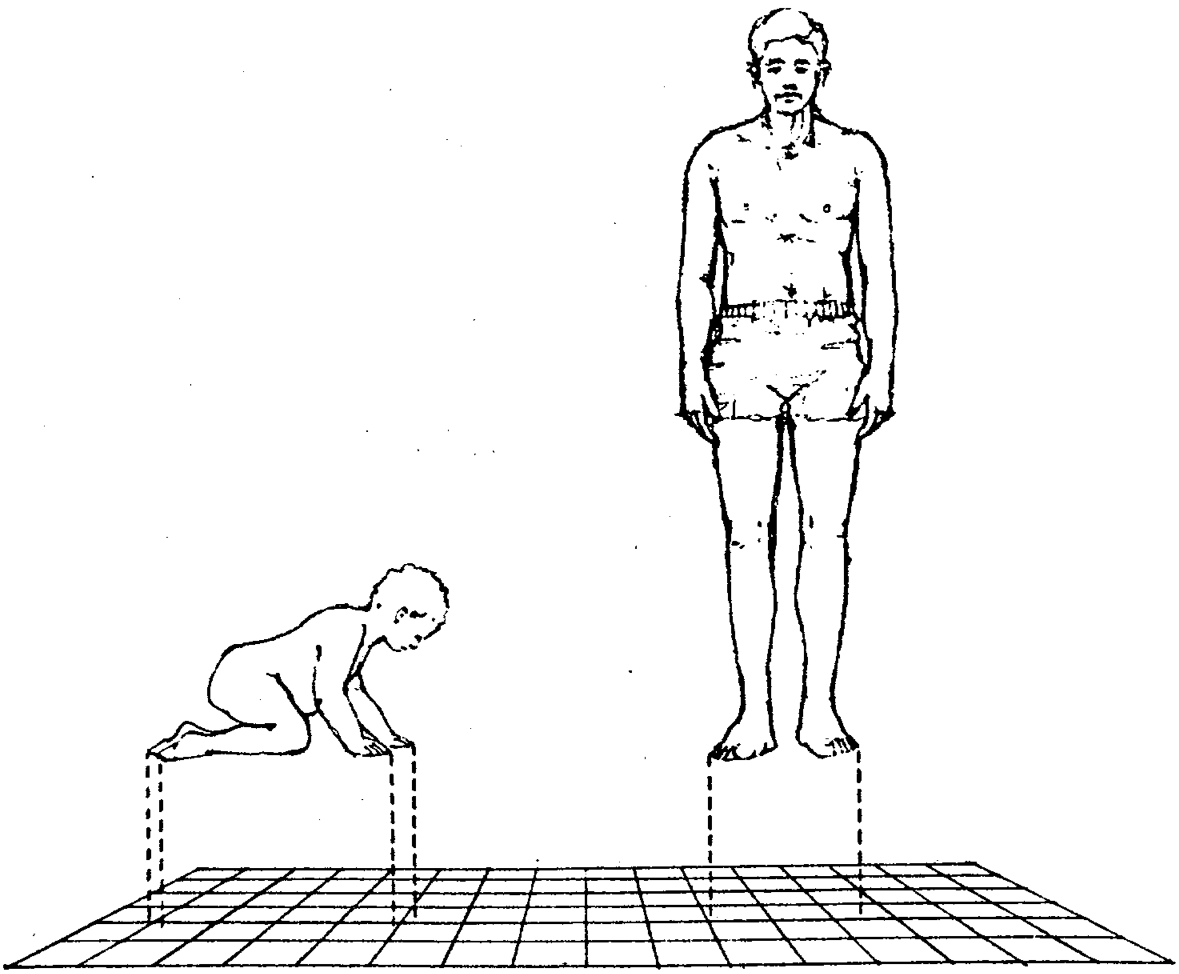
Inverted Image

1. Left/right reversal
2. Static recognition of alpha-numeric display difficult
3. Dynamic operations reversed
4. Delayed and inaccurate decisions

DISCREPANCIES BETWEEN ONE-G
TRAINING AND ZERO-G OPERATIONS



Zero-G Posture (Feet Restrained) | Zero-G Posture (Feet Unrestrained) | One-G Posture



One-G Conditioning

A lifetime of conditioning in a one-g environment determines many perception and reaction skills.

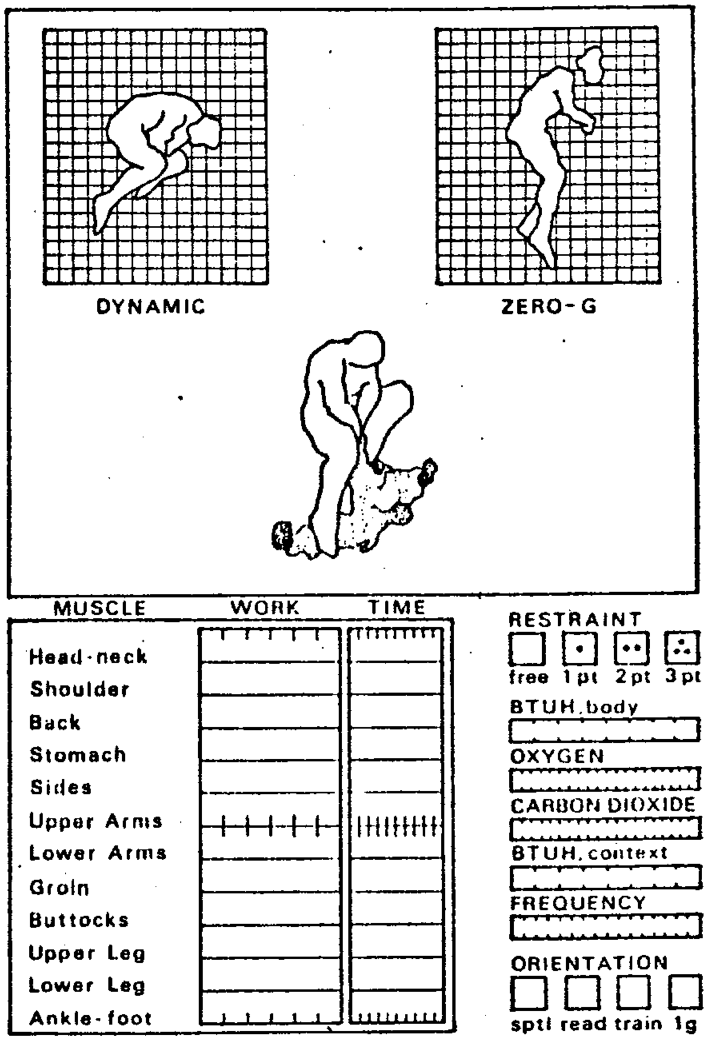
The Zero-G Activity Analysis is envisioned as a means of recording the characteristics of individual tasks. Ideally, all the tasks required for a particular mission would be compiled in a bulletin for reference in design and procedure decisions.

Work diagram - graphic portrayal of individual muscle work superimposed on N.B.P.

Profile, unit extreme posture exhibited for that activity

Nominal view - 3D representation of activity

Body description by major muscle groups



Desired restraint necessary for efficient performance.

Heat produced by activity

Quantity of O_2 consumed

Quantity of CO_2 produced

Heat produced by equipment and other crewmembers within the immediate vacinity

No. of times the activity is performed in 24 hour period

Orientation required for that activity

Work exerted by muscle groups for that activity - calibration based on measurement through cybex isokinetic dynamometer, infared photography, EMG or photogrametry

Time each muscle group is working

OBSERVATIONS

Zero-G Constant

In understanding the significance of zero-g, a convenient parallel of perception exists in the shift from the ptolemaic concept of a geocentric universe to the Copernican interpretation of the heliocentric order. There are, however, inconsistencies in this analogy which should be pointed out. The difference between whether or not the universe (solar system) was geo or heliocentric is one of operation. Whereas, the difference between 0-g and 1-g as a standard is one of measure. This by no means, reduces its significance. In fact, the condition of 0-g is truly a universal constant and the independent gravities associated with suns and planets are variables within that system. At this time, it is important to distinguish between the meaning of standard and constant. This is not an exercise in semantic hair-splitting; there is an important perceptible difference. A standard is a declared, devised, created base within a value structure. For example, 212°F and 100°C both represent the same physical condition--the temperature at which water boils, which is familiar and useful. A constant is inflexible and invariable and cannot be an assigned value. Within this same thermal metaphor, absolute zero would represent the constant. On a galactic appreciation, the temperature system and point at which water boils is variable, however, absolute value remains constant.

In lieu of this distinction, the 1-g acceleration of earth is a familiar and useful standard, yet zero-g remains the constant.

Acceleration Gradient

The collection of acceleration conditions begins to reveal some unexpected characteristics. For example, in the one-g environment convection, as a means of heat transfer, is considered fundamental. Yet this activity is a function of gravity and changes with that force. Therefore, there is no convection in zero-g and convective action is increased under greater acceleration loads. This is important, since breathing requires an exchange of gases normally facilitated by this mechanism. Also, heat from the body is removed via convection. This characteristic is unique to aerospace and its impact on design must be seriously considered.

REFERENCES

Publications

1. Analysis of Human Motion, Second ed., M. Gladys Scott, Appelton - Centry - Crofts, NY pp. 112-117.

2. "Anthropometric Changes in Weightlessness", W. Thornton, M.D. Scientist Astronaut, NASA.

3. "Characteristics of Postural Self-Regulation in Complex Spatial Environments and Aftereffects of Weightlessness", V.I.Myasmikov, D.P. Kozerenko and N.M. Rudomyotkin, Life Sciences and Space Research, Vol. XIV.

4. Gravitational Stress in Aerospace Medicine, D. H. Ganer, M.D., and G.D. Zuidensk, M.D., ed. 1961, Little Brown and Company Publishers.

5. Kinesiology, 6th ed., K.F. Wells, Ph.D. and K. Luttgens, Ph.D, 1976, W.B. Saunders Company.

6. "Mechanoreceptors, Gravireceptors", H.O. Strughold, Journal of Astronautics Vol. IV, Winter 1957.

7. Neutral Body Posture in Zero-G, Skylab Experience Bulletin No. 17, R. L. Bond, R. T. Gundersen and J.T. Jackson.

8. "Physiological Effects of Gravitation", O.G. Gazenko and A.A.Gzurdyhian Life Sciences and Space Research IV.

9. "Physiological Effects of Sustained Acceleration", Life Sciences and Space Research Vol. XIV.

10. "The Evolutionary Role of Gravity", N.P. Dubinin and E.N. Vaulina, Life Sciences and Space Research, XIV.

11. Zero-G Workstation Design, JSC Internal Note No. 76-EW1, R.T. Gundersen and R.L. Bond.

Additional information was gained through analysis of Skylab crew photographs and discussions with J.T. Jackson and R.T. Gundersen in the Spacecraft Design Division at NASA, JSC.