16. ANTHROPOMETRY AND TEMPORO-SPATIAL ENVIRONMENT

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16. ANTHROPOMETRY AND TEMPORO-SPATIAL ENVIRONMENT

The management of workspace, clothing and time elements in space operations is a major factor in optimizing crew comfort and efficiency. The anthropometric sizing of the astronaut population will be used whenever these data are available. Alteration of optimum workspace by zero gravity has already been covered under zero gravity in Acceleration (No. 7). Confinement and biorhythmic factors will complete the section.

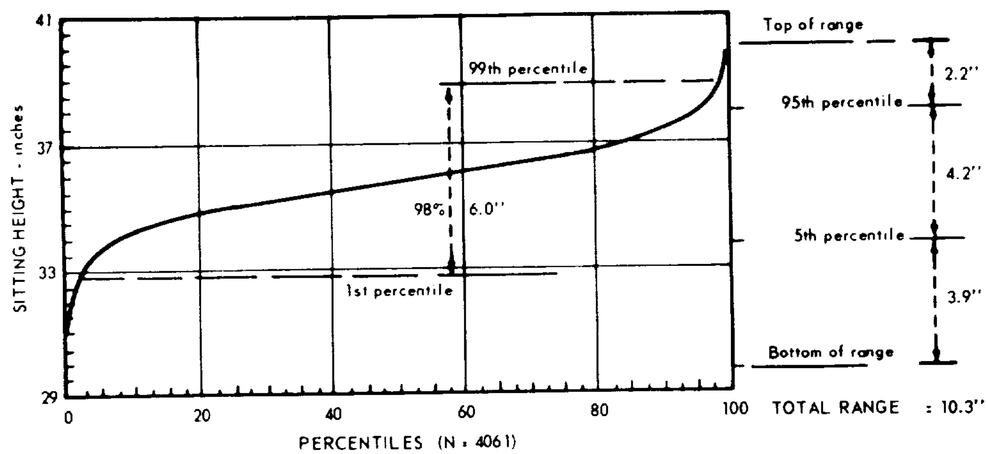
ANTHROPOMETRIC FACTORS IN WORKSPACE ANALYSIS

Several reviews are available of anthropometric factors in engineering design (71, 72, 145, 163, 164, 165, 213, 224, 234, 241, 246, 263, 294, 310). These cover static and dynamic body dimensions of the general population, as well as specific military groups. These may be used in the design of the appropriate ground based- as well as flight equipment whenever the specific dimensions of the astronaut group are not critical.

Those aspects of spacecraft design that are related to the anthropological (or physical) characteristics and the performance of the crew include: (25, 213, 224, 233, 234, 246)

- Design of protective clothing and portable life support systems (fit, mobility, task performance considerations) (129, 131, 232, 236, 243, 245, 246, 247, 331, 332, 333, 336, 371)
- Layout of the workspace in the spacecraft cabins (89, 129, 131, 232, 233, 236, 243, 245, 246, 247, 331, 333, 373)
- Design of the occupancy and restraint systems (fit, mobility, and support considerations (129, 131, 232, 246, 331, 332, 333, 336)
- Selection and design of displays and controls (88, 129, 130, 131, 160, 213, 224, 232, 233, 234, 243, 245, 247, 331, 332, 333, 336)
- Design of the equipment for maintainability (102, 333)
- Design of training equipment (to support crew performance) (130, 232, 332, 333, 336)
- Safety and hazard standards related to the spacecraft (123, 243, 245, 246, 247, 330, 331, 332, 333, 336)

Most of the anthropometric data are presented as percentiles of the population distribution. The use of percentile values as opposed to average or mean values is illustrated in Figure 16-1. In the charts presented in this section, whenever possible the size and composition of the population sample from which the data are derived are indicated (72).



The meaning of percentile. Percentiles comprise the 100 equal parts into which the entire range of values is divided for any given dimension. As an illustration, sitting heights of a large sample of men were measured and the values distributed graphically into the 100 percentiles as shown in the graph above.

The designer should design according to the concept of "design limits" or "range of accommodation." This concept, exemplified in the graph, involves the evaluation of percentile ranges. Note that the variability of the extreme 10% (the largest 5% and the smallest 5% combined) exceeds the variability of the central 90%, and so does the variability of the extreme 2% (largest 1% and smallest 1% combined). By proper analysis of the data on the using population, the designer can efficiently provide precisely the adjustability needed for any desired segment of the population.

Figure 16-1

The Use of Percentile Values in Anthropometry

(After Hertzberg and Clauser (164))

Human dimensions are measured in a standardized manner. Such standardization is critical if data from one population are to be compared with data from a different population. One must know the position of the body, the points on the body surface from which measurements are made, and whether the body was nude or clothed. Sketches accompany many of the charts to indicate how the measurements were taken.

In choosing design values from tables of anthropometric or biomechanical data, the engineer should select that value which will accommodate the maximum practicable percentage of the potential user population. For example, an access hatch should be large enough for the largest man to pass through; a switch for a panel to be operated by a seated, restrained operator should be located at a distance no farther than that which the man with the shortest arm can efficiently reach to actuate the switch. A control should not require more force than the weakest man who is to use the equipment can be expected to apply, yet the control should be able to withstand more force than the strongest man can be expected to apply under normal conditions. For astronauts it is vital that the entire range be accommodated, but for non-astronauts using ground-based equipment, 95% or -- if space is critical -- 90% of the range may suffice. Furthermore, the principle of mock-up trials, using subjects who are physically representative of the using population, wearing typical outfits, and performing simulated tasks, should be used before final decisions on design are made. For ground-based operations, anthropometric data are required on the general population. The basic body dimensions of a generalized U. S. male population is noted in Figure 16-2. The U. S. National Health Examination Survey, conducted in 1962-64, gives 10 key dimensions for a truly representative sample of the U. S. population. Data are presented by age group (18-24, 25-29, etc., to age 79) covering the total population (71, 334).

Anthropometric data are required for design of equipment used in military aircraft supporting launch, recovery and in-flight monitoring operations. Dimensions of the USAF flying personnel are noted in Figure 16-3. Correlations between the dimensions of this population are available (164). Table 16-4 covers the overall head, body, and limb measurements of the astronaut population. The body dimensions of from 3 to 38 astronauts were used to establish means, standard deviations, and ranges (94).

The need for biomechanical data regarding the center of gravity (CG) and moments of inertia of the human body and body segments arises in several fields of application. Such data are useful in determining the stability and angular acceleration of equipment occupied or operated by persons in various postural attitudes; in the design of seats, particularly aircraft ejection seats and fastening devices; in dummy construction; in assessing the ability to apply torque while in the weightless state and the consequences of such application; and in the study of human biomechanics. An excellent review of the techniques of measurement is available (84). Data in the older literature (35, 201) have been updated by more recent studies (22, 23, 77).

Moment of inertia (I_{CG}) about the segment CG is equal to the product of segment mass and radius of gyration squared. Moment of inertia about a proximal joint center (I_0) is related to I_{CG} by the formula:

$$I_0 = I_{CG} + mD^2, \qquad (1)$$

where m is the segment mass and D is the distance from the joint center to the CG. The moments of inertia of the segments can be determined by a free-swinging pendulum system. The segments were suspended from the proximal joint center, the oscillation period measured, and the moment of inertia determined by the relation:

$$I_0 = \frac{mgL}{4\pi^2 f^2} \qquad (2)$$

where I_0 = moment of inertia about the point of suspension,

m = mass of the segment (weight/g),

Body dimensions of United States males, as estimated and and synthesized for use in commercial aircraft interior design. Adapted from a chart prepared by J. A. Roebuck, Douglas Aircraft Co., Inc., from data of Hooton (169), Randall et al (263), Daniels et al (73), Hertzberg et al (165), and McFarland et al (214).

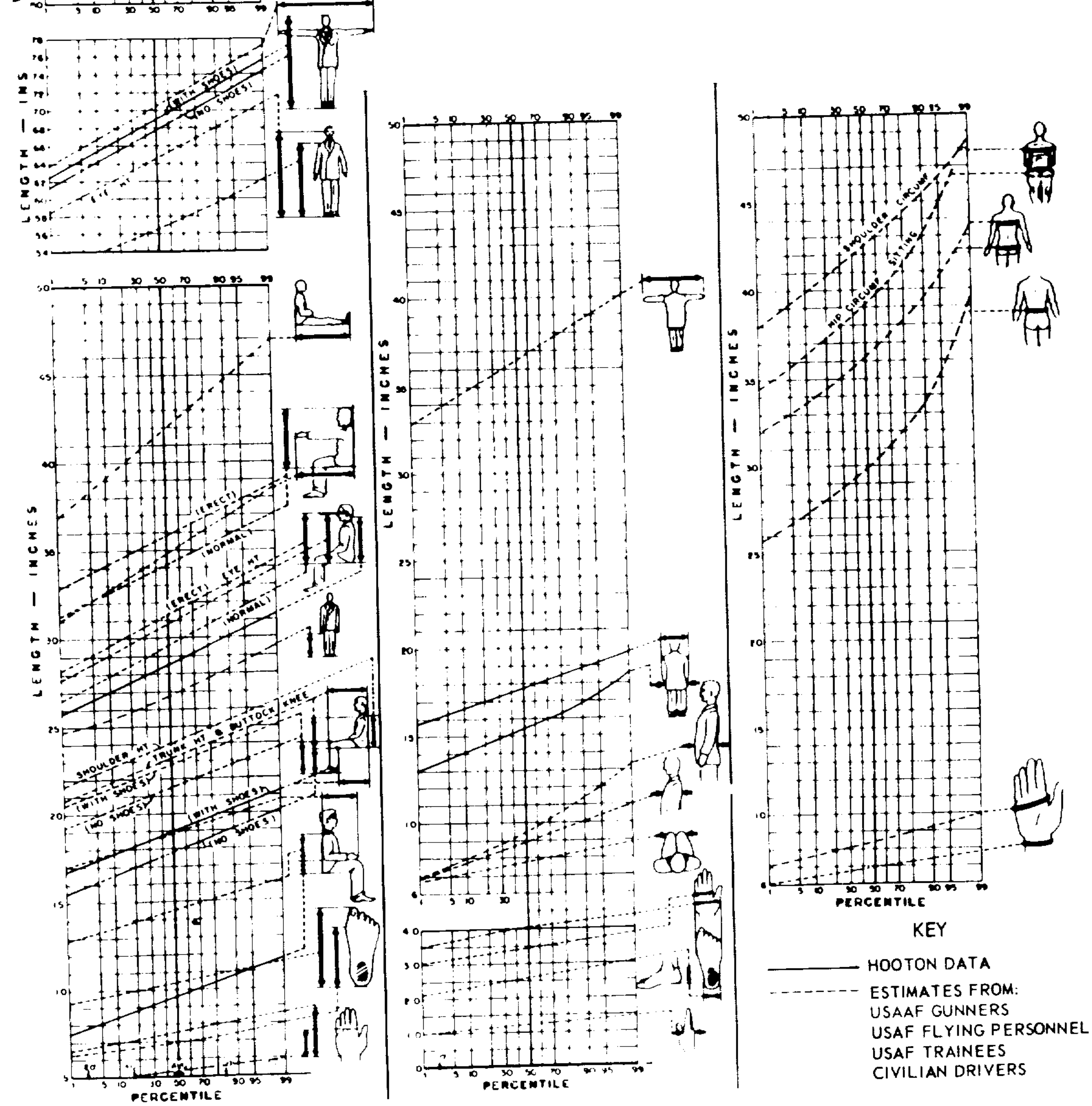
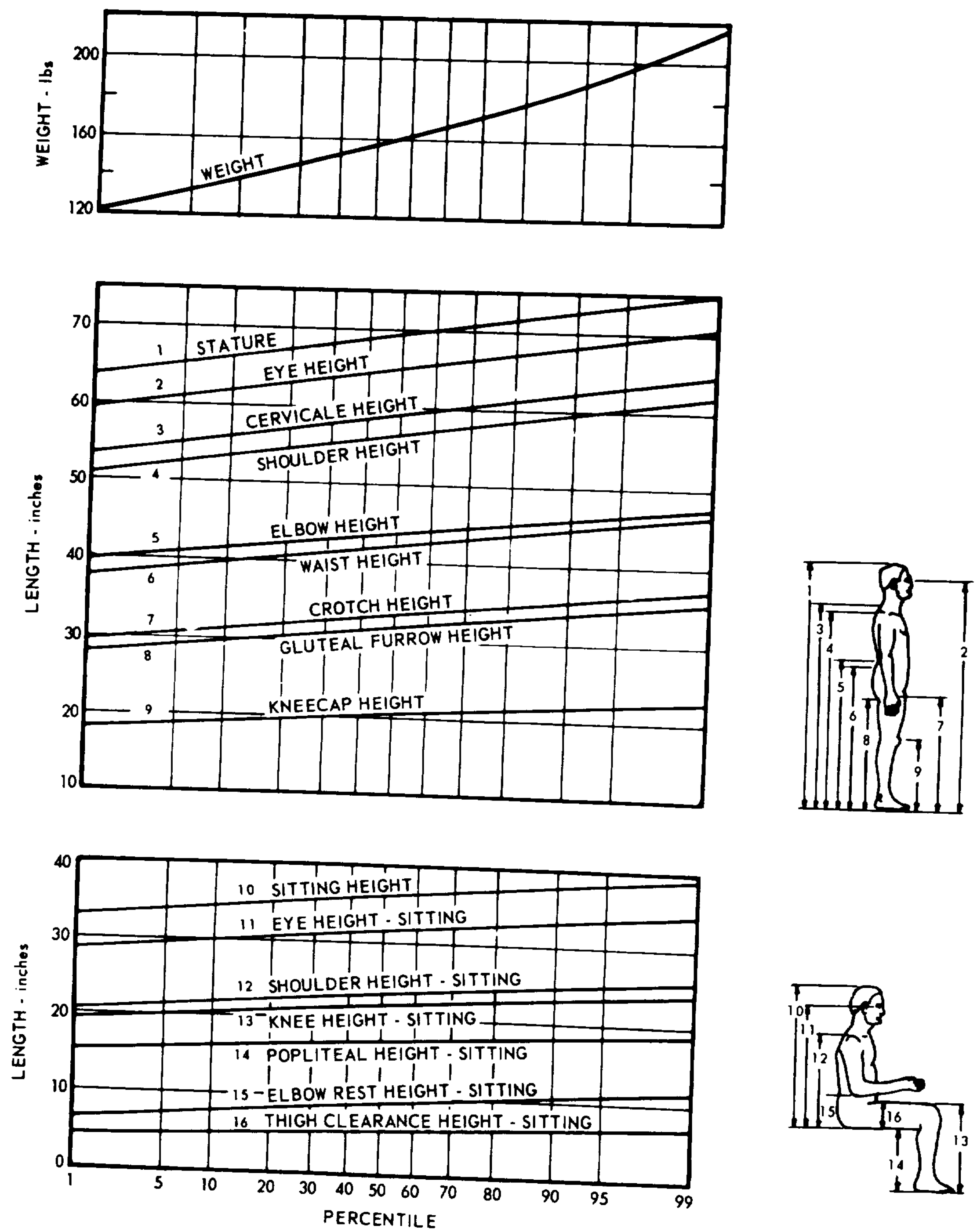


Figure 16-2

Body Dimensions of U. S. Males

(After Hertzberg and Clauser (164))



Body dimensions of a sample of approximately 4060 flying personnel of the U. S. Air Force.

Figure 16-3

Dimensions of Flying Personnel

(After Hertzberg and Clauser [164])

Figure 16-3 (continued)

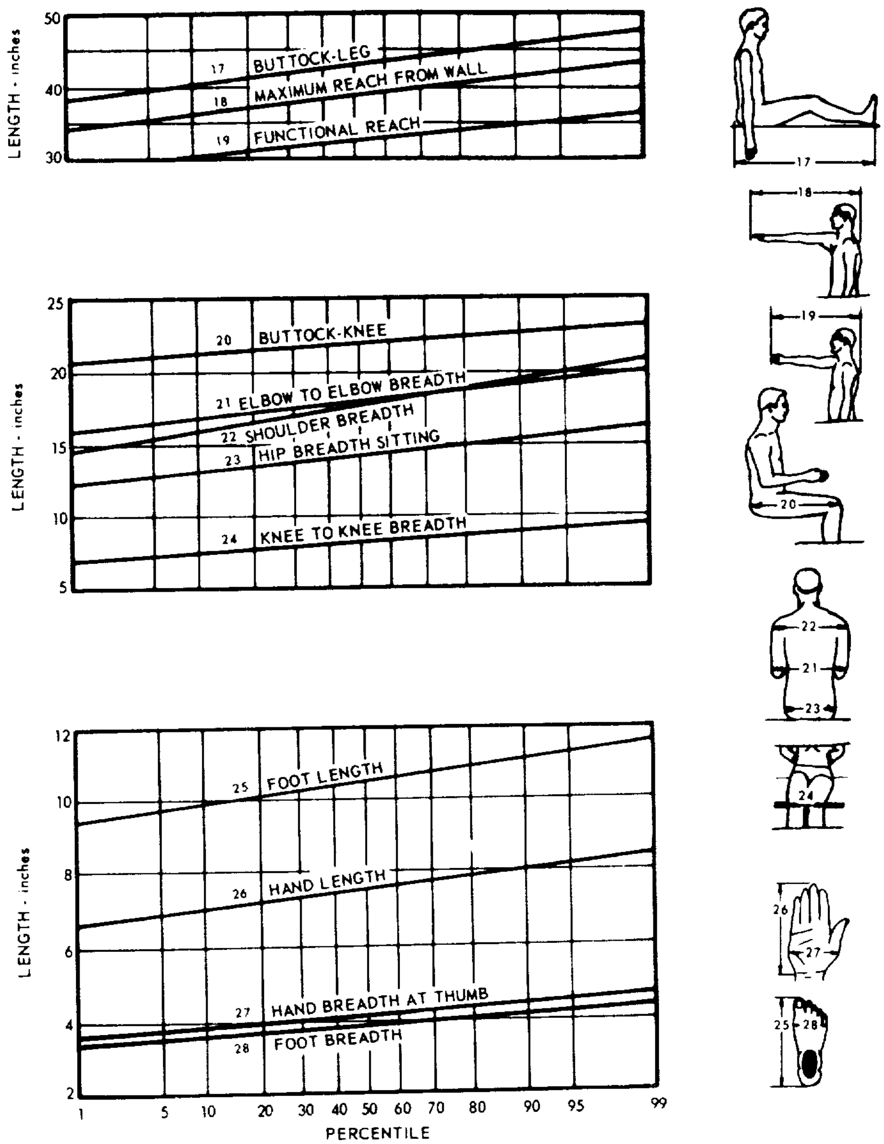


Table 16-4

Anthropometry of the Astronaut Population

(See end of table for description of non-standard measurements)*

(From the data of Fedderson and Reed[94])

a. Overall Dimensions of the Head, Body, and Limbs of the Astronaut Population

Measurement	Obser-vations	Centimeters				Inches			
		Mean	Std. Dev.	Range Low	Range High	Mean	Std. Dev.	Range Low	Range High
1. Weight of Body	31	74.37	6.67	63.50	90.26	163.94	14.71	140.00	199.00
2. Height of Body, Erect	36	177.00	4.09	168.70	183.40	69.71	1.61	66.42	72.21
3. Height of Body, Normal	28	176.43	3.91	167.80	183.40	69.46	1.54	66.06	72.20
4. Height of Body, Sitting, Normal	28	92.41	2.58	87.70	97.90	36.38	1.02	34.53	38.54
5. Height of Eyes, Standing	27	164.03	5.24	151.70	178.00	64.58	2.06	59.72	70.08
6. Height of Eyes, Seated	24	80.73	2.93	74.20	85.20	31.78	1.15	29.21	33.54
7. Height to Tragion, Seated	17	79.10	2.30	74.20	82.80	31.14	0.91	29.21	32.60
8. Height to Cervical Level, Standing	28	152.98	7.15	145.50	185.40	60.23	2.82	57.28	72.99
9. Height to Cervical Level, Seated	21	65.88	2.92	58.30	70.00	25.94	1.15	22.95	27.56
10. Height to Right Mid-shoulder*	38	149.82	3.94	141.10	157.70	58.99	1.55	55.55	62.09
11. Height to Left Mid-shoulder*	38	150.01	3.95	142.20	158.00	59.06	1.56	55.98	62.20
12. Height to Right Shoulder	28	144.95	3.77	137.20	151.10	57.07	1.49	54.02	59.49
13. Height to Left Shoulder	28	145.24	3.78	136.80	151.30	57.18	1.49	53.86	59.57
14. Height to Acromion, Standing	28	144.25	3.74	136.60	151.20	56.79	1.47	53.78	59.53
15. Height to Acromion, Seated	24	59.96	2.26	55.30	64.00	23.61	0.89	21.77	25.20
16. Height to Nipple, Standing	28	129.11	4.20	120.80	142.20	50.83	1.65	47.56	55.98
17. Height to Armpit, Seated	10	45.23	3.54	40.60	50.20	17.81	1.39	15.98	19.77
18. Height to Elbow, Standing	3	106.60	3.92	103.50	111.00	41.97	1.54	40.75	43.70
19 Height to Elbow, Seated	18	24.06	2.83	19.20	28.00	9.47	1.11	7.56	11.02
20. Height to Wrist, Standing	3	83.30	3.83	80.00	87.50	32.80	1.50	31.50	34.45
21. Height to Knuckles, Standing	3	74.97	2.14	73.10	77.30	29.52	0.84	28.78	30.43
22. Height to Supersternal Level, Standing	28	143.68	3.46	136.70	149.70	56.57	1.36	53.82	58.94
23. Height to Substernal Level, Standing	10	124.28	3.34	118.60	128.60	48.93	1.31	46.69	50.62
24. Height to Xiphoid Level, Standing	6	118.92	2.38	115.60	122.00	46.82	0.94	45.51	48.03
25. Height to 10th Rib	8	113.06	3.23	106.80	116.10	44.51	1.27	42.05	45.71

Table 16-4 (continued)

a. Overall Dimensions of the Head, Body, and Limbs of the Astronaut Population (continued)

Measurement	Obser-vations	Centimeters				Inches			
		Mean	Std. Dev.	Range Low	Range High	Mean	Std. Dev.	Range Low	Range High
26. Height to Cristal Level	22	106.19	2.91	99.80	110.80	41.81	1.15	39.29	43.62
27. Height to Trunk, Standing	18	165.81	4.91	158.30	173.70	65.28	1.93	62.32	68.39
28. Height to Trunk, Seated	10	159.86	6.36	153.00	169.60	62.94	2.50	60.24	66.77
29. Height to Waist*	28	107.03	2.52	101.40	110.90	42.14	0.99	39.92	43.66
30. Length from Crown to Rump	24	96.11	2.47	91.80	100.40	37.84	0.97	36.14	39.53
31. Height from Acromion to Vertex	3	37.43	1.23	36.40	38.80	14.74	0.48	14.33	15.28
32. Height from Cervical Level to Vertex	24	25.85	1.20	23.20	28.00	10.18	0.47	9.13	11.02
33. Height to Trochanteric Level	28	91.77	2.81	86.80	96.40	36.13	1.11	34.17	37.95
34. Height to Crotch	38	83.12	2.48	78.20	87.60	32.72	0.98	30.79	34.49
35. Height to Gluteal Furrow	11	80.18	2.53	76.40	84.00	31.57	1.00	30.08	33.07
36. Height to Knee	21	55.54	1.58	51.80	58.00	21.87	0.62	20.39	22.83
37. Height to Superior Kneecap Level	28	52.20	1.81	49.30	57.20	20.55	0.71	19.41	22.52
38. Height to Center Knee Floor	28	49.79	2.20	47.20	58.00	19.60	0.87	18.58	22.83
39. Height to Popliteal Position	18	43.14	2.01	38.50	47.60	16.98	0.79	15.16	18.74
40. Height to Tibia	24	46.60	1.74	42.60	48.80	18.35	0.69	16.77	19.21
41. Breadth from Forearm to Forearm	18	51.16	2.94	45.70	56.50	20.14	1.16	17.99	22.24
42. Breadth from Elbow to Elbow	20	46.13	2.75	41.80	51.30	18.16	1.08	16.46	20.20
43. Breadth from Knee to Knee	28	20.69	1.18	18.90	22.70	8.15	0.46	7.44	8.94

b. Dimensions of the Head of the Astronaut Population

Measurement	Obser-vations	Centimeters				Inches			
		Mean	Std. Dev.	Range Low	Range High	Mean	Std. Dev.	Range Low	Range High
1. Length of Head	28	19.96	0.47	19.20	21.20	7.86	0.19	7.56	8.35
2. Breadth of Head	28	15.55	0.57	14.50	17.30	6.12	0.22	5.71	6.81
3. Circumference of Head	28	57.80	1.35	54.61	60.01	22.56	0.53	21.50	23.63

b. Dimensions of the Head of the Astronaut Population (continued)

Measurement	Observations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
4. Height of Face, Total	25	11.94	0.64	10.80	13.30	4.70	0.25	4.25	5.24
5. Height from Pupil to Vertex	27	11.51	1.36	9.40	14.70	4.53	0.54	3.70	5.79
6. Height from Stomion to Vertex	18	18.32	1.31	16.40	21.30	7.21	0.52	6.46	8.39
7. Height from Tragion to Vertex	25	13.09	0.64	11.90	14.40	5.15	0.25	4.69	5.68
8. Length from Menton to Crinion	10	18.43	0.94	16.90	19.40	7.26	0.37	6.65	7.63
9. Length from Menton to Subnasal	10	6.64	0.61	5.80	7.80	2.61	0.24	2.28	3.07
10. Breadth from Ear to Ear	17	18.97	0.83	17.70	20.60	7.47	0.33	6.99	8.11
11. Distance Between Pupils	18	6.33	0.31	5.70	7.00	2.49	0.12	2.24	2.76
12. Depth from Nasal Root to Wall	13	19.95	0.38	19.30	20.50	7.85	0.15	7.60	8.07
13. Depth from Pronasal Position to Wall	18	22.11	0.58	21.00	23.20	8.70	0.23	8.29	9.13
14. Depth from Pupil to Wall	24	18.56	0.62	17.50	19.70	7.31	0.24	6.89	7.76
15. Depth from External Canthus to Wall	6	17.97	0.41	17.40	18.60	7.07	0.16	6.85	7.32
16. Depth from Tragion to Wall	18	9.82	0.78	8.60	11.10	3.87	0.31	3.39	4.37
17. Breadth of Ear	18	3.74	0.25	3.30	4.10	1.47	0.10	1.23	1.61
18. Length of Ear	18	6.56	0.47	5.10	7.10	2.58	0.19	2.01	2.80
19. Length of Ear above Tragion	18	3.08	0.45	2.60	4.10	1.21	0.18	1.02	1.61
20. Breadth of Nose	7	3.44	0.26	3.20	3.80	1.35	0.10	1.26	1.50
21. Breadth of Nasal Root	7	1.51	0.24	1.30	2.00	0.59	0.09	0.51	0.79
22. Length of Nose	14	5.16	0.27	4.70	5.60	2.03	0.11	1.85	2.20
23. Diameter between Tragion	9	14.39	0.46	13.40	15.00	5.67	0.18	5.28	5.91
24. Length of Bitragion-Coronal Arc	6	34.67	0.66	33.40	35.30	13.65	0.26	13.15	13.90
25. Length of Bitragion-Crinion Arc	8	32.29	1.15	30.60	34.00	12.71	0.45	12.05	13.39
26. Length of Bitragion-Inion Arc	6	28.93	1.16	27.70	30.60	11.39	0.46	10.91	12.05
27. Length of Bitragion-Menton Arc	10	31.81	0.87	30.50	33.30	12.52	0.34	12.01	13.11

Table 16-4 (continued)

b. Dimensions of the Head of the Astronaut Population (continued)

Measurement	Obser-vations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
28. Length of Bitragion-Sub-mandibular Arc	6	30.05	0.89	28.80	31.50	11.83	0.35	11.34	12.40
29. Length of Bitragion-Subnasal Arc	6	28.48	0.70	27.50	29.50	11.21	0.28	10.83	11.61
30. Breadth between Gonia	13	11.07	0.39	10.30	11.60	4.36	0.15	4.06	4.57
31. Bizygomatic Diameter between Zygomatic Bones	21	14.30	0.51	13.70	15.60	5.63	0.20	5.39	6.14
32. Length of Lips	18	5.33	0.39	4.60	6.10	2.10	0.15	1.81	2.40
33. Circumference of Neck	28	38.50	1.65	34.61	41.59	15.16	0.65	13.63	16.38
34. Length of Anterior Neck	28	10.31	1.14	7.62	12.70	4.06	0.45	3.00	5.00
35. Length of Posterior Neck	28	10.18	0.91	8.26	12.70	4.01	0.36	3.25	5.00
36. Depth from Larynx to Wall	3	16.40	1.10	15.30	17.50	6.46	0.43	6.02	6.89
37. Mid-Shoulder to Top of Head*	11	27.68	1.46	25.40	30.48	10.50	0.58	10.00	12.00

c. Dimensions of the Trunk and Torso of the Astronaut Population

Measurement	Obser-vations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
1. Breadth of Shoulders, Acromion	28	40.24	1.70	36.20	43.30	15.84	0.67	14.25	17.05
2. Breadth of Shoulders, Across Deltoids	28	47.54	3.79	35.80	52.70	18.72	1.49	14.09	20.75
3. Circumference of Shoulders	28	117.01	4.57	109.22	128.27	46.07	1.80	43.00	50.50
4. Breadth of Chest	28	32.46	2.12	28.70	38.10	12.78	0.83	11.30	15.00
5. Breadth of Chest, Bone	8	29.93	1.72	28.00	33.20	11.78	0.68	11.02	13.07
6. Breadth of Inter Scye	28	36.13	1.95	31.90	39.80	14.23	0.77	12.58	15.67
7. Breadth of Biacromial	28	40.83	1.80	37.60	44.80	16.07	0.71	14.80	17.64
8. Circumference of Chest at Scye	38	100.87	4.22	95.25	111.76	39.71	1.66	37.50	44.00

c. Dimensions of the Trunk and Torso of the Astronaut Population (continued)

Measurement	Observations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
9. Circumference of Chest at Nipple	38	96.90	4.15	89.54	104.77	38.15	1.63	35.25	41.25
10. Circumference of Right* Vertical Trunk	36	168.80	6.10	158.75	181.61	66.46	2.40	62.50	71.50
11. Depth of Chest	28	24.03	1.64	21.30	27.50	9.46	0.65	8.39	10.83
12. Breadth of Waist	28	30.34	1.65	27.60	33.60	11.94	0.65	10.87	13.23
13. Diameter of Left Vertical Trunk*	38	66.17	2.35	62.00	70.50	26.05	0.93	24.41	27.76
14. Diameter of Right Vertical Trunk*	38	66.30	2.35	61.40	70.20	26.10	0.92	24.17	27.64
15. Width of Waist, Front	7	32.31	1.21	30.70	34.40	12.72	0.48	12.09	13.54
16. Width of Waist, Back	7	39.04	1.97	37.00	42.00	15.37	0.78	14.57	16.54
17. Depth of Waist	18	21.14	1.72	18.80	25.20	8.32	0.68	7.40	9.92
18. Front Length of Waist*	28	38.07	2.17	34.29	42.55	14.99	0.86	13.50	16.75
19. Back Length of Waist*	28	46.75	1.74	43.82	50.80	18.41	0.68	17.25	20.00
20. Circumference of Waist	38	82.46	4.74	72.07	92.07	32.46	1.87	28.38	36.25
21. Breadth of Hip	28	34.70	1.77	31.30	38.90	13.66	0.70	12.32	15.32
22. Breadth of Hips, Seated	27	36.46	1.54	34.00	39.90	14.35	0.61	13.39	15.71
23. Circumference of Buttocks*	38	96.19	4.31	90.17	109.22	37.87	1.40	35.50	43.00
24. Breadth across Trochanters	22	33.04	1.31	31.30	35.70	13.01	0.52	12.32	14.06
25. Breadth across Iliac Crest	22	28.45	1.29	26.70	31.30	11.20	0.51	10.51	12.32
26. Length of Gluteal Arc*	28	28.70	1.49	24.77	31.43	11.30	0.59	9.75	12.38
27. Length of Seat	10	47.75	1.58	46.20	51.00	18.80	0.62	18.19	20.08
28. Length of Crotch*	28	70.18	3.60	63.18	76.87	27.63	1.42	24.88	30.25

Table 16-4 (continued)

d. Dimensions of the Arms and Hands of the Astronaut Population

Measurement	Observations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
Arms									
1. Length from Acromion to Radiale	18	33.58	1.28	31.40	36.90	13.22	0.50	12.36	14.53
2. Length from Shoulder to Elbow	28	36.82	1.19	34.70	39.90	14.50	0.44	13.66	15.71
3. Length from Shoulder to Elbow Pivot	28	33.53	1.58	30.80	36.83	13.20	0.62	12.13	14.50
4. Length of Forearm to Wrist	11	29.30	1.02	27.60	31.20	11.54	0.40	10.87	12.28
5. Length of Forearm to Grip	23	35.40	1.07	33.30	37.00	13.94	0.42	13.11	14.57
6. Length from Forearm to Hand	28	47.58	2.04	43.50	51.80	18.73	0.80	17.13	20.39
7. Scye Circumference, Right*	38	46.37	2.17	42.23	50.80	18.26	0.85	16.63	20.00
8. Scye Circumference, Left*	38	45.88	2.13	40.64	50.17	18.06	0.84	16.00	19.75
9. Circumference of Axillary Arm	28	31.86	1.88	27.94	35.56	12.54	0.74	11.00	14.00
10. Circumference of Upper Arm, Relaxed	17	30.49	1.82	26.50	32.60	12.00	0.72	10.43	12.83
11. Circumference of Biceps, Flexed	28	33.66	1.99	29.21	38.10	13.25	0.78	11.50	15.00
12. Breadth of Elbow	10	9.10	1.45	7.00	10.50	3.58	0.57	2.76	4.13
13. Circumference of Elbow, Relaxed	9	28.21	1.37	26.30	30.40	11.10	0.54	10.35	11.97
14. Circumference of Elbow, Flexed	28	32.21	1.87	29.21	37.15	12.68	0.74	11.50	14.63
15. Circumference of Forearm, Relaxed	23	28.11	1.00	26.50	30.00	11.07	0.39	10.43	11.81
16. Circumference of Forearm, Flexed	28	29.35	1.61	26.67	33.65	11.56	0.63	10.50	13.25
17. Breadth of Wrist	28	5.95	0.22	5.60	6.60	2.34	0.09	2.20	2.60
18. Length from Elbow Pivot to Wrist	28	27.29	1.10	25.40	29.53	10.75	0.43	10.00	11.63
19. Circumference of Wrist	28	17.54	1.42	15.88	23.50	6.91	0.56	6.25	9.25
20. Sleeve Inseam, Right*	27	48.38	2.80	36.20	52.39	19.05	1.10	14.25	20.63
21. Span of Arms	37	180.37	4.55	171.13	188.60	71.01	1.79	67.38	74.25

d. Dimensions of the Arms and Hands of the Astronaut Population (continued)

Measurement	Observations	Centimeters				Inches			
		Mean	Std. Dev.	Range Low	Range High	Mean	Std. Dev.	Range Low	Range High
Hands									
1. Length of Hand	25	18.98	1.28	14.30	21.60	7.47	0.50	5.63	8.50
2. Length from Wrist to Forefinger Tip	31	19.80	1.52	17.15	24.77	7.60	0.60	6.75	9.75
3. Breadth of Hand at Metacarpal	17	8.88	0.37	8.10	9.70	3.50	0.15	3.19	3.82
4. Breadth of Hand at Thumb	8	10.49	0.58	9.70	11.40	4.13	0.23	3.82	4.49
5. Circumference of Hand at Metacarpal-phalangeal Joint	33	21.18	2.99	5.90	24.79	8.37	1.18	2.13	9.75

e. Dimensions of the Legs and Feet of the Astronaut Population

Measurement	Observations	Centimeters				Inches			
		Mean	Std. Dev.	Range Low	Range High	Mean	Std. Dev.	Range Low	Range High
Legs									
1. Length from Buttock to Knee	23	60.39	1.51	57.50	63.30	23.78	0.60	22.64	24.92
2. Height of Thigh, Seated	10	15.44	0.91	14.30	17.30	6.08	0.36	5.63	6.81
3. Circumference of Upper Thigh, Standing	28	57.94	4.89	52.39	77.15	22.81	1.93	20.63	30.38
4. Circumference of Mid-Thigh, Standing	28	53.62	2.79	50.14	61.50	21.11	1.10	19.75	24.25
5. Circumference of Lower Thigh, Standing	28	39.49	1.90	36.51	43.82	15.55	0.75	14.38	17.25
6. Circumference of Knee	28	39.52	1.54	37.14	42.86	15.56	0.61	14.63	16.88
7. Circumference of Calf	28	38.52	1.96	34.61	41.91	15.17	0.77	13.63	16.50
8. Circumference of Ankle	28	22.46	1.10	20.20	25.50	8.84	0.43	7.95	10.04
Feet									
1. Length of Right Foot, Standing	28	24.99	3.19	19.05	30.48	9.84	1.26	7.50	12.00
2. Length of Left Foot, Standing	28	24.95	3.12	19.05	31.75	9.82	1.23	7.50	12.50
3. Length of Foot, No Weight	15	26.43	1.05	24.80	28.50	10.41	0.41	9.76	11.22

Table 16-4 (continued)

e. Dimensions of the Legs and Feet of the Astronaut Population (continued)

Measurement	Observations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
4. Length of Instep, Right Foot	28	27.31	3.57	20.32	34.29	10.75	1.40	8.00	13.50
5. Length of Instep, Left Foot	28	26.49	3.03	22.86	31.75	10.43	1.19	9.00	12.50
6. Breadth of Foot, Standing	27	10.29	0.54	9.40	11.50	4.05	0.21	3.70	4.53
7. Breadth of Foot, No Weight	15	9.55	0.63	8.90	11.20	3.76	0.25	3.50	4.41
8. Breadth of Heel	10	6.81	0.26	6.40	7.20	2.68	0.10	2.52	2.83
9. Breadth of Heel, No Weight	15	6.25	0.35	5.50	6.90	2.46	0.14	2.17	2.72
10. Medial Malleolus Height	16	8.84	0.62	8.10	9.70	3.48	0.24	3.19	3.82
11. Lateral Malleolus Height	15	7.06	0.32	6.40	7.60	2.78	0.13	2.52	2.99
12. Circumference of Instep, Right Foot*	28	34.28	1.44	31.43	37.46	13.60	0.57	12.38	14.75
13. Circumference of Instep, Left Foot*	28	34.27	1.45	31.12	37.46	13.49	0.57	12.25	14.75

f. Dimensions of the Skinfolds of the Astronaut Population

Measurement	Observations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
1. Subscapular	10	0.90	0.23	0.70	1.50	0.35	0.09	0.28	0.59
2. Juxta-Nipple	10	0.56	0.18	0.40	0.95	0.22	0.07	0.16	0.37
3. Mid-Axillary Line-Xiphoid	10	0.74	0.74	0.29	0.50	1.50	0.29	0.11	0.59
4. Triceps	10	0.71	0.17	0.40	1.00	0.28	0.07	0.16	0.39

g. Reach with the Arm (Functional Arm Reach) of the Astronaut Population

Measurement	Observations	Centimeters Mean	Centimeters Std. Dev.	Centimeters Range Low	Centimeters Range High	Inches Mean	Inches Std. Dev.	Inches Range Low	Inches Range High
1. Entire Arm	24	79.83	3.20	73.90	87.50	31.43	1.26	29.10	34.45
2. Forearm	9	41.84	1.24	39.00	43.10	16.47	0.49	15.35	16.97
3. Length of Extended Arm*	11	72.13	2.20	68.26	74.61	28.40	0.87	26.88	29.38

*Description of Non-Standard Measurements

1.	Back Length of Waist	Distance from waist back mark to cervical prominence.
2.	Circumference of Buttocks	Measured at point of maximum circumference.
3.	Extended Arm Length	Distance from apex of armpit (equidistant between anterior and posterior folds) along arms (extended laterally and horizontally) to the tip of forefinger.
4.	Front Length of Waist	Distance from waist front mark to the bottom of sternal notch.
5.	Instep Circumference	Circumference of foot measured with poles at apex of heel and dorsum of foot above peak of arch.
6.	Length of Crotch	Distance measured along the skin from the anterior waistline through the crotch to the posterior waistline.
7.	Length of Gluteal Arc	Distance measured along the skin from the top of buttock fold, craniad, to posterior waist point.
8.	Mid-Shoulder	Point on top of shoulder at 4" distance from the dorsal cervical prominence.
9.	Mid-Shoulder to Top of Head	Vertical distance from the horizontal line at mid-shoulder point to horizontal line at top of head.
10.	Scye Circumference	Circumference of shoulder measured along a line extending vertically from the apex of the armpit concavity.
11.	Sleeve Inseam	Distance from apex of armpit to first joint of wrist.
12.	Vertical Trunk Diameter and Circumference	Distance of the straight-line projection from mid-shoulder point to apex of crotch and the circumference along this line (following the skin contours).
13.	Waist Level	Measured at the level of the iliac crest.

L = distance from the CG to the suspension point,

f = frequency of oscillation and

g = acceleration of gravity (980 cm/sec^2);

and

$$I_{CG} = I_0 - mL^2, \tag{3}$$

where I_{CG} = moment of inertia about the CG.

A shift in whole body moment of inertia because of changes in posture or movement of limbs will be equivalent to the algebraic term of the individual segment changes in moment of inertia about the axis of rotation. The contribution of each segment to total moment of inertia is determined by the equation:

$$I_{Total} = (I_{CG} + mx^2), \tag{4}$$

where I_{CG} = moment of inertia about segment CG

m = mass of the segment,

x = distance of the segment CG from the axis of rotation.

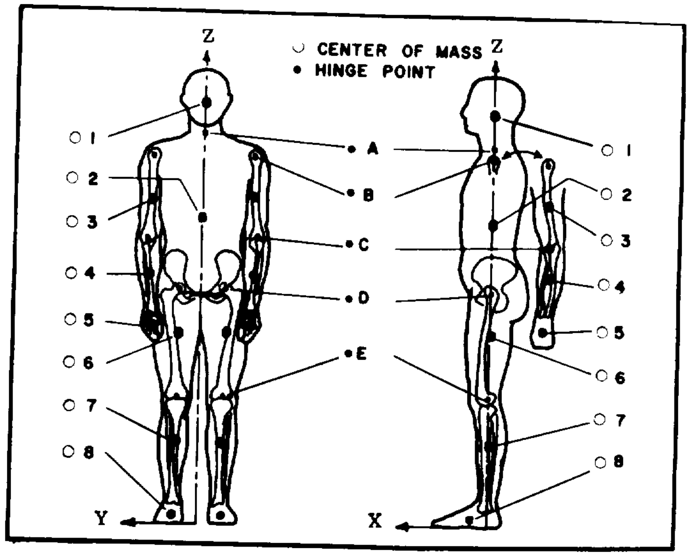
Consequently the change in I_{Total} is the difference between the sum of mx^2 before and after change in posture.

Table 16-5a shows diagrammatically the hinge points and centers of mass of the body segments. Table 16-5b gives the coordinates of these points. Table 16-5c represents the biomechanical properties of the body segments of the USAF 50th percentile man. Table 16-5d gives regression equations for computing the mass of body segments from total body weight. These were determined from a reanalysis of the data in references (35) and (77). Calculations have also been made of the CG's and moments of inertia. Table 16-6a presents the centers of gravity and moments of inertia of the total body of 50th percentile USAF male population in different postures given in British Engineering Units; Figure 16-6b gives similar data in the metric system with regression equations. Table 16-6c represents formulas which can be used to calculate moments of inertia of body segments. In Table 16-6d, the moments of inertia of these segments are shown for two body positions. Tables 16-11 b, c, and d present the effect of pressure suits on centers of gravity and moments of inertia of subjects in pressure suits (346).

Inertial data of these types have been used to predict with reasonable accuracy dynamic responses of man in orbital weightlessness (197, 206, 358) and for impact dynamics (47). In preliminary tests, these models appear to offer much in terms of semiquantitative prediction of body response to work tasks under subgravity as well as under the zero gravity condition. Prime use is in analysis of work, self-rotation maneuvers, and translation potentials of men in zero gravity. The data have also been used in the design of control systems for astronaut maneuvering units (AMU) and other EVA devices (189, 322). Computer models of these systems (86, 206, 281, 297, 358, 372) appear to offer a better solution to these dynamic problems. Problems of hydrodynamic mass and drag areas during underwater simulation of weightlessness are covered in the discussion of Figures 7-68 and Table 7-69.

Figure 16-5

Centers of Gravity and Specific Gravity of Man



a. Diagram of Hinge Points and Centers of Mass

(After Whitsett [358])

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	○ 1	0	0	64.10
Torso	○ 2	0	0	46.80
Upper Arm	○ 3	0	7.88	50.83
Lower Arm	○ 4	0	7.88	39.20
Hand	○ 5	0	7.88	31.68
Upper Leg	○ 6	0	3.30	27.68
Lower Leg	○ 7	0	3.30	11.80
Foot	○ 8	2.45	3.30	1.37

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

(After Whitsett [358])

Figure 16-5 (continued)

Segment	Weight (lbs)	Density (lbs/ft^3)	Length (inches)	Centroid Location (% length)
Head	11.20	71.6	10.04	50.0
Torso	78.90	68.6	24.56	50.0
Upper Arm	5.10	70.0	13.00	43.6
Lower Arm	3.03	70.0	10.00	43.0
Hand	1.16	71.7	3.69	50.0
Upper Leg	16.33	68.6	15.80	43.3
Lower Leg	8.05	68.6	15.99	43.3
Foot	2.39	68.6	2.73	50.0

c. Biomechanical Properties of the Segments of the USAF 50th Percentile Man

(After Whitsett[358] from the data of Clauser, Hertzberg et al[165], and Dempster[77])

Body Segment	Regression Equation	Standard Deviation of the Residuals
Head, neck and trunk	= 0.47 x Total body wt. + 5.4	(± 2.9)
Total upper extremities	= 0.13 x Total body wt. - 1.4	(± 1.0)
Both Upper arms	= 0.08 x Total body wt. - 1.3	(± 0.5)
Forearms plus hands[a]	= 0.06 x Total body wt. - 0.6	(± 0.5)
Both forearms[a]	= 0.04 x Total body wt. - 0.2	(± 0.5)
Both hands	= 0.01 x Total body wt. + 0.3	(± 0.2)
Total lower extremities	= 0.31 x Total body wt. + 1.2	(± 2.2)
Both upper legs	= 0.18 x Total body wt. + 1.5	(± 1.6)
Both lower legs plus feet	= 0.13 x Total body wt. - 0.2	(± 0.9)
Both lower legs	= 0.11 x Total body wt. - 0.9	(± 0.7)
Both feet	= 0.02 x Total body wt. + 0.7	(± 0.3)

[a] N = 11, all others N = 12.

d. Regression Equations for Computing the Mass (in kg) of Body Segments

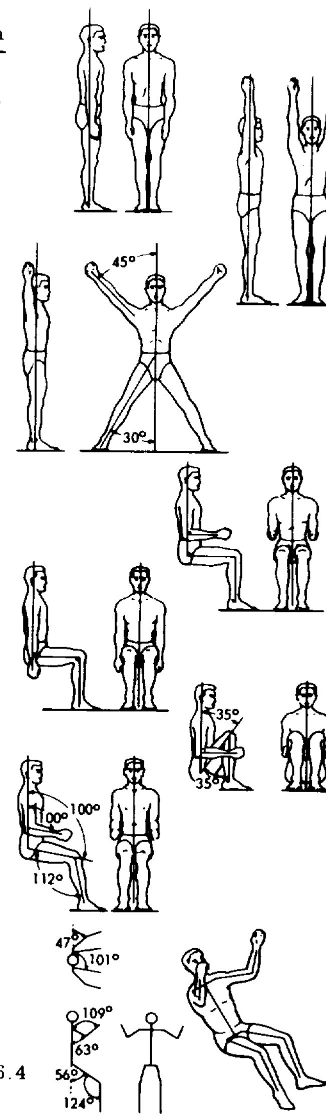
(From Barter [22])

Figure 16-6

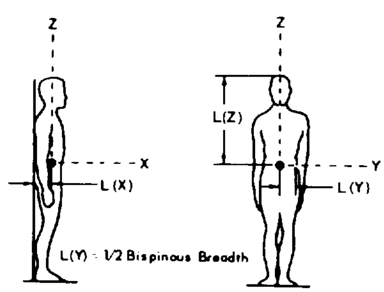
Centers of Gravity and Moments of Inertia of USAF Males in Different Postures

a. Whole-Body (British Engineering Units)

	Axis	Center of Gravity (in.) Mean	S. D.	Moment of Inertia (lb-in. -sec^2) Mean	S. D.
1. Standing	x	3.5	0.20	115.0	19.3
	y	4.8	0.39	103.0	17.9
	z	31.0	1.45	11.3	2.2
2. Standing, arms over head	x	3.5	0.22	152.0	26.1
	y	4.8	0.39	137.0	25.3
	z	28.6	1.33	11.1	1.9
3. Spread eagle	x	3.3	0.19	151.0	27.1
	y	4.8	0.39	114.0	21.3
	z	28.5	1.90	36.6	7.9
4. Sitting	x	7.9	0.36	61.1	10.3
	y	4.8	0.39	66.6	11.6
	z	26 5	1.14	33.5	5.8
5. Sitting, fore-arms down	x	7.7	0.34	62.4	9.7
	y	4.8	0.39	68.1	12.0
	z	26.8	1.16	33.8	5.9
6. Sitting, thighs elevated	x	7.2	0.37	39.1	6.0
	y	4.8	0.39	38.0	5.8
	z	23.1	0.78	26.3	5.1
7. Mercury configuration	x	7.9	0.34	65.8	10.3
	y	4.8	0.39	75.2	14.0
	z	27.1	1.14	34.2	5.6
8. Relaxed (Weightless)	x	7.3	0.33	92.2	13.3
	y	4.8	0.39	88.2	13.3
	z	27.5	1.44	35.9	5.4



Sample size 66. Mean age 33.2 yrs; S. D. age 7.2 yrs. Mean weight 166.4 lbs; S. D. weight 19.8 lbs. Mean stature 69.4 in; S. D. stature 2.9 in.



The location of the centers of gravity of the body was measured along the Z-axis from the top of the head, L(Z), along the X-axis from the back plane, L(Y), and along the Y-axis from the anterior superior spine of the ilium, L(X). However, since body symmetry with respect to the sagittal plane was assumed, L(Y) is defined as equal to one-half bispinous breadth (distance between anterior-superior iliac spines).

(After Hertzberg and Clauser[164], adapted from Santschi et al[279])

Figure 16-6 (continued)

b. Whole-Body (Metric Units) - with Correlation Coefficients and Regression Equations Relating Stature and Weight to Moment of Inertia (N = 66)

Position	Axis	Center of Gravity [a] (Cm) Mean	S.D.	Moment of Inertia (Gm $Cm^2 x 10^6$) Mean	S.D.	$R_{i,sw}$	Moment of Inertia Regression Equations [b] (Gm Cm^2 x 10^6) S.E.			
Standing (arms at sides)	X	8.9	0.51	130.0	21.8	.98	4.73	-262.0	+1.68S	+1.28W
	Y	12.2	0.99	116.0	20.6	.96	5.96	-240.0	+1.53S	+1.15W
	Z	78.8	3.68	12.8	2.5	.93	0.95	-0.683	-0.044S	+0.279W
Standing (arms over head)	X	8.9	0.56	172.0	29.5	.98	6.36	-371.0	+2.39S	+1.63W
	Y	12.2	0.99	155.0	28.6	.96	7.79	-376.0	+2.38S	+1.47W
	Z	72.7	3.38	12.6	2.1	.86	0.98	1.6	-0.038S	+0.234W
Spread Eagle	X	8.4	0.48	171.0	30.6	.98	5.54	-399.0	+2.51S	+1.69W
	Y	12.2	0.99	129.0	24.1	.96	7.06	-305.0	+1.91S	+1.29W
	Z	72.4	4.82	41.4	8.9	.93	3.19	-114.0	+0.677S	+0.484W
Sitting (elbows at 90°)	X	20.1	0.91	69.1	10.6	.92	4.53	-104.0	+0.637S	+0.804W
	Y	12.2	0.99	75.4	13.1	.92	5.10	-153.0	+1.01S	+0.669W
	Z	67.3	2.89	37.9	6.6	.97	1.64	-59.6	+0.34S	+0.502W
Sitting (forearms down)	X	19.6	0.86	70.5	11.0	.91	4.50	-89.0	+0.574S	+0.771W
	Y	12.2	0.99	77.0	13.6	.92	5.28	-144.0	+0.913S	+0.802W
	Z	68.1	2.95	38.2	6.7	.97	1.54	-60.8	+0.341S	+0.514W
Sitting (thighs elevated)	X	18.3	0.94	44.2	6.8	.89	3.16	-38.2	+0.242S	+0.529W
	Y	12.2	0.99	43.0	6.6	.77	4.14	-25.1	+0.193S	+0.449W
	Z	58.7	1.98	29.7	5.8	.92	2.26	-34.4	+0.146S	+0.509W
Mercury Position	X	20.1	0.86	74.4	10.6	.93	4.24	-107.0	+0.699S	+0.768W
	Y	12.2	0.99	85.1	15.8	.94	5.61	-198.0	+1.27S	+0.794W
	Z	68.8	2.89	38.7	6.3	.96	1.85	-50.9	+0.297S	+0.492W
Relaxed (weightless)	X	18.5	0.84	104.0	15.0	.96	4.20	-120.0	+0.788S	+1.13W
	Y	12.2	0.99	99.8	15.0	.94	5.13	-157.0	+1.08S	+0.879W
	Z	69.9	3.66	40.6	6.1	.96	1.74	-53.4	+0.346S	+0.440W

[a] Location of CGs are with respect to the back plane, anterior superior spine of the ilium, and top of the head.
[b] S is stature in centimeters; W is weight in kilograms.

(After Damon et al[71], adapted from Santschi et al[279])

c. Formulas for Calculating Local Moments of Inertia of Body Segments

Segment	Moments of Inertia $I_{x_{CG}}$	$I_{y_{CG}}$	$I_{z_{CG}}$
Head	$\frac{1}{5}m(a^2+b^2)$	$I_{x_{CG}}$	$\frac{2}{5}m\,a^2$
Torso	$\frac{1}{12}m(3a^2+\ell^2)$	$\frac{1}{12}m(3b^2+\ell^2)$	$\frac{1}{4}m(a^2+b^2)$
Upper and Lower Arms and Legs	$m\left[A\left(\frac{m}{\delta\ell}\right)+B\ell^2\right]$	$I_{x_{CG}}$	$2\frac{m^2}{\delta\ell}A$
Hand	$\frac{2}{5}m\left(\frac{d}{2}\right)^2$	$I_{x_{CG}}$	$I_{x_{CG}}$
Foot	$\frac{1}{6}m\ell^2$	$\frac{1}{12}m(c^2+\ell^2)$	$I_{y_{CG}}$

m = mass
a = semi-major axis
b = semi-minor axis
d = diameter

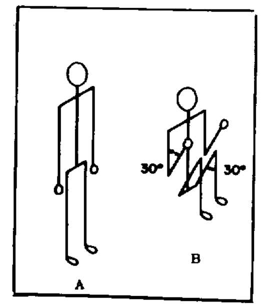
ℓ = length
A and B are constants for segments (see Ref.358)
c = instep length of foot
δ = average density

(After Whitsett [358])

Figure 16-6 (continued)

d. Moments of Inertia of the Segments of 50th Percentile USAF Man for Two Positions

		Segments*								
		Head	Torso	Upper Arms	Lower Arms	Hands	Upper Legs	Lower Legs	Feet	Total
$I_{x_{cg}}$	Position A	0.0183	1.0000	0.0157	0.0056	0.0004	0.0776	0.0372	0.0006	1.2927
	Position B	0.0183	1.0000	0.0157	0.0044	0.0004	0.0620	0.0372	0.0006	1.2589
mD^2	Position A	1.5114	1.0125	0.2199	0.0405	0.0292	0.4964	1.3114	0.7388	8.1963
	Position B	0.7859	0.0092	0.0932	0.0407	0.0303	0.1496	0.0588	0.1252	1.7907
I_x	Position A	1.5297	2.0125	0.2356	0.0461	0.0296	0.5740	1.3486	0.7394	9.4890
	Position B	0.8042	1.0092	0.1089	0.0451	0.0307	0.2116	0.0960	0.1258	3.0496
$I_{y_{cg}}$	Position A	0.0183	0.9300	0.0157	0.0056	0.0004	0.0776	0.0372	0.0028	1.2269
	Position B	0.0183	0.9300	0.0157	0.0056	0.0004	0.0776	0.0372	0.0028	1.2269
mD^2	Position A	1.5114	1.0125	0.1517	0.0000	0.0137	0.4582	1.2925	0.7361	7.8284
	Position B	0.7950	0.0734	0.0292	0.0002	0.0188	0.1190	0.1015	0.1560	1.7176
I_y	Position A	1.5297	1.9425	0.1674	0.0056	0.0141	0.5358	1.3297	0.7389	9.0553
	Position B	0.8133	1.0034	0.0449	0.0058	0.0192	0.1966	0.1387	0.1588	2.9445
$I_{z_{cg}}$	Position A	0.0124	0.2300	0.0018	0.0008	0.0004	0.0154	0.0037	0.0028	0.2922
	Position B	0.0124	0.2300	0.0018	0.0020	0.0004	0.0310	0.0037	0.0028	0.3258
mD^2	Position A	0.0000	0.0001	0.0682	0.0405	0.0155	0.0382	0.0188	0.0085	0.3797
	Position B	0.0091	0.0642	0.0723	0.0405	0.0195	0.0459	0.0804	0.0420	0.6746
I_z	Position A	0.0124	0.2301	0.0700	0.0413	0.0159	0.0536	0.0226	0.0113	0.6719
	Position B	0.0215	0.2942	0.0742	0.0426	0.0199	0.0769	0.0841	0.0448	1.0004

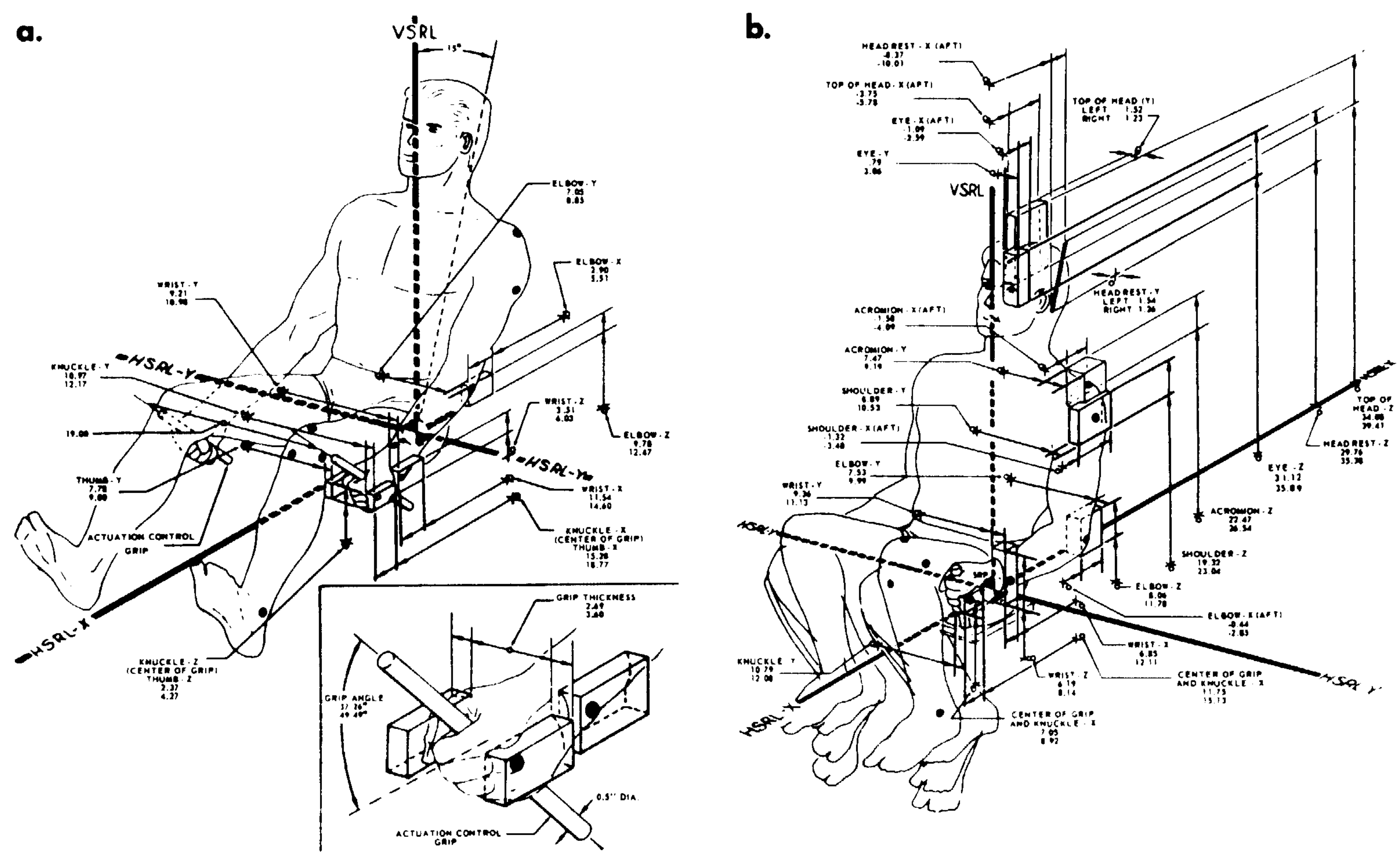


*Positions A and B are shown in figure.
†All values are slug-ft^2.

Determination of specific gravity can be made from anthropometric data (70). Attempts have been made to relate the specific gravity of different individuals to the somato type classification of Sheldon (85, 250). This formula for specific gravity works only for navy divers for which it was developed. It failed to predict densitometrically determined density (or specific gravity) or percentage of body fat among athletic young men (70). The best prediction of density is actually based on averaging two skin fold measurements by the equations (253): Density = 1.0923 -0.0203 (triceps skinfold, in cm.); Density = 1.0896 -0.0179 (subscapular skinfold, in cm.). To obtain fat from density, Fat = (4.0439/density -3.6266). This formula of Grande is based on a reference man with 17.8% of total body fat (121).

The dimensions of a typical 5th to 95th percentile, seated, pilot operator are seen in Figure 16-7. Data are available on three-dimensional arm reach in the seated position (71, 192). Data are also available on the design of new seat concepts for aerospace vehicles (258) (see also sections on Impact No. 7, and Vibration No. 8. Figure 16-8 covers workspace requirements for the 95th percentile USAF population.

Body areas are needed for thermal and energetic analyses. (See Thermal Environment, (No. 6) and Oxygen-CO_2-Energy, (No. 10). Table 6-22 represents a cylindrical model of man for calculation of heat transfer coefficients. Figure 6-16 is a nomograph for calculation of the surface area of the USAF male population from height and weight data. Figure 10-13 is a graph which can be used in the same calculation for the average male population. In analysis of radiative heat transfer, the total radiation area (Figure 6-17) and the projected areas (Figure 6-18) can be used (133, 164, 291). Drag areas and hydrodynamic mass of suited subjects are presented in Figure 7-68 and



Dimensions (in inches) of nude seated pilots, 5th to 95th percentile. Normal flight position is shown at left, ejection position on the right. SRP is the seat reference point, from which the horizontal (H) plane is defined for and aft (x co-ordinates) and side to side (y co-ordinates). L means "line," as in VSRL -- vertical seat reference line, in the Z direction.

Source: Chaffee (55)

Figure 16-7

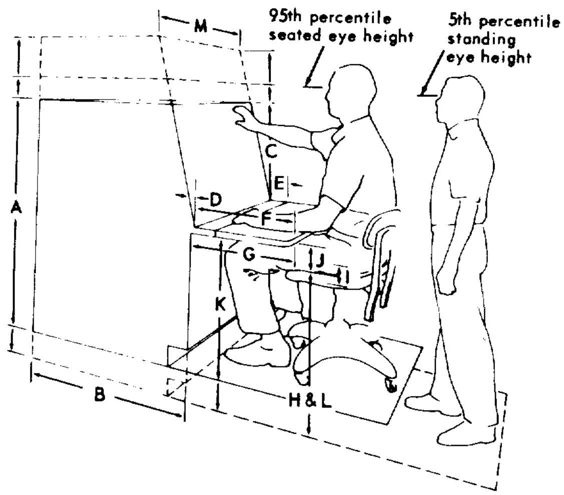
Dimensions of the Seated Operator

(After Hertzberg and Clauser[164])

Table 16-8

Work Space Dimensions

(After Hertzberg and Clauser(164))



Type of Console	Maximum console height from standing surface	Console depth at base	Vertical dimension of panel, including sills	Console panel angle-- from vertical	Minimum pencil-shelf depth	Minimum writing surface depth--including pencil shelf	Minimum knee clearance	Foot support to seat[1]	Seat adjustability	Minimum thigh clearance at midpoint of "I"	Writing surface height from standing surface	Seat height at midpoint of "I"	Maximum console panel breadth
	A	B	C	D	E	F	G	H	I	J	K	L	M
1. Sit-Stand	62.0	Opt.	26	15°	4	16	18	18	4	6.5	36.0	28.5	36
2. Sit (w/vision over top)	47.5* to 58.0	Opt.	22	15°	4	16	18	18	4	6.5	25.5 to 36.0	18.0 to 28.5	36
3. Sit (w/o vision over top)	51.5** to 62.0	Opt.	26	15°	4	16	18	18	4	6.5	25.5 to 36.0	18.0 to 28.5	36
4. Stand (w/vision over top)	62.0	Opt.	26	15°	4	16	--	--	--	--	36.0	---	36
5. Stand (w/o vision over top)	72.0	Opt.	36	15°	4	16	--	--	--	--	36.0	---	36

* "A" must never be more than 29.5 inches greater than "L".
** "A" must never be more than 33.5 inches greater than "L".

[1] When seat-to-standing surface exceeds 18", a heel catch should be provided.

Table of standard values for critical dimensions used in the design of instrument consoles for the seated and/or standing operator, with and without a requirement on the operator to maintain horizontal visual contact with other displays or test apparatus beyond the console. Design values for each console established to accommodate 95+ percent of USAF population.

Source: Anthropology Branch, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, 1963.

Table 7-69. Buttock contact areas and thigh dimensions for the specific population indicated are seen in Figure 16-9.

Presence of clothing increases the body dimensions. Group support equipment in space operations often makes use of military support. Figure 16-10 covers the increase dimensions to be expected from clothing on support personn

The increase in body dimensions resulting from pressure-suit wear will vary with design of the suit. Table 16-11a covers increases from the USAF MC-2 suits. Tables 16-11b and c present changes in body dimensions of astronauts in NASA soft and hard suits. Figure 16-11d shows the changes in center of gravity; and Tables 16d and e, the changes in center of gravity and moment of inertia of the whole body produced by space suits, pressurized and unpressurized. Table 16-11f gives regression equations which can be used to calculate these changes in moments of inertia from data on body weight.

Stowage volumes for soft (223) and hard (26) suits have been determined. The soft suit may be packed into a slab volume 64 x 27 x 7 inches and the slab arced along its length with a radius of 49 inches. The helmet can be considered a sphere of about 16 inches maximum diameter; and back pack, a volume of about 12x16x9 inches. The hard suit can be stowed in a volume of 46x25x16 inches including helmet. These dimensions are only approximate values for typical prototype suits.

Workspace Factors

Division of workspace into functional compartments must also be considered (54, 93, 109, 266). (See also section on Confinement).

In the Mercury spacecraft there was an internal volume of approximately 54 cubic feet of which 4 cubic feet was occupied by the astronaut. Since the astronaut was never required to leave his couch for either personal or mission requirements, such a limited volume could be tolerated over the period of even the longest mission of 22 orbits. The Gemini spacecraft, on the other hand, provided an internal volume of approximately 88 cubic feet or 11 cubic feet less per man than that provided by Mercury. Details of Gemini cabins are available (217, 231). Since the Gemini missions were considerably more demanding due to duration and extravehicular activities, the lack of significant, useable work space was exhibited by the constraints placed upon work/rest cycles, stowage provisions in and around the hatches, headrest areas, and limited leg movement in the foot-well, to name a few.

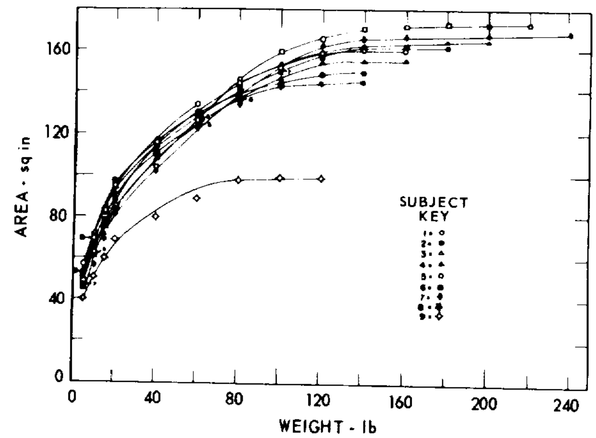
Although the Apollo command module spacecraft provides an internal volume of approximately 320 cubic feet, it must be remembered that this space is distributed across three couch stations, two work stations in the lower equipment bay, a guidance and navigation station, and two sleep stations under the couches. The cubage at these stations, though marginal, is sufficient to meet mission requirements provided that the intravehicular activity at the various stations is properly sequenced (244). However, for missions of longer duration, considerably greater volume at each station would have to be provided to meet increased stowage requirements. Based on these and similar considerations, (see section below on Confinement), the following

Figure 16-9

Buttock Areas and Thigh Dimensions

(After Hertzberg and Clauser[164])

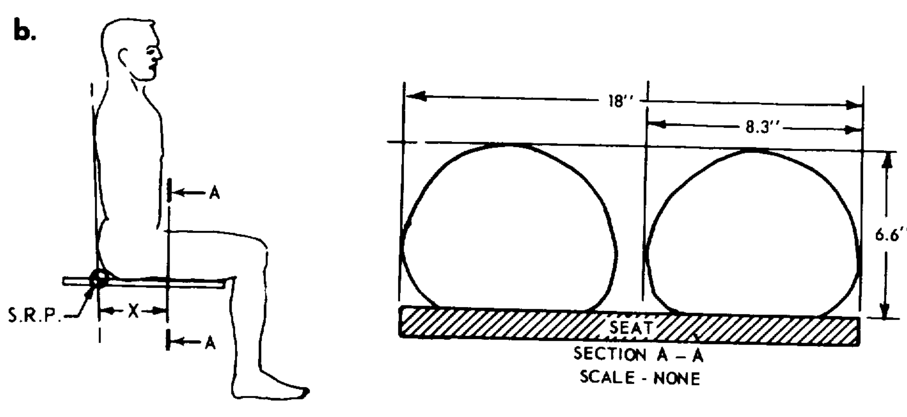
a.



Buttock contact areas of nine men who were gradually lowered onto a measuring plate until their full weights were supported. Subjects fell within the following ranges: age 27-41 years; height 66-74 inches; weight 120-269 pounds. When these contact areas had been established, loads were increased by having the subjects hold weights in their arms to determine what increase in contact area would result. Loads of 20, 40, and 60 pounds caused no measurable increase in buttock contact area.

(Adapted from Swearingen et al[319])

b.



Height and width of the thighs, shown on the right, from a section taken just ahead of the intersection of thigh and trunk as shown in the drawing on the left. The x distance from the Seat Reference Point (SRP) to the section varied from 9.5 to 12 inches. Dimensions for the thigh are 95th percentiles, meaning that 5% of the AF flying population will have larger dimensions. The thigh heights were measured, the thigh widths computed from the relation: Width = 1.37 Height.

(Adapted from Esch[91])

Table 16-10

Increase in Dimensions from Clothing

(After Hertzberg and Clauser[164])

	Civilians		Army				Air Force		
	Men street clothing	Women street clothing	summer uniform	fall uniform	winter uniform	winter combat	full flight gear	light flight assembly	winter flight assembly
weight (lbs)	5.0	3.5	9.4	11.8	18.6	22.9			20.0
stature	1.0	0.5-3.0	2.65	2.65	2.65	2.75	-2.0	3.3	1.9
abdomen depth			0.94	1.18	1.95	2.54	5.0		1.4
arm reach, anterior			0.04	0.08	0.20	0.37			0.4
buttock-knee length			0.20	0.30	0.54	0.70	2.0		0.5
chest breadth							2.5		0.6
chest depth			0.41	0.96	1.80	1.54	4.5	0.8	1.4
elbow breadth			0.56	1.04	1.84	2.12	11.0		4.4
eye level height, sitting			0.04	0.08	0.16	0.22			0.4
foot breadth	0.3		0.20	0.20	0.20	0.20			1.2
foot length	1.2		1.60	1.60	1.60	1.60			2.7
hand breadth						0.30			0.4
hand length						0.15			0.3
head breadth			2.8	2.8	2.8	2.8			0.4
head length			3.5	3.5	3.5	3.5			0.4
head height			1.35	1.35	1.35	1.45			0.2
hip breadth			0.56	0.76	1.08	1.40			1.3
hip breadth, sitting			0.56	0.76	1.08	1.40	5.5	2.9	1.7
knee breadth			0.48	0.48	0.72	1.68	9.5		2.5
knee height, sitting			1.32	1.32	1.44	1.44			1.8
shoulder breadth			0.24	0.88	1.52	1.16	6.0	0.4	1.3
shoulder-elbow length			0.14	0.50	0.94	0.62			0.3
shoulder height, sitting			0.16	0.58	0.92	0.80			0.6
sitting height			1.39	1.43	1.61	1.67		2.1	0.6

(All dimensions are given in inches)

Civilians, men: underwear, shirt, trousers, tie, socks, shoes
Civilians, women: underwear, dress, or blouse or sweater and skirt, shoes
Army, summer uniform: underwear, khakis or O. D.'s or fatigues, socks, shoes, helmet and liner
Army, fall uniform: underwear, khakis or O. D.'s or fatigues, blouse or field jacket, socks, shoes, helmet and liner
Army, winter uniform: underwear, khakis or O. D.'s or fatigues, blouse or field jacket, overcoat, socks, shoes, helmet and liner
Army, winter combat: underwear, khakis or O. D.'s or fatigues, combat suit, overcoat, socks, shoes, gloves, wool cap, helmet and liner
Air Force, full flight gear: T-1 partial pressure suit, inflated, ventilation suit, deflated, MD-1 anti-exposure suit and MD 3A liner, long cotton underwear
Air Force, light flight assembly: T-5 partial pressure suit, uninflated, K-1 pressure helmet and boots
Air Force, winter flight assembly: World War II heavy winter flying clothing, including jacket, trousers, helmet, boots, and gloves

Source: Anthropology Branch, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, 1963.

Figure 16-11

Anthropometric Study of Pressure Suits

a. Increase in Dimensions from Soft, Full Pressure Suits

Measurement	Nude		Uninflated		Inflated	
	Median	Range	Median	Range	Median	Range
shoulder circumference	48.3	(45.1-50.5)	56.1	(54.7-61.0)	63.0	(60.0-65.0)
chest circumference	39.6	(37.7-42.2)	48.3	(48.0-52.0)	52.5	(50.5-54.2)
waist circumference	34.3	(32.0-38.8)	44.4	(42.0-47.2)	47.3	(45.2-50.0)
upper thigh circumference	25.1	(22.3-26.0)	25.7	(24.5-28.0)	27.0	(25.3-29.0)
lower thigh circumference	17.0	(15.6-18.5)	20.8	(18.2-23.6)	22.1	(21.1-24.5)
calf circumference	14.9	(14.5-17.0)	16.9	(16.2-19.4)	18.3	(16.9-19.9)
ankle circumference	9.2	(8.9-10.5)	12.1	(11.4-13.6)	12.1	(12.0-13.8)
biceps circumference	13.5	(12.7-14.5)	14.8	(14.0-16.3)	16.2	(14.9-17.0)
wrist circumference	7.0	(6.6- 7.2)	8.1	(7.9- 8.4)	9.0	(8.3- 9.2)
vertical trunk circumference	67.4	(64.4-71.5)	66.8	(64.9-70.0)		
knee circumference	15.9	(15.0-17.1)	22.1	(20.0-23.0)	21.8	(20.0-23.4)
vertical trunk circumference	64.2	(63.7-67.5)	66.5	(65.0-69.6)	67.3	(66.0-70.4)
buttock circumference	42.0	(39.1-45.5)	46.7	(45.3-51.0)	49.9	(47.3-51.0)
shoulder breadth	19.2	(18.2-19.8)	20.6	(18.6-22.0)	23.7	(13.8-25.5)
chest breadth	13.0	(10.9-12.9)	13.8	(12.7-15.1)	14.7	(14.4-15.6)
hip breadth	13.7	(12.9-14.4)	15.4	(14.1-16.3)	17.4	(16.2-18.6)
hip depth	10.3	(9.5-12.0)	11.4	(10.8-11.7)	15.0	(15.0)
chest depth	10.2	(9.8-10.7)	13.1	(12.1-13.5)	14.9	(14.2-15.2)
elbow-elbow breadth	19.9	(18.6-22.1)	23.2	(20.7-25.1)	27.7	(25.8-30.1)
knee-knee breadth	8.2	(7.8- 9.3)	12.0	(10.7-13.5)	21.3	(18.6-22.6)
sitting height	35.7	(34.7-37.7)	34.8	(33.7-36.2)	36.8	(35.6-38.5)
eye height	31.2	(29.6-33.0)	30.4	(28.4-31.7)	31.3	(29.4-32.2)
shoulder height	23.5	(22.7-24.9)	23.5	(22.1-24.5)	24.3	(23.4-25.3)
knee height	21.9	(21.3-22.8)	23.3	(22.6-23.9)	24.0	(22.9-24.6)
popliteal height	17.5	(17.2-19.8)	18.1	(17.0-18.4)	18.2	(16.8-18.9)
elbow rest height	7.8	(7.5- 9.1)	8.2	(6.3-10.1)	10.0	(9.5-11.0)
shoulder-elbow length	15.0	(14.2-15.4)	15.4	(14.5-16.1)	15.8	(15.2-16.0)
forearm-hand length	19.2	(18.5-20.0)	19.4	(18.9-20.3)	19.8	(18.6-20.7)
foot length	10.5	(10.3-11.0)	12.6	(11.8-12.7)	12.3	(11.7-12.6)
hand length	7.7	(7.5- 8.5)	7.5	(7.2- 7.7)	7.1	(6.8- 7.5)
palm length	4.5	(4.4- 4.5)	3.5	(3.9- 4.3)	4.0	(3.2- 5.9)
crotch height (standing)	33.3	(31.1-34.8)	32.4	(30.8-33.4)		
thigh clearance	6.5	(5.5- 7.1)	6.4	(6.1- 7.0)	8.1	(7.6- 8.2)

All measurements were taken on seated subject, except crotch height. All dimensions are given in inches. These measurements were taken on six subjects wearing the MC-2(X-15 type) full-pressure suit.

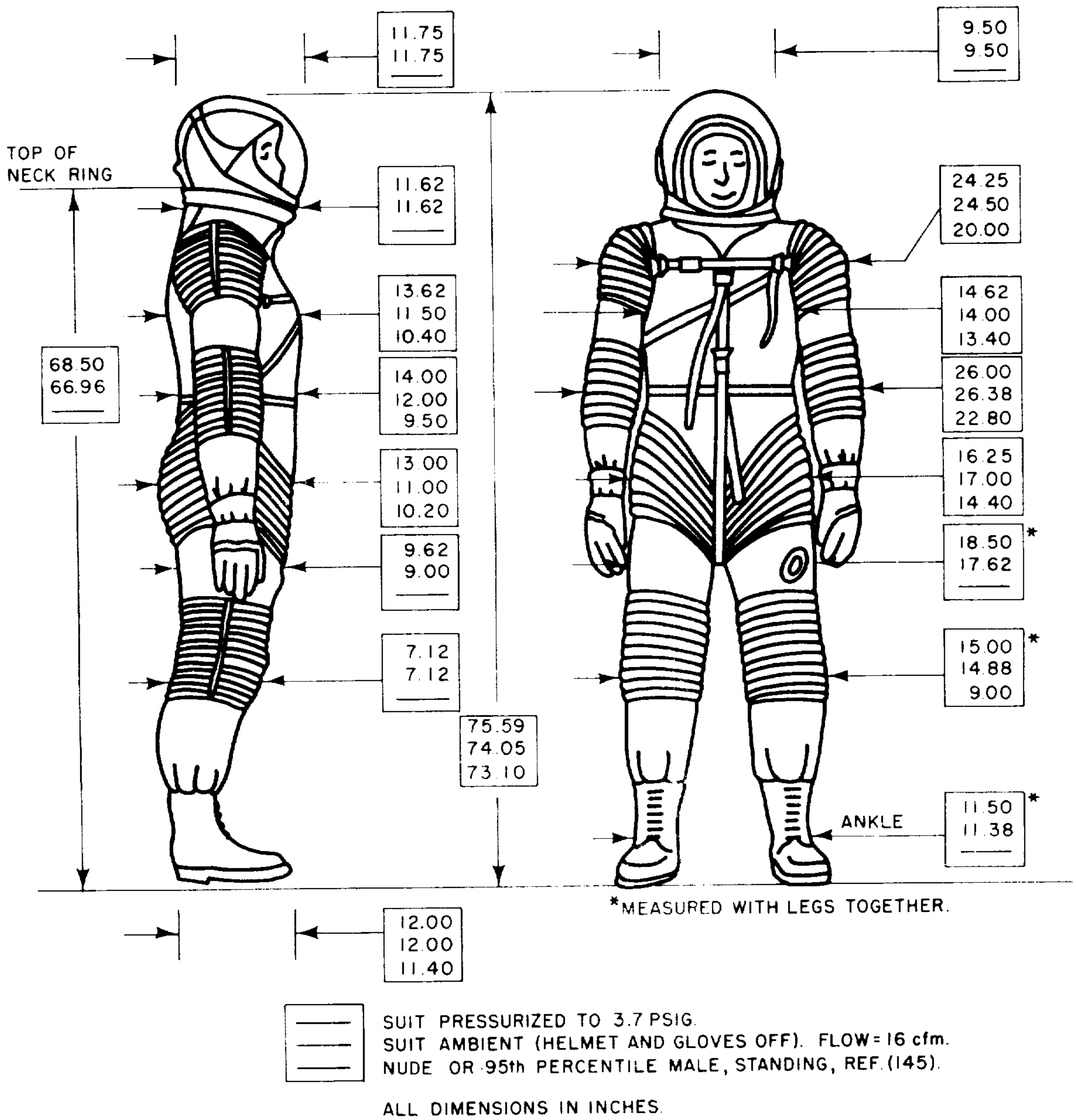
Source: Anthropology Branch, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, 1963.

(After Hertzberg and Clauser[164])

Figure 16-11 (continued)

b. Maximum Dimensions of a NASA Prototype, Soft, Full-Pressure Suit in the Unpressurized and Pressurized Condition

These data, noted in indices, cover the large-long size of a S/N007 or (A6L) PGA designed for a subject 6′, 1.5″ tall and 190 lbs weight, representing approximately the 95th percentile male. Extra vehicular operations require an addition to the total height of 1.5″ for the EVVA visor assembly and 0.6″ for EV boots giving a total standing height, pressurized, of 77.71 inches.



(After Fedderson and Reed[94])

Figure 16-11 (continued)

c. Anthropometry of the RX-5 Hard Space Suit

The hard suit is composed of 6 body elements, each with up to 6 different sizes noted by Roman numerals. The suit described below is a composite of different body elements assembled for a specific astronaut. Adjustments for other sizes are noted after each specific element. All dimensions are noted in inches.

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) (+.75" Adjustment possible)	LENGTH ONLY SIZE I -1.20 (Short Adjustment) II - .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 + .40 I -1.20 II - .80 III - .40
4. FOREARM - SIZE III	LENGTH CHANGE ONLY SIZE I -1.40 II - .70 IV + .70
5. THIGH - SIZE II (Adjusted to Short Position) (+.87" Adjustment possible)	LENGTH CHANGE ONLY SIZE I - .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 - .70 III + .60 IV +1.20 V +1.80 VI +2.40

(After Breslin, C. and Brosseau, P.L., Litton Systems, Inc.; Applied Technology Division, unpublished data, 1968)

Figure 16-11 (continued)

c. Anthropometery of the RX-5 Hard Space Suit (continued)

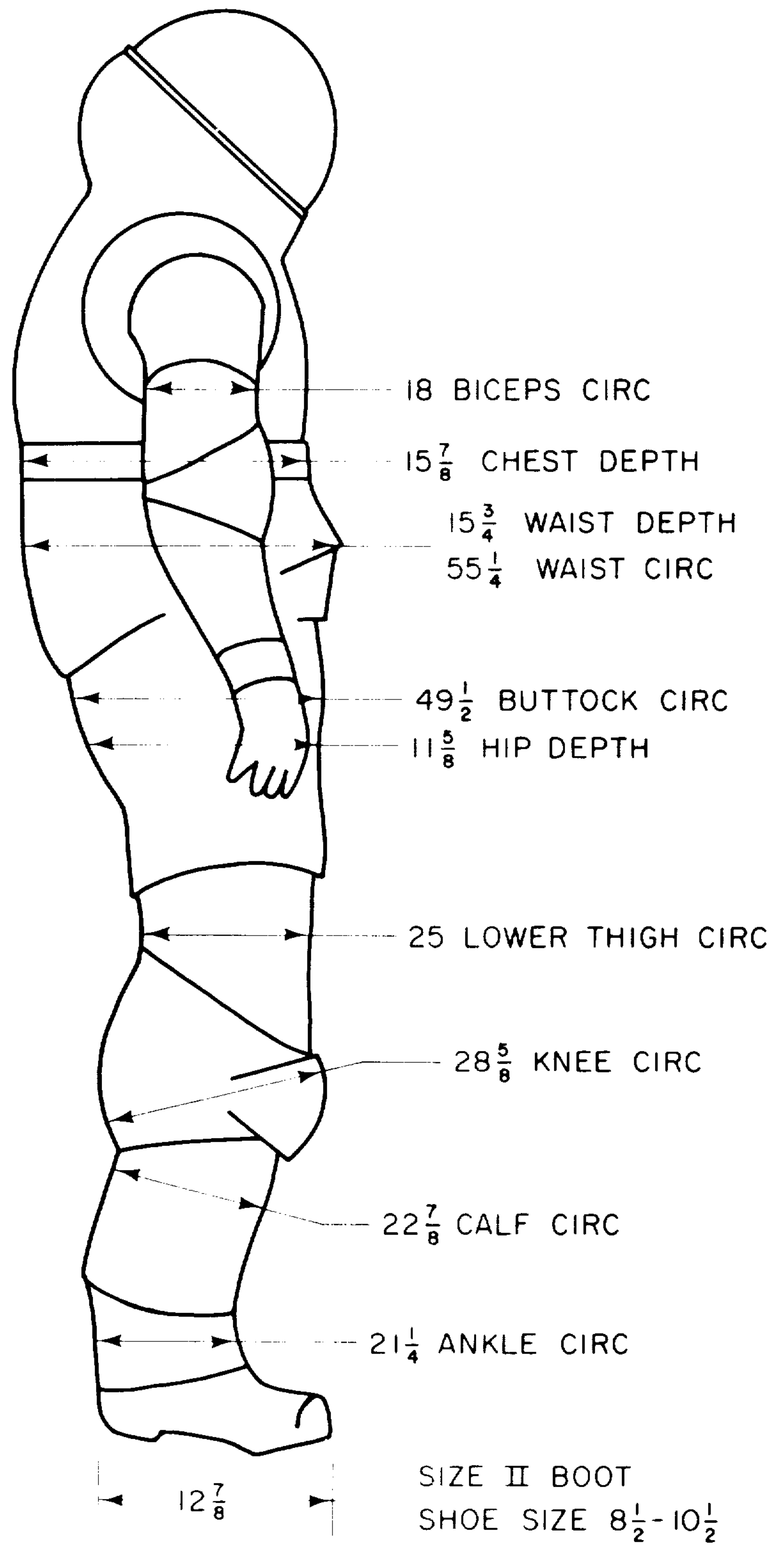


Figure 16-11 (continued)

c. Anthropometry of the RX-5 Hard Space Suit (continued)

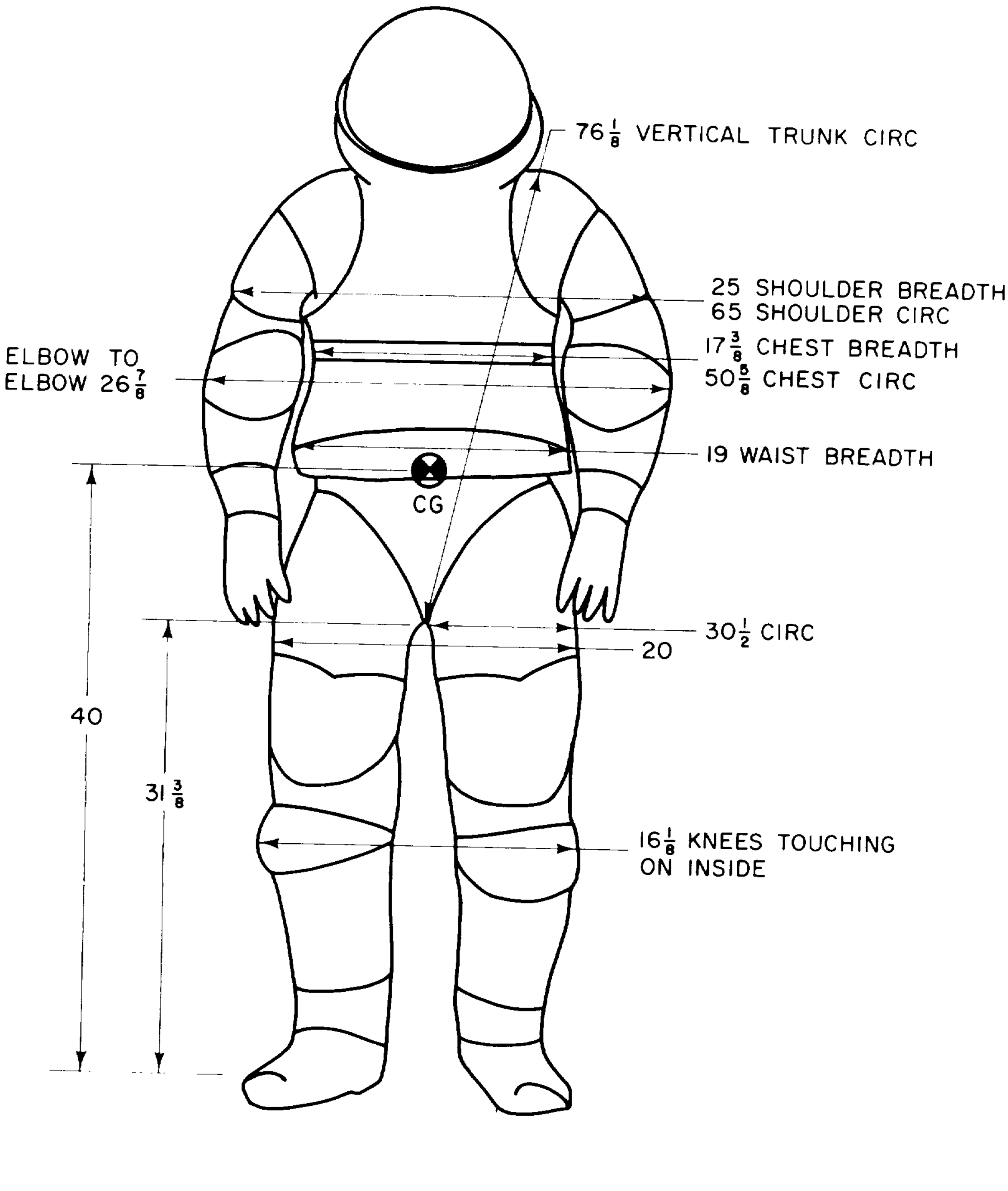


Figure 16-11 (continued)

c. Anthropometry of the RX-5 Hard Space Suit (continued)

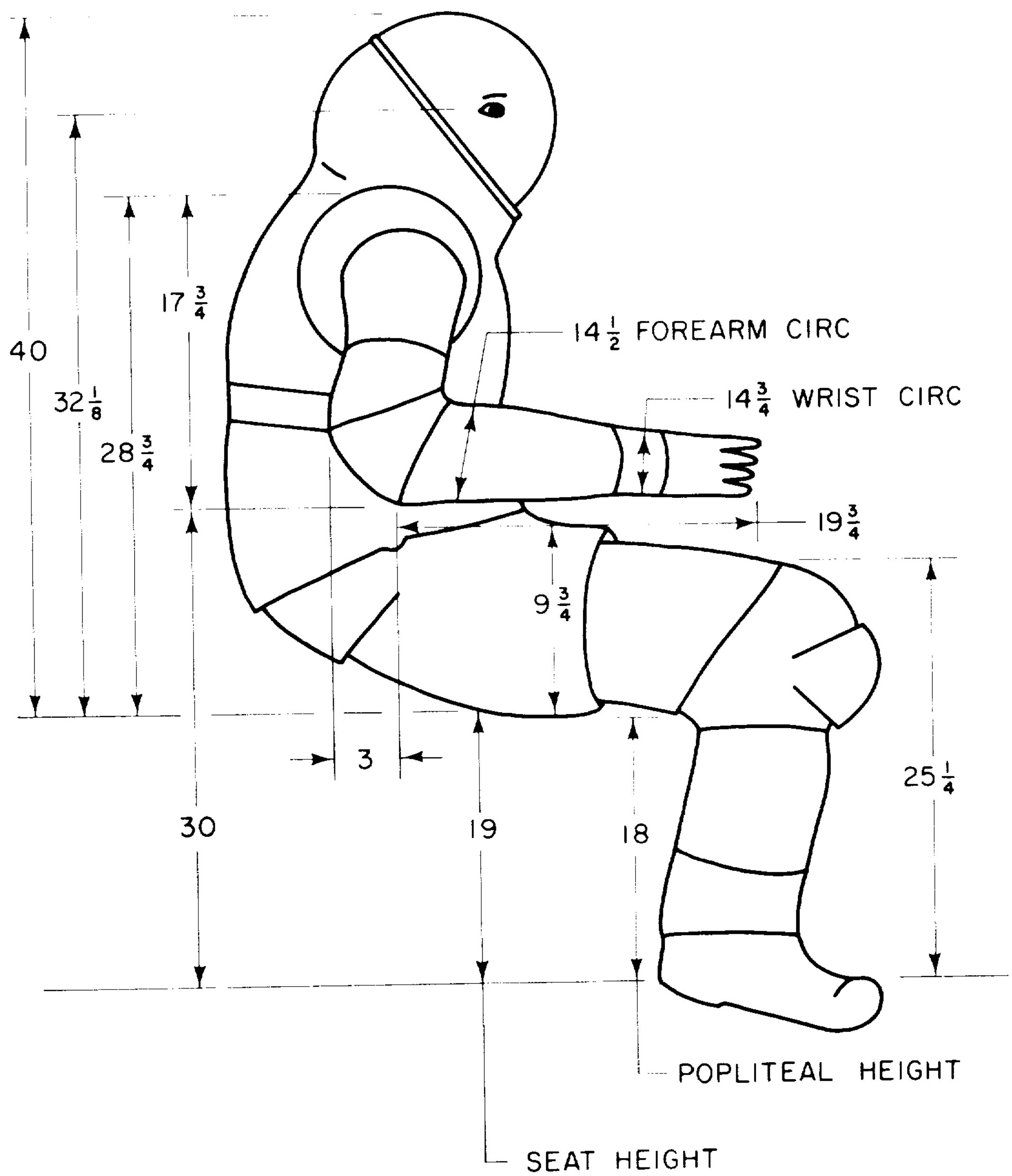


Figure 16-11 (continued)

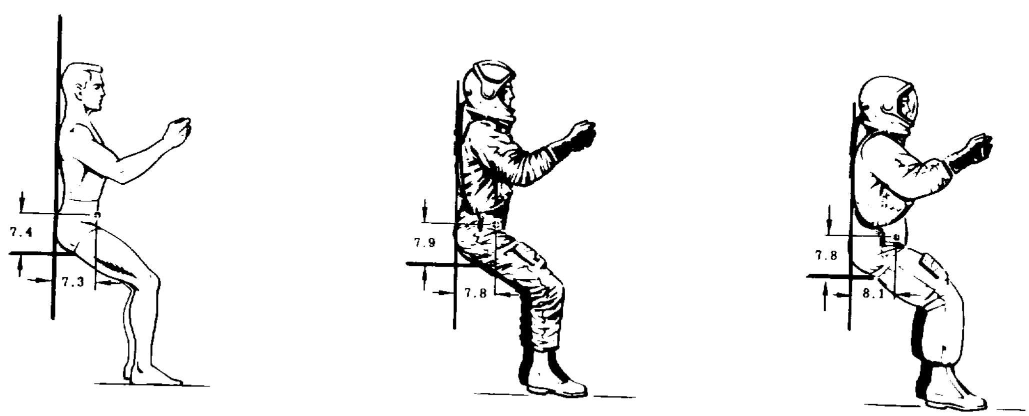
d. Mean Centers of Gravity of Pressure-Suited Subjects

Nude

Unpressurized

Pressurized

1. Sitting



Nude

Unpressurized

Pressurized

2. Relaxed (Weightless)

(After DuBois et al[83])

Figure 16-11 (continued)

e. Arithmetic Means and Standard Deviations of the Sample Centers of Gravity and Moments of Inertia (N = 19)

	Axis	Center of Gravity (in.) Mean	S.D.	Moment of Inertia (lb. in.sec.^{2}) Mean	S.D.
1. Sitting					
Nude	x	7.89	0.41	56.3	8.22
	y	4.79	0.27	66.5	9.98
	z	9.16	0.29	28.3	5.10
Unpressurized	x	8.33	0.39	67.5	9.16
	y	4.79	0.27	82.8	11.30
	z	9.76	0.30	33.6	5.72
Pressurized	x	8.62	0.38	68.8	8.70
	y	4.79	0.27	82.4	11.30
	z	9.70	0.28	34.0	5.72
2. Relaxed (Weightless)					
Nude	x	7.34	0.38	99.2	14.20
	y	4.79	0.27	89.8	15.20
	z	7.39	0.42	31.2	5.04
Unpressurized	x	7.81	0.30	118.0	15.30
	y	4.79	0.27	114.0	15.00
	z	7.86	0.45	36.2	5.03
Pressurized	x	8.08	0.29	118.0	15.20
	y	4.79	0.27	114.0	15.70
	z	7.81	0.48	36.1	4.85

Mean Age 27.4 yrs. S.D. Age 5.3 yrs.
Mean Weight 164.6 lbs. S.D. Weight 17.4 lbs.
Mean Stature 69.0 in. S.D. Stature 2.3 in.
Mean Clothing Weight 23.2 lbs. S.D. Clothing Weight 0.5 lb.

(After DuBois et al[83])

Figure 16-11 (continued)

f. Correlation of Moment of Inertia with Stature and Weight in Pressure-Suited Subjects (N = 19)

	Axis	$R_{i.sw}$	S.E.*	I_o Regression Equation*
1. Sitting				
Nude	x	0.95	2.67	-105.0 + 1.59S + 0.317W
	y	0.91	4.07	-135.0 + 2.10S + 0.344W
	z	0.97	1.17	- 70.4 + 0.923S + 0.212W
Unpressurized	x	0.93	3.42	-114.0 + 1.82S + 0.337W
	y	0.97	2.77	-181.0 + 2.96S + 0.362W
	z	0.97	1.47	- 79.5 + 1.09S + 0.229W
Pressurized	x	0.93	3.24	-120.0 + 2.06S + 0.281W
	y	0.94	3.79	-157.0 + 2.54S + 0.389W
	z	0.96	1.53	- 78.1 + 1.07S + 0.230W
2. Relaxed (Weightless)				
Nude	x	0.97	3.30	-191.0 + 2.88S + 0.556W
	y	0.95	4.60	-265.0 + 4.04S + 0.461W
	z	0.94	1.75	- 46.0 + 0.567S + 0.231W
Unpressurized	x	0.95	4.62	-197.0 + 3.19S + 0.574W
	y	0.96	4.38	-217.0 + 3.59S + 0.506W
	z	0.96	1.33	- 54.8 + 0.801S + 0.217W
Pressurized	x	0.97	3.93	-208.0 + 3.42S + 0.550W
	y	0.96	4.44	-254.0 + 4.18S + 0.482W
	z	0.96	1.36	- 48.7 + 0.720S + 0.214W

$r_{sw} = 0.44$ S.E. = 2.02 in. S = 59.58 + 0.057W

*I_o and S.E. in lb.in.sec.^{2}

S in in.

W in lbs.

(After DuBois et al[83])

recommendations regarding minimal volumetric requirements for missions extending from a few months to a year may be made:

Sleep/rest station volume should not be less than 300 cubic feet per man and so configured as to accommodate stowage of spare clothing (constant-wear garments and flight coveralls), suit-inflation capability, and donning of the pressure suits.

Work station volume should be dictated by operational requirements and so designed as to meet the following cirteria:

- Separate from sleep/rest station.
- Contingency functions designed for pressure suited interface and given priority consideration in location/placement.
- Individual pressurization capability.
- Unrestricted access to all controls and displays.
- Restraints and tethers to permit performance of all work functions with two hands if the need should arise.
- Non-interference between duty station crewmen if more than one is working.

Air locks and hatches should be designed so that the actuating mechanism is no higher than shoulder height and positioned for easy visual access in a standing, 1G position. For umbilical operations, the hatches should not be less than 31 inches in diameter and for operations with a self-contained life support system they should not be less than 43 inches in diameter to provide easy egress/ingress capability. Air locks should be designed to an inner diameter of at least 5 feet to provide pressurized turn-around capability and should contain a handrail or protruding handrails along the axis of body rotation. The air locks themselves should be designed for operation by one man with simple unlocking/locking mechanisms, with mechanical advantages for aid in overcoming residual pressure forces inside the spacecraft, and hinged for rotation to provide unencumbered access to tunnel areas.

Studies have been performed on the design of air locks and hatches in zero gravity operations. The subjects were filmed during repetitive trials and the position-velocity time profiles of the maneuvers were analyzed for three simulation modes; ground-normal gravity, aircraft-zero gravity, and water immersion neutral buoyancy. These simulation studies indicate that:

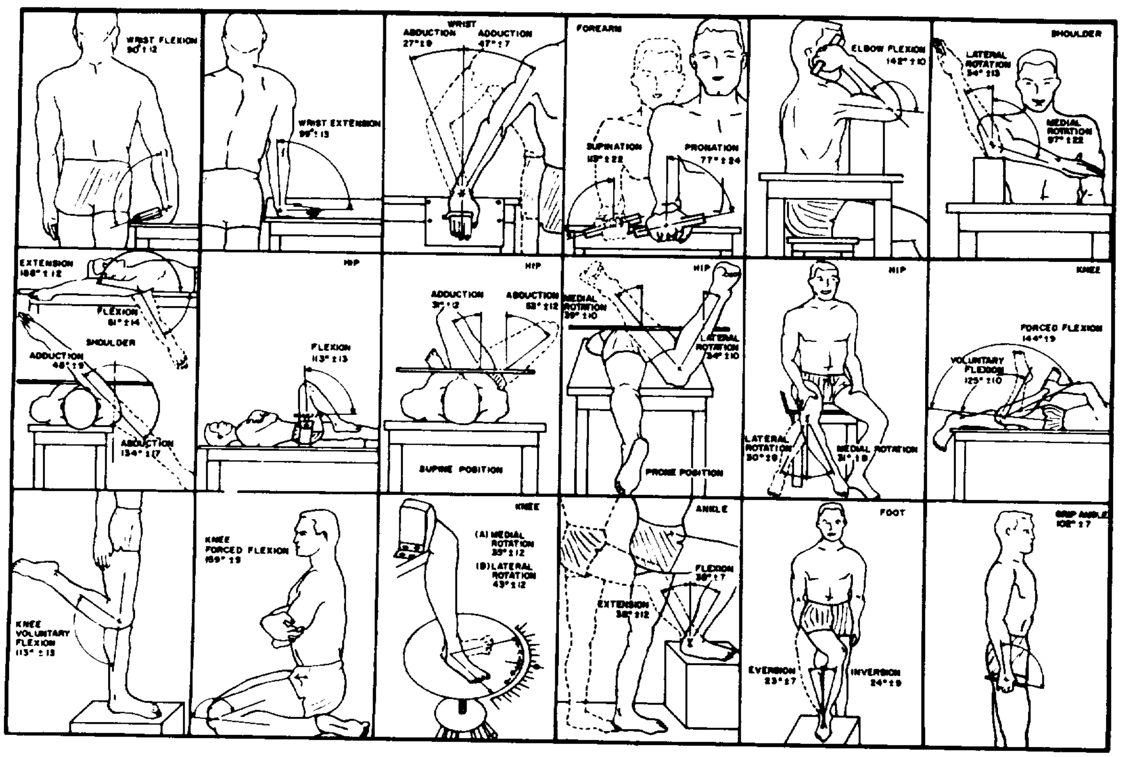
- A 48"-diameter,6' length airlock passageway with 32" circular hatches is sufficient, from a space standpoint, for an astronaut to adequately perform a manual ingress-egress maneuver.
- Counter rotation to applied torques, and movement due to applied linear forces due to lack of gravity-dependent reaction forces of the body must be counteracted to insure adequate operation.
- Hatch diameters less than 26" should not be utilized due to impediment to free travel and suit interactions.

- Ingress-egress maneuvers in airlocks of 48" diameter or less, requiring internal turnaround of a pressure-suited astronaut, dictate strengthening of the suit faceplate to prevent accidental depressurization.
- Airlock hardware requiring operation by an astronaut in a pressurized suit must be sized to accommodate the lack of tactual and visual ability concommitant with pressure-suited operations.
- Airlock passageways should remain as free of hardware appurtenances as design factors dictate to prevent suit interaction.

Future space vehicles and lunar bases have been studied from the point of view of workspace. Optimization of laboratories and crew stations for large orbiting crafts (259) and other space vehicles (223) has received preliminary study. Workspace analysis has been performed for lunar laboratories and bases (49, 237).

Force-Motion Analysis

The range of body motion is an important factor in workspace and operations analysis. Figure 16-12 shows the joint motion capability of a young male population. The recorded motion range in the nude should not be much different for



Range of joint motion in 39 young men, showing the median value in degrees, ± 1 standard deviation. If ± 2 SD are taken, 95% of the sample of 39 is included. Compared with the 1950 Air Force survey of over 4000 flying men, this sample is 6.8 years younger, 6.0 lbs heavier, and 1.4 inches taller.

Figure 16-12

Joint Motion Capability of a Young Male Population

(After Hertzber and Clauser[164])

the typical astronaut in shirtsleeve environment. Dynamic characteristics and range of motions required for operation of lunar scientific equipment are given in References (115, 184) and in Tables 16-19 to 16-23.

Forces and angular motion exerted on sidearm controllers are noted in Figures 16-13a and b. Forces exerted on hand controls by male college students are noted in Figure 16-14a. Design of control devices can be quite complex. In the Gemini program, rudder pedals were initially envisaged; however, weight and space limitations forced abandonment of pedals in favor of placing a third axis on the manual controller (217). Either crew member could operate the controller while in the restrained position through wrist articulation and palm pivot motion only, to preclude body movements from being transmitted to the controller. The handle was spring loaded to provide an increasing resistance as the handle was moved away from neutral. Controller force/displacement originally had a step function designed in all three axes, but was later revised to a smooth curve as shown in Figure 6-14b for all three axes. Redundant switches were incorporated for selectivity energizing solenoid valves in the attitude control system. Total travel of the hand controller was 10 ±1 degrees from neutral in pitch and yaw axes and 9 ±1 degrees in the roll axis. Rotary movement of the handle about a transverse axis located at the palm pivot point effected a corresponding spacecraft motion about the pitch axis. Rotary displacement in a clockwise or counterclockwise direction in a transverse plane with respect to an adjustable canted axis below the pilot's wrist effected a similar movement about the spacecraft roll axis. Clockwise or counterclockwise rotation of the controller about the longitudinal axis of the handle effected a corresponding movement about the yaw axis. Due to extended operation in this mode, the resistant stick forces tended to cause wrist fatigue. Thus, the control stick was modified to assimilate a T at the top. This enabled the pilot to grasp the top of the stick palm down if desired for more ease of yaw control. A guard was built up on the top to prevent depressing the communications transmit buttons while grasping the stick in this manner. Evaluation of the many attitude controller designs included operation of the stick with a bare hand, a soft glove or a pressurized glove, as well as consideration of the man pressurized or unpressurized, in zero-g or under heavy re-entry g loads. The attitude controller worked best in conjunction with a rotary mode selector slightly forward and left of the stick. This was needed to allow the pilot minimal three-axis response for fine maneuvering such as docking (pulse) or larger orders of magnitude in response for gross corrections (rate command or direct). The modes made available to the pilot were:

a. HOR SCAN - The horizon sensors provided a reference in pitch and roll to automatically control a limit-cycle mode ±5 degrees in these axes. The yaw axis was maintained by the pilot using the pulse mode which was maintained on all axes in this mode.

b. RATE CMD - Pitch, roll and yaw rate gyro outputs were compared with controller positions to produce attitude rates proportional to controller deflection. (Operationally, this mode was effective in correcting the fairly high cross-coupling rates developed when the maneuver controller was used to translate.)

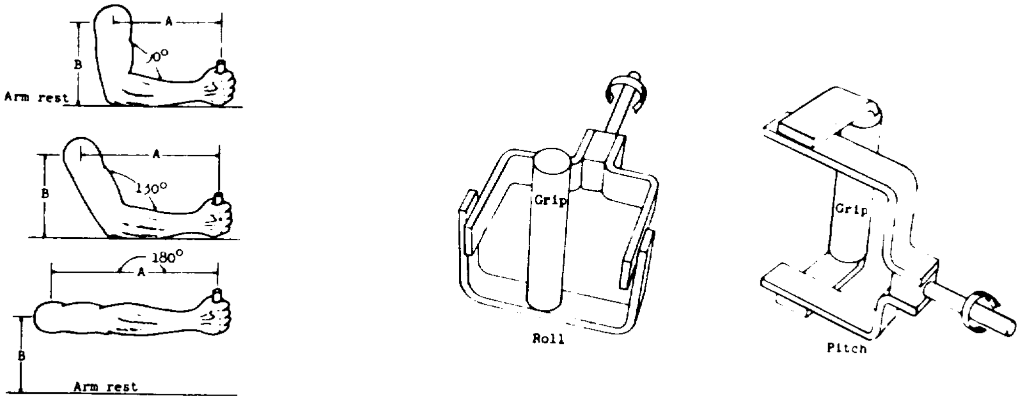
c. DIRECT - Provided direct control to open thrust chamber solenoids when the attitude controller was deflected approximately 25% of full travel. (The utmost discretion was used in this mode, as it tended to waste fuel.)

Figure 16-13

Forces Exerted on Side-Arm Controllers

(After Hertzberg and Clauser[164])

a.

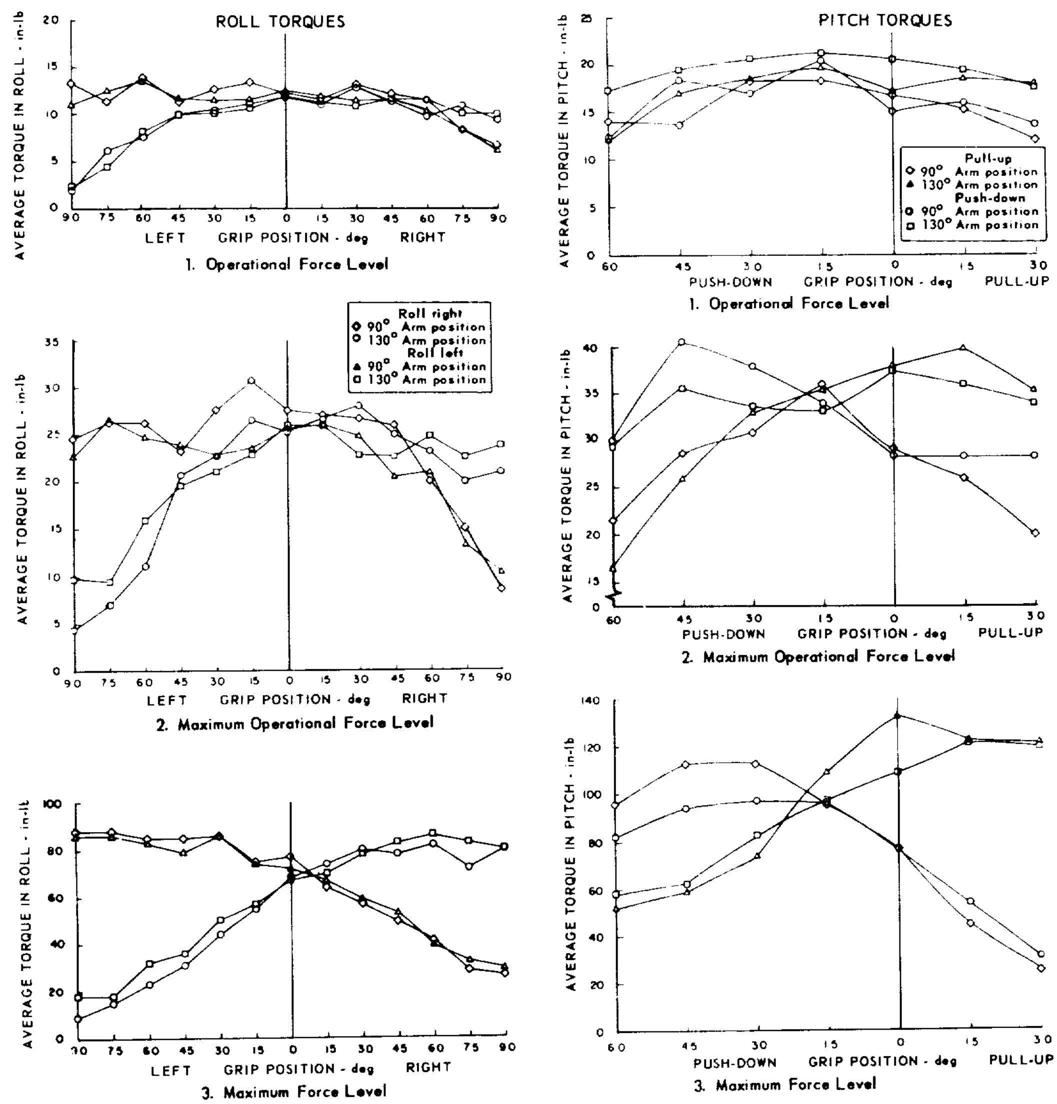


Pilot	Distance A in.			Distance B, in.		Maximum controller angle (unconstrained), deg							
						Right Roll		Left Roll		Forward Pitch		Rearward Pitch	
	Measured at elbow angle of -												
	90°	130°	180°	90°	130°	90°	130°	90°	130°	90°	130°	90°	130°
1	15.00	19.00	26.25	13.00	12.50	105	105	80	75	45	35	30	40
2	11.50	18.00	25.00	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	25.00	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°.

Figure 16-13 (continued)

b.



Source: Brissenden (38)

These graphs show the forces the pilots could develop at two elbow angles. They were instructed to apply the following levels of exertion:

(1) Operational force - chosen as the comfortable level for continuous control maneuvers.

(2) Maximum Operational force - acceptable for short periods, applicable to any maneuver requiring maximum control capability.

(3) Maximum force -- the greatest force pilots could exert in each grip position.

Figure 16-14

Design Factors for Hand Controls in Spacecraft

a. Forces Exerted on Hand Controls

Vertical Handgrip

N = 55

Right Arm

Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.
Push	60	34	92	150	38
	90	36	86	154	33
	120	36	103	172	43
	150	42	123	194	45
	180	50	138	210	49
Pull	60	24	63	74	23
	90	37	88	135	30
	120	42	104	154	31
	150	56	122	189	36
	180	52	120	171	37
Left	60	20	52	87	19
	90	18	50	97	23
	120	22	53	100	26
	150	20	54	104	25
	180	20	50	104	26
Right	60	17	42	82	20
	90	16	37	68	18
	120	15	34	62	17
	150	15	33	64	18
	180	14	34	62	24
Up	60	20	49	82	18
	90	20	56	106	22
	120	24	60	124	24
	150	18	56	118	28
	180	14	43	88	22
Down	60	20	51	89	21
	90	26	53	88	20
	120	26	58	98	23
	150	20	47	80	18
	180	17	41	82	18

Left Arm

Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.
Push	60	22	79	164	31
	90	22	83	172	35
	120	26	99	180	42
	150	30	111	192	48
	180	42	126	196	47
Pull	60	26	64	110	23
	90	32	80	122	28
	120	34	94	152	34
	150	42	112	168	37
	180	50	116	172	37
Left	60	12	32	62	17
	90	10	33	72	19
	120	10	30	68	18
	150	8	29	66	20
	180	8	30	64	20
Right	60	17	50	83	21
	90	16	48	87	22
	120	20	45	89	21
	150	15	47	113	27
	180	13	43	92	22
Up	60	15	44	82	18
	90	17	52	100	22
	120	17	54	102	25
	150	15	52	110	27
	180	9	41	83	23
Down	60	18	46	76	18
	90	21	49	92	20
	120	21	51	102	23
	150	18	41	74	16
	180	13	35	72	15

Source: Hunsicker (171)

Horizontal Handgrip

N = 30

Right Arm--Wrist Pronated

Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.
Push	60	40	94	156	36
	90	25	65	100	24
	120	23	46	70	15
	150	18	40	66	18
	180	17	32	59	12
Pull	60	13	37	50	16
	90	14	32	54	13
	120	13	26	43	10
	150	12	29	48	10
	180	11	28	48	12
Left	60	19	41	72	19
	90	12	31	64	15
	120	9	26	53	13
	150	9	21	39	11
	180	10	19	34	7
Right	60	16	48	73	18
	90	16	39	59	15
	120		34	47	11
	150	18	32	45	7
	180	16	31	57	13
Up	60	23	49	79	20
	90	28	69	112	29
	120	41	91	138	30
	150	43	99	165	38
	180	35	95	156	35
Down	60	23	61	158	35
	90	22	83	142	35
	120	37	92	161	35
	150	40	90	154	34
	180	41	87	143	31

Left Arm--Wrist Pronated

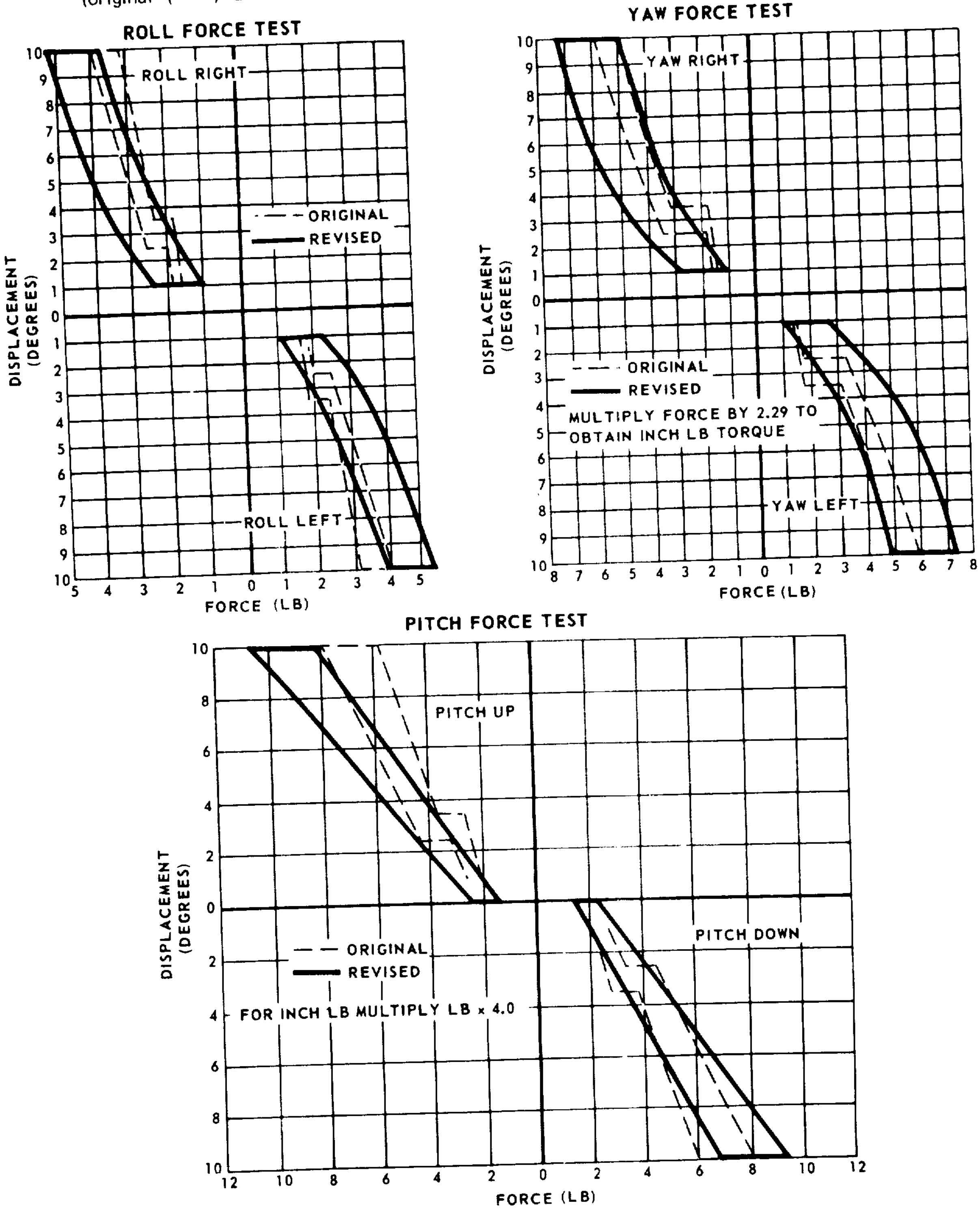
Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.
Push	60	33	86	138	35
	90	27	60	93	28
	120	17	43	71	17
	150	15	37	69	18
	180	12	32	59	13
Pull	60	20	39	64	18
	90	17	37	63	18
	120	12	30	56	14
	150	15	32	52	13
	180	16	34	61	15
Left	60	20	42	66	15
	90	17	38	60	12
	120	17	34	53	8
	150	17	31	54	11
	180	15	28	41	8
Right	60	18	36	51	15
	90	11	27	54	11
	120	10	22	39	10
	150	9	23	53	16
	180	10	20	49	13
Up	60	22	57	100	22
	90	37	77	123	24
	120	45	91	145	30
	150	58	100	159	32
	180	47	101	171	
Down	60	18	74	139	35
	90	23	75	136	34
	120	29	75	148	
	150	39	79	136	19
	180	34	76	138	31

Source: Hunsicker (172)

Controls designed to be actuated by human force should be operable by the weakest individuals of the using population but able to withstand the maximum force the strongest individuals of the using population can apply. The tables show the maximum forces (measured in pounds) exerted on vertical or horizontal handgrips by male college students, tested in a seated position.

Figure 16-14 (continued)

b. Hand Forces for Attitude Control in the Gemini Spacecraft (original (—) and revised (- - - -)



d. PULSE - For each deflection of the controller away from the center position, a single short duration (20 msec) pulse was applied to the appropriate axis.

e. RATE CMD, RE-ENT - Similar to rate command with a wider neutral and and gain crossfeed from roll to yaw. (Designed for use in manual re-entry.)

f. RE-ENT - Pitch and yaw axes in rate damping control mode, with roll axis slaved to bank-angle command from the computer.

g. PLAT - ACME accepted attitude information from the platform and provided outputs to the thrusters to maintain spacecraft attitude automatically within pitch, yaw and roll deadbands.

h. PARA - A mode designed for use with a paraglider which was eliminated before the first manned flight. (On Spacecraft V and up, this selector position was used for the PLATFORM mode.)

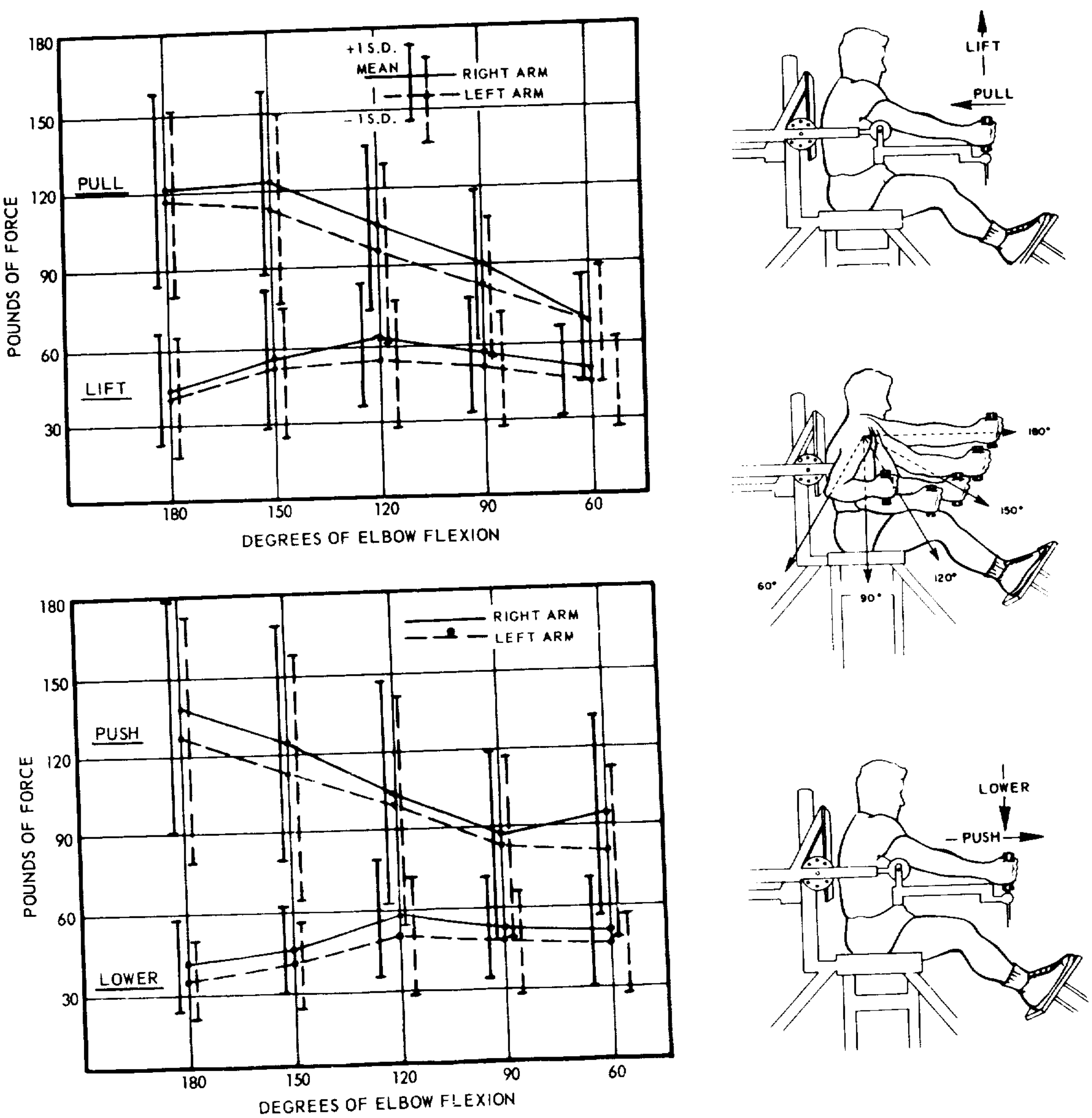
Arm strength with elbow flexion is recorded in Figure 16-15. Leg strength is recorded in Figure 16-16 and lifting strength in Figure 16-17. Cranking speeds and other motion factors for shirtsleeved males have recently been reviewed (71).

A handbook of control design for pressure-suited subjects has been published (295). Controls and displays used in Gemini have been reviewed (217, 231). Data are available on static and dynamic factors in design of wheeled vehicles for terrestrial (56) and lunar operations (132, 140); also, for manned space-simulation chambers (9, 10, 15, 58, 218, 227).

Complex motor control and integration of man into the machine control loop has received much study in relation to aircraft and spacecraft problems. Several major reviews and symposia are available (References 7-532, 7-694, 7-689) and (178, 238, 257, 262, 302, 317, 343, 345, 373). A Soviet review of this subject has also been presented (78). General assessments of optimal human performance in space systems have been made (238, 239, 292). More specific human control studies have been made of spaceflight tasks. These include: manual space navigation (242), orbital docking of large attitude-stabilized components and other systems (59, 272), lunar landing vehicles (9, 179, 205). The visual aspects of rendezvous and docking control has been reviewed on pages 2-96 to 2-108 of the section on Light, (No. 2). Finally, studies on the simulation of lunar missions with emphasis on learning and retention of complex skills have been published (69) and Reference (7-254).

Human performance in the different acceleration environments including subgravity and zero gravity has been covered in Oxygen-CO_2-Energy, (No. 10) and in Acceleration, (No. 7). Effects of training on the performance of motor skills during the Gemini EVA were reviewed on pages 7-129 to 7-154. Training plans for Apollo are available (248). Soviet studies of responses to intra and extravehicular exercise in Voskhods I and II are now published. (See also pages 7-131 and 7-132.)

Human factors in the assembly and maintenance of large space structures are under current study (282, 372). The effects of human motions and forces on the stability of orbiting vehicles have been simulated (81, 321).



Mean values and standard deviations for the strength of pulling, lifting, pushing, and lowering with each arm and with the elbow flexed at the angles indicated, on the right. The sample group was 55 college men, selected to approximate the characteristics of aircrewmen. Testing was done with a strain gauge dynamometer to record the forces on the isometric handgrip (which does not move appreciably).

Source: Hunsicker[171], additional data may be found in Morgan et al[224]

Figure 16-15

Arm Strength with Elbow Flexion

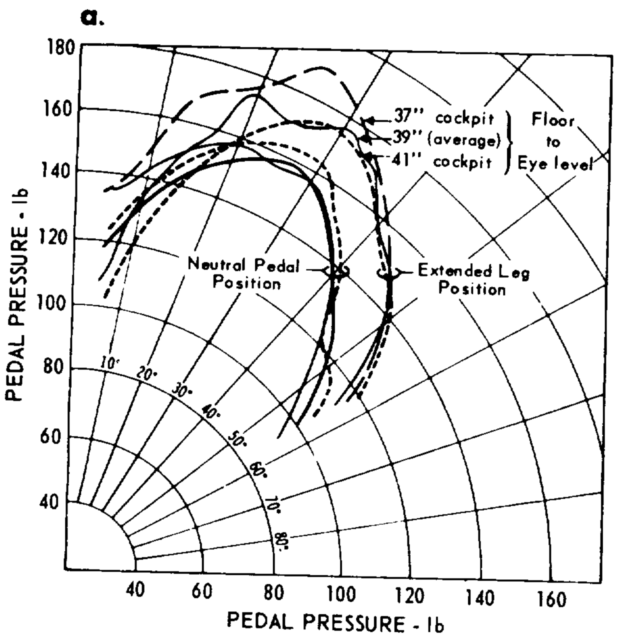
(After Hertzberg and Clauser[164])

Figure 16-16

Leg Strength

(After Hertzberg and Clauser[164])

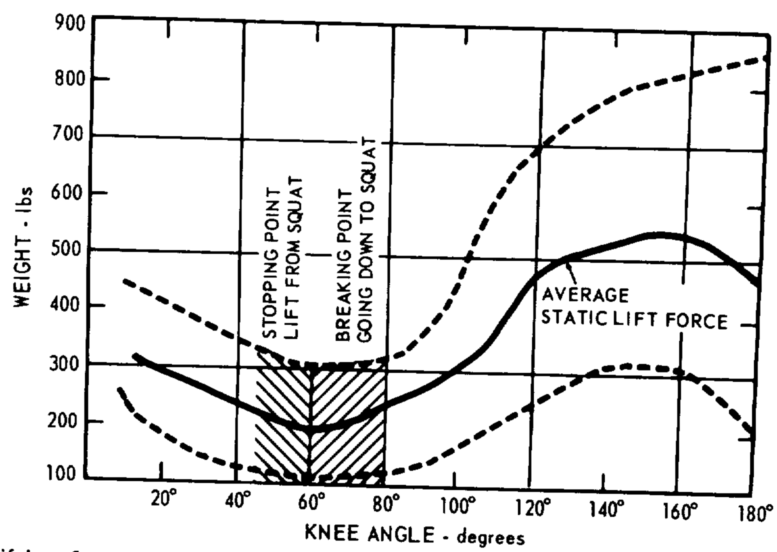
a.



Foot rotation forces on an aircraft brake pedal measured at various angles of the brake pedal in neutral and extended leg positions. Floor to eye height was also varied from 37 to 41 inches. Data are averages of 100 subjects.

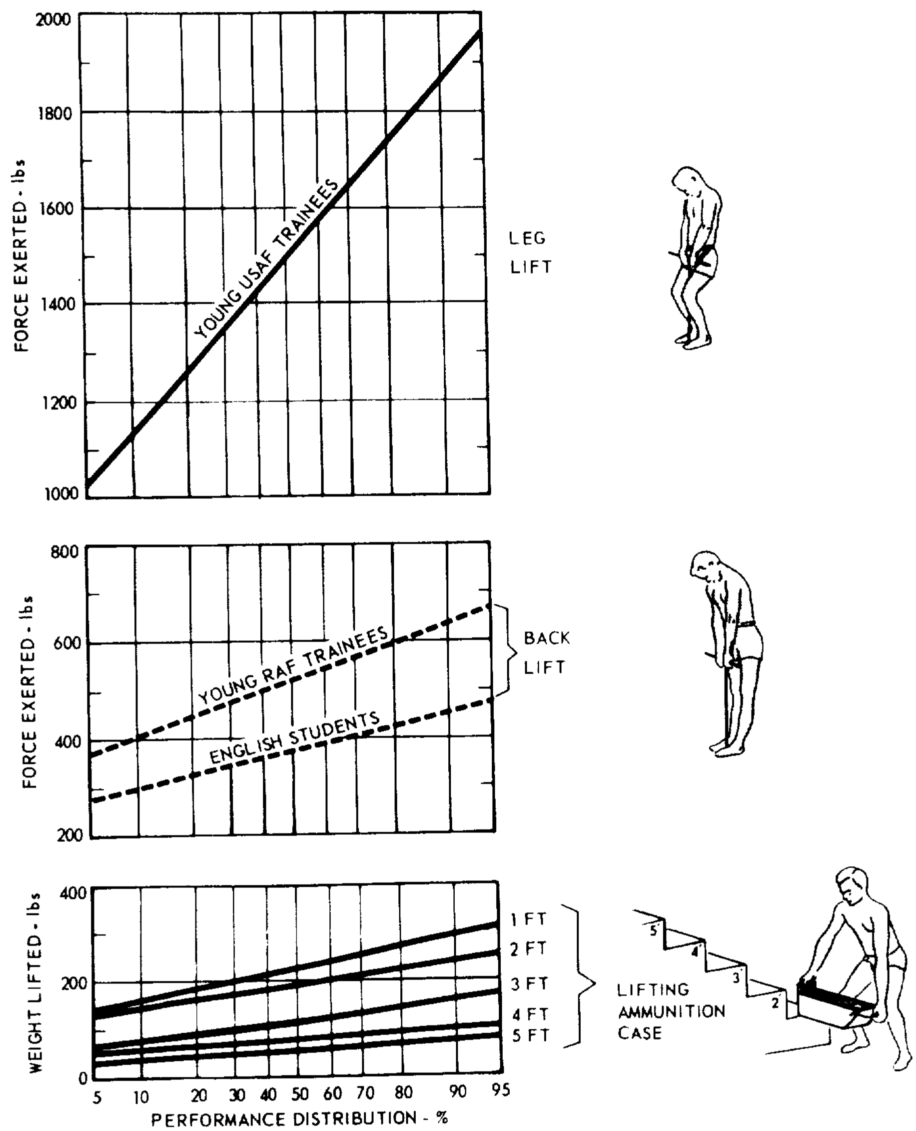
Source: Hertzberg[162])

b.



The static lifting forces applied against dynamometers by 13 subjects with knees variously bent as shown by the scale of knee angles. The central line shows average values, and the outer dashed line shows the range of forces. In addition, subjects were tested in dynamic lift, shown by the two shaded areas, using bar bell weights on their shoulders. Maximum rise from full squatting posture is shown in the left hand shaded bar as the maximum angle of knee extension. The right hand shaded bar shows the "angle of break," determined by starting with weights on the shoulders and a full standing position, then gradually squatting until the leg could no longer restrain the motion and a rapid downward motion began.

Source: Swearingen et al[318]



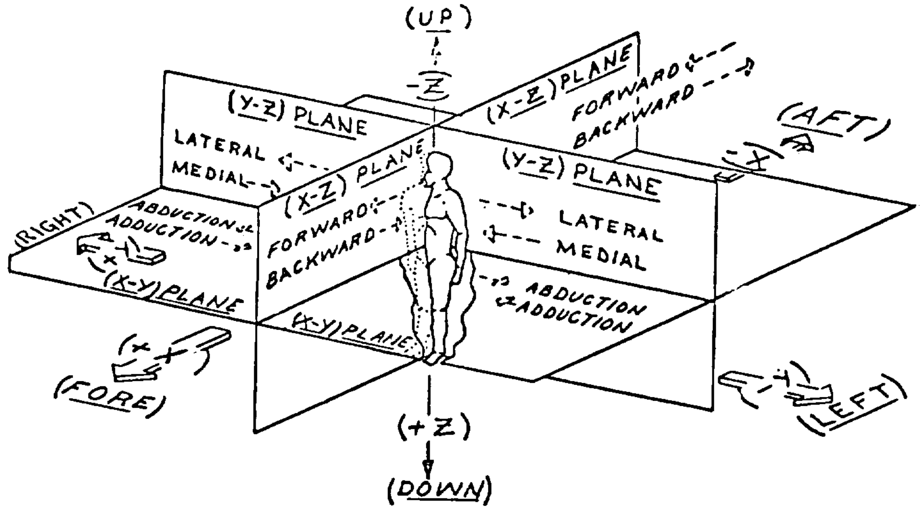
The variations in lifting strength as different lifting tasks are measured. Each of the three types of lift shown is plotted on a probability grid to show the percentile performances. Note the low values for lift when an awkward load (the ammunition case from the F-86H aircraft) must be raised. Note also the very high values when the strong leg muscles are ideally employed, as shown in the upper set labeled "Leg Lift". Here, not only the hands were used to grip the dynamometer bar; a special belt and fastener helped transfer the force to the handle. These data may be of value in planning post-landing survival maneuvers.

Adapted from Catheart et al(52), Clarke(64), and Emanuel and Chaffee(90)

Figure 16-17

Lifting Strength

(After Hertzberg and Clauser(164))



Plane Definitions:

a. (Y - Z Plane) - Frontal Plane

b. (X - Z Plane) - Sagittal Plane

c. (X - Y Plane) - Transverse Plane

Type of Limb Movement Terms:

a. Flexion - Bending or decreasing the angle between parts of the body.

b. Extension - Straightening or increasing the angle between parts of the body.

c. Stretch - Lengthening of body part.

d. Rotation - Revolution about the axis of a body part.

e. Pronation - Face down.

f. Supination - On back or Face up.

Direction of Limb Movement Terms:

a. Forward = +X Direction

b. Backward = -X Direction

c. Upward = -Z Direction

d. Downward = +Z Direction

e. Right = +Y Direction

f. Left = -Y Direction

g. Lateral = Away from (X-Z) plane (in Y-Z plane)

h. Medial = Toward (X-Z) plane (in Y-Z plane)

i. Abduction = Away from (X-Z) plane (in X-Y plane)

j. Adduction = Toward (X-Z) plane (in X-Y plane)

Figure 16-18

Terminology and Definitions for Describing the Mobility of the Pressure Garment Assembly

(After NASA[336])

Extravehicular Garments and Mobility

Special consideration must be given to anthropometric factors in planning extravehicular mobility. Suggestions have been made regarding critical areas in the design of the Apollo Extravehicular Mobility Unit (EMU) which consists of the following subsystems (336): Pressure Garment Assembly (PGA), Constant Wear Garment (CWG), Liquid Cooling Garment (LCG), Thermal and Meteoroid Garment (TMG), Extravehicular Visor Assembly (EVA), Portable Life Support System (PLSS), Emergency Oxygen System (EOS).

Design features should prevent impediments to astronaut in the performanc of his tasks which include:

- Donning, doffing and checkout of applicable EMU subsystems within the command Module (CM) (185).
- Donning, doffing and checkout of the TMG, EVA, PLSS, and EOS within the LEM in both a pressurized and depressurized cabin (185).
- Egress and ingress through all the CM or the LM hatches in free space and/or (for LM only) on the lunar surface while carrying scientific or maintenance equipment (207, 346). (See discussion on page 16-36.)
- Descending and ascending LM vertical ladders (309).
- Walking over the lunar surface while carrying assorted tools, scientific and navigation equipment (Figure 7-73) (290, 309).
- Performing various scientific experiments on the lunar surface such as hook-up and emplacement of passive recording instruments, seismometers, geophones, radiation detection devices, magnetometers, power supplies; setup and operation of cameras, levels, transits, stud guns; collection and packaging of lunar soil specimens, etc. (115, 184, 185) (Figure 7-73).
- Performing specific mobility tasks on lunar surface, unassisted, such as crouching in a deep knee bend; kneeling on one and/or both knees; crawling forward and backward; getting up from a prone or supine position; bending and picking up small objects on the ground without kneeling (309).

Analyses of many of these tasks have been presented under performance in zero and subgravity of Acceleration, (No. 7). Intra and extravehicular activities of suited subjects in Gemini have been covered in great detail by NASA reviews (216, 231).

Pressure Garment Assemblies (Soft and Hard Suits)

The Pressure Garment Assembly (PGA) is an anthropomorphic pressure vessel encompassing the entire body. The Assembly is individually sized to the existing astronaut population (Figure 16-4). The PGA is tailored as closel as possible to actual body contours and to necessary internal PGA components and should provide break points at natural body break-points to enhance mobility and reduce excessive bulk. The crewman should be comfortable in a pressurized PGA, fully restrained in the Command Module couch under the effect of a sustained acceleration of 5 g's, $+G_x$, eyeballs in. It has been recommended that the following exterior dimensions not be exceeded:

1. Across shoulder: 23-3/4 inches;
2. Across elbows: 23-3/4 inches;
3. Across knees: 16 inches.

The combined center of gravity of the PGA and the crewman should be located within two (2) inches vertically and one (1) inch horizontally of the CG of a nude, standing crewman as noted in Figures 16-6, 16-7, and 6-11.

The mobility requirements for the PGA are described in terms of the terminology and definitions provided in Figure 16-18. The types of mobility of concern to PGA design include the following:

- Elementary movements, or movements of the body, limbs, or head in one plane.
- Complex movements, which are movements of the arms, wrists, hands and fingers which require a high degree of psychomotor coordination and movement in more than one plane (295).
- Total body movements, which include movements involved in walking, lifting objects, etc.
- Suit equilibrium positions, which are positions the garments tend to seek when no torque is being applied to the joints.

The movements of the head, body, limbs, and/or elementary movements, which the astronaut should be capable of performing with the PGA vented or pressurized to 3. 7±.2 psi are indicated in Table 16-19. This table indicates the minimum range of movement in degrees for each of the movements and the maximum torque in inch-pounds (or foot-pounds) required to initiate and sustain the movement.

The complex movements of the arms, wrists, hands, and fingers which the Apollo crew should be capable of performing both extravehicularly and intravehicularly with the suit pressurized to 3. 7 ±.2 psig are indicated in Tables 16-20 to 16-22. The coordinated movements of the torso, arms, legs, hands, feet, and head such as are required during lunar surface operations and during the extravehicular phase of orbital flight with the suit pressurized between 3. 5 and 3. 9 psig are indicated in Tables 16-22 a and b. Data for the design of equipment and altered movement patterns resulting from zero gravity have been covered in the section on zero gravity in Acceleration (No. 7).

As general anthropomorphic factors in the design of extravehicular garments, the following have been suggested (336). If equilibrium positions exist for the garments, i. e., positions into which the garments will spring to or seek if no restrictive force is applied by the crewman in the EMU, they

Table 16-19

Maximum Performance Requirements for the Elementary Body Movements Intravehicular and Extravehicular Wear, Vented or at 3.7 Psia

(After NASA--CSD-A-096[336])

MOVEMENTS	RANGE OF MOVEMENTS (In degrees)	MAXIMUM TORQUE REQUIRED
A. NECK MOBILITY		
Flexion (forward-backward)	120	0
Flexion (left-right)	30	0
Rotation (Abduction-Adduction)	140	0
B. SHOULDER MOBILITY		
Adduction	45	1 ft. lb_f
Abduction	125	1 ft. lb_f
Lateral - Medial	150	1 ft. lb_f
Flexion	170	1 ft. lb_f
Extension	50	1 ft. lb_f
Rotation (X-Z Plane) Down-up	135	1 ft. lb_f
Rotation (Y-Z Plane): Lateral Rotation	35	1 ft. lb_f
Medial Rotation	95	1 ft. lb_f
C. ELBOW MOBILITY		
Flexion - Extension	140	1 ft. lb_f
D. FOREARM MOBILITY		
Supination (Palms up)	90	.2 ft. lb_f
Pronation (Palms down)	75	.2 ft. lb_f
E. WRIST MOBILITY		
Palmar Flexion	75	.2 ft. lb_f
Dorsiflexion	65	.2 ft. lb_f
Abduction	50	.2 ft. lb_f
Adduction	30	.2 ft. lb_f
F. TRUNK - TORSO MOBILITY		
Trunk Rotation (abduction - adduction)	70	2 ft. lb_f
Torso Flexion (lateral - medial)	50	2 ft. lb_f
Torso Flexion (forward)	90	2 ft. lb_f
Torso Flexion (backward)	25	2 ft. lb_f
G. HIP MOBILITY		
Abduction (leg straight)	45	2 ft. lb_f
Adduction (knee bent)	30	2 ft. lb_f
Abduction (knee bent)	35	2 ft. lb_f
Rotation (sitting): Lateral	30	2 ft. lb_f
Rotation (sitting): Medial	30	2 ft. lb_f
Flexion	115	2 ft. lb_f
Extension	35	2 ft. lb_f
H. KNEE MOBILITY		
Flexion (standing)	110	1 ft. lb_f
Rotation (medial)	35	1 ft. lb_f
Rotation (lateral)	35	1 ft. lb_f
Flexion (kneeling)	155	1 ft. lb_f
J. ANKLE MOBILITY		
Extension	40	3.0 ft. lb_f
Flexion	35	3.0 ft. lb_f
Abduction	25	3.0 ft. lb_f
Adduction	25	3.0 ft. lb_f

Table 16-20

Elemental Movements of the Wrist, Hands, and Fingers Required in Apollo EMU Operations

(After NASA-CSD-A-096[336])

Movements or Operations	Description of Performance	Intravehicular 0.18 PSIG	Intravehicular 3.5-3.9 PSIG	Extravehicular
Palmar	Write legibly with pencil	x	x	x
	Operate .375" dia. rotary knob	x	x	x
	Utilize small screwdriver	x	x	x
Tip Prehension	Pick up small objects as:			
	- Small screws	x	x	
	- Small rocks			x
Lateral Prehension	Operate 2 and 3 position spacecraft toggle switches			
	- Vertically	x	x	x
	- Horizontally	x	x	x
Grasp	Use a screwdriver	x	x	x
	Use pliers	x	x	x
	Use crescent wrench	x	x	x
	Use socket wrench	x	x	x
	Use hand-controller	x	x	
Finger: Pushbutton Ops.	Operate pushbutton within panel of pushbuttons	x	x	x
Finger: Pulling Ops.	Operate T-handle control	x	x	x
	Operate D-handle control	x	x	x
	Operate ring handle control	x	x	x
Thumb	Operate thumbwheel	x	x	x
	Operate button on control handle	x	x	
Hand Rotation	Operate discrete position rotary switch	x	x	x
Wrist Movements	Move wrist side to side while opening and closing fingers	x	x	x
	Move wrist up and down while opening and closing fingers	x	x	x
Whole Hand Movement	Hold hand at any desired position	x	x	x

Intravehicular wear = CWG and PGA or LCG and PGA

x = required

Table 16-21

Movements of the Wrist, Hands, and Fingers Related to the Intravehicular Operation of the Pressure Garment Assembly in Apollo

(After NASA-CSD-A-096[336])

Components of PGA Defining the Complex Movements Requirements	0.18 PSIG (Suit Ventilated) CM (Couch Pos.)	CM (Vert. Pos.)	LEM (Vert. Pos.)	3.5-3.9 PSIG CM* (Couch Pos.)	CM (Vert. Pos.)	LEM (Vert. Pos.)
1. Helmet Ring Disconnect	x	x	x			
2. EV Visor Positioning						
3. EV Visor Attachment			x			x
4. Medical Injection Fitting	x	x	x	x	x	x
5. PLSS Controls and Attachments		x	x		x	x
6. EOS Controls		x	x			
7. Multiple Gas Disconnect	x	x	x	x	x	x
8. WMS Disconnect	x	x	x	x	x	x
9. Multiple Water Disconnect		x	x		x	x
10. Electrical Disconnect	x	x	x	x	x	x

x = required

* Provided there is no interference from the restraint harness.

Table 16-22

Complex Total Body Mobility Requirements Required for Intravehicular and Extravehicular Phases of Apollo at 1/6 G and Zero G

(After NASA-CSD-A-096[336])

a. Total Mobility Performance Criteria at 1/6 G, PGA Pressurized to 3.5 to 3.9 Psig

1. Climb ladder at slopes up to 27° with rungs spaced every 8 inches.
2. Remove equipment from LEM with LEM at 27° position.
3. Crouching in a deep knee bend for three minutes.
4. Kneeling on one knee for five minutes and working in kneeling position.
5. Crawling forward 5 feet, then backward to starting point.
6. Getting to and up from supine and prone positions (unassisted) within 30 seconds.
7. Pickup and carry 2nd astronaut.
8. Walking erect on 3° inclined treadmill at 3 mph for 10 minutes; jumping over small crevices; taking long strides.

Table 16-22 (continued)

a. Total Mobility Performance Criteria at 1/6 G, PGA Pressurized to 3.5 to 3.9 Psig (cont.)

9. Bending over to reach and pick up small objects on ground without the necessity of kneeling.

10. Operate PLSS controls.

11. Moving from standing erect to sitting position (unassisted) without making suit adjustments.

12. Lift without squatting.

13. Donning extravehicular wear with assistance,as necessary, while pressurized. This includes:

    a. External Thermal Garment (ETG) (including boots, garment
    b. and supplementary visor)
    c. Meteoroid Protection Garment (MPG)
    d. Portable Life Support System (PLSS)
    e. Emergency Oxygen System (EOS)

14. Forward reach while in kneeling position and torque at distance obtained.

15. Crawl face up or down thru LEM access hatch.

16. Capability to bend down in LEM and shut and lock LEM hatch.

17. Operate overhead hatch.

18. Change LiOH cannisters.

19. Handle equipment in torso-bent position in restricted area.

20. Self donning PLSS.

b. Complex Mobility Performance Criteria at Zero G

1. Operate stem unit (transfer).
2. Handle equipment and carry out tunnel transfer.
3. Don Extravehicular Mobility Unit
4. Work at navigation and Guidance Consoles in the Command and Lunar modules.
5. Handle Portable Life Support System in Lunar module
6. Access to Command Module lower equipment bay and capability to handle equipment.
7. Capability to carry out couch operations in Command Module.
8. Capability to carry out free space transfer.

should correspond as closely as possible to the "natural" position for each related task. Design should be compatible with the quick donning requirements. Closing and sealing operations should be possible without requiring assistance and/or while donning in the dark. Design should permit donning within a single time period of at least fifteen minutes without assistance in an illuminated CM while at zero gravity. Design of elastic and foamed garments to replace pressurized suits has been suggested (161, 270, 346).

The following features may act as aids to facilitate donning of the PGA:

- Non-bunching, low bulk, inner layers which are resistant to dimensional buildup.
- Smooth inner surface containing no pockets, flaps, or discontinuities.
- Incorporation of positive alignment devices for engaging mating parts.
- Minimum number of components requiring connections prior to pressurization.
- Positive indications of correct installation of mating parts.
- Engagement of a locking latch at the neck should be accomplished with a force of no more than 10 pounds.

Within the pressure garment, the liquid cooled garment, LCG, should be a moderately form-fitting flexible garment encompassing the entire body with the exception of the head and hands. (270) It should resist bunching, not bind or restrict the crewman or cause pressure points, and be constructed of absorbent loose weave material to permit capillary wicking of body moisture for evaporation. The flexible liquid coolant tubes should be located in a pattern which assures intimate contact with the typical astronaut skin surface at all times. (See section on liquid-cooled garments in Thermal Environment No. 6).

In the Apollo program it is planned that the Thermal-Meteoroid Garment (TMG) will encompass the entire EMU with the exception of the PLSS and the helmet assembly which will incorporate separate thermal and meteoroid protection (270). The TMG will consist of a parka, trousers, a pair of lunar boots and a pair of mittens. It will be conformal to the PGA and not contain excessive material which may cause folds or bunching. The outer layer of the TMG will be abrasion resistant, particularly in the area of the knees. The performance of the TMG should not be altered by adhesion of lunar dust. Provision should be made for the attachment of indicators and dosimeter devices in the areas which are readily accessible to the crewman during the lunar surface mission. Access should be permitted to the intravehicular-extravehicular controls, displays, connectors, and adjustment devices while in a pressureized PGA as noted in Tables 16-19 and 16-20. Design of the meteoroid garment of Gemini is covered in Pressure (No. 12) and reference (216). Data for the design of radiant insulations of the TMG are covered in Thermal Environment (No. 6); and for meteoroid protection, in Pressure, (No. 12).

A detailed analysis of the several different Gemini suits has been published (217). Data are also available on current prototype suits. The range of weigh volumes, mobilities and visual fields attained in prototype Apollo suits are covered in Table 16-23 (75, 185, 206, 270). Table 16-23 a and b review component weights of the soft and hard suits. Table 16-23 c gives the gaseous volumes of individual components of hard and soft suits (276). The residual volumes of Table 12-19 represent the volumes remaining in the suit after disruption of major seals. The total gaseous volume of a typical soft suit and PLSS (excluding respiratory tract of the astronaut) is 28 liters. The gaseous volume of the soft-suit helmets vary from 2 to 3 liters. The total gaseous volume of a typical hard suit and back pack is about 75 liters. The helmet of the hard suit is a hemisphere of about 12 inches in diameter. The total volume of the helmet is about 7400 cc; the volume of the head, about 3000 cc; and the free gaseous volume inside the helmet, about 4400 cc. Table 16-23c also gives the orifice areas at major seals and cross section areas of the body at seal sites. These data can be used for calculating pressure decay curves during explosive decompression (276).

Figures 23-d and e cover range of mobilities for 3 different soft suits. Wearing the LCG, the test subject was appropriately positioned and restrained on the mobility-notation table, and the angular excursion for the following movements were obtained for the unsuited, vented, and pressurized (3. 7 psig). Figure 12-23 e presents data on restriction of movement relative to the nude. Using these data, and a weighting system developed for this study (185) the space suits were rated as follows: In the vented condition, suit C ranked first, suit A second, and suit B third; pressurized to 3. 7 psig, suit A ranked first, suit C second, and suit B third. In a final rating for the angular-range study, suit C ranked first, suit A second, and suit B third. After studying the stroboscopic motion series and viewing the movies of mobility sequences, the three space suits were rated by the evaluation team. For the 3. 7 psig condition, with and without the TMG, suit A was ranked first, suit C second, and suit B third. The two evaluations (angular-range study along with the strobe and movie sequences) were considered together in arriving at a final rating on general mobility. Since the strobe and cine sequences included a broader

Table 16-23

Range of Weights, Volumes, Mobilities, and Visual Fields
Attained in Prototype Apollo Space Suits

a. Component Weights of Prototype Apollo Soft Suits (in grams and pounds)

Type of suit	Helmet with communications	Gloves, pair	Limb-torso suit	PGA (a)	EV Visor assembly	Water garment	Constant wear garment
Suit B	1865 4.10	494.5 1.89	10 870 2.38	13 229.5 29.2	1325 2.94	1483 3.26	268 .59
Suit A	1216 2.68	638 1.40	10 590 23.3	12 444 27.4	1007 2.22	0	0
Suit C	1203 2.65	649.5 1.43	8 730.5 19.3	10 583 23.3	1169.5 2.57	[b]1029.5 2.26	312 .69

[a]Weight of PGA respresents sum of weights for helmet, gloves, and limb-torso suit.
[b]Weight included no connectors.

(After Jones[185])

Table 16-23 (continued)

b. Weight of Hard Suit Components (in pounds)

Component	RX-2A	RX-3 Goals	Current Estimates	Micrometeoroid Protection (Honeycomb Layup)
Helmet and Sun Visor	3.67	4.5	5.0	0.5
Gloves	1.30	1.0	1.0	-
Wrist Joints	-	1.0	1.6	-
Lower Arm	1.04	1.2	1.4	0.2
Elbow Joints	2.80	1.0	1.0	-
Upper Arm	2.30	2.0	2.4	0.2
Shoulder Joints	7.34	6.4	6.4	-
Torso, Upper	9.85	4.8	4.8	0.1
Torso, Lower	5.80	5.2	5.2	0.1
Waist Joint	6.26	5.1	5.1	0.1
Body Seal Mechanism	4.76	1.5	1.5	-
Pants	3.94	2.9	2.9	0.1
Thigh Joints	10.52	8.0	8.4	0.9
Knee Joints	5.48	3.6	3.6	-
Calves	3.24	3.0	3.0	1.4
Ankles	3.40	1.0	2.2	-
Boots	4.08	3.0	3.0	-
Internal Pads and Ducting	4.37	2.8	2.8	-
Misc. (Head rest — inter-com, connectors, etc.)	-	2.0	2.0	-
Total	80.15	60.0	63.3	3.6

RX-3 Suit Weight minus Micrometeroroid Protection - 59.7

Shoulder Breadth of Both Suits - 23 inches

Leakage Rate - 25 Scc/min (2.1 x 10^{-3} cfm)

Maximum Joint Torque -- 0.28 m-kg (2.0 lb-ft)

(After Litton Industries[206])

Table 16-23 (continued)

c. Effective Volumes and Orifices During Explosive Decompression of Soft and Hard Space Suits by Seal Disruption

Critical Volumes	Apollo Soft Suit	Apollo Hard Suit
Total free volume of suit, PLSS, and hoses	28 liters	75 liters
Free volume of helmet	~2.5 liters	4.4 liters
Free volume in PLSS and hoses (2 hoses, 3/4" ID, and 2 1/2 feet and 6 feet long)	3.8 liters	3.8 liters
Free volume of suit below neck ring	22 liters	67 liters
Neck Seal		
Diameter of seal	9" ID	11.8" ID
X-area	411 cm^2	706 cm^2
Angle of elevation of seal	17°	40°
X-area of neck subtended by seal	116 cm^2	145 cm^2
Orifice at neck seal	295 cm^2	561 cm^2
Wrist Seal		
Diameter Seal	4" ID	3.87" ID
X-area of seal	81.4 cm^2	76 cm^2
X-area of wrist at seal	21.5 cm^2	21.5 cm^2
Orifice at wrist seal	60 cm^2	54 cm^2
Thigh Seal		(RX 4 and 5)
Diameter	-	7 7/8"
X-area seal	-	314 cm^2
X-area of lower thigh	-	137 cm^2
Orifice of thigh seal	-	177 cm^2

(After Roth[276])

Table 16-23 (continued)

c. Effective Volumes and Orifices During Explosive Decompression of Soft and Hard Space Suits by Seal Disruption (cont.)

	Apollo Soft Suit	Apollo Hard Suit
		(RX 3 and 4 only)
Ankle Seal		
Major axes of ellipse	-	5 9/16" and 7 5/32"
X-area of seal	-	207 cm^2
Ankle area (6 1/2" from ground)	-	39 cm^2
Orifice at ankle seal	-	168 cm^2
Waist Seal		
Diameter	-	16" ID
X-area of body seal	-	1300 cm^2
Area of abdomen (1" above umbilicus)	-	490 cm^2
Orifice at waist seal	-	810 cm^2
Fingers		
Diameter of glove finger	1" ID	1" ID
X-area of glove finger	5.1 cm^2	5.1 cm^2
X-section of finger (1/16" clearance)	3.9 cm^2	3.9 cm^2
Orifice at finger	1.2 cm^2	1.2 cm^2
Gas Umbilical Hose from Space Chamber		
Diameter	1 1/4"	1 1/4"
X-area	7.9 cm^2	7.9 cm^2
Gas Umbilicals from PLSS		
Diameter	3/4"	3/4"
X-area per hose	2.8 cm^2	2.8 cm^2

Table 16-23 (continued)

d. Summary of Mobility Table Analysis of 3 Prototype Apollo Soft Suits

Movement a.	Nude base-line, deg	Angles of excursion						Percent of motion: nude to vent and vent to 3.7 psig					
		Suit C		Suit A		Suit B		Suit C		Suit A		Suit B	
		Vent	3.7 psig	Vent	3.7 psig	Vent	3.7 psig	N to V (b)	V to P (c)	N to V (b)	V to P (c)	N to V (b)	V to P (c)
1. Forearm, supination-pronation	180	194	175	168	179	180	180	100	90	93	100	100	100
2. Wrist, flexion-extension	160	178	132	140	125	146	132	100	74	87.5	89	91	90
3. Hip, adduction-abduction	180	41	32	35	15	40	35	23	78	19.4	43	22	87.5
4. Hip, flexion-extension	120	90	40	80	65	70	62	75	45	67	81	58	89
5. Shoulder, flexion-extension	250	216	190	182	168	160	139	86.5	88	73	92	64	87
6. Shoulder, frontal plane, adduction-abduction	155	115	95	125	117	80	86	74	83	81	94	52	100
7. Shoulder rotation	160	170	204	185	165	164	150	100	100	100	89	100	91
8. Elbow, flexion-extension	150	167	106	162	150	145	127	100	63	100	93	97	88
9. Wrist-forearm, flexion-extension	120	125	112	105	89	98	105	100	90	87.5	85	82	100
10. Hip, rotation	133	130	101	125	106	126	78	98	78	94	85	95	62
11. Ankle, flexion-extension	78	79	82	70	56	68	70	100	100	90	80	87	100
12. Trunk, rotation	100	70		60		48		70		60		48	
13. Shoulder, transverse plane, adduction-abduction	193	168	121	112	102	118	132	87	72	58	91	61	100
14. Knee, flexion-extension	140	160	125	143	145	135	130	100	78	100	100	96.5	96
15. Foot, flexion	43	53						100					
16. Trunk-hip, flexion-extension	68	80		44		54		100		65		79	
17. Trunk-hip, lateral flexion	78	50		32		16		64		41		21	

[a]Seventeen movements are described in the paragraph entitled "Angular range study" in Ref.(185).
[b]Nude measures compared with vent measures.
[c]Vent measures compared with pressurized measures.

(After Jones[185])

Table 16-23 (continued)

e. Angular Data for Restriction of Pressurized Joint Mobility and Suit-Joint Interface of Three Prototype Soft Suits Relative to the Nude Condition

Movement	Suit C				Suit A				Suit B			
	Nude	3.7 psig	Diff.	Percent at 3.7 (a)	Nude	3.7 psig	Diff.	Percent at 3.7 (a)	Nude	3.7 psig	Diff.	Percent at 3.7 (a)
Wrist Adduction	37	24	13	64.8	34	34	0	100	30	24	6	80.0
Abduction[b]	40	48	-8	120	34	42	-8	123.5	35	30	5	85.6
Dorsiflexion	62	56	6	90.3	63	57	7	90.4	75	68	7	90.6
Palmar flexion	87	68	19	78	60	56	4	93.3	70	53	17	75.7
Elbow Flexion	152	122	30	80.2	153	137	16	89.5	151	122	29	80.8
Extension[c]	--	--	--	--	0	5	-5		7	11	-4	157.0
Shoulder Neutral lateral	0	-10	-10		-4	-7	3		-18			
Neutral (front view)	11	39	28	35.5	4	20	16			35		
Abduction	158	83	75	52.5	167	125	42	74.8	146	78	68	53.4
Flexion	163	92	61	56.4	189	136	53	71.9	145	63	82	43.4
Extension	66	65	1	98.4	83	47	36	56.6	59			
Hip Flexion	99	57	42	57.5	123	55	68	44.7	114	58	56	50.9
Knee Neutral position	-4	-2	2	50	-2	20	22		3	3	0	100
Flexion[c]	130	93	37	71.5	96	--	--	--	95	87	8	91.5

[a]Percent of motion retained in the pressurized state (percent of nude).

[b]This measure will be repeated at a later data.

[c]This measure is, as yet, incomplete.

(After Jones[185])

Table 16-23 (continued)

f. Mobility Ranges at 5 Psia Pressurization and Other Performance Data on the Apollo Hard Suit

These data represent the mobility ranges of each of the articulations provided by the Apollo Chamber Suit. These limits are achieved at torque levels under 2 ft-lbs. in every case.

Shoulder Mobility	% of Nude Range	Maximum Range
Adduction	73	35^{o}
Abduction	90	120^{o}
Lateral/Medial	89	108^{o}
Flexion	87	123^{o}
Extension	62	38^{o}
Rotation/Lateral	100	35^{o}
Medial	100	120^{o}
Waist Mobility		
Flexion	90	40^{o}
Side-to-Side	95	$\pm 15^{o}$
Hip Mobility		
Flexion	80	90^{o}
Extension	60	10^{o}
Abduction	38	20^{o}
Knee Mobility		
Flexion	88	140^{o}
Ankle Mobility		
Adduction/Abduction	85	$\pm 20^{o}$
Flexion/Extension	96	$\pm 35^{o}$
Elbow Mobility		
Flexion	85	120^{o}
Wrist Mobility		
Adduction/Abduction	81	$\pm 30^{o}$
Flexion/Extension	64	$\pm 60^{o}$
Rotary Motion	100	360^{o}

LEAK RATE. 30 ± 10 scc/min, unaffected by repeated donnings and doffings. OPERATING PRESSURE. Design operating pressure is 5 psia; however normal operation is assured within the 3.5-7.0 psia range accommodating an atmosphere, 100% oxygen...or mixed gases at the higher pressure. CENTER OF GRAVITY. The center of gravity of the suit complements that of the human occupant assuring stability throughout the entire mobility range. DON/DOFF CAPABILITY. Self donning and doffing can be accomplished within 60 second periods.

(After Litton Industries[206])

Table 16-23 (continued)

g. Barehand Sums Compared with Soft-Suited Raw Scores on the Purdue Pegboard Hand Dexterity Test

	Right hand		Left hand		Both hands		Sum of scores on all hands		Assembly	
	Score	Percent (a)	Score	Percent (a)	Score	Percent (a)	Score	Percent (a)	Score	Percent (a)
Barehanded (Optimal performance)	108	100	111	100	80	100	299	100	253	100
Vented										
Suit C	68	62.96	66	59.46	45.5	56.88	179.5	60.03	106	41.90
Suit B	76	70.37	78	70.27	52	65.00	206	68.90	133	52.57
Suit A	75	69.44	75	67.57	55	68.75	205	68.56	146	57.71
Pressurized										
Suit C	33	30.56	36	32.43	18	22.50	87	29.10	45	17.79
Suit B	49	45.37	49	44.14	32.5	40.63	130.5	43.65	79	31.23
Suit A	57	52.78	48	43.24	33.5	41.88	138.5	46.32	82	32.41

[a]Percent of performance retained.

The differences were analyzed by the Kruskal-Wallis one way analysis variance. Analysis of the four parts of the pegboard test indicated that the difference was significant at 0.01 level in all cases except in the left-hand and both-hands test sequences under the vented condition. The both-hands test was significant at the 0.05 level, and the left-hand test was significant at the 0.10 level.

(After Jones[185])

range of mission-related movements, this portion of the test received a highe weighting. In the final rating on general mobility, suit A placed first, suit C second, and suit B third.

For the strobe and cine sequences, suit A showed a clear superiority ove the other two suits for pressurized mobility, both with and without the TMG. The arm and shoulder mobility was particularly good; and the subject could hold his hands over his head, relaxing and allowing his arms to remain elevat without having to fight a severe torque to keep them there. Hip flexion was al particularly good, for the pressurized subject could raise his leg more than 1 to 20 inches without leaning back and swinging around sideways to carry out th maneuver as was necessary in the other two suits. A factor of considerable significance was the ease and smoothness of motion carried out with suit A during pressurized mobility. The other two suits did not allow this ease of motion. The mobility concepts manifested in suit A have the most developme impact. However, it would appear that an ankle joint would add much to walk-ing, and an improvement in wrist stability and mobility is certainly needed. I addition, a method of allowing torso-bending should be investigated. Another factor to be considered is the improvement in pressurized shoulder mobility brought about by the suit C TMG top. An increase of 54° in shoulder flexion-extension and an increase of 62° in shoulder rotation were noted when data we compared with the suit B TMG top. While there is a great deal of improveme to be made in the area of pressurized mobility in the TMG, it is noted that this concept has a great deal to offer, and it was recommended that further developmental study be carried out to improve the concept. Data are also available on the eye-heart angle in the pressurized state on contour couches (185). Data are available on the reach capabilities of prototype soft suits along all the complex planes (185).

Table 16-23 f gives the mobility restriction and other performance data for the Rx-3 hard suit.

Gloves and Boots

The intravehicular glove should be a conformal flexible envelope designed to promote hand dexterity, high tactile sensitivity, mobility, and free articulation of the hand and wrist when pressurized (270). Adequate restraint should be available to maintain normal curvature at the palm area, to prevent balooning and the resultant loss of hand mobility. The restraint elements utilized should be located such that the glove's lines of greatest articulation will closely correspond to the natural bending lines of the palm and the fingers. Mobility features and glove restraints should be compatible with dimensional changes in the hand, such as foreshortening of the palm and lengthening of the back of the hand for clenching; or changes in surface length due to differences in band radius, as in bending the wrist. The design of the glove must be such that when pressurized or unpressurized, it will allow the crewman to realize the mobility described in Table 16-20 without fatigue, strain or discomfort. The size, flexibility and materials of the glove should be such as to enable the wearer to perform all tasks required for spacecraft operations (295), and provide for the abrasion and scuffing which results from the use of the hand and fingers within the spacecraft. If possible, the intravehicular glove should incorporate a removable GFE fingertip lighting system for each glove. The fingertip lighting system should consist of light sources to be installed on the back tip of the index and second finger of each glove.

In the design of the pressure retaining extravehicular gloves provided for use with the PGA during all extravehicular operations, thermal and abrasion protection are foremost problems. The gloves should allow the wearer free articulation of the hand for motions described in Table 16-20 and should not restrict the crewman's dexterity or tactility in performing emergency and maintenance tasks, in manipulating intravehicular and extravehicular task equipment,and in performing the tasks proposed (181, 295, 372). Especially important is facility in operation of PLSS controls during normal and emergency operation. (See Table 16-21). The gloves and fasteners used for attaching the PLSS to the PGA should be designed such that they can be fastened or unfastened with one hand.

Thermal limits for finger pain in glove design have been covered in Thermal (No. 6).

Glove and boot design in the Gemini extravehicular program has been recently reviewed (217). Hand dexterity data are available on the Apollo soft-suit prototypes. The Purdue Pegboard Test was administered to the suited test subject in the vented and pressurized (3.7 psig) suit conditions. During two sessions of testing, six trials per suit were given for each of the two suit conditions. The test conductor turned the pegboard 180° for all trials so that wrist and finger mobility, rather than arm-reach mobility, was the influential factor. The subject was also given six trials of the test while he was bare-handed, and these data were considered to represent optimal performance.

Table 16-23g shows a comparison between barehand (optimal = 100 percent) performance and the performance retained with each suit under each condition. The fourth column of this table is the combined score of the three preceding test sequences in which only pins were used. This comparison shows clear differences in the performances of the three suits.

Ratings placed suit A in first place, suit B in second, and suit C in third. Suit C allowed considerably less wrist and finger dexterity than either of the other suits. The reduction in dexterity from the barehand level, a reduction applying to all the suits, had several causes. Fingertip lights were detrimenta expecially in suit C. Also, the gloves of suit C were the thickest and most cumbersome. On this suit, the wire fingernails in the thumb of the left glove came loose and interfered with test performance, and the gloves cut the subject's knuckles. Since fingertip lights interfered with hand dexterity, it was recommended that the placement of these lights be improved. The concept of fingernails on the gloves appears worthy and should be developed further, but definite improvement is necessary because the fingernails on the gloves of suit C became bent and actually interfered with dexterity. Another factor needing further development is the thickness of the material encasing the fingers. The thin material used in the gloves of suits A and B showed definite advantages over the thick material in the fingers of suit C.

Placement of the palm-restraint device should be optimized in order to allow the hand to bend below the knuckles. If the restraint device is too high and near the fingers, the subject is unable to grasp and can only flex the upper part of the fingers. Wrist stability should also be improved in all gloves, expecially in the gloves of suits A and C.

All of the gloves produced pressure points at the base of the thumb and on top of the hand. These pressure points brought about excessive tiring of the hand and forearm, and induced cramping in the thumb and forearm. Consequently, considerable developmental work is needed to improve the gloves, because none of these gloves would meet the multiplicity of requirements involved in long-term pressurized wear.

Optimum design of footwear for lunar and planetary operations is now under study. (See Ref. 10-2111 for review of soil factors.)

Helmet and Visors

The optical aspects of helmet and visor design have been covered in Light (No. 2). Anthropomorphic factors must also be considered. Data on the Gemini helmet and visor systems are available (217, 231). The following are recommendations made for the Apollo program (336). The crewman should be able to see all PGA components which require visual aid for connectic and/or adjustment, particularly downward to a point on the front torso centerline six (6) inches below the neck ring. With the crewman standing and nodding in an erect PGA, he should be able to see the toes of his boots. The vertical field of vision of a crewman in a pressurized PGA and secured to the CM couch must not be reduced by fault of the helmet, upward or downward, when the crewman is subjected to a sustained acceleration of $+10G_x$, eyeballs in. Unrestricted range of vision should be as follows:

Horizontal Plane:	120° left, 120° right
Vertical Plane:	105° down, 90° up

With the head moved forward, eye relief for the primary pressure retention visor should be 2.06 inches. This eye relief must apply over a vertical range from 45° up to 10° down.

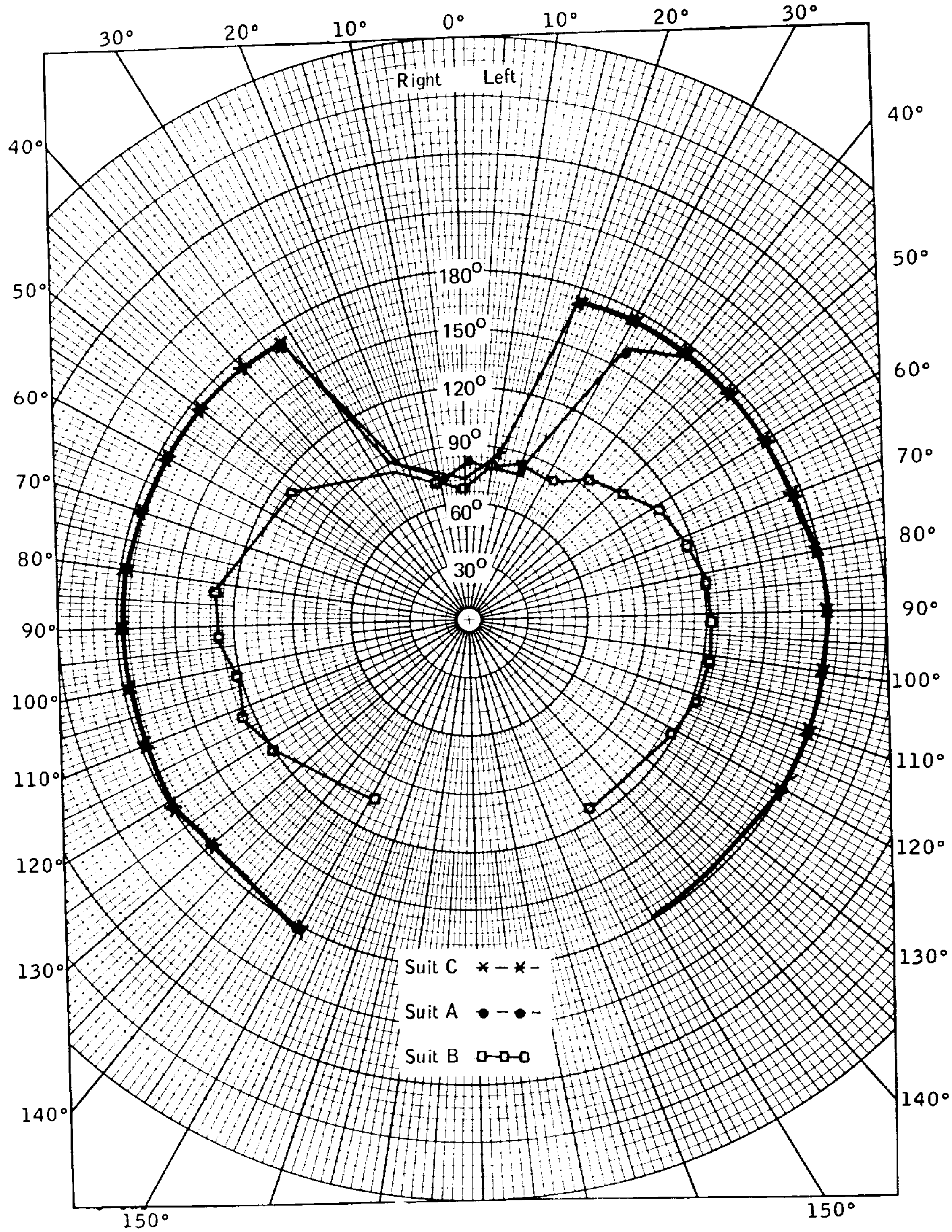
Table 16-24 covers the visual field capability of several prototype Apollo suits (185). In positioning the subject and the helmet in relation to the optical perimeter, the test helmet was rotated on the neck ring to aline the helmet center mark with the neck ring center mark; the subject's head was then positioned inside the helmet to aline the longitudinal center line of the head with the helmet and center marks of the neck ring. The complete system (head and helmet) was then positioned with the center of the subject's eye pupil normal to both the 90° and the 0° positions on the optical perimeter; and the helmet neck ring angle with the horizontal,positioned according to manufacturer's specifications. After completing this zeroing procedure, the helmet was secured in this zero position. During the test, the subject was allowed complete freedom of movement in the helmet, since the objective of the test was to ascertain the visual-field capabilities of each helmet as opposed to the subject's visual-field capabilities. Subsequent to the test, the subject was instructed to indicate the point at which he could no longer see the target as it was moved on the perimeter arm of 29 inch radius from directly in front (0°) to directly behind (180°). This procedure was followed for each angular increment of the perimeter arm, with four readings taken at each increment. The target was a disc one cm in diameter. Two additional measures were used to determine the downward and upward "operational" visual capabilities of each suit. These measures were taken with the subject standing and zeroed under the perimeter. To determine upward visual capabilities, the subject was instructed to follow the target on the perimeter arm as it was moved directly over him (the subject was allowed to bend his torso). To determine downward visual capabilities, the same test configuration was used; that is, the subject was standing and zeroed under the perimeter, but was allowed to bend his torso. The subject was instructed to indicate the highest point on his suit that he could see. A line from this point on the suit through the center of the eye pupil to the perimeter arm was then constructed to determine the downward visual angle measured from the horizontal. All of the above measures were taken under two conditions, pressurized (3.7 psig) and vented. To control test-subject variability, the same test subject was used throughout the visual-field test.

The mean value of the four trials for each angular increment of the perimeter was computed and plotted as shown in Figures 16-24 a and b. Table 16-24c shows the restriction under the "operational test and percent of specifications (see above and p 2-79 in Light No. 2). Upward visual-field restrictions

Figure 16-24

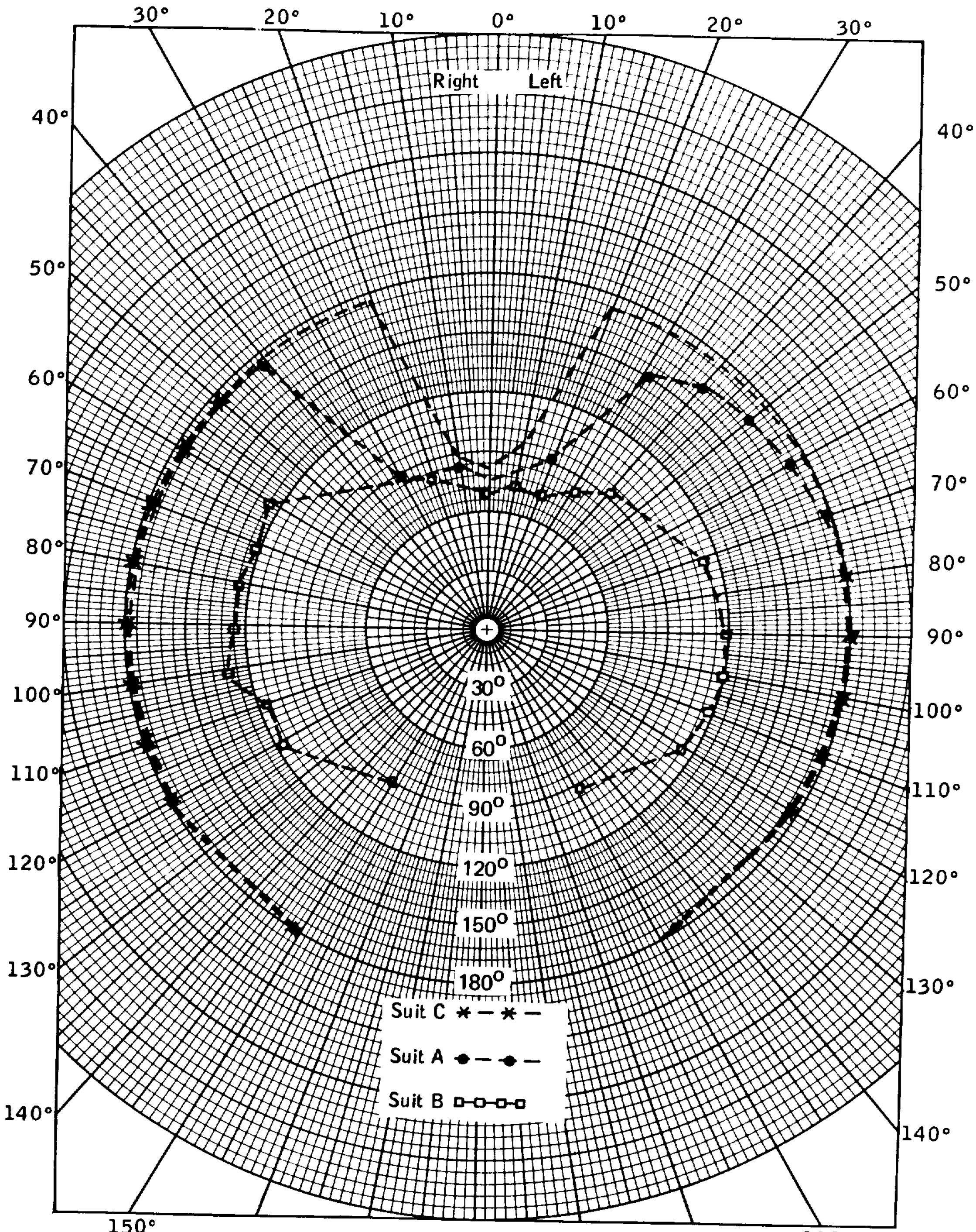
Dynamic Visual Fields within Soft-Suit Helmets

(After Jones[185])



a. Visual-Field Capability of 3 Prototype Soft Suits, Pressurized Condition (Torso bending not allowed - See text)

Figure 16-24 (continued)



b. Visual-Field Capability of 3 Prototype Soft Suits, Vented Condition (Torso bending not allowed - See text)

Figure 16-24 (continued)

c. Suit Visual Capabilities - Up, Down, and Lateral Under "Operational" Conditions (Torso bending allowed)

	Suit B, visual angle, degrees	Percent of specification (a)	Suit C, visual angle, degrees	Percent of specification (a)	Suit A, visual angle, degrees	Percent of specification (a)
Vented, UP,[b] 3.7 psig	120	133	118	131	140	155
	110	122	115	127	105	116
Vented, DOWN,[b] 3.7 psig	96	91	95	90	97	92
	91	87	95	90	95	90
Vented, LATERAL, 3.7 psig	245.8	102	360	150	355	148
	249.1	104	360	150	355	148

[a]Specification: Up 90°; Down 105°; Lateral 240°.

[b]Operational measurements. (See text for details.)

in both suit A and suit C are intensified because the helmet of each suit is positioned in front of the suit longitudinal center line. This position limits the upward visual capabilities because ventrodorsal (backward) movement of the subject's head is restricted in each helmet. This helmet configuration also increases the eye-heart angle of both suit A and suit C. Suit A is superior in downward and upward visual capabilities, when the pressurized and vented conditions are considered as a single unit of interest rather than being considered separately. Operationally, this is a valid conclusion. It should be noted, however, that insofar as operational downward vision is concerned, each suit possesses the capability for the subject to see his respective gas connectors. Left visual-field restrictions for the suit A helmet are due to asymmetry of the helmet exterior painting rather than to any structural defect. It was recommended that the helmet of suit A be repositioned to a configuration more congruent with suit centering, thereby eliminating downward visual and eye-heart angle disadvantages. It was also recommended that the possibilities of a totally transparent helmet shell be explored to allow maximum visual field.

In the final rating, suit A rated first, suit C second, and suit B third. Under static and operational conditions, suit A provided evidence of superior visual-field capabilities. It should be pointed out that there was little difference between suit A and suit C, but there was a significant difference between these two suits and suit B which rated third.

CONFINEMENT, ISOLATION AND SENSORY DEPRIVATION

The confinement, social isolation and sensory deprivation factors are to be considered in space operations (99, 109, 236, 313, 326). The semantic problem may be dissected by the following classification (108):

Confinement

a) Physical
  - i) Restrictive
  - ii) Determinative

Isolation

a) Social
  - i) Solitude
    - A. Single
    - B. Group
  - ii) Rejection
    - A. Single
    - B. Group

b) Sensory-Perceptual
  - i) Sensory and perceptual reduction
  - ii) Sensory and perceptual distortion

Confinement may be physical, temporal, or both. Physical confinement may be restrictive, in the form of physical restraint, or determinative in that the subject is free to move within his confines. Temporal confinement may be restrictive if the subject is forcibly limited in his activities for an imposed time, or determinative if he has to accomplish some achievement within an independently determined time. Social isolation involves isolation of individuals or small groups. It may be found in the presence of full sensory stimulation. Rarely, if ever, do confinement and isolation exist as single entities. Sensory or perceptual isolation, which involves essentially disturbances of perception, may arise from sensory reduction, or be associated with sensory distortion. It also may arise when stimuli do not provide adequate pattern information. Sensation may be present without perception. These are usually related to forced individual isolation.

It should be emphasized that there has been relatively little research in this general area. Much of the written material comprises reviews of a few basic experiments. The data in this section must be used with great caution.

Confinement

Confinement may be defined as a physical and temporal limitation on the activities and translational motions of an individual or group, occasioned by constraint, and sometimes associated with elements of perceptual and social isolation (11, 108, 230). The following section is taken directly from a recent review (108).

Along with many other modulating factors the response of the individual to confinement is primarily dependent upon the stress imposed by closeness of confinement, the extent of restriction, and the duration (11, 350). The initial response is one of general physiological activation, with an increased heart rate, respiratory rate, and blood pressure. Excretion of ketosteroids and catecholamines tends to increase, while evidence of increased autonomic activation is given by a decrease in skin resistance, or increased skin conductance. These findings suggest a non-specific response to stress. Within about 3 to 7 days a new threshold is established and physiologic activity begins to recede to preconfinement level or below, although the pattern can be reactivated by emergencies. Continuation of the confinement, with reduced mobility and limited exercise, gives rise to signs of physical deconditioning, manifest particularly in the cardiovascular system, in musculoskeletal deconditioning, in fluid balance, and in hemopoietic system (45). These mimic the response to weightlessness (108). (See also zero gravity environment in Acceleration (No. 7)).

In a well-motivated, trained individual, if habitability is close to acceptable, there may well be no overt psychological effects; and even a covert response, as judged by interview, diaries, and measurement techniques, may be negligible (108). The occurrence of aberrant subjective and behavioral reactions, in particular, is to a considerable extent influenced by training, motivation, and experience. When manifest, they may occur in the form of overt or covert resentment, hostility, and frustration, directed in the case of the single confinee, at the environment itself, or at the unseen investigators or remote controllers (11, 108, 137, 158, 325, 361). Among multiple confinees, it is apparent that maintenance of good interpersonal relations can be considered of major significance. Among two-man crews in close proximity, considerable irritation can develop from the repetition of seemingly innocuous habits, inadequacies of personal hygiene, or divisions of labor, while three-man groups may be even more unstable, since any two can unite against the third. With multi-man groups the formation of cliques can become a real possibility. Personal space factors are important correlates of social emotional states for humans as well as for other animals (51, 207). Territoriality needs are known to be important to a very wide phylogenetic range of animal forms, including man. In the confined group, territoriality preferences may be difficult to satisfy (158). It has, nevertheless, been clearly and repeatedly shown that with careful selection, common motivation and wise leadership, crews can unite to minimize difficulty and ensure the success of a mission, although covert hostilities may be revealed later (289). However, details of this situation and training are still research questions.

Physical discomfort in terrestrial conditions can be severe. The discomfort, however, is more a function of immobility than confinement, as has been demonstrated in conditions where the same free volume per man is available, but in the one case the subjects are restricted, and in the other they have space-sharing mobility. Furthermore, since the discomfort is largely associated with the development of pressure points from the gravitational vector, it has not been a major feature of actual space operation.

The occurrence of perceptual aberrations, in the form of illusions and hallucinations, has been widely disseminated in the anecdotal and experimental literature. It is apparent, however, that this phenomenon is primarily associated with isolation and not with confinement (308). In fact where two individuals are simultaneously confined it is rarely recorded, and never with three or more. The occurrence of perceptual aberrations is, in fact, a feature of reduced or distorted sensory input, and does not take place in the presence of good consensual validation. Numerous studies have been undertaken to examine such capacities as constructive thinking capability, memory, problem solving, performance skils, etc. under conditions of confinement (108). It is characteristic of the findings that while impairment may occur under conditions of isolation and reduced sensory input,there is little or no interference with intellectual function and performance capacity in confinement,per se, unless the demands of the tasks are inappropriate, or unless the confinement is extreme, or is accompanied by very adverse environmental conditions of heat, humidity, noise, etc.

Sixty studies of confinement under terrestrial and space conditions have been compared in Table 16-25a and the relation of symptoms to the volume and duration,plotted in Figure 16-25b. Classification is on a three point scale according to the amount of impairment observed, namely: no impairment (grade 1), detectable impairment (grade 2), and marked impairment (grade 3). Marked impairment was considered to be manifest psychophysiological change which migh prejudice the safety or successful outcome of a mission. Detectable impairment was considered to be present in a situation which was tolerable, but was accompanied by measurable evidence of disturbance which could reduce proficiency. The classification of no impairment included those situations where some disturbance of homeostasis or comfort might have existed without loss of proficiency. It is considered that a classification scheme of this nature even though it makes use of widely different criteria for volumes and responses and is of a subjective nature, provides distinctions sufficiently obvious as to permit unobjectionable grading (108).

Three impairment zones can be defined in terms of duration and volume as indicated by the broad demarcation lines. The upper line defines a threshold of minimum volume per man which will be acceptable in most circumstances, even when modifying factors are not optimum. The lower line defines a threshold which will be unacceptable in most circumstances even if modifying factors are optimum. Between lies a zone where acceptability depends to some degree on optimum habitability, and personal factors. Extrapolation of the two lines suggests a junction at about 60 days at a volume which may represent the minimum acceptable for prolonged durations. The further direction of the curves is not known at this time, but it is interesting to note that Soviet work suggests that there is a resurgence of stress phenomena at about 60 days, in which case the threshold curve may again rise (108, 202). It is considered that the impairment which was demonstrated in the "Hope" studies resulted from the rigors of demanding work schedules, and not from confinement per se (5, 6). The marked impairment in the 152 days of confinement in the University of Maryland study is believed to be due to the nature of the programmed environment, publicity etc., and not to the confinement which, in fact, was minimal (97). The third and most significant exception is found in the Gemini series of flights. Since these were successful, the impairment cannot be classified as a grade three. Nevertheless, despite enthusiastic reports, considerable impairment did exist, particularly in the Gemini VII mission, as manifested by post-flight testing. In fact, it is probable that only the dedicated motivation and discipline of the crews, along with the added benefits of space sharing, made the missions as successful as they were.

Key factors altering the curve are motivation, discipline, and experience. The habitability of the confined chamber both with respect to environmental

Table 16-25

Confinement Studies on Humans

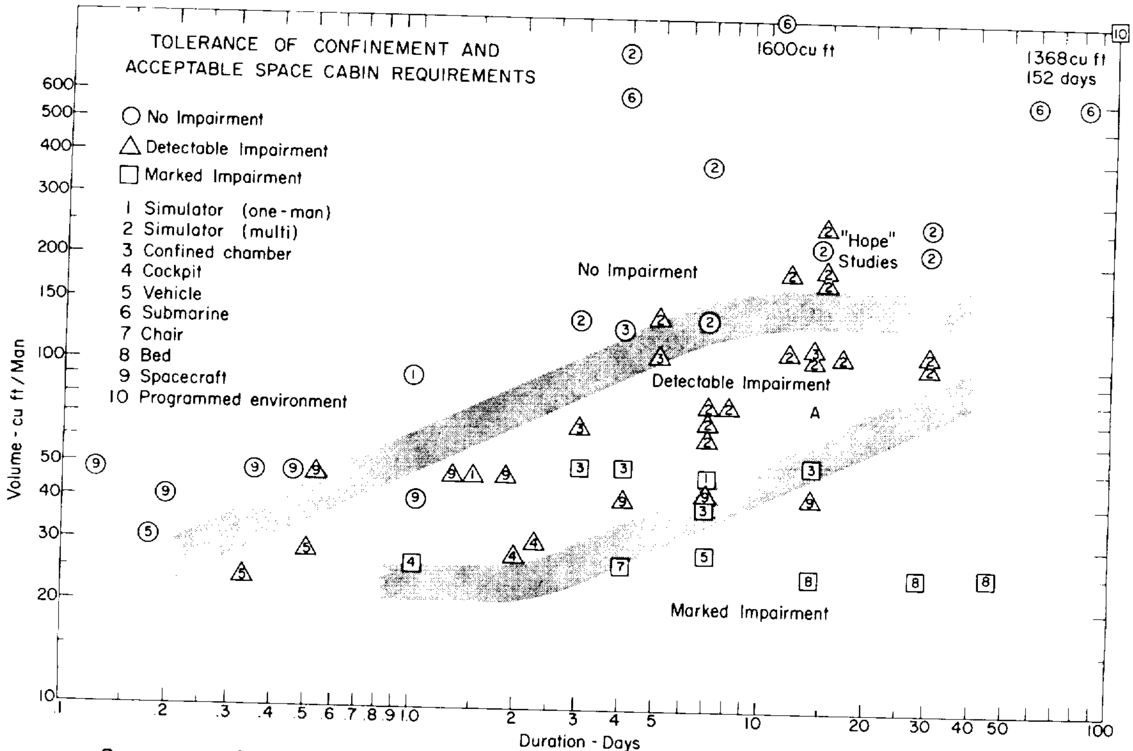
a. Extent of Impairment Resulting from Confinement (See text for details)

Type of Study	Operational Conditions	Volume per man (cu. ft.)	Duration (days)	Impairment Psych	Impairment Physio	References
Simulator Single	SAM one-man	47	7	3	2	AF-SAM-59-101, 1959
	SAM one-man	47	1½	2	1	AF-SAM-60-80, 1960
	Vostok one-man	90	?1	1	1	FTD-TT-62-1619, 1962
Simulator Multi	Lockheed-Georgia OPN-360	183-250	15	2	2	WADD-TR-60-248, 1960
	HOPE II	187	15	2	2	WADD-AMRL-TDR-63-87, 1963
	HOPE III	110	30	2	2	WADD-AMRL-TDR-63-87, 1963
	HOPE IV & V	110	12	2	2	WADD-AMRL-TDR-64-63, 1964
	HOPE VI & VII	187	12	2	2	WADD-AMRL-TDR-64-63, 1964
	Navy ACEL	75	7	2	2	NAMC-ACEL-383, 1958
	Navy ACEL	75	8	2	2	NAMC-ACEL-413, 1959
	N. A. A. conical	67	7	2	2	IAS Meeting, Los Angeles, 1962
	N. A. A. cylindrical	375	7	1	1	AIAA and ASMA Conf., L. A., 1963
	N. A. A. disc	800	4	1	1	AIAA and ASMA Conf., L. A., 1963
	SAM two-man	106	14	2	2	Aerospace Med., 30:722, 1959
	SAM two-man	106	17	2	2	Aerospace Med., 32:603, 1961
	SAM two-man	106	30	2	2	SAM-TDR-63-27, 1963
	Republic	211	14	1	1	RAC-393-1, 1962
	Douglas	250	30	1	1	ASME Conf., Los Angeles, 1965
	GE	215	30	1	1	GE Doc. 64-SD-679, 1964
	Martin Baltimore	133	3	1	1	MAR-ER-12693, 1962
	Martin Baltimore	133	7	1	1	IAS-63-18, 1963
	NASA Ames	61.5	7	2	2	NASA-TN-D-2065, 1964
	WADC long range	140	5	2	2	Aerospace Med., 30:599, 1959
Confined Chamber	U. of Maryland (Single)	1368	152	3	3	Univ. of Maryland, 1963
	U. of Georgia (Multi)	65	3	2	2	GEOU 226-FR, 1963
	U. of Georgia "	52	3	3	2	GEOU 226-FR, 1963
	U. of Georgia "	52	4	3	2	GEOU 226-FR, 1963
	U. of Georgia "	52	14	3	2	GEOU 226-FR, 1963
	U. of Georgia "	39	7	3	2	GEOU 226-FR, 1963
	USNRDL "	117	14	2	2	USNRDL-TR-418, 1960
	USNRDL "	117	5	2	2	USNRDL-TR-502, 1961
	Lockheed-Georgia (Multi)	125	4	1	1	WADD-TR-60-248, 1960
	"Coffin" (Single)	28	7	3	3	Science, 140:306, 1963
Cockpit	F-84	<30	2 1/3	2	2	WADD-TR-55-395, 1955
	WADD capsule	27.5	2	2	1	WADD-ASD-TR-61-577, 1961
Vehicle	APC M59	30	1/6	1	1	AHEL-TM-3-60, 1960
	APC M113	23.3	1/3	2	2	AHEL-TM-17-60, 1960
	APC M113	28	1/2	2	2	AHEL-TM-1-61, 1961
	APC M113	25.5	1	3	?	AHEL-TM-23-61, 1961
	APC M113	25.5	1	3	3	AHEL-TM-7-62, 1962
Submarine	Nautilus	1600	11	1	1	USN Med. Res. Lab. Rept. 281, 1957
	Seawolf	570	60	1	1	USN Med. Res. Lab Rept. 358, 1961
	Nautilus	570	4	1	1	USAF Med. J., 10:451, 1959
	Triton	570	83	1	1	"Unusual Environments and "Human Behavior" 1963
Chair	SAM	< 25	4	1	3	Aerospace Med., 35: 646, 1964
Bed	Lankenau	< 25	45	1	3	WADD-AMRL-TDR-63-37, 1963
	SAM	< 25	28	1	3	Aerospace Med., 12:1194, 1964
	SAM	< 25	14	1	3	Aerospace Med., 35:931, 1964
Spacecraft	MA-6	47	1/3	1	1	NASA Doc 398, 1962
	MA-7, 8	47	1/2	1	2	NASA SP-6, 1962
	MA-9	47	1 1/2	1	2	NASA SP-45, 1963
	Vostok I	90	1/2	1	1	FTD-TT-62-1619, 1962
	Vostok II	90	>1	1	2	FTD-TT-62-1619, 1962
	Gemini III	40	1/5	1	1	Gemini Mid-Program Conf. Proceedings, Part 1 & 2 MSC, Houston, Texas, 1966
	Gemini IV	40	4	1	2	
	Gemini V	40	8	1	2	
	Gemini VI	40	1	1	1	
	Gemini VII	40	14	1	2	

(After Fraser[107])

Table 16-25 (continued)

b. Free Volume-Duration Tolerance Factors in Confinement



a. Summary of experimental data.

(After Fraser[108])

c. 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

(After Fraser[109])

factors such as atmospheric pressure and composition, heat, humidity, and noise, and with respect to hygiene, dietetic, recreational, and work facilities, is another factor. The nature of the actual activities and tasks demanded is also a significant factor, particularly the meaningfulness, and the degree of complexity. The requirement for realism and/or relevance in simulated tasks is also significant, in order to prevent disinterest. Knowledge of the expected duration of confinement is still another factor which affects tolerance not only subjectively, but objectively, in that a characteristic rise in morale and activity can be shown to occur at the midpoint of a known period, and again a day or so before the end. A most significant factor concerns physical fitness and exercise There is no doubt that in terrestrial confinement, adequate exercise and mobility not only prevent deconditioning, but improve morale, and may even be associate with improved task performance. How much is adequate, however, is not clear and furthermore it must be remembered that weightlessness and immobility may well be synergistic in their causative relation to physical deconditioning. A final modifying factor relates to the number of confinees. As already noted, an increase in the number of confinees reduces some and creates other problems. At the same time it allows the possibilities of space-sharing, which effectively increases the available free-volume per men.

Disregarding cultural and other variables which may alter these thresholds Figure 16-25b indicates that for durations of 7 to 30 days, for small group crews, about 125-150 cubic feet per man of free space would be the minimum acceptable volume (134 - 138). Acceptability could be still further improved by promoting optimum habitability and working conditions (see below). Marked impairment would be expected with a free volume per man of less than 40 cubic feet for 7 days, or less than 85 cubic feet per man for 30 days.

For missions of months and years duration the critical volume factor is not as clear (109). (See Figure 16-26). An additive model of crew space for long duration missions includes the following (36):

Volume = (Seated volume per man + work volume per man + ingress volume per man) x (Number of men)

+ Transfer volume per station

+ Intercompartmental transfer volume

+ Rest volume per crew off duty

+ Sustenance volume per crew

+ Logistics work space or equipment station

+ Equipment and storage volume for sustenance

+ Volume for waste

From anthropometric and other data, adequacy was defined as a minimum volume of 50 cubic feet per man (multiman) for 2 days, 260 cubic feet per man for one or two months, and 600 cubic feet per man for many months in Figure 16-26, Reference (36). Another approach using these criteria with an

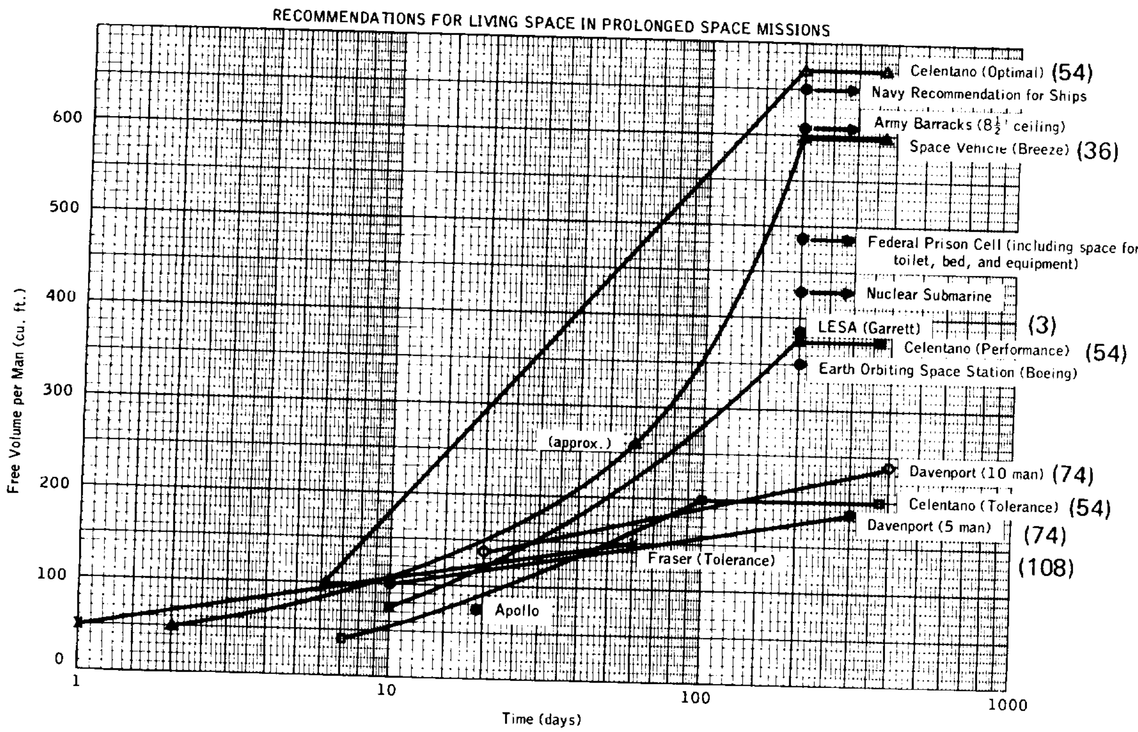


Figure 16-26

Recommendations for Living Space in Prolonged Space Missions

(See text)

(After Fraser (109))

adjustment for the debatable fact that an increased volume per man becomes necessary with increase in the number of crew, is also presented for 5 and 10 man crews in Figure 16-26, Reference (74).

Others have argued and shown in simulator studies that the occupants of a cabin allowing a large area, and other habitable features, would show little if any physiological differences from those in a normal life situation with a relatively sedentary occupation, such as that of an office worker (54). This study resulted in the curve of tolerability, the curves of acceptable performance, and the curve of optimal habitability shown in Figure 16-26. While the tolerance curve falls in line with other suggestions (74, 109), and may well represent minimal acceptability, there is some doubt as to whether the other two curves actually demarcate volumes for adequate and optimal habitability with the degree of accuracy implied. At the same time, the fact that free volumes found in certain operational situations, such as Army barrack allowances, Federal Prison allowances, and nuclear submarine allotments, lie within that range, suggests that the curves (54) are reasonable approximations. The data for Army barracks, prison, and nuclear submarines (11) are shown at the 200 day level for convenience. The arrows alongside indicate that the volumes designated may be occupied for longer periods.

Some other recommended volumes are also found to lie in the range suggested by Figure 16-26 (3, 235). On the basis of requirements for Arctic expeditions, a free volume of as much as 2000 cubic feet per man has been suggested for multiman operations (57). A volume of this size appears unnecessarily large and luxurious for space vehicle conditions.

Although the volume requirements per man cannot be specified with any degree of authority, it would seem that for durations of 300-400 days, or perhaps beyond, the absolute minimal acceptable volume for multiman operations would be in the region of 200-250 cubic feet per man; the acceptable would be about 350-400 cubic feet; and the optimal,about 600-700 cubic feet, utilizing the volume for all purposes related to living conditions. To maximize habitability for long-duration missions, it has been suggested that design requirements should be based on the optimal level of 600-700 cubic feet per man (109)

The mode of utilization and configuration of available space can be examine from different points of view, but several ground rules can be assumed. Thus, space must be provided for conduct of tasks relating to the mission, to vehicle management, and psychophysiological support. Space is also required for rest and off-duty time, for dining and food management, and for hygienic provisions Under some circumstances, minimum hygienic facilities can be tolerated for long periods of time (296). Therefore, it is convenient to think of configuratio in terms of functional units relating to these activities, although it should be realized that functional units are not necessarily topographical units. In other words, the volume allocated to one unit need not necessarily be located in one region of a vehicle. Except by invoking tradition, custom, and usage, it is difficult to justify logically the need for separating available volume into distinct regions, nor is it easy to determine how many such regions there should be. There is no doubt that highly motivated individuals, such as astronauts, can work, eat, rest, and sleep for days without leaving their seats, and still maintain acceptable performance. At the same time, various studies of habitable conditions (92, 109, 144, 368) have emphasized the need for variety, change, relief of monotony, and perhaps most of all, the desire to protect some modicum of voluntary privacy and storage of personal possessions.

It has been suggested that four functional units might therefore be delineate namely:

Work unit: for the conduct of operational tasks, vehicle management, and psychophysiological support.

Public unit: for use in dining, food management, communal recreation, leisure, and exercise.

Personal unit: for sleeping, personal privacy, and personal storage.

Service unit: for toilet purposes, laundry, and public storage.

Several studies of the partition of this space for long duration mission have suggested the relative volumes of available space which might be occupied by each functional unit as follows (3, 74, 109):

Work unit:	40%
Public unit:	25%
Personal unit:	20%
Service unit:	15%

It is emphasized that these suggested proportions are approximate and tentative and represent merely a relative breakdown of available volume under what might be considered optimal conditions. In each case the actual proportions would be influenced by the requirements of the mission and the capacities of the vehicle and dwelling, and would need to be determined empirically by analysis of the requirements and the use of models and mock-ups.

Social Isolation (158)

Social isolation represents a separate source of potential difficulty in confined environments (6, 7, 8, 11, 34, 44, 49, 109, 135, 137, 155, 156 157, 159, 160, 168, 240, 357, 360, 368). Confinement, however, is not a necessary component of social isolation (134, 305). Man is a social animal, highly dependent on other men in a variety of ways. The human personality typically includes a variety of social needs such as dominance and affiliation that can only be satisfied in interaction with other people. In a small isolated group, these needs are more likely to be frustrated than in a normal social situation where a wider variety of other people can be found (134, 135, 138, 158, 159, 361,). The small, isolated group also provides its members with fewer opportunities to make social comparisons, a process thought to be important in the development and maintenance of stable, accurate self evaluations. Men use social comparisons for testing the validity of their own performance, and the appropriateness of their own emotional reactions (15, 182). Both social need satisfactions and opportunities for social reality testing can be severely impaired in a small, isolated group. This can result in a heightened sense of frustration, decreased accuracy and stability of self concepts, and development inappropriate, invalid group norms that may be at variance with or irrelevant to the group's initial primary mission.

Another aspect of being confined with a relatively few other people is the degree to which it accelerates the social acquaintance or social penetration process. Anecdotal reports suggest that certain people in such situations use each other as significant sources of stimuli to a greater degree than is normal, and get to know the intimate details of each other's lives very thoroughly. The rate at which intimate information about each other is acquired, however, may exceed the rate at which individuals can learn to accept individual idiosyncaracies or markedly different value systems (158). The theory of social balance holds that tensions are created between individuals when they have different attitudes or oral opinions about a third person, object, or set of objects. The more central these attitudes and opinions are to the personalities involved, the greater amount of tension social imbalance will create. In the normal course of social existence, men avoid intimate contact with others whose value systems are markedly different. In the confined group, such avoidance may be impossible.

The accumulation and escalation of interpersonal tensions generated by lack of social need-satisfactions and social imbalance makes interpersonal conflict in confined groups a more difficult problem to manage than it normally would be. Lack of privacy, inability to establish and maintain territorial ownership, inability to find convenient scapegoats outside the group for displaced aggression, and restricted opportunities for releasing tension through muscular activity all may contribute to evermounting interpersonal hostility. Pairs of men hypothetically incompatible with regard to people showed a high degree of territoriality behavior, whereas incompatibility with regard to non-people-oriented considerations, such as dogmatism and need achievement, did not particularly produce territoriality (318). Incompatibility with regard to egocentric frames of reference, such as dominance needs and dogmatism, produced a high rate of "together activity"--largely argumentive in nature--while incompatibility on sociocentric frames of reference such as needs for affiliation and achievement generated a tendency towards social withdrawal--more alone than together activity.

Even though reporting higher levels of subjective stress, isolated pairs of subjects tend to perform better on group task than do unconfined controls (158) This appears to be due to the performance enhancement value of moderate levels of stress in isolation (96). A high rate of test mission aborts, can be generated by simply reducing the variety of tasks required of subjects and increasing their expectations regarding duration of confinement from unspecified to time-limited exposures (158). The stresses of stimulus reduction isolation, and confinement can be considerably relieved by stimulus enrichment procedures, increased communication with the outside world, and careful attention to group composition considerations (158, 159). It is clear from anecdotal literature that small groups of men can survive four months of social isolation and confinement. Longer periods of time are considerably more doubtful. More thought and research needs to be given to these aspects of man in a closed system for prolonged periods of time (182, 304). Model building and computer simulation of the problems is continuing (119, 273). Selection of group members and leadership criteria are also under study (134, 135, 138, 139, 219, 255, 264, 284, 285, 286, 287, 288, 289, 322).

Sensory and Perceptual Deprivation

Exposure to this condition may be expected in space operations most often when other members of a crew are dead or lost and the lone survivor is cut off from communication with earth. However, monotonous confinement of groups can result in problems in this sphere. Stimulus reduction or comparative monotony is not necessarily associated with confinement (301). It is now generally recognized that man needs a minimum level of stimulus variety below which somewhat bizarre, maladaptive behavior and subjective experiences are reported (13, 44, 67, 110, 158, 167, 191, 196, 203, 210, 228, 250, 308, 316, 348, 349, 375, 377, 378, 380). These may include a tendency to withdraw into ones self, intense fears of losing ones rationality, hallucinatory behavior, decrements in certain perceptual and cognitive functions, increased need for stimulus inputs of almost any nature, and changes in sensory acuity, generally in the direction of heightened tactile and auditory sensitivity. Darkness or monotonous, diffuse light patterns of low intensity predispose to the hallicinating behavior (110) Marked reduction in frequency of EEG alpha-rhythms have been seen as possibly indicative of a central nervous system change (312, 348, 349, 376, 379). Significantly, the EEG does not return to normal for several days following a two week period of sensory deprivation. These results have been reported from studies of sensory and/or perceptual deprivation, but such data as are available suggest that similar phenomena perhaps to a less intense degree occur in group confinement situations involvng a relatively monotonous existence even though not stimulus-deprived in the raditional sense (158, 174, 301). Internal time consciousness is altered by such conditions (101, 220, 314), but exposure of more than 3 hours is probably required (283).

A great deal of attention should be given to developing a habitable living arrangement, in particular with private areas affording relief from constant nteraction with other crew members (108, 109) (see also page 16-76). Provisions should be made for both active and passive types of recreation (109). It is also mportant that optimum amounts of communication with Earth be provided, to ninimize the sense of isolation, but avoid excessive communication. One nust avoid aggravating conflicts which often arise from interaction between solated group and "external controllers" (325).

The possibility of giving the men experience in the situation of confinement, ocial isolation and sensory deprivation for training purposes should be mandaory (255). If handled properly, this would give the men a chance to experience ome of the frustrations inherent in these situations, some of the behaviors hat may appear in themselves and others, and to practice ways of handling hem. Such experiences, perhaps repeated several times, with an opportunity or discussions intervening, could provide the means for effectively handling uch occurrences as they arise during the mission itself. Giving the astronauts uch experiences is in accordance with the current philosophy of their training rogram, in that emphasis has been placed upon their experiencing, in as reat a degree of realism as possible, all anticipated situations of space flight rior to their undertaking the mission itself. Experience with detailed simulaion of a lunar mission is available (124, 125, 126, 127). These may be ised as models of operational study of crew interaction and efficiency. However, a problem arises regarding how much simulation would be required for onger missions of many months (109). A compromise that seems attractive would e to prepare a series of films showing groups of men in laboratory situations f confinement, demonstrating examples of boredom, aggression and conflict, oth overt and covert, and the methods, good and bad, used by the personnel o deal with these events (100). This could then constitute a basis for roundable discussions by the astronauts, along the lines of evaluating how likely t would be that such situations would arise in space flight, how effectively the ituations were dealt with by the personnel in the films, and what methods night be more effective in space flight.

A general review of problem areas in the handling of confinement, social solation and sensory deprivation is available (369). A review of Soviet studies n this area has been published (196).

WORK-REST-SLEEP CYCLES (WRS)

Man is influenced by the diurnal periodicity of the physical world surounding him. His typical work-rest-sleep cycle (WRS) is thus based on a 4-hour rhythm (16, 17, 20, 260, 307, 326). His physiological function and, s a result, his psychological performance vary according to this rhythm. As result, any alteration in the WRS to which the man is adapted will cause variations in physiological functions and psychological performance (6).

Diurnal or Circadian Rhythms

Figure 16-27 is an example of some of the diurnal or circadian rhythms. At lease 50 are known (19). The variations in function are the result of discrepancies in phase relationships between man's endogenous metabolic clock,according to which many physiologic functions are moderated with regular periodicity, and the external environment (65, 141, 260, 278, 280, 298, 307, 326, 353, 354, 355, 356). The biological functions, the most easily measured of which are pulse rate and body temperature, become "entrained to" or synchronized with this schedule. These functions follow a rather consistent course with a daily high point sometime during the early evening hours (between 1600 and 2000) and a low during the early morning hours (between 0400 and 1000). This cycling occurs whether the man is awake or

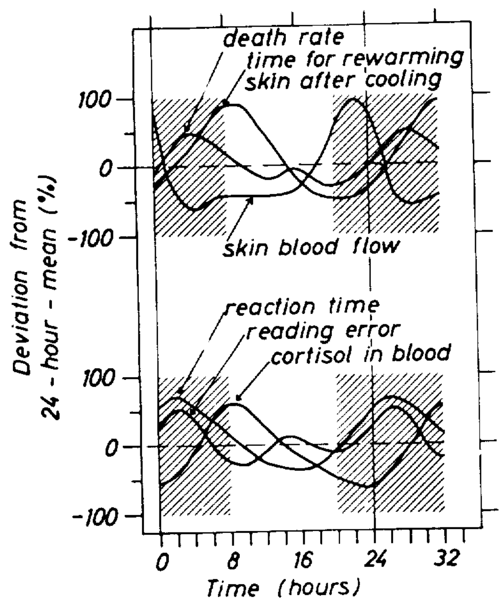


Figure 16-27

Schematically Drawn Curves, Indicating the Approximate Phase and Range for 6 Circadian Functions in Man.

(From several publications of text)

Dashed area represents dark-time.

(After Aschoff (19))

asleep. A further relevant point is that this curve is maintained for a period of four to six days after a marked change in the day/night relationship (153 154). It is also relevant that this curve is generally maintained by individuals working night shifts. This presumably results from social factors governing the man's off-duty activities. When the endogenous metabolic clock is out of phase with the external environment (e. g., when one remains awake from 2200 to 0800, a time when one is usually accustomed to sleeping), human performance decreases and a man is said to be in a state of asynchrony (153 154, 314). In this state, hunger and somnolence or insomnia will be present at the "wrong" times. This can be demonstrated by taking various physiological measurements during asynchrony (body temperature (193), endocrine and salt excretion patterns in urine (24, 117, 141), heart rate (193), EEG (103), and gastrointestinal motility (193)) and comparing them with those obtained on the same individual when in synchrony with his external environment. There is a suggestion that physical immobilization reduces the intensity of the usual physiological cycles (251).

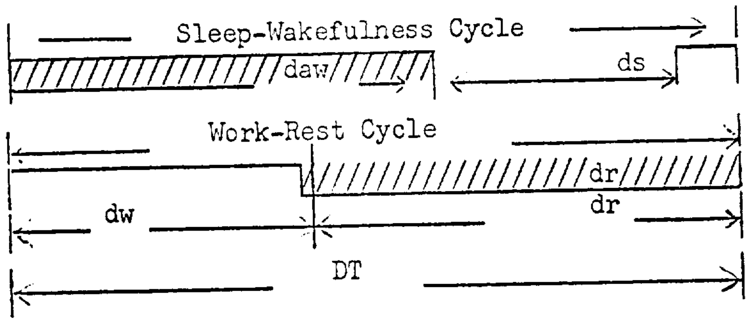
Studies of phase shift in free-running cycles without time cues are now under way (16, 37, 280). These are of vital importance to WRS programming. When men are kept isolated in a constant light, temperature, and sound environment where no time cues are available, their endogenous rhythms begin to override the previously entrained functions. There is a continuous delay in the time of getting up as well as in the time of urine calcium and potassium excretion and body temperature rise. The average period for all functions is 25.1 hours. The urine volume, calcium and potassium have a 26.1 hour cycle. Little is known of the mechanisms of these internal,oscillating control systems (16). Cyclic change in light intensity entrains the rhythm more than does temperature cycle (19). Alteration of the key cuing mechanism or "Zeitgeber" can desynchronize the different physiological cycles from one another. Personalities and activity habits of isolated individuals interact to modulate physiological and performance responses to environments free of time cues (280). Theoretical studies suggest that organisms with a natural period which is relatively short as compared to the time-cue cycle become entrained with a leading phase, the amount of phase angle difference depending on the ratio of the two natural frequencies (18, 19, 353). The longer the natural period, the more it lags in phase behind the time cue during entrainment. It is possible to train animals and man to an artificial time cue which is a multiple of 1:3 to the natural cue. This suggests that scheduling of the WRS cycle should be so devised as to have the time cue cycle a submultiple of 24 hours. Evidence that this is so will be discussed below (2, 6).

The problem created by scheduling WRS cycles for long aerospace mission is complicated by the cumulative effects of prolonged alteration in W, R, and S on performance (79, 267). It is compounded by the possibility that an emergency may require continuous performance of alertness at high levels for unknown lengths of time. Most of the present knowledge about work-rest-sleep cycles comes from ground-based studies obtained over periods of less than 24 hours. Small numbers of subjects, variability of motivation, and diversified backgrounds make generalization from the literature difficult. Both temporal and non-temporal factors affect work, rest, and sleep. The temporal components are summarized in Figure 16-28.

Major emphasis in the literature has been placed on the durations of the work (dw) and sleep (ds) periods, moderate emphasis on the total "daily" periodicity (DT), and very little on the ratios of work to rest (dw/dr) and sleep to wakefulness (ds/daw).

Sleep Duration

Satisfactory psychological performance is dependent upon an adequate sleep-wakefulness cycle, but few studies have been done to determine the optimum number of hours of sleep required per hours of waking time, i. e., ds/daw. The usual study has investigated the ratios, ds/DT, (DT = 24 hours) to determine the amount of sleep spontaneously taken per day without regard to performance. It has not been demonstrated at this point whether man needs 6-8 hours of sleep in every 24 or if, up to a limit, man can take any number of hours of wakefulness as long as they are offset by hours spent sleeping in the ratio ds/daw = 1/2-3. On the short side, the quality of afternoon performance improves almost linearly as sleep duration is increased from one to six



The work-rest cycle: dw/dr
The duration of the work periods: dw
The sleep-wakefulness cycle: ds/daw
The duration of the sleep period: ds
The total "daily" periodicity: DT

Figure 16-28

Man's Daily Activities Categorized to Form a Sleep-Wakefulness Cycle and a Work-Rest Cycle. (The two cycles are not habitually in phase with each other.)

(After Deutsch[79], adapted from Kleitman[193])

hours (338). Beyond a duration of six hours of sleep, improvement is less marked and is completely absent when sleep is lengthened from 8 to 10 hours in every 24.

One could infer that the ds/daw ratio for optimum performance is 1/2-3. This is consistent with the results of Table 16-30 in which a ration ds/daw = 1/3 was found adequate (1).

It is known that some finite amount of sleep is required to preserve the physiological balance between waste and repair. The exact amount needed can be expected to vary with the individual's metabolic state and the type of work being done. Relatively large variations in needs have been demonstrated in the literature (142, 193, 195, 249, 327, 370). Statistical evaluation of ds (DT = 24 hours),as observed in large numbers of normal volunteers,points to a mean value of 7.5-8 hours required per 24 (66, 193, 194). S's in one study stated they "felt better" after an 8-hour sleep period than after 6 (327). Performance measures did not bear out this difference in "feeling," however, as the S's with 6 hours sleep performed equally as well as those with 8. Although there may be no physiological need for the extra two hours sleep as far as performance is concerned, it still has a beneficial effect upon the subjective feelings of the subjects and is, therefore, probably desirable.

Under normal conditions, a man goes to bed when he is tired and ready for sleep, and, generally, he has difficulty falling asleep at other times, presumably because of the influence of the "activation period" of his previously entrained cycle. This problem comes into focus when there has been a drastic alteration in the sleep/wakefulness schedule in relation to the activation curve. The individual has difficulty getting to sleep even when he has been awake for well beyond his normal span of wakefulness. Even though the activation curve may continue its normal course, there is an apparent psychological adaptation after about four days on a new schedule. This underscores the desirability of preadaptation to a given schedule if that schedule is to differ significantly from the normal regime of 16 hours of wakefulness and 8 hours of rest (62).

Weightlessness will undoubtedly have some effect on the ds required.

Speculation has it that less sleep will probably be required since the decreased metabolic energy needed to function in a weightless field may decrease the need for sleep, thus creating additional waking hours (314). Experimental attempts, however, to simulate weightlessness using water immersion techniques have led to conflicting results. A ratio of ds/DT = 2/24 was found to be the maximum required during one seven-day study (122). Other subjects immersed 10 hours out of 24 noted no alteration in their pre-test ds/DT ratio of 8/24 (123).

The following have been the experiences in orbital flight (27). Astronaut Gordon Cooper--22orbits, 34 hr., 20 min., 1963--found that even early in flight, when he had no tasks to perform and the spacecraft was oriented so that the earth was not in veiw from the window, he easily dozed off for brief naps. During the period designated for sleep he slept only in a series of naps lasting no more than one hour each. His total sleep time was about four and one-half hours. He stated that if there had been another person along to monitor the systems he could have slept for much longer periods. He further stated that he slept perhaps a little more soundly than on earth (53). The long period of alertness, of course, enabled Cooper to utilize his orbital time to the optimum for his operational and exploratory tasks.

In 1965 two more orbital flights by American astronauts were made, in which special attention was given to the sleep and wakefulness cycle (29). Difficulty in sleep programming was elucidated by the problems in this flight. The GT-4 and 5 crews (4 and 8-day missions) reported no difficulty in performance related to the 45 minute darkness and daylight cycle created by orbital flight. There were some definite sleep problems. A great deal of difficulty was encountered in obtaining satisfactory sleep periods on the 4-day mission. Even though the flight plan was modified during the mission in order to allow extra time for sleep, it was apparent, post-flight, that no long sleep period was obtained by either crewman. The longest consecutive sleep period appeared to be 4 hours, and the command pilot estimated that he did not get more than 7-1/2 to 8 hours good sleep in the entire 4 days. Factors contributing to this lack of sleep included: (1) the firing of the thrusters by the pilot who was awake; (2) the communications contacts, because the communications could not be completely turned off; and (3) the requirements of housekeeping and observing, which made it difficult to settle down to sleep. Also the responsibility felt by the crew tended to interfere with adequate sleep.

An attempt was made to remove a few of these variables on the 8-day mission and to program the sleep periods in conjunction with normal nighttime at Cape Kennedy. This required the command pilot to sleep from 6 p.m. until midnight, Eastern-Standard Time, and the pilot to sleep from midnight until 6 a.m., each getting a 2-hour nap during the day. This program did not work out well due to flight plan activities and the fact that the crew tended to retain the midnight to 6 a.m. - Cape Kennedy nighttime period. The 8-day crew also commented that the spacecraft was so quiet that any communication or noise, such as removing items attached with Velcro, aroused them.

On the 14-day flight, the flight plan was designed to allow the crew to sleep during hours which generally corresponded to nighttime at Cape Kennedy. There was a 10-hour period established for this sleep, and it worked out very well with their normal schedule (Figure 16-29). In addition, both crewmen slept at the same time, thus eliminating unnecessary noise from the actions of the other crew member. The beginning of the scheduled rest and sleep period was altered to move it one-half hour earlier each night during the mission in order to allow the crew to be up and active throughout the series of passes across the southern United States. Neither crewman slept as soundly in orbit as he did on earth, and this inflight observation was confirmed in the post-flight debriefing. The pilot seemed to fall asleep more easily and could sleep more restfully than the command pilot. The command pilot felt that it was unnatural to sleep in a seated position, and he continued to awaken spontaneously during his sleep period and would monitor the cabin displays. He did become increasingly fatigued over a period of several days, then would sleep soundly and start his cycle of light, intermittent sleep to the point of fatigue all over again. This response may represent inability to sleep in a seat or natural reaction to responsibility. The cabin was kept quite comfortable during the sleep periods by the use of the Polaroid screen and some foil from the food packs on the windows. The noise of the pneumatic pressure cuff for Experiment M-1 did interfere with sleep on both the 8- and 14-day missions. The crew of the 4-day flight was markedly fatigued following the mission. The 8-day crew were less so, and the 14-day crew the least fatigued of all. The 14-day crew did feel there was some irritability and loss of patience during the last 2 days of the mission, but they continued to be alert and sharp in their responses, and no evidence of performance decrement was noted. (See electroencephalographic data below.)

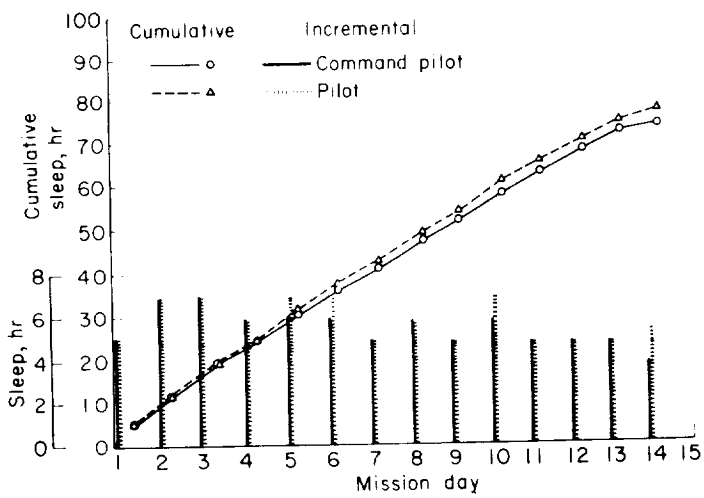


Figure 16-29

Sleep Data for Gemini VII Flight Crew

(After Berry et al[29])

Soviet experience with sleep in orbit is of interest. The sleep of Soviet cosmonaut, Gherman Titov - 17 orbits, 25 hr., 18 min., 1961--was not without interruptions (323). After seven orbits he felt a definite state of fatigue. When he flew over Moscow at 6:15 p. m., he prepared for sleep, according to schedule, by releasing special belts from the side of the pilot's seat. He strapped his body to the contour seat, and after adjusting the seat to the bed position, he promptly fell asleep, but awakened much earlier than scheduled. This happened during the eighth orbit. When he opened his eyes he saw his arms dangling weightlessly, and his hands floating in mid-air. "The sight was incredible," Titov reports. "I pulled my arms down and folded them across my chest. Everything was fine--until I relaxed. My arms floated away from me again as quickly as the conscious pressure of my muscles relaxed and I passed into sleep. Two or three attempts at sleep in this manner proved fruitless. Finally I tucked my arms beneath a belt. In seconds I was again sound asleep." Titov further states: "Once you have your arms and legs arranged properly, space sleep is fine. There is no need to turn over from time to time as a man normally does in his own bed. Because of the condition of weightlessness there is no pressure on the body; nothing goes numb. It is marvelous; the body is astoundingly light and buoyant...I slept like a baby." He awoke at 2:37 a. m., Moscow time, and was a full 30 minutes behind schedule because of oversleeping. He immediately started the required "morning calisthenics." Thereafter he carried out all scheduled assignments. Only his motion sickness interfered with normal performance. It is of interest to note that Titov's sleeping period coincided largely with nighttime over Russia. This also was true of the other Russian cosmonauts, and may have been so planned.

Valery Bykovsky - 81 orbits, 119 hr., 1963--slept four times for periods of eight hours, alternating with periods of sixteen hours of wakefulness (252). During this flight and that of Valentina Tereshkova - 47 orbits, 71 hr., 1963--"the diurnal periodicity of physiological functions changed only during the first and last days of the weightless state, which was most probably associated with the emotional strain." During the phases of wakefulness, brief rest periods were usually scheduled for times when the spaceship was not over Russia. "It should also be noted that at night, during sleep, nearly all cosmonauts displayed a greater reduction in pulse rate than that recorded during the same hours in earlier space simulated flight." (116).

The three-man team of the spaceship Voskhod - 16 orbits, 24 hr., 17 min., 1964 - rested and slept in shifts during their 24-hour flight.

The reported sleep and wakefulness time patterns in orbital space flight reflect, by and large, the physiological circadian cycle of 24 hours. For orbiting astronauts, the earth temporal zones are irrelevant to the sleep cycle. With regard to these zones they are--in a state of asynchrony. Their basic guiding time has been Greenwich time or Universal Time (U. T.). Nevertheless, for physiological and operational reasons it seems to be very desirable that their physiological clocks remain synchronized with the local time of the launch time zone, or in a broader sense, to the time zone range of the home country to which they were adapted during the prelaunch period (314). But in extended (geocentric and heliocentric) space flights, the astronauts probably will follow a physiological sleep and wakefulness cycle adjusted to their duties, and not necessarily completely corresponding to the temporal pattern of the physiological circadian cycle on earth. If operational necessity requires that the basic sleep-wakefulness cycle be of a non-24-hour periodicity, then an artificial cycle that is longer than 24 hours might be better than one that is shorter (37, 194, 195). This suggestion might be questioned, however, in view of the long and successful experience of the United States Navy in maintaining watch schedules based on work-rest and sleep-wakefulness cycles of 12-hour duration. However, since the 24-hour schedule is a multiple of 12, it may be that the 12-hour schedule is qualitatively more similar to the 24-hour schedule than is an 18-hour schedule. (see below)

On the moon, the physiological sleep and activity cycle will be completely independent of the physical or selenographic day-night cycle, which is 27 terrestrial days in length. In addition to sunshine, with an illuminance of 140,000 lux (lumens per square meter), the earthshine at full earth with an illuminance 75 times stronger than that of the moonshine on earth at full moon, provides a photic situation approaching a dim daylight situation on earth (314). Furthermore, there may be locations with no effective illumination at all (caverns), or places with constant sunlight as on the "mountains of eternal light" near the south pole. Be that as it may, the photic environment on the moon does not provide a "Zeitgeber" comparable to the 24-hour dark-light cycle on earth. Therefore, the astronauts might adopt a sleep and activity cycle of the terrestrial circadian pattern, modified by their special tasks and by the lower gravity on the moon.

On the planet Mars, the day-night cycle is only 37 minutes longer than that on earth (314). The sky is dark bluish in color, excepting regions covered with thin whitish clouds. Solar illuminance on the Martian surface at noon may reach one-third of that on earth. Thus, the temporal dark-light alternation on Mars offers time cues similar to those on earth.

Duration of the Work Periods (dw)

Studies of the work periods (dw) have been typically conducted using a total "daily" periodicity (DT) of 24 hours, and have measured performance as a function of the total duration of the work period in industrial settings. The primary factors to be considered in the selection of the length of the duty period relate to the nature of the activity required of the operator in the performance of his duties (62). Account must be taken of both the levels and varieties of the demands placed on him in carrying out his tasks. For example, some tasks involve only passive performance on the part of the operator in that several minutes may elapse during which no event to which he must respond will occur; this sort of task is exemplified in radar watchkeeping. At the other extreme are tasks that require active participation of the man by more or less continually taking actions of some sort, e. g., manual control of the vehicle on re-entry. An important psychological factor underlying this distinction is the effect that these two different kinds of tasks exert on the operator's level of alertness. Passive tasks produce or contribute to decreased alertness whereas, at least up to some level of workload, active tasks tend to sustain or increase alertness. The variety of tasks--again up to some level of workload--also tends to promote alertness. However, moderately high workloads on tasks that require the "simultaneous performance" of psychologically disparate functions (e. g., mental calculations and code solving) are quite vulnerable to losses in alertness, and this is especially true for task combinations in which timing is critical. Thus, in a sense, an alertness paradox is produced (62).

Many of the conditions under which performance decrements have been observed in laboratory studies are not at all likely to occur in properly human-engineered man-machine systems. Typical of this class of studies is the vigilance experiment. Here, the occurrence of decrements is largely dependent upon the presentation of a single task using infrequently occurring, near-threshold signals of uncertain nature to which the man must respond (303). With these conditions, decrements are exhibited over performance intervals as short as 30 minutes. However, even with single tasks, when the signals have high attention value or are alternated or made redundant, performance can be maintained for much longer periods without apparent decrement (39 , 40, 128, 212). Electrophysiological (EEG, EOG, GSR and nuchal electrogram) correlates of vigilance are under study (28, 30, 225).

With tasks in which the operator has control over his rate of activity (as in industrial situations involving piece-work production), the man typically works at a near maximum rate for a period; he then takes either an official or unofficial rest break, after which he resumes his original rate. Thus the period of continuous work in most industrial jobs is typically about two hours is seldom longer than four hours.

The optimum length of duty period has not been investigated except within rather narrowly defined limits as regards the numbers and kinds of tasks the man is required to perform. Thus, even though the operational work situation and performance requirements can be specified exactly, substantive data relevant to the determination of the appropriate length of duty periods are in short supply. However, the data that do exist suggest that work periods on the order of four hours represent the duration of performance that should be expected as a matter of routine without encroaching on the maximum efficiency of which the operator is capable (Figure 16-30). When the level of performance necessary to satisfy the mission requirements is substantially below the operator's maximum capabilities, this figure can be increased. But, in determining how much it can be increased, importance attaches to the probability that an emergency might arise that would require maximum capabilities and to the speed with which the operator would have to be able to exercise those capabilities. Fortunately, except when his condition has reached a point of extreme deterioration, man can rather quickly rise to most any situation. The critical questions are, "How rapidly must he rise? how far? and for how long?" (62).

The Work-Rest Cycle

The ideal work-rest cycle would be one in which the total "daily" periodicity (DT) equaled 24 hours, distributed in a manner to which humans are already adapted. The 90 minute day-night cycle of orbital flight makes this ideal rather difficult to attain in the operational situation.

The most common division, used in the U. S. submarine fleet, is the 4-on and 8-off schedule of standing watch, which is operation on an artificial 12-hour cycle (193, 194). Reports in the literature would indicate that while the duties of a submariner may be satisfactorily carried out on such a schedule, efforts to establish a 12-hour physiologic rhythm in man have been uniformly unsuccessful on subjective, biochemical and hematological bases (142, 221, 222).

Experiments have been performed to discover what dw/dr ratios and durations yield the best performance. The results of this experimentation are summarized in Table 16-30. Unfortunately the durations are not very long. The consistency, however, within experiments and the consistency between recommendations is interesting. Both authors of earlier studies, (References 1 and 43), recommended a dw/dr ratio of 2/1 (hours : 4/2) and indicate a general agreement of little or no performance decrement being

Table 16-30

Results of Experiments Relative to Performance During Various Work-Rest Cycles

Ratio dw/dr	Hours dw/dr	Comments	DT	Subjects #	Days N	Ref.
2/1*	4/2	"Wide variation in individual performance; subjects worked effectively ."	6	11	15	1
2/1*	4/2	"Experiment too short" but "no difference in performance", data	6	12	4	1
3/1	6/2*	indicated trend toward better 4/2 performance if experiment had been prolonged. "	8	10	4	1
1/1	8/8	4/4 and 2/2 adjusted "better" than did 8/8 and 6/6.				1
1/1	6/6					1
1/1*	4/4					1
1/1	2/2	Maximum severity--not recommended for routine use.				1
2/1*	4/2*	No marked performance decrement; recommended over 6/2.	6		8	43
1/2	4/8	Confirms that it is difficult to establish a physiological 12-hour (DT)--See Ref. 90.	12			193
1/1	4/4		8	2	7	265
1/1	4/4		8			311
2/1	4/2	With proper selection and motivation this schedule can be attained with no degradation in performance.	6	6	15	6
1/1	4/4	Best schedule studied. Function appeared normal; physiological phase shift toward end of period noted.	8	10	30	6
2/1	4/2	Steady work period of 40 hours on day 6 and 7 poorly tolerated; performance is generally poorer than equivalent 4/4 schedule.	8	6	12	5
1/1	4/4	Steady work period of 44 hours on day 6 and 7 well tolerated; performance was good.	6	10	12	5

noted. In addition, the dw/dr = 2/1 ratio is recommended by both over the dw/dr = 3/1 ratio on a subjective and objective basis. One group feels that it is probably feasible to expect a highly motivated man to maintain acceptable performance levels on a 4/2 schedule for a period as long as 15 days, and, probably,30 on the basis of some subjective statements. The results of other subjective studies indicated that some individuals adjust more favorably in groups where a 4-on and 4-off schedule was used (1, 61, 265, 311).

Recent laboratory studies have shown that most subjects can maintain satisfactory performance without decrements over a period of 30 days while following a 4-hours work, 4-hours rest schedule around the clock (5, 6). A modified control study was conducted using a 4-hours work, 4-hours rest, 4-hours work, 12-hours rest schedule. No limitations were placed on subjects during the 12-hour rest period. The performance of this group of subjects over a period of 12 days was essentially the same as that of subjects working 12 hours per day while confined to a simulated crew compartment. On the assumption that a 30 day period was sufficient to reveal any adverse reactions, one can conclude from these results that the short (4-hour) sleep periods were sufficient to maintain the "psychological status" of the operators. These subjects, who were rated pilots, felt that they could have performed their normal flying duties on a 4/4 schedule throughout the period of the study and the majority thought they could have continued to do so indefinitely. Periods of sleeplessness during the 4/4 schedule were better tolerated than on a 4/2 schedule.

In the 30-day study with subjects following a 4-work/4-rest schedule, there was some evidence that the magnitude of the normal physiological periodicity was reduced toward the end of a month. Specifically, whereas for the first 25 days of the study the fluctuations were significant, during the 26th through the 30th days the cycling was not significant. In studies of submarine personnel it was found that crewmen on a 12-hour duty/rest cycle showed a double, body-temperature curve (193). These results suggest the possibility that the subjects in the 30-day study on a 4/4 schedule may have been tending toward a "triple" curve of physiological cycling. Further work is required on the mechanism behind these phase shifts. It may be that the 4/4 schedules do not present sufficient time cues. Not all of the physiological functions appeared to behave similarly. In only one of the groups did pulse rate really reach a new steady phase-angle difference. The cause of delay in phase angle shift is also not clear. An understanding of these phenomena will permit more valid extrapolation to missions of longer duration.

Human variation in ability to adapt to an atypical (non-24 hour) WRS cycle has ranged from one week to six years (37, 122, 193, 204, 267). Average times required seem to be in range of 2-3 weeks for complete adaptation (335). Reports of abrupt, rapid adaptation are more surprising than failures to adapt. All investigators seem to agree on the wide degree of variation in the rate and completeness of adaptation and the work out-put after adaptation (112). It is possible that only a five day adaptation period may be required for normal function (1, 261).

The ratio of mean temperature range (MR) to the range of the mean temperature (RM) has been used as a measure of adaptability (193). The degree of fit of observed temperature cycle to expected changes after being on new cycle 24 hours has also been used as a measure of adaptability.

The maintenance of a stable sleep-wakefulness cycle, as indicated by a superimposable body-temperature curve, peaking during wakefulness and dropping during sleep, serves a dual purpose. It promotes greater alertness and efficiency during working hours, and easier onset of sleep. The consistent, day-to-day adherence of a stable sleep-wakefulness cycle is, therefore, to be recommended.

Efficiency During Wakefulness

Efficiency during wakefulness is a major criterion. Efficiency of performance follows a 24-hour rhythm (193). It is low upon arising, shows an initial ascent phase, a plateau in the middle of the day, and a terminal descent phase. Performance immediately upon getting up from a period of sleep is often poorer than it was just before retiring and is worse after deeper stages of sleep (148, 149, 338). During split, sleep-wakefulness cycles (4 hours asleep, 4 hours awake, 4 hours asleep), a "very low" capacity for work through the middle four-hour waking period is seen (193). Similar findings were noted using a 3-hour sleep, 3-hour awake, 3-hour sleep schedule (173).

Over a long period of time these circadian periodicities in efficiency have direct implications on the performance levels to be expected of the operator. These implications are borne out in data obtained in laboratory confinement studies. The performance of the man on some tasks and task combinations reflects the same sort of periodicity that is found in the biological measures.

In the 30-day study with the 4/4 schedule referred to in Table 16-30, this cycling was present even though the low point of the performance curve always exceeded in efficiency the high point of comparable subjects following a more demanding schedule (6). In this regard, it should be noted that it may well be that the data obtained using a 4/4 schedule actually give an optimistic view of the criticality of the association between the biological and performance data (62). Specifically, since the duty periods never exceeded four hours, the potentially detrimental effect of the boredom resulting from continuous confrontation by the tasks might not have developed to the extent that would very likely be the case with longer duty periods. Although one cannot rule out the possibility that performance was depressed by the short sleep periods, the control data (4-work, 4-rest, 4-work, and 12-rest) tend to contradict this hypothesis. Sleeplessness periods during these schedules are better tolerated than in 4/2 schedules especially for tasks requiring sustained attention (5). Performance returns to approximately the level that would be expected had there been no period of sleep loss after the subjects on the 4/4 schedule had had two sleep periods (8 hours of sleep - 12 hours by the clock) and those on the 4/2 schedule had had three sleep periods (6 hours of sleep - 14 hours by the clock).

Superficially, it would appear that a schedule should be selected that would require the man to perform only during the high portion of his daily curve of activation. This would, in theory, provide on the order of 10 to 12 hours per day of "high-level" performance. However, examination of the industrial literature as well as laboratory and field research related to military operations suggests that ten hours represent too long a period of work at one stretch to expect performance to be maintained without at least an increase in the probability of errors and/or decrements.

Non-Temporal Factors

Non-temporal factors affecting the WRS cycle include:

1. The number of crew members on board.
2. The duty assignments or responsibilities of each crew member.
3. The need for time sharing of work space and facilities.

4. The need for equal division of task loading, rest and sleep time.

5. The need for completion of all tasks.

6. Emergency situations.

These non-temporal factors will probably dictate the initial WRS cycles n the first orbital lab flights. The best WRS cycle will be one adjusted to luties, independent of the ambient sun-shadow cycle (i. e., the earth-orbital pace environment) and not necessarily corresponding to the time pattern of he earth day-night cycle. This non-24-hour cycle should be one to which the stronaut should be able to adapt in a reasonable amount of time and with which e can maintain synchronization of his metabolic clock to ensure his best sychological performance.

The use of shorter work periods provides an advantage in the event that an nusual requirement for man-hours should arise either because of a particular eature of a mission segment or because of an emergency (62, 147). That dvantage would be realized during the period in which the system is "recovering" from the increased demand. Specifically, the man may have suffered a eriod of partial or even total sleep loss while coping with an emergency. hould that have been the case, he probably would find it substantially easier o maintain a satisfactory degree of alertness for a 4-hour duty period as compared to, for example, a 10-hour period until such time as he regains his re-emergency status. Preliminary studies suggest that subjects in a 16/8 chedule tend to tolerate sleep deprivation for 2 days (on day 6 and 7) and recover faster than subjects on 4/2 and 4/4 work/rest schedules (147).

To the extent that a high level of performance will be required on what vill approach a twenty-four hour per day basis, then serious consideration nust be given to the selection of the work-rest schedule. The duration of the luty periods should be limited to a figure that will preclude the development f task-specific fatigue or boredom. With the anticipated exposures to the asks to be on a day-after-day basis, a work period that seems to be suitable t the beginning of a mission may become intolerably long after a period of everal weeks or months. This requires specific study. In addition, sleep eriods should be arranged so that they will come at essentially the same time ach day so that adjustment to (or in) the circadian rhythms will be facilitated. These two factors considered together imply a trade-off between the necessary r desirable duration and numbers of sleep periods and the duration of the ndividual duty periods.

The general conclusion reached from these past studies is that man is airly well accustomed to a sleep-wakefulness cycle of a 24-hour duration and hat he had diurnal variations in both performance and physiological functioning that coincide with this rhythm. When an atypical cycle is imposed, his hysiological rhythms may be expected to show some adaptation to the non-4-hour periodicity--but adaptation is not likely to be complete nor to be niform for all individuals. Concomitant decrements in performance, however, nay not occur, especially if the sleep-wakefulness ratio is held constant. The erformance decrement, whatever its degree, precipitated by the imposition f a typical work-rest-sleep cycle can be minimized in the following ways:

- The ideal solution is to avoid any non-24-hour work-rest-sleep cycle (i. e., use 8-on, 16-off).
- Where this is impossible, employ pre-flight, pre-synchronization periods for crews using the non-24-hour cycle proposed for that flight.
- Coordinate pre-flight pre-synchronization with the abilities of the individual crew members to adapt (those who adapt least well should be kept close to their typical schedule).
- Drugs may be utilized as a useful, but undesirable, tool if synchronization is found to be difficult, but more information is required on drug influence on cyclical phenomena.
- Local (orbital) adaptation to a typical cycle can be accomplished by new crew members as they are rotated to the lab (if they are not required to go on duty immediately upon arrival).

Further experimentation with various combinations of non-24-hour cycles in the weightless environment may yield additional, useful information.

Ground controllers and other operations personnel are often faced with asynchronous patterns during unusual work schedules or when flying to duty posts across several time zones (95, 152, 153, 199, 200, 267, 314, 315, 337). The asynchrony in both east to west and west to east flights produce subjective fatigue and temporal changes in heart rate and body temperature, but significant physiological deficit has been found only in the east to west flights. North-south flights do produce fatigue, but do not show asynchronous physiological patterns along with the psychological deficits (154 The duration of fatigue is usually shorter than the time lag in physiological phase shifts. Large inter-individual differences are noted with some individuals requiring up to 5 days for phase shift after Oklahoma City to Tokyo jet flights. Older individuals appear more subjectively sensitive to the asychrony than younger ones. First, if a traveler to a distant location requires full alertness for a certain occasion he should, if possible, travel to his destinatio several days in advance, so that he will be adjusted to the new locality before he is called on to perform his tasks. Secondly, a coordination of the physiological with the physical day-night cycle can be achieved by presetting his physiological clock; i. e., by adopting 3 to 5 days in advance of the trip, a sleep and wakefulness pattern which corresponds to the physical day-night cycle of the place of destination (315).

Sleep Depth and Deprivation

The general sleep requirements in space operations were covered above. Depth of sleep can be measured by electroencephalographic techniques. Wave patterns can be distinguished for the awake state, eyes closed and the four stages of increasing depth of sleep (76, 365). The physiological basis for these patterns as well as occulomotor patterns are under study (187, 188 211, 226, 268, 269, 279, 320, 347). As noted above, sleep patterns recorded in the first 51 hours of orbital flight are similar to those on earth. Irregular and aperiodic fluctuations in depth of sleep are normal occurences (41, 76). They are often associated with dream states (76, 150, 166, 211, 229, 274, 306).

An electroencephalographic study of sleep was carried out in Gemini VII (42, 190). Baseline, multi-channeled EEG and other psychophysiological data were recorded on Borman during all stages of sleep and the working state on earth and compared with those in flight. Fifty-four hours of inflight data were obtained at which time the scalp electrode was dislodged. Eight hours after liftoff the command pilot closed his eyes and remained quiet for almost 2 hours without showing signs of drowsiness or sleep.

"The first inflight sleep period showed marked fluctuations between light sleep and arousal, with occasional brief episodes of stage 3 sleep for the first 80 minutes. At that time stage 4 sleep was reached, but in less than 15 minutes abrupt arousal and termination of sleep occurred.

On the second day, at 33 hours and 10 minutes after lift-off, the command pilot again closed his eyes and showed immediate evidence of drowsiness. Within 34 minutes he was in the deepest level of sleep (stage 4). During this prolonged period of sleep, there were cyclic alterations in level similar to those which occur in this astronaut during a full night of sleep under normal conditions. Generally, each successive swing toward deeper sleep, after the first period of stage 4 has been obtained, only reaches successively lighter levels; but, in Borman's second night of sleep, stage 4 was reached and maintained for 20 minutes or more at three different times after the first episode. It is interesting to speculate as to whether this increase in the number of stage 4 periods reflected an effect of deprivation of sleep during the first 24 hours.

After approximately 7 hours of sleep, a partial arousal from stage 4 sleep occurred, and, after a brief period (12 minutes) of fluctuating between stages 2 and 3, Borman remained in a state fluctuating between drowsiness and stage 1 sleep until finally fully roused about 1.5 hours later. Whether any periods of so-called "paradoxical" sleep, rapid eye movement sleep, or dreaming sleep occurred during this oscitant period cannot be determined with certainty from these records because of the absence of eye movement records and because paradoxical sleep is generally very similar in its character to ordinary stage 1 sleep. However, two periods of a pattern which resemble an admixture of certain characteristics of stage 1 and stage 2 sleep, and which resemble some of the activity which this group and other investigators have observed in paradoxical sleep, were recorded for relatively long periods in the second day's sleep (at 11:05 G. M. T. and 14:20 G. M. T.) (187, 188). These consist of runs of 3 per second "saw-tooth" waves, runs of low-voltage theta and alpha activity, low-voltage beta activity without spindles, and occasional slow transients with a time course of about 1 second."

For further study of sleep and other neurological phenomena, data banks EEG taken on the astronauts are available (113, 341).

One must also consider sleep deprivation. This acute or chronic stress is accompanied by only a few consistent physiological changes (114, 118, 210, 326). The only marked changes consistently found are those that occur in neurological testing and in the electrical activity of the brain with increased convulsive tendency (14, 27, 31, 186, 275, 329). Decrease in pulse rate is not always found (254, 310). Blood sugar, hemoglobin, red and white cell count, excretion of 17-ketosteroids, total nitrogen and creatine, and the level of adrenal-like substances in the blood may be unchanged (328). Bioenergetics may be altered at a biochemical level (114). Body weight, blood pressure, hand steadiness, auditory acuity, depth perception, and dark adaptation also have shown no significant changes as a function of sleep loss (87). Only after 46 hours of sleeplessness has minor decrement been noted in visual acuity, muscle balance and stereoscopic function (256). After 5 hours of sleep, a return to normal was noted. Factors in the repayment of sleep debt have also been studied (98, 347). Specific deprivation of paradoxical and other stages of sleep are now under study (186, 187, 367).

Changes in estimates of fatigue have been reported, but marked difference in subjective factors among some of the studies prevent the drawing of direct conclusions (13). Correlation with performance degradation is variable. A moderate correlation has been reported between feelings of fatigue and the performance of mental multiplication (12). Correlations have also been found between a subject's estimation of fatigue and his actual performance of vigilance, interpretive, and grid-matching tasks (105, 106, 351). In contrast, air traffic controllers, on the job, developed feelings of weariness with sleep deprivation. These were not accompanied by performance decrements (293). There are also indications that judgements based on the appearance of a subject do not necessarily correlate with the subject's performance. Changes in behavior, personality, and physical appearance resulting from a 50-hour period of sleep deprivation have been found more pronounced than would be suggested by any performance decrements observed (63). A number of investigators have reported that increased irritability is among the first signs of pilot fatigue (80, 82, 215). Psychotic hallucinatory and regressive behavior is often brought about especially when confinement and isolation are superimposed on sleep deprivation (6, 101, 118, 277, 352). The symptoms appear to be related to the specific phase of sleep being deprived (367). Stage 4 deprivation produces depressive responses; stage 1-REM, irratability and emotional lability.

Of interest to contingency planners and commanders is the sequence of progressive deterioration of performance as sleep deprivation is prolonged. A review of this pattern has been made from which the following is taken directly (326). Following denial of one night's rest, detection of visual targets deteriorates markedly (364); choice behavior demands more time and exhibits more error (363); reading rate decreases although comprehension does not (170). Visual blurring and diplopia are accompanied with the beginning of misperception (364, 366), and where learing of a complex mental task is still taking place, the increment is reduced (60).

As the sleepless period begins to involve longer periods, effects are reported when noted. Thus, after 40 hours, mental work in arithmetic and color naming appear to suffer (344), as do ability to recall names and objects from recent conversation. After 50 to 65 hours, momentary hallucinations are reported (364). Critical flicker frequency and speed of manual and leg movement decrease after 60 hours with the diurnal pattern of coordination and travel movements persisting, indicating some more basic physiological determinant (146). Memory as represented in the ACE test of intelligence, deteriorates after 72 hours. Serious lapses now seem to appear with the deterioration in function reflecting the involvement of or dependence upon alertness and sensory checking (363, 366). It seems that the performance and sensory deficit has been established by about 65 hours, for no appreciable drop is noted in these factors, temporal disorientation, or cognitive organization after that period (364). As one passes this three-night period, the personality factors reflect perceptual changes or deterioration as manifest in emotional disturbances (50), which seem to predominate until psychotic episodes (persecutory) appear after 120 hours without sleep (364).

Several studies have demonstrated decreases in performance as the cumulative effects of sustaining slightly reduced daily sleep over prolonged periods of time. Measures of performance and muscle tonus have been compared as they were affected by four successive periods of nightly sleep -- 4, 10, 8, and 6 hours, respectively--repeated 7 times over an interval of 28 days (111). Greater work output was accompanied by greater tonus, and muscle tonus appeared to vary more with sleep loss than did performance. This suggests the presence of some form of tonic muscular compensation during performance testing. Also, the cumulative effects of prolonged sleep loss tended to offset the efficacy of the tonic muscular compensation. The experimental effects in this study, however, were confounded, to a degree, by the different durations of sleep allowed on each day of every replication. This was particularly noticeable in the scores that followed 10 hours of sleep because they more nearly approximated those following the 4-hour sleep period than those following the 6- or 8-hour sleep periods. Since the 10-hour sleep period was always preceded by the 4-hour, it is very likely that a carry-over effect was present.

A schedule of 7 consecutive hours of nightly sleep during one month has been compared with an experimental schedule of interrupted nightly sleep during the following month (173). On each night of the experimental month the subject slept 3 hours, remained awake 3 hours, and then slept 3 additional hours. No difference in performance was found between the two schedules; in those tests where learning was present, improvement continued at the same rates regardless of the alternation-of-sleep routine.

In another study two "capable and highly motivated" subjects were required to perform continuously without sleep for a period of 24 hours (120). The task situation was a complex one that required the constant attention of each subject. The tasks, enclosed in two "flight" simulators, were selected to measure eye-limb coordination, problem solving, estimation of closure rates, selection and manipulation of controls, and the noticing of environmental changes both inside and outside the simulator. As indicated by each of the seven specific measures used, performance followed a pattern of rising to a peak after 6 to 10 hours and then dropping off sharply to a low point reached during the final 2 or 3 hours of the test. Differences between the two subjects and among the several tasks used were also quite evident. End-spurt effects were avoided by slowing the subjects' clocks so that after 24 hours had actually elapsed, the clocks indicated that the subjects still had about 3 hours to work.

The vigilance performances of subjects who had just returned from flying 15-hour sorties at night have been found to be surpassed by those of otherwise comparable subjects who had just flown the same sorties during the day (104). Although this decrement may be interpreted as being a function of the loss of sleep, it may also be interpreted as being the result of differences in the difficulty of day versus night flying.

Motivation, monotony, complexity of task, arousal factors, and many other variables control the degradation of performance of the sleep deprivation (39, 40, 68, 87, 118, 326, 347, 352, 362, 366). Specific periods of sleep are more sensitive than others to behavioral and other responses of deprivation(367) Sleep deprivation of different forms will alter performance when superimposed on individuals in the process of adapting, or even fully adapted, to altered WRS cycles. Preliminary studies are discussed above.

Induction of sleep by electrical means has received study in recent years (33, 175, 176, 177, 183, 374). The advantage over drug-induced sleep is reversibility. However, techniques are still in the preliminary stage of development. Under some emergency situations on long duration flights, such techniques may be of value. Anesthesia may also be induced electrically (175, 177, 180, 183, 198, 299, 300, 359). Learning and memory during natural sleep are under study (32).

REFERENCES

16-1. Adams, O. S., Chiles, W. D., Human Performance as a Function of the Work-Rest Cycle, WADC-TR-60-248, Wright Air Development Center, Wright-Patterson AFB, Ohio, Mar. 1960.

16-2. Adams, O. S. Chiles, W. D., Prolonged Human Performance as a Function of the Work-Rest Cycle, Aerospace Med., 34: 132-138, 1963.

16-3. AiResearch Mfg. Co., Division of Garrett Corp., Study of Human Factors and Environmental Control, Lunar Exploration Systems for Apollo, Vol. 5, SS-3243-5, Los Angeles, Calif. 1966.

16-4. Akulinichev, I. T., Antoshchenko, A. S., Znachko, V. A., et al., Some Results of Monitoring the Medical Condition of P. I. Belyayev and A. A. Leonov during Training and during Orbital Flight, Kosmicheskiye Issledovniya, 4(2): 311-319, 1966. (Abstracted in Soviet Biotechnology and Bioastronautics, Jan-June 1966, LC-ATD-67-13, Library of Congress, Aerospace Technology Div., Washington, D. C., Mar. 1967, p. 159).

16-5. Alluisi, E. A., Chiles, W. D., Hall, T. J., Combined Effects of Sleep Loss and Demanding Work-Rest Schedules on Crew Performance, AMRL-TR-64-63, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, June 1964.

16-6. Alluisi, E. A., Chiles, W. D., Hall, T. J., et al., Human Group Performance during Confinement, AMRL-TDR-63-87, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Nov. 1963.

16-7. Altman, I., Haythorn, W. W., Effects of Social Isolation and Group Composition on Performance, Naval Medical Research Institute, Bethesda, Md., (no date), (AD-642 599).

16-8. Altman, I., Haythorn, W. W., Interpersonal Exchange in Isolation, Research Task No. MR005.12-2005.01, Naval Medical Research Institute, Bethesda, Md., Dec. 1964.

16-9. American Institute of Aeronautics and Astronautics, Space Simulation Testing Conference, Pasadena, Calif. Nov. 16-18, 1964, AIAA Publication CP-11, N. Y., 1965.

16-10. American Society for Testing and Materials, Factors in the Operation of Manned Space Chambers, A Symposium presented at the 5th Pacific Area National Meeting, ASTM, Seattle, Wash., Oct. 31-Nov. 5, 1965, ASTM Special Publication No. 398, Feb. 1966.

16-11. Appley, M. H., Trumbull, R., (eds.), Psychological Stress, Issues in Research, Appleton-Century-Crofts, N. Y., 1966.

16-12. Arai, T., Mental Fatigue, Teach. Coll. Contr. Educ., No. 54, 1912.

16-13. Armed Services Technical Information Agency, Sensory Deprivation and Isolation, A Report Bibliography, 1961-June 1962, ARB-10654, Arlington, Va., AD-446952.

16-14. Armington, J. C., Mitnick, L. L., Electroencephalogram and Sleep Deprivation, J. Appl. Physiol., 14: 247-250, 1959.

16-15. ARO, Inc., 5th Annual Symposium on Space Environment Simulation, Arnold Air Force Station, Tenn., May 21-22, 1964. (AD-441312).

16-16. Aschoff, J., (ed.), Circadian Clocks, Proceedings of the Feldafing Summer School, Sept. 7-18, 1964, North-Holland Publishing Company, Amsterdam, 1964.

16-17. Aschoff, J., Circadian Rhythms in Man, Science, 148: 1427-1432, June 11, 1965.

16-18. Aschoff, J., Entrainment of Circadian Rhythms by Zeitgebers AFOSR-66-2251, Air Force Office of Scientific Research, Arlington, Va., Sept. 1966. (AD-640-631).

16-19. Aschoff, J., Significance of Circadian Rhythms for Space Flight, in Proceedings of the 3rd International Symposium on Bioastronautics and the Exploration of Space, Brooks AFB, Texas, Nov. 16-18, 1964, pp. 465-484. (AD-627 686).

16-20. Aschoof, J., Survival Value of Diurnal Rhythms, Symp. Zool. Soc. Lond., No. 13: 79-98, Aug. 1964.

16-21. Aviation Week & Space Technology, Future Space Missions Outlined; 12-24 Man Space Station Proposed, 78(23): 147, June 10, 1963

16-22. Barter, J. T., Estimation of the Mass of Body Segments, WADC-TR-57-260, Wright Air Development Center, Wright-Patterson AFB, Ohio, Apr. 1957. (AD-118222).

16-23. Barter, J. T., Emanuel, I., Truett, B., A Statistical Evaluation of Joint Range Data, WADC-TN-57-311, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1957.

16-24. Bartter, F., Delea, C. S., Halberg, F., A Map of Blood and Urinary Changes Related to Circadian Variations in Adrenal Cortical Functions in Normal Subjects, Ann. N. Y. Acad. Sci., 98, Art 4: 969-983, Oct. 1962.

16-25. Bellcomm, Inc., Apollo Program Specification, SE-005-001-1, Washington, D. C., Mar. 1966.

16-26. Benjamin, F. B., Directorate of Space Medicine, Office of Manned Space Flight, National Aeronautics and Space Administration, Washington, D. C., personal communication, 1968.

16-27. Bennett, D. R., Mattson, R. H., Ziter, F. A., et al., Sleep Deprivation: Neurological and Electroencephalographic Effects, Aerospace Med., 35: 888-890, Sept. 1964.

16-28. Berger, R. J., Meier, G. W., An Automatic Analyzer of States of Vigilance, Psychophysiology, 2(2): 141-145, Oct. 1965.

16-29. Berry, C. A., Coons, D. O., Catterson, A. D., et al., Man's Response to Long-Duration Flight in the Gemini Spacecraft, in Gemini Midprogram Conference Including Experiment Results, NASA-Manned Spacecraft Center, Houston, Texas, Feb. 23-25, 1966, NASA-SP-121, 1966, pp. 235-261.

16-30. Bio-Dynamics, Inc., Study on Vigilance and Alertness, Cambridge, Mass., 1963.

16-31. Bjerner, B., Alpha Depression and Lowered Pulse Rate during Delayed Actions in a Serial Reaction Test: A Study in Sleep Deprivation, Acta Physiol. Scand. 19, Suppl. 65: 1-93, 1949.

16-32. Bliznichenko, L. A., Information Input and Fixation in the Human Memory during Natural Sleep, JPRS-41255, Joint Publications Research Service, Washington, D. C., June 1967. (Translation of selected portions of Monograph entitled Vvod i Zakrepleniye Informatsii v Pamyati Cheloveka vo Vremya Yestestvennogo Sna, Bliznichenko, L. A., Kiev, Naukova Dumka, 1966).

16-33. Bogen, J. E., Glissando Electronarcosis, Some Semantic Confusions in Psychiatric Electrotherapy, Dis. Ner. Sys., 24(7): 1-13, 1963.

16-34. Braun, J. R., Sells, S. B., Military Small Group Performance under Isolation and Stress - Critical Review, III. Environmental Stress and Behavior Ecology, AAL-TDR-62-33, Artic Aeromedical Lab., Ft. Wainwright, Alaska, June 1962.

16-35. Braune, O., Fischer, O., Uber Den Schwerpunkt des Menschlichen Korpers, Abh. d. Math. & Physich. Klasse d. Koenigl. Sachs. Gesellisch. d. Wissensch., 1889.

16-36. Breeze, R. K., Space Vehicle Environmental Control Requirements Based on Equipment and Physiological Criteria, ASD-TR-61-161 (Pt. 1), Aeronautical Systems Div., Wright-Patterson AFB, Ohio, 1961.

16-37. Brindley, G. S., Intrinsic 24-Hour Rhythms in Human Physiology and the Relevance to the Planning of Work Programmers, FPRC-871, Flying Personnel Research Committee, Air Ministry, London, 1954.

16-38. Brissenden, R. F., Some Ground Measurements of the Forces Applied by Pilots to a Side-Located Aircraft Controller, NACA-TN-4171, Nov. 1957.

16-39. Broadbent, D. E., On the Dangers of Over-Arousal, presented at Basic Environmental Problems of Man in Space, Medical Res. Council, Applied Psychology Res. Unit, Cambridge, Eng., 2nd International Symposium, Paris, June 14-18, 1965.

16-40. Broadbent, D. E., Perception and Communication, Pergamon Press, New York, 1958.

16-41. Brooks, C. McC., Hoffman, B. F., Suckling, E. E., et al., Sleep and Variations in Certain Functional Activities Accompanying Cyclic Changes in Depth of Sleep, J. Appl. Physiol., 9: 97-104, 1956.

16-42. Burch, N. R., Dossett, R. G., Vorderman, A. L., et al., Period Analysis of the Electroencephalogram from the Orbital Flight of Genimi VII, NASA-CR-91661, Nov. 1967.

16-43. Burns, N. M., Environmental Requirements of Sealed Cabins for Space and Orbital Flights; A Second Study. Part I. Rationale and Habitability Aspects of Confinement Study, NAMC-ACEL-413, Naval Air Material Center, Air Crew Equipment Lab., Philadelphia, Pa., Dec. 1959.

16-44 Burns, N. M., Isolation and Sensory Deprivation, in Unusual Environment and Human Behavior; Physiological and Psychological Problem of Man in Space, Burns, N. M., Chambers, R. M., Hendler, E., (eds.), Free Press of Glencoe, N. Y., 1963.

16-45. Busby, D. E., Clinical Space Medicine: A Prospective Look at Medical Problems from Hazards of Space Operations, NASA-CR-856, July 1967.

16-46. Buyanov, P. V., Kovalev, V. V., Terent'yev, V. G., et al., Results of Preflight and Postflight Medical Examinations of Voskhod-1 Crew Members, Kosmicheskiye issledovaniya, 4(1): 151-155, 1966. (Abstracted in Soviet Biotechnology and Bioastronautics, Jan.-June 1966, LC-ATD-67-13, Library of Congress, Aerospace Technology Div., Washington, D. C., Mar. 1967, p. 150).

16-47. Calvit, H. H., Rosenthal, A. F., Analysis of the Structural Dynamics of the Human Body, Final Report 1, Department of Engineering Mechanics, Pennsylvania State University, University Park, Pa., (no date). (Prepared under Contract DA-36-034-AMC-0207R). (AD-610394).

16-48. Cameron, D. E., Levy, L., Ban, T., et. al., Sensory Deprivation: Effects upon the Functioning Human in Space Systems, in Psychophysiological Aspects of Space Flight Symposium, Brooks AFB, Texas, 1960, Flaherty, B. E., (ed.), Columbia Univ. Press, N. Y., 1961, pp. 225-237.

16-49 Canaveral Council of Technical Societies, Proceedings of the 2nd Space Congress, Cocoa Beach, Fla., Apr. 5-7, 1965.

16-50. Cappon, D., Banks, R., Studies in Perceptual Distortion: Opportunistic Observations on Sleep Deprivation during a Talkathon, AMA Arch. Gen. Psychiat., 2(3): 346-349, 1960.

16-51. Carthy, J. D., Ebling, F. J., (eds.), The Natural History of Aggression, Proceedings of a Symposium, London, Oct. 21-22, 1963, Academic Press, N. Y., 1964.

16-52. Cathcart, E. P., Hughes, D. E. R., Chalmers, J. G., The Physique of Man in Industry, IHRB-71, Industrial Health Research Board, Medical Research Council, London, 1935.

16-53. Catterson, A. D., McCutcheon, E. P., Minners, H. A., et al., Aeromedical Observations, in Mercury Project Summary Including Results of the Fourth Manned Orbital Flight, May 15-16, 1963, NASA-SP-45, Oct. 1963, pp. 299-326.

16-54. Celentano, J. T., Amorelli, D., Freeman, G. G., Establishing a Habitability Index for Space Stations and Planetary Bases, AIAA-63-139, North American Aviation, Inc., Downey, Calif., paper presented at AIAA/Aerospace Medical Assn., Manned Space Laboratory Conference, Los Angeles, Calif., May 2, 1963.

16-55. Chaffee, J. W., Anthropometric Photogrammetry as Applied to Escape Capsule Design, Human Factors, 3: 36-52, 1961.

16-56. Chaillet, R. F., Honigfeld, A. R., Human Factors Engineering Design Standard for Wheeled Vehicles, HEL-Standard S-6-66, Army Human Engineering Labs., Aberdeen Proving Ground, Md., Sept. 1966.

16-57. Chamberlin, J. A., Orbital Space Station Design for Permanent Residence, AIAA-66-936, NASA-Manned Spacecraft Center, Houston, Texas, presented at AIAA 3rd Annual Meeting, Boston, Mass., Nov. 29-Dec. 2, 1966.

16-58. Chappee, J. H., Smith, G. B., Jr., Man-Rating Considerations in the Design and Operation of Hard Vacuum Chambers, in AIAA Space Simulation Testing Conference, Pasadena, Calif., Nov. 16-18, 1964, AIAA-CP-11, 1964, pp. 60-64.

16-59. Chiarappa, D., Analysis and Design of Space Vehicle Flight Control Systems. Vol. VIII. Rendezvous and Docking, NASA-CR-827, July 1967.

16-60. Chiles, W. D., The Effects of Sleep Deprivation on Performance of a Complex Mental Task, WADD-TN-55-423, Wright Air Development Div., Wright-Patterson AFB, Ohio, Sept. 1955.

16-61. Chiles, W. D., Adams, O. S., Human Performance and the Work-Rest Schedule, ASD-TR-61-270, Aeronautical Systems Div., Wright-Patterson AFB, Ohio, July 1961.

16-62. Chiles, W. D., Work-Rest Schedules under Conditions of Long Term Performance, in Proceedings of the NASA Symposium on the Effects of Confinement on Long Duration Manned Space Flights, NASA-Office of Manned Space Flight, Washington, D. C., Nov. 17, 1966, pp. 20-26.

16-63. Clark, R. E., Hoffman, A. C., Hudson, B. B., et al., The Effects of Sleep Loss on Performance of a Complex Task, OSRD-3153, National Defense Research Comm., Office of Scientific Research and Development, Washington, D. C., 1943.

16-64. Clarke, H., Analysis of Physical Fitness Index Test Scores of Air Crew Students at the Close of a Physical Conditioning Program, Res. Quart., 16: 192-195, 1945.

16-65. Clegg, B. R., Schaefer, K. E., Studies of Circadian Cycles in Human Subjects during Prolonged Isolation in a Constant Environment Using 8-Channel Telemetry Systems, NSMC-MR-66-4, Naval Submarine Medical Center, New London, Groton, Conn., Feb. 1966.

16-66. Cohen, E. L., Length and Depth of Sleep, Lancet, No. 2: 830-831, Dec. 23, 1944.

16-67. Cooper, G. D., Adams, H. B., Cohen, L. D., Personality Changes After Sensory Deprivation, J. Nerv. Ment. Dis., 140(2): 103-118, 1965.

16-68. Corcoran, D. W. J., Influence of Task Complexity and Practice on Performance After Loss of Sleep, J. Appl. Psychol., 48(6): 339-343, 1964.

16-69. Cotterman, T. E., Wood, M. E., Retention of Simulated Lunar Landing Mission Skills: A Test of Pilot Reliability, AMRL-TR-66-222, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Apr. 1967.

16-70. Damon, A., Goldman, R. F., Predicting Fat from Body Measurements: Densitometric Validation of Ten Anthropometric Equations, Human Biol., 35: 32-44, 1964.

16-71. Damon, A., Stoudt, H. W., McFarland, R. A., The Human Body in Equipment Design, Harvard Univ. Press, Cambridge, Mass., 1966.

16-72. Daniels, G. S., Churchill, E., The "Average Man"?, WADC-TN-53-7, Wright Air Development Center, Wright-Patterson AFB, Ohio, Dec. 1952.

16-73. Daniels, G. S., Meyers, H. C., Worrall, S. H., Anthropometry of Male Basic Trainees, WADC-TR-53-49, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1953.

16-74. Davenport, E. W., Congdon, S. P., Pierce, B. F., The Minimum Volumetric Requirements of Man in Space, AIAA-63-250, presented at General Dynamics/ Astronautics, San Diego, Calif., AIAA Summer Meeting, Los Angeles, Calif., June 17-20, 1963.

16-75. David, H. M., Douglas Cites Test Results of Simulated Zero G Study, Missiles and Rockets, 18(20): 40-43, May 16, 1966.

16-76. Dement, W., Kleitman, N., Cyclic Variations in EEG During Sleep and Their Relation to Eye Movements, Body Motility, and Dreaming, Electroenceph. Clin. Neurophysiol., 9: 673-690, 1957.

16-77. Dempster, W. T., Space Requirements of the Seated Operator, WADC-TR-55-159, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1955.

16-78. Denisov, V. G., Onishchenko, V. F., Yazdovskiy, The Psychophysiological Capacity of Astronauts Relative to the Control of a Space Craft and Its Systems (Engineering Psychology), in Medical and Biological Problems of Spaceflights. Space Biology and Medicine, Yazdovskiy, V. I., (ed.), JPRS-38935, Joint Publications Research Service, Washington, D. C., Dec. 1966, Chapt. 17, pp. 543-601. (Translation of book entitled Kosmicheskaya Biologiya i Meditsina. Mediko-Biologicheskiye Problemy Kosmicheskikh Poletov, Yazdovskiy, V. I., (ed.), Nauka Publishing House, Moscow, 1966.)

16-79. Deutsch, S., Executive Secretary, National Aeronautics and Space Administration, Research Advisory Committee on Biotechnology and Human Research, Work-Rest-Sleep Cycles Relative to Prolonged Space Flights: A review, Sept. 25, 1964.

16-80. Dougherty, J. E., Effects of Increased Flying Time on Aviation Instructors, War. Med., 3: 297, 302, 1943.

16-81. Douglas Aircraft Co., Inc., Experimental Study of Dynamic Effects of Crew Motion in a Manned Orbital Research Laboratory (MORL), NASA-CR-66186, Missile and Space System Division, Huntington Beach, Calif., Oct. 1966. (Prepared under NASA Contract NAS1-5937).

16-82. Drew, G. C., Experimental Study of Mental Fatigue, FPRC-227, Flying Personnel Research Committee, Air Ministry, London, 1940.

16-83. DuBois, J., Santschi, W. R., Walton, D. M., Moments of Inertia and Centers of Gravity of the Living Human Body Encumbered by a Full Pressure Suit, AMRL-TR-64-110, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Nov. 1964.

16-84. Duggar, B. C., The Center of Gravity and Moment of Inertia of the Human Body, in The Human Body in Equipment Design, Damon, A., Stoudt, H. W., McFarland, R. A., Harvard University Press, Cambridge, Mass., 1966, pp. 157-186.

16-85. Dupertuis, C. W., Pitts, G. C., Osserman, E. F., et al., The Relations of Specific Gravity to Body Build in a Group of Healthy Men, Proj. NM-004-006.03.06, Naval Medical Research Institute, Bethesda, Md., 1950.

16-86. Dutzmann, R. J., Aspects of Extra-Vehicular Mobility of a Human Operator in Space, SAE-857H, presented at Air Transport and Space Meeting, N. Y., Apr. 27-30, 1964, Society of Automotive Engineers, Inc., N. Y., 1964.

16-87. Edwards, A. S., Effects of the Loss of One Hundred Hours of Sleep, Amer. J. Psychol., 54: 80-91, 1941.

16-88. Ely, J. H., Thomson, R. M., Orlansky, J., Design of Controls, Chapter VI of the Joint Services Human Engineering Guide to Equipment Design, WADC-TR-56-172, Wright Air Development Center, Wright-Patterson AFB, Ohio, Nov 1956.

16-89. Ely, J. H., Thomson, R. M., Orlansky, J., Layout of Workplaces, Chapt. V of the Joint Services Human Engineering Guide to Equipment Design, WADC-TR-56-171, Wright Air Development Center, Wright-Patterson AFB, Ohio, Sept. 1956

16-90. Emanuel, I., Chaffee, J. W., A Study of Human Weight-Lifting Capabilities for Loading Ammunition into the F-86H Aircraft, WADC-TR-56-367, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1956.

16-91. Esch, L. J., North American Aviation Inc., Downey, Calif., unpublished data, Oct. 1958.

16-92. Ewart, E. S., A Survey of Potential Morale, Motivation, and Retention Problems at Ballistic Missile Sites, WADC-TN-58-66, Wright Air Development Center, Wright-Patterson AFB, Ohio, Oct. 1958. (AD-203399).

16-93. Feddersen, W. E., Crew Station Design and Volume Requirements, in Proceedings of the NASA Symposium on The Effects of Confinement on Long Duration Manned Space Flights, NASA-Office of Manned Space Flight, Washington, D. C., Nov. 17, 1966. pp. 16-19.

16-94. Fedderson, W. E., Reed, J., National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, unpublished data, 1967.

16-95. Fenno, R. M., Air Crew Conditioning for Long-Range Flight, Aerospace Med., 33: 447-452, Apr. 1962.

.6-96. Fiedler, F. E., Effect of Inter-Group Competition on Group Member Adjustment, Illinois Univ., Urbana, Ill, 1966. (AD-645-220).

.6-97. Findley, J. D., Migler, B. M., Brady, J. V., A Long-Term Study of Human Performance in a Continuously Programmed Experimental Environment, Univ of Maryland, College Park, Md., Nov. 1963.

6-98. Fischgold, H., Debt of Sleep, Air France, Paris, paper presented at Official Ceremony of the International Academy of Aviation and Space Medicine, 16th Congress of the International Astronautical Federation, Athens, Greece, Sept. 1965.

6-99. Flaherty, B. E., (ed.), Psychophysiological Aspects of Space Flight, Columbia Univ. Press, N. Y., 1961.

16-100. Flanagan, J. C., The Critical Incident Technique, Psychol. Bull., 51(4): 327-358, July 1954.

16-101. Flinn, D. E., Functional States of Altered Awareness during Flight, Aerospace Med., 36: 537-544, June 1965.

16-102. Folley, J. D., Jr., Altman, J. W., Guide to Design of Electronic Equipment for Maintainability, WADC-TR-56-218, Wright Air Development Center, Wright-Patterson AFB, Ohio, Apr. 1956.

16-103. Frank, G. S., Lange, H., Pavy, R., Circadian Cycles and Correlations among EEG Output, Discrimination Tests, Body Temperature and Other Physiological Functions in Normal Men, Neurology, 13(4): 359, 1963. (Abstract of paper presented at the 15th annual Mtg. of the Amer. Academy of Neurology. Minneapolis, Minn., Apr. 25-27, 1963).

16-104. Fraser, D. C., A Study of Fatigue in Aircrew. II. Comparison of The Effects of Day and Night Flying, FPRC-925, Flying Personnel Research Committee, Air Ministry, London, 1955.

16-105. Fraser, D. C., A Study of Fatigue in Aircrew. IV. Overview of the Problem, FPRC-984, Flying Personnel Research Committee, Air Ministry, London, 1957.

16-106. Fraser, D. C., Samuel, G. D., Aircrew Fatigue in Long Range Maritime Reconnaissance. 10. Effects on Vigilance, FPRC-907-10, Flying Personnel Research Committee, Air Ministry, London, 1956.

16-107. Fraser, T. M., An Overview of Confinement as a Factor in Manned Spaceflight, in Proceedings of the NASA Symposium on The Effects of Confinement on Long Duration Manned Space Flights, NASA-Office of Manned Space Flight, Washington, D. C., Nov. 17, 1966, pp. 1-7.

16-108. Fraser, T. M., The Effects of Confinement as a Factor in Manned Space Flight, NASA-CR-511, July, 1966.

16-109. Fraser, T. M., The Intangibles of Habitability during Long Duratior Space Missions, NASA-CR-1084, June 1968.

16-110. Freedman, S. J., Greenblatt, M., Studies in Human Isolation, WADC-TR-59-266, Wright Air Development Center, Wright-Patterson AFB, Ohio, Sept. 1959.

16-111. Freeman, G. L., Compensatory Reinforcements of Muscular Tension Subsequent to Sleep Loss, J. Exp. Psychol., 15: 267-283, 1932.

16-112. Freeman, G. L., Hovland, C. I., Diurnal Variation of Performance and Related Psychological Processes, Psychol. Bull., 31: 777-779, 1934.

16-113. French, J. D., Adey, W. R., Walter, D. O., Computer Analysis of EEG Data for a Normative Library, NASA-CR-65578, Apr. 1966.

16-114. Frohman, C. E., Luby, E. D., Some Biochemical Findings in Sleep Deprivation, in Symposium on Medical Aspects of Stress in the Military Climate, Washington, D. C., Apr. 22-24, 1964, pp. 203-213.

16-115. Fuchs, R. A., Experimenter's Design Handbook for the Manned Lunar Surface Program, HAC-SSD-60352R, Hughes Aircraft Co., El Segundo, Calif., Jan. 1967. (Prepared under NASA Contract NAS8-20244).

16-116. Gazenko, O. G., Medical Investigations of Spaceships Vostok and Voskhod, in Proceedings of 3rd International Symposium on Bioastronautics and the Exploration of Space, Brooks AFB Texas, Nov. 16-18, 1964, pp. 357-384. (AD-627686).

16-117. Gerritzen, F., Influence of Light on Human Circadian Rhythm, Aerospace Med., 37: 66-70, Jan. 1966.

16-118. Gifford, S., Murawski, B. J., Minimal Sleep Deprivation Alone and in Small Groups: Effects on Ego-Functioning and 24-Hour Body Temperature and Adrenocortical Patterns, in Symposium on Medical Aspects of Stress in the Military Climate, Washington, D. C., Apr. 22-24, 1964, pp. 157-185.

16-119. Glaser, R., Klaus, D. J., Reinforment Analysis of Group Performance, Psychol. Monogr., 80(13): 1-23, 1966.

16-120. Gorham, W. A., Orr, D. B., Trittipoe, T. G., Research on Behavior Impairment due to Stress; An Experiment in Long Term Performance, American Research Institute, Washington, D. C., 1958. (Prepared under Contract AF 41(657)-39).

16-121. Grande, F., Nutrition and Energy Balance in Body Composition Studies, in Techniques for Measuring Body Composition, Brozek, J., Henschel, A., (eds.), National Academy of Sciences, National Research Council, Washington, D. C., 1961, pp. 168-188. (AD-286506).

16-122. Graveline, D., Balke, B., McKenzie, R. E., et al., Psychobiologic Effects of Water Immersion Induced Hypodynamics, Aerospace Med., 32: 387-400, 1961.

16-123. Graybiel, A., Clark, B., Symptoms Resulting from Prolonged Immersion in Water, Aerospace Med., 32: 181-196, 1961.

16-124. Grodsky, M. A., An Investigation of Crew Performance during a Simulated Seven-Day Lunar Orbit Mission, Part I. Performance Results, RM-121, Martin Co., Baltimore, Md. 1962.

16-125. Grodsky, M. A., Bryant, J. P., Integrated Mission Simulation for Long Term Space Flight, Martin Co. Baltimore, Md., in Proceedings of AIAA Simulation for Aerospace Flight Conference, August, 1963.

16-126. Grodsky, M. A., Mandour, J., Roberts, D., et al., Crew Performance Studies for Manned Space Flight, Vol. I, II, III, ER-14141, Martin Co., Baltimore, Md., June 1966.

16-127. Grodsky, M. A., Roberts, D., Mandour, J., Test of Pilot Retention of Simulated Lunar Mission Skills, ER-14139, Martin Co., Baltimore, Md., Mar. 1966.

16-128. Gruber, A., Sensory Alternation and Performance in a Vigilance Task, Human Factors, 6: 3-12, Feb. 1964.

16-129. Grumman Aircraft Engineering Corp., Human Engineering Criteria for the Lunar Excursion Module, Bethpage, N. Y., (Draft), 1964.

16-130. Grumman Aircraft Engineering Corp., Human Engineering Design Criteria for LEM Ground Support Equipment, LED-480-8, Bethpage N. Y., Mar. 1, 1964.

16-131. Grumman Aircraft Engineering Corp., LEM Technical Specification, LSP-470-1, Bethpage, N. Y., June 7, 1965.

16-132. Grumman Aircraft Engineering Corp., Man System Locomotion and Display Criteria for Extraterrestrial Vehicles, NASA-CR-71757, Dec. 1965.

16-133. Guibert, A., Taylor, C. L., Radiation Area of the Human Body, AF-TR-7606, Wright-Patterson AFB, Ohio, Dec. 1951.

16-134. Gunderson, E. K. E., Adaptation to Extreme Environments, The Antarctic Volunteer, Rep. 66-4, Navy Medical Neuropsychiatric Research Unit, San Diego, Calif., Mar. 1966.

16-135. Gunderson, E. K. E., Adaptation to Extreme Environments, Prediction of Performance, Rep. 66-17, Navy Medical Neuropsychiatric Research Unit, San Diego, Calif., Apr. 1966.

16-136. Gunderson, E. K. E., Mahan, J. L., Cultural and Psychological Differences among Occuaptional Groups, J. Psychol., 62: 287-304, 1966.

16-137. Gunderson, E. K. E., Nelson, P. D., Adaptation of Small Groups to Extreme Environments, Aerospace Med., 34: 1111-1115, Dec. 1963.

16-138. Gunderson, E. K. E., Nelson, P. D., Criterion Measures for Extremely Isolated Groups, Rep. 65-6, Navy Medical Neuropsychiatric Research Unit, San Diego, Calif., Mar. 1965. (Also in Personnel Psychol., 19(1): 67-80, Spring, 1966).

16-139. Gustafson, D. P., Comparison of Role Differentiation in Several Situations, SU-62-TR-15, Stanford Univ., Calif., Dec. 1966. (AD-646768).

16-140. Haaland, J. E., Man System Criteria For Extraterrestrial Roving Vehicles, NASA-CR-78245, June 1966.

16-141. Halberg, F., Organisms as Circadian Systems; Temporal Analysis of Their Physiologic and Pathologic Responses Including Injury and Death, in Symposium on Medical Aspects of Stress in the Military Climate, Washington, D. C., Apr. 22-24, 1964, pp. 1-38.

16-142. Halberg, F., Physiologic 24-Hour Periodicity, Z. Vitam Hormon Fermentforsch., 10: 225, 1959.

16-143. Hanavan, E. P. Jr., A Mathematical Model of the Human Body, AMRL-TR-64-102, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Oct. 1964.

16-144. Hanna, T. D., Gaito, J., Performance and Habitability Aspects of Sealed Cabins, Aerospace Med., 31: 399-406, 1960.

16-145. Hansen, R., Cornog, D. Y., Hertzberg, H. T. E., Annotated Bibliography of Applied Physical Anthropology in Human Engineering, WADC-TR-56-30, Wright Air Development Center, Wright-Patterson AFB, Ohio, May 1958.

16-146. Harris, S. J., The Effects of Sleep Loss on Component Movements of Human Motion, J. Appl. Psychol., 44(1): 50-55, Feb. 1960.

16-147. Hartman, B. O., Cantrell, G. K., MOL: Crew Performance on Demanding Work/Rest Schedules Compounded by Sleep Deprivation, SAM-TR-67-99, School of Aerospace Medicine, Brooks AFB, Texas, Nov. 1967.

16-148. Hartman, B. O., Langdon, D. E., Second Study on Performance upon Sudden Awakening, SAM-TR-65-61, School of Aerospace Medicine, Brooks AFB, Texas, Aug. 1966.

16-149. Hartman, B. O., Langdon, D. E., McKenzie, R. E., Third Study on Performance upon Sudden Awakening, SAM-TR-65-63, School of Aerospace Med., Brooks AFB, Texas, Aug. 1965.

16-150. Hartman, E. L., The D-State: A Review and Discussion of Studies on the Physiological State Concomitant with Dreaming, New Eng. J. Med., 273: 30-35, July 1965.

16-151. Harvey, O. J., Ware, R., Personality Differences in Dissonance Resolution, Rep. TR-18, Univ. of Colorado, Boulder, Colo., Oct. 1966. (AD-641-511).

16-152. Hauty, G. T., Adams, T., Phase Shifts of the Human Circadian System and Performance Deficit during the Periods of Transition. I. East-West Flight, AM-65-28, Federal Aviation Agency, Office of Aviation Medicine, Oklahoma City, Okla., Dec. 1965. (Also in Aerospace Med., 37: 668-674, July 1966).

16-153. Hauty, G. T., Adams, T., Phase Shifts of the Human Circadian System and Performance Deficit during the Periods of Transition. II. West-East Flight, AM-65-29, Federal Aviation Agency, Office of Aviation Medicine, Oklahoma City, Okla., Dec. 1965. (Also in Aerospace Med., 37: 1027-1033, Oct. 1966).

16-154. Hauty, G. T., Adams, T., Phase Shifts of the Human Circadian System and Performance Deficit during the Period of Transition. III. North-South Flight, AM-65-30, Federal Aviation Agency, Office Aviation Medicine, Oklahoma City, Okla., Dec. 1965.

16-155. Haythorn, W. W., Alone Together, Naval Medical Research Institute, Bethesda, Md., 1966. (AD-641-288).

16-156. Haythorn, W. W., Compatability in Isolated Groups, Naval Medical Research Institute, Bethesda, Md., (no date).

16-157. Haythorn, W. W., Project ARGUS, 1967: Five Year Review and Preview, NMRI-MF-022.-1.03-1002, Rep. 31, Naval Medical Research Institute, Bethesda, Md., Aug. 1967.

16-158. Haythorn, W. W., Social Emotional Considerations in Confined Groups, in Proceedings of the NASA Symposium on the Effects of Confinement on Long Duration Manned Space Flights, NASA-Office of Manned Space Flight, Washington, D. C., Nov. 17, 1966, pp. 8-15.

16-159. Haythorn, W. W., Altman, I., Personality Factors in Isolated Environments, in Psychological Stress, Issues in Research, Appley, M. H., Trumbull, R., (eds.), Appleton-Century-Croft, N. Y., 1966, pp. 363-399.

16-160. Haythorn, W. W., Altman, I., Myers, T. I., Emotional Symptomatology and Stress in Isolated Groups 1, 2, Naval Medical Research Institute, Bethesda, Md., 1964.

16-161. Heitz, R. M., Jones, G. W., Research on Closed-Cell Sponge as a Pressure Technique for Protective Assemblies, AMRL-TR-66-183, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Feb. 1967.

16-162. Hertzberg, H. T. E., Dynamic Anthropometry of Working Positions, Human Factors, 2: 147-155, 1960.

16-163. Hertzberg, H. T. E., Some Contributions of Applied Physical Anthropology to Human Engineering, WADD-TR-60-19, Wright Air Development Div., Wright-Patterson AFB, Ohio, Jan. 1960.

16-164. Hertzberg, H. T. E., Clauser, C., Size and Motion, in Bioastronautic Data Book, Webb, P., (ed.), NASA-Sp-3006, 1964, Sect. 14, pp. 241-271.

16-165. Hertzberg, H. T. E., Daniels, G. S., Churchill, E., Anthropometry of Flying Personnel-1950, WADC-TR-52-321, Wright Air Development Center, Wright-Patterson AFB, Ohio, Sept. 1954.

16-166. Hobson, J. A., Goldfrank, F., Snyder, F., Respiration and Mental Activity in Sleep, J. Pschiat. Res., 3: 79-90. 1965.

16-167. Holt, R. R., Goldberger, L., Personological Correlates of Reactions to Perceptual Isolation, WADC-TR-59-735, Wright Air Development Center, Wright-Patterson AFB, Ohio, Nov. 1959.

16-168. Honigfeld, A. R., Group Behavior in Confinement: Review and Annotated Bibliography, AHEL-TM-14-65, Army Human Engineering Labs., Aberdeen Proving Ground, Md., Oct. 1965.

16-169. Hooton, E. A., A Survey in Seating, Heywood-Wakefield Co., Gardner, Mass., 1945.

16-170. Hudson, B. B., Searle, L. V., Effect of Sleep Deprivation upon Performance, USN, NDRC Contract OEM-SR-581, Rep. 4, 1942.

16-171. Hunsicker, P. A., Arm Strength at Selected Degrees of Elbow Flexion, WADC-TR-54-548, Wright Air Development Center, Wright-Patterson AFB, Ohio, Aug. 1955.

16-172. Hunsicker, P. A., A Study of Muscle Forces and Fatigue, WADC-TR-57-586, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1957.

16-173. Husband, R. W., The Comparative Value of Continuous vs. Interrupted Sleep, J. Exp. Psychol., 18: 792-796, 1935.

16-174. Husserl, E., The Phenomenology of Internal Time-Consciousness, Indiana Univ. Press., Bloomington, 1964. (Translation of Husserl's Vorlesungen zur Phanomenologie des Inneren Zeitbewusstseins by James S. Churchill and edited by Martin Heidegger).

16-175. Ivanov-Muromskiy, K. A., Electronarcosis and Electrosleep in Man and Animals, JPRS-42233, Joint Publications Research Service, Washington, D. C., Aug. 1967. (Translation of book entitled Electricheskiy Narkoz i Elektroson Cheloveka i Zhivotnykh, Ivanov-Muromskiy, K. A., Naukova Dumka Publishing House, Kiev, 1966).

16-176. Ivanov-Muromskiy, K. A., Treatment of Disorders of the Nervous System by Electrically Induced Sleep, JPRS-31347, Joint Publications Research Service, Washington, D. C., Aug. 1965. (Translation of Splyachyy Mozok, 1964, pp. 64-76).

16-177. Iwanovksy, A., Dodge, C. H., Electrosleep and Electroanesthesia, Theory and Clinical Experience, Foreign Science Bulletin, 4(2): 1-64, Feb. 1968.

16-178. Jackson, G. A., Measuring Human Performance with a Parameter Tracking Version of the Crossover Model, NASA-CR-910, Oct. 1967.

16-179. Jarvis, C. R., Flight-Test Evaluation of an On-Off Rate Command Attitude Control System of a Manned Lunar Landing Research Vehicle, NASA-TN-D-3903, Apr. 1967.

16-180. Jensen, D. R., (ed.), Symposium on Electroanesthesia, Colorado State Univ., Fort Collins, Colo., Mar. 30, 1964.

16-181. Johnson, L. B., Havener, P. W., Experimental Research Studies on Tools for Extravehicular Maintenance in Space, Phase II Final Report, NASA-CR-91052, Aug. 31, 1967.

16-182. Johnston, W. A., Howell, W. C., Effect of Team Feedback on Individual Performance and Self-Evaluation, AFOSR-66-1948, Air Force Office of Scientific Research, Washington, D. C., Sept. 1966. (AD-640-404).

16-183. Joint Publications Research Service, Electrosleep and Electroanesthesia (Electronarcosis), JPRS-40444, Washington, D. C., Mar. 1967. (Translation of book entitled Electroson i Elektroanesteziya (Elektronarkoz), Moscow, 1966, (6 Parts).)

16-184. Jones, K. C., Human Engineering Design Criteria Handbook for Lunar Scientific Equipment, NASA-CR-77348, Apr. 3, 1966.

16-185. Jones, R. L., Evaluation and Comparison of Three Space Suit Assemblies, NASA-TN-D-3482, July 1966.

16-186. Jouvet, J., Behavioural and EEG Effects of Paradoxical Sleep Deprivation in the Cat, in Proceedings of the International Union of Physiological Sciences, 23rd International Congress, Tokyo, 1965, Lectures and Symposia, Excerpta Medica Foundation, 1965, pp. 344-353.

16-187. Jouvet, M., Paradoxical Sleep, A Study of Its Nature and Mechanisms, Prog. in Brain Res., 18: 20-62, 1965.

16-188. Jouvet, M., Study of the Duality of States of Sleep and of the Mechanisms of the Paradoxical Phase, in Editions Du Centre National De La Recherche Scientifique, 1965, pp. 397-449.

16-189. Keller, T., Breul, H., Weston, R., et al., Hands-Free Precision Control for EVA, An Exploratory Study, NASA-CR-73105, Jan. 1967.

16-190. Kelloway, P., Experiment M-8, Inflight Sleep Analysis, in Gemini Midprogram Conference Including Experiment Results, NASA-Manned Spacecraft Center, Houston, Texas, Feb. 23-25, 1966, NASA-SP-121, 1966, pp. 423-429.

16-191. Kenna, J. C., Sensory Deprivation Phenomena; Critical Review and Explanatory Models, Proc. Roy. Soc. Med., 55: 1005-1010, Dec. 1962.

16-192. Kennedy, K. W., Reach Capability of the USAF Population, Phase I. The Outer Boundaries of Grasping-Reach Envelopes for the Shirt-Sleeved, Seated Operator, AMRL-TDR-64-59, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, 1964.

16-193. Kleitman, N., Modifiability of the 24-Hour Periodicities, in Sleep and Wakefulness, Kleitman, N., Univ. of Chicago Press, Chicago, 1963, Chapt. 18, pp. 172-184.

16-194. Kleitman, N., The Sleep-Wakefulness Cycle of Submarine Personnel in A Survey Report on Human Factors in Undersea Warfare, National Research Council Panel on Psychology and Physiology Report, Washington, D. C., 1949, pp. 329-341.

16-195. Kleitman, N., Mullin, F. J., Cooperman, N. R., Sleep Characteristics, Univ. of Chicago Press, Chicago, 1937, p. 86.

16-196. Kosmolinskiy, F. P., The Problem of Sensory Deprivation in Space Medicine, in Space Biology and Medicine, Vol. I(4), 1967, JPRS-43726, Joint Publication Research Service, Washington, D. C., Dec. 1967, pp. 1-13. (Translation of Kosmicheskaya Biologiya i Meditsina, 1(4): 3-11, 1967.

16-197. Kulwicki, P. V., Schlei, E. J., Weightless Man: Self-Rotational Techniques, AMRL-TDR-62-129, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Oct. 1962. (AD-400354).

16-198. Kuzin, M. I., Zhukovskiy, V. D., Sachkov, V. I., Use of Inter-Ferential Currents in Combined Anaesthesia in Surgery, NASA-TT-F-10090, Apr. 1966. (Translation of Primeneniye Interferentsionnykh Tokov v Kombinirovannom Obezbolivanii Pri Khururgicheskikh Operatsiyakh).

16-199. Lafontaine, E., Lavernhe, J., Courillon, J., et al., Influence of Air Travel East-West and Vise-Versa on Circadian Rhythms of Urinary Elimination of Potassium and 17-Hydroxycorticosteroids, Aerospace Med., 38: 944-947, Sept. 1967.

16-200. Lavernhe, J., Lafontaine, E., Laplane, R., The Subjective Effects of the Time Shift (Poll Taken among the Flight Personnel of Air France), NASA-TT-F-11370, Nov. 1967. (Translation of Les Effets Subjectifs des Decalages Horaires (Une Enquete Aupres du Personnel Navigant d'Air-France), Rev. Med. Aeron., 4(15): 30-36, 1965.

16-201. Lay, W. E., Fisher, L. D., Riding Comfort, SAE Trans., 47: 482-496, 1940.

16-202. Lebedinskiy, A. V., Levinskiy, S. V., Nefedov, Y. G., General Principles Concerning the Reaction of the Organism to the Complex Environmental Factors Existing in the Spacecraft Cabins, NASA-TT-F-273, 1964.

16-203. Leiderman, P. H., Stern, R., Selected Bibliography of Sensory Deprivation and Related Subjects, ASD-TR-61-259, Aeronautical Systems Div., Wright-Patterson AFB, Ohio, July 1961.

16-204. Lindhard, J., Investigations into the Conditions Governing Temperature of the Body, Denmark Expedition to the North Shore of Greenland, 1910, pp. 75-175.

16-205. Ling-Temco-Vought, Inc., NASA Lunar Module Visual Simulation Study, Vol. I. Lunar Mission Descent, Ascent, and Rendezvous, LTV-00.884 (Vol. I), Astonautics Div., Dallas, Texas, Dec. 21, 1966. (Prepared under NASA Contract NAS-9-4746).

16-206. Litton Systems, Inc., The Litton Extravehicular and Lunar Surface Suit, Pub. 4653, (SSL 66:01), Space Sciences Labs., Beverly Hills, Calif., Jan. 1966.

16-207. Loats, H. L. Jr., Bruchey, W. J. Jr., A Study of the Performance of an Astronaut during Ingress and Egress Maneuvers through Airlocks and Passageways, NASA-CR-971, Apr. 1968.

16-208. Loats, H. L. Jr., Mattingly, G. S., Brush, C. E., A Study of the Performance of an Astronaut during Ingress and Egress Maneuvers through Airlocks and Passageways, Final Report, Phase I, ERA-64-6, NASA-CR-66340, Aug. 1964; NASA-CR-66341, Vol. I - Summary, Final Report, Phase II, ERA-65-3, Apr. 1965; NASA-CR-66342. Vol II. Technical Discussions, Final Report, Phase II, ERA-65-3, Apr. 1965; NASA-CR-66343, Vol. III, Appendices, Final Report, Phase II, ERA-65-3, Mar. 1965. (Prepared under NASA Contract NAS1-4059, Environmental Research Associates, Randallstown, Md.).

16-209. Lorenz, K., On Agression, Harcourt, Brace & World, Inc., N. Y., June 1966.

16-210. Luby, E. D., Biochemical, Psychological and Behavioral Responses to Sleep Deprivation, Ann. N. Y. Acad. Sci., 96: 71-79, 1962.

16-211. Luce, G. G., McGinty, D., Current Research on Sleep and Dreams, PHS-1389, National Institute of Mental Health, Bethesda, Md., 1965.

16-212. Luce, T. S., Vigilance as a Function of Stimulus Variety and Response Complexity, Human Factors, 6: 101-110, Feb. 1964.

16-213. McCormick, E. J., Human Factors Engineering, McGraw-Hill, N. Y., 1964.

16-214. McFarland, R. A., Damon, A., Stoudt, H. W. Jr., Anthropometry in the Design of the Driver's Workspace, Amer. J. Phys. Anthrop., 16: 1-23, 1958.

16-215. McGrath, S. D., Wittkower, E. D., Gleghorn, R. A., Some Observations on Aircrew Fatigue in the RCAF--Tokyo Airlift, J. Aviat. Med., 25: 23-37, 1954.

16-216. Machell, R. M., (ed.), Summary of Gemini Extravehicular Activities, NASA-SP-149, 1967.

16-217. Malik, P. W., Souris, G. A., Project Gemini, A Technical Summary, NASA-CR-1106, June 1968.

16-218. Maloney, J. A., Man-Rated Chamber Considerations for Simulation Tests of Gemini Spacecraft, in AIAA Space Simulation Testing Conference, Pasadena, Calif., Nov. 16-18, 1964, AIAA-CP-11, 1964, pp. 52-59.

16-219. Meuwese, W., Fiedler, F. E., Leadership and Group Creativity under Varying Conditions of Stress, IU-TR-22, Illinois Univ., Urbana, Ill., Mar. 1965. (AD-616-327).

16-220. Michon, J. A., Studies on Subjective Duration. I. Differential Sensitivity in the Perception of Repeated Temporal Intervals, Acta Psychologica, 22: 441-450, 1964.

16-221. Mills, J. N., Diurnal Rhythm in Urine Flow, J. Physiol. (London), 113: 528-536, 1951.

16-222. Mills, J. N., Stanbury, S. W., Persistent 24-Hour Renal Excretory Rhythm on a 12-Hour Cycle of Activity, J. Physiol. (London), 117: 22-37, 1952.

16-223. Moran, J. A., Tiller, P. R., Investigation of Aerospace Vehicle Crew Station Criteria, FDL-TDR-64-86, Flight Dynamics Lab., Wright-Patterson AFB, Ohio, July 1964. (AD-452187).

16-224. Morgan, C. T., Cook, J. S., Chapanis, A., Lund, M. W., (eds.), Juman Engineering Guide to Equipment Design, McGraw-Hill, N. Y., 1963.

16-225. Morrell, F., Morrell, L. D., Electrophysiological Correlates of Vigilance and Learning, NASA-CR-85843, 1967.

16-226. Mouret, J., Jeannerod, J., Jouvet, M., Action of the Oculomotor System during Sleep, Confin. Neurol., 25: 291-299, 1965.

16-227. Musgrave, P. W., Carter, D. I., Aerospace Medicine Considerations in Manrating Space Environment Simulators, AMD-TR-66-2, Aerospace Medical Div., Brooks AFB, Texas, June 1966.

16-228. Myers, T. I., Murphy, D. B., Smith, S., et al., Experimental Studies of Sensory Deprivation and Social Isolation, HUMRRO-TR-66-8, Human Resources Research Office George Washington Univ., Washington, D. C., June 1966.

16-229. Nahum, L. H., Circadian Cycles in Man: The Dream Cycles, Conn. Med., (Editorials); 29(9): 626, 629, 630, Sept. 1965.

16-230. National Aeronautics and Space Administration, Effects of Confinement, Bibliography, 1958 - Aug. 1963, Bib. No. 255, Part I, Washington D. C., Aug. 1963.

16-231. National Aeronautics and Space Administration, Gemini Summary Conference, Manned Spacecraft Center, Houston, Texas, Feb. 1-2, 1967, NASA-SP-138, 1967.

16-232. National Aeronautics and Space Administration, Human Engineering Design Criteria for Spacecraft Systems GSE (General Specification), NASA-MC-999-0017B, Manned Spacecraft Center, Houston, Texas, July 9, 1964.

16-233. National Aeronautics and Space Administration, Human Engineering Design Criteria, Reference Abstracts, NASA-MSFC-10M01827, George C. Marchall Space Flight Center, Huntsville, Ala., Nov. 1966.

16-234. National Aeronautics and Space Administration, Human Factors Engineering Program Standard, NASA-MSFC-STD-391, George C. Marshall Space Flight Center, Huntsville, Ala., July 28, 1965.

16-235. National Aeronautics and Space Administration, Preliminary Technical Data for Earth Orbiting Space Station; Vol. 2. Standards and Criteria, NASA-MSC-EA-R-66-1, Manned Spacecraft Center, Houston, Texas, Nov. 19, 1966.

16-236. National Aeronautics and Space Administration, Proceedings of the NASA Symposium on the Effects of Confinement on Long Duration Manned Space Flights, Parts I and II. Office of Manned Space Flight, Space Medicine, NASA, Washington, D. C., Nov. 17, 1966.

16-237. National Aeronautics and Space Administration, Selected Papers on Environmental and Attitude Control of Manned Spacecraft, NASA-TM-X-1325, Dec. 1966.

16-238. National Aeronautics and Space Administration, 3rd Annual NASA - University Conference on Manual Control, Los Angeles, Calif., Mar. 1-3, 1967, NASA-SP-144, 1967.

16-239. Naval Material Command, Washington, D. C., National Academy of Engineering, Washington, D. C., Proceedings of Symposium on Human Performance Quantification in Systems Effectiveness, Washington, D. C., Jan. 17-18, 1967. (AD-650791).

16-240. Nelson, P. D., Gunderson, E. K. E., Effective Individual Performance in Small Antarctic Stations: A Summary of Criterion Studies, NMNRU-63-8, Navy Medical Neuropsychiatric Research Unit, San Diego, Calif., Apr. 1963.

16-241. Newman, R. W., White, R. M., Reference Anthropometry of Army Men Rep. 180, Army Quartermaster Research and Development Center, Natick, Mass., 1951.

16-242. Nordtvedt, K. Jr., A Theory of Manual Space Navigation, NASA-CR-841, July 1967.

16-243. North American Aviation, Inc., Apollo Command and Service Module System, Specification (Block I), NAA-SID-63-313, Downey, Calif., Feb. 1965.

16-244. North American Aviation, Inc., CSM Master End Item Specification Block II (U), NAA-SID-64-1345, Space and Information Systems Division, Feb. 22, 1965. (Prepared under NASA Contract NAS9-150).

16-245. North American Aviation, Inc., CSM Technical Specification (Block II), NAA-SID-64-1344, Downey, Calif., Nov. 1964.

16-246. North American Aviation, Inc., General Specification: Human Engineering Design Criteria for Spacecraft Systems, Downey, Calif., Sept. 1962.

16-247. North American Aviation, Inc., Lunar Excursion Module Performance and Interface Specification (Block II) NAA-SID-62 1244, Downey, Calif., Feb. 1965.

16-248. North American Aviation, Inc., Training Plan Block 1/11, NASA CR-81847 Pt. 1 and 2, NAA-SID-65-1408, Pt. 1 and 2, Space and Information Systems Div., Huntington Beach, Calif., July 30, 1966. (Prepared under NASA Contract NAS9-150).

16-249. Omwake, K. T., Effect of Varying Periods of Sleep on Nervous Stability, J. Appl. Psychol., 16: 623-632, 1932.

16-250. Orne, M. T., Scheibe, K. E., The Contribution of Nondeprivation Factors in the Production of Sensory Deprivation Effects: The Psychology of the "Panic Button", AFOSR-64-0826, Air Force Office of Scientific Res., Washington, D. C., 1964. (Also in J. Abnorm. Soc. Psychol., 68(1): 3-12, 1964).

16-251. Panferova, N. Ye., The Diurnal Rhythm of Functions of Humans in Conditions of Limited Mobility, FTD-TT-65-1994 Foreign Technology Div., Wright-Patterson AFB, Ohio, Nov. 1966. (AD-646291).

16-252. Parin, V. V., Volynkin, Yu. M., Vassilyev, P. V., Manned Space Flight (Some Scientific Results), presented at COSPAR Symposium, Florence, Italy, May, 1964.

16-253. Pascale, L. R., Grossman, M. I., Sloane, H. S., et al., Correlations between Thickness of Skin-Folds and Body Density in 88 Soldiers, Human Biol., 28 (2): 165-176, May 1956.

16-254. Patrick, G. T. W., Gilbert, J. A., On the Effects of Loss of Sleep, Psychol. Rev., 3: 469-483, 1896.

16-255. Patton, R. M., Preventive and Remedial Measures Related to Crew Activities and Performance, in Proceedings of the NASA Symposium on the Effects of Confinement on Long Duration Manned Space Flights, NASA-Office of Manned Space Flight, Washington, D. C., Nov. 17, 1966, pp. 27-32.

16-256. Paul, A., Effects of Sleep Deprivation on Visual Function, Aerospace Med., 36: 617-620, July 1965.

16-257. Pew, R. W., Recent Psychological Research Relevant to the Human Factors Engineering of Man Machine Systems, AFOSR-67-1824, Air Force Office of Scientific Research, Arlington, Va., Aug. 1967. (Also in the Proceedings of the National Electronics Conference, Chicago, Ill., Oct. 1965).

16-258. Peterson, R. L., Personnel Seating Research for Air Force Aerospace Vehicles, SAE-851C, presented at the Air Transport and Space Meeting, N. Y., Apr. 27-30, 1964, Society of Automotive Engineers, Inc., N. Y., 1964.

16-259. Petersen, T. K., Jencks, H. S., Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept. Vol. XI: Laboratory Configuration and Interiors, DAC-SM-46082, Douglas Aircraft Co., Inc., Santa Monica, Calif., Sept. 1964.

16-260. Pittendrigh, C. S., Perspective in the Study of Biological Clocks, in Symposium on Perspectives in Marine Biology, Univ. of California Press, Berkeley, Calif., 1960, pp. 239-268.

16-261. Polimanti, O., Sopra la Possibilita di Rena Inversione Della Temperatura, Z. allg. Physiol., 16: 506-512, 1914.

16-262 Rabideau, G. F., Semple, C. A. Jr., Human Engineering Support to Air Force Flight Control and Flight Display Integration Program, The Bunker-Ramo Corp., N. Y., Mar. 1966. (Prepared under Contract AF-33(657)-8600).

16-263. Randall, F. E., Damon, A., Benton, R. S., et al., Human Body Size in Military Aircraft and Personnel Equipment, AF-TR-5501, Wright-Patterson AFB, Ohio, 1946.

16-264. Rasmussen, J. E., Selection and Effectiveness Considerations Arising from Enforced Confinement of Small Groups, in 2nd Manned Space Flight Meeting, NASA/AIAA, Dallas, Texas, Apr. 22-24, 1963, pp. 114-119.

16-265. Rathert, G. A., Minimum Crew Space Habitability for the Lunar Mission, ARS-2644-62, NASA-Ames Res. Center, Moffett Field, Calif., paper presented at the American Rocket Society 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., Nov. 13-18, 1962.

16-266. Rathert, G. A., McFadden, N. M., Weick, R. F., et al., Minimum Crew Space Habitability for the Lunar Mission, NASA-TN-D-2065, Feb. 1964.

16-267. Ray, J. T., Martin, O. E. Jr., Alluisi, E. A., Human Performance as a Function of the Work-Rest Cycle; A Review of Selected Studies, NAS-NRC-882, National Academy of Sciences, Nation Research Council, Washington, D. C., 1961.

16-268. Remond, A., Treatment of Information on the Electrical Activity of the Brain, Vie. Med., 46: 21-34, 1965. (Text in French).

16-269. Rhodes, J. M., Reite, M. R., Brown, D., et al., Cortical Subcortical Relationships of the Chimpanzee during Different Phases of Sleep, in Editions Du Centre National de la Recherche Scientifique, 1965, pp. 451-473.

16-270. Richardson, D. L., Research to Advance Extravehicular Protective Technology, AMRL-TR-66-250, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Apr. 1967.

16-271. Rickles, W. H. Jr., Study of EEG and Somatovegetative Physiology of the Immature Chimpanzee during Sleep, ARL-TR-65-19, Aeromedical Research Lab., Holloman AFB, N. M. Sept. 1965.

16-272. Riley, D. R., Suit, W. T., A Simulator Study of Pilot Control of Remote Orbital Docking of Large Attitude-Stabilized Components, NASA-TN-D-4263, Dec., 1967.

16-273. Roby, T. B., Nickerson, R. S., Steps toward Computer Simulation of Small Group Behavior, ESD-TDR-63-629, Electronic Systems Division, L. G. Hanscom Field, Mass., 1963.

16-274. Roffwarg, H. P., Dement, W. C., Muzio, J. N., et al., Dream Imagery: Relationship to Rapid Eye Movements of Sleep, Arch. Gen. Psychiat., 7: 235-258, 1962.

16-275. Ross, J. J., Neurological Findings after Prolonged Sleep Deprivation, Arch. Neurol., 12: 399-403, 1965.

16-276. Roth, E. M., Rapid (Explosive) Decompression Emergencies in Pressure-Suited Subjects, Lovelace Foundation for Medical Education and Research, Albuquerque, N. M., Mar. 12, 1968. (Prepared under NASA Contract NASr-115).

16-277. Ruff, G. E., Levy, E. Z., Thaler, V. H., Studies of Isolation and Confinement, Aerospace Med., 30: 599-604.

16-278. Sage, A. P., Justice, K. E., Melsa, J. L., Study and Research on Electronic Simulation of the Biological Clock II, ASD-TDR-63-136, Aeronautical Systems Div., Wright-Patterson AFB, Ohio, May 1963.

16-279. Santischi, W. R., DuBois, J., Omoto, C., Moments of Inertia and Centers of Gravity of the Living Human Body, AMRL-TDR-63-36, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, May 1963.

16-280. Schaefer, K. E., Clegg, B. R., Carey, C. R., et al., Effect of Isolation in a Constant Environment on Periodicity of Physiological Functions and Performance, NSMC-488, Naval Submarine Medical Center, Groton, Conn., Feb. 1967. (Joint NASA/Navy Report).

16-281. Schlei, E. J., Vergamini, P. L., On the Rotational Mechanics of a Weightless Man, Memo 156, University of Dayton Research Institute, Dayton, Ohio, Nov. 1961.

16-282. Schuerch, H., Some Considerations of Manned Extravehicular Activities in Assembly and Operation of Large Space Structures, NASA-CR-871, Sept. 1967.

16-283. Schwartz, B. K., An Investigation of the Effects of Isolation on Time Perception and Its Physiological Correlates, NADC-MR-6718, Naval Air Development Center, Johnsville, Warminster, Pa., Nov. 1967.

16-284. Sells, S. B., Military Small Group Performance under Isolation and Stress; Critical Review. I. Informal, Natural Groups, Development, Structure and Function, AAL-TDR-62-31, Arctic Aeromedical Lab., Fort Wainwright, Alaska, June 1962.

16-285. Sells, S. B., Military Small Group Performance under Isolation and Stress; Critical Review. II. Dimensions of Group Structure and Group Behavior, AAL-TDR-62-32, Arctic Aeromedical Lab., F. Wainwright, Alaska, June 1962.

16-286. Sells, S. B., Military Small Group Performance under Isolation and Stress; Critical Review. III. Environmental Stress and Behavior Ecology, AAL-TDR-62-33, Arctic Aeromedical Lab., Fort Wainwright, Alaska, June 1962.

16-287. Sells, S. B., Military Small Group Performance under Isolation and Stress; Critical Review. IV. Selection Indoctrination, and Training for Arctic Remote Duty, AAL-TDR-62-34, Arctic Aeromedical Lab., Ft. Wainwright, Alaska, June 1962.

16-288. Sells, S. B., Military Small Group Performance under Isolation and Stress; Critical Review. V. Psychological Principles of Management and Leadership, AAI-TDR-62-35, Arctic Aeromedical Lab., Ft. Wainwright, Alaska, June 1962.

16-289. Sells, S. B., A Model for the Social Sy stem for the Multi-Man Extended Duration Space Ship, NASA-CR-76330, 1965. (Also in Aerospace Med., 37: 1130-1135, Nov. 1966).

16-290. Seminara, J. L., Lunar Simulation, LMSC-679964, Lockheed Missiles and Space Co., Sunnyvale, Calif., Dec. 1967.

16-291. Sendroy, J. Jr., Collison, H. A., Nomogram for the Determination of Human Body Surface Area from Height and Weight, NMRI-2, Naval Medical Research Institute, Bethesda, Md., July 1960. (Also in J. Appl Physiol., 15: 958-959, 1960).

16-292. Serendipity Associates, A Descriptive Model for Determining Optimal Human Performance in Systems, Vols. 1, 2, 3, and 4, NASA-CR-876, 877, 878, and 879, Chatsworth, Calif., Jan. 1968. (Prepared under NASA Contract NAS-2-2955).

16-293. Shaw, J. W., The Effect of Continued Performance in a Task of Air Traffic Control, FPRC-883, Flying Personnel Research Committee, Air Ministry, London, 1954.

16-294. Sheldon, W. S., Stevens, S. S., Tucker, W. B., The Varieties of Human Physique, Harper & Bros., N. Y., 1940.

16-295. Siegel, A. I., Lanterman, R. S., Intano, G. P., Human Engineering Aspects of Control Design for Pressure Suited Operators, NAEC-ACEL-546, Naval Air Engineering Center, Philadelphia, Pa., May 1967.

16-296. Slonim, A. R., Effects of Minimal Personal Hygiene and Related Procedures during Prolonged Confinement, AMRL-TR-66-146, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Oct. 1966.

16-297. Smith, P. G., Kane, T. R., The Reorientation of a Human Being in Free Fall, NASA-CR-86671, May 1967.

16-298. Smith, R. E., Circadian Variation in Human Heat Conductance, AAL-TR-67-6, Arctic Aeromedical Lab., Ft. Wainwright, Alaska, May 1967.

16-299. Smith, R. H., Electrical Anesthesia, Charles C. Thomas, Springfield, Ill., 1963.

16-300. Smith, R. H., Electronarcosis by a Combination of Direct and Alternating Current, Univ. of California Medical Center, San Francisco, Calif., Mar. 1965. (AD-460-394).

16-301. Smith, R. L., Monotony and Motivation: Theory of Vigilance, Dunlap and Associated, Inc., Santa Monica, Calif., June 1966. (AD-801-690).

16-302. Smith, R. M., Analysis and Design of Space Vehicle Flight Control Systems. Vol. X. Man in the Loop, NASA-CR-829, July 1967.

16-303. Smith, R. P., Warm, J. S., Alluisi, E. A., Effects of Temporal Uncertainty on Watchkeeping Performance, Percep. Psychophysics, 1: 293-299, 1966.

16-304. Smith, S., Development of a Complex, Time-Shared, Perceptual-Motor Skills Task for Use in Studies of Isolation and Confinement, Proj. No. MF-22.1.3-1002-15, Naval Medical Research Institute, Bethesda, Md., Aug. 1966.

16-305. Smith. W. M., Observation over the Lifetime of a Small Isolated Group: Structure, Danger, Boredom, and Vision, Psychological Reports, 19 (Monograph Suppl. 3): 475-514, 1966.

16-306. Snyder, F., Autonomic Nervous System Manifestations during Sleep and Dreaming, presented at Assoc. for Research in Nervous and Mental Disease, Annual Meeting, N. Y., Dec., 14, 1965.

16-307. Sollberger, A., Studies of Temporal Variations in Biological Variables, in Fifth International Conference, Society of Biological Rhythm (Suppl.), Stockholm, Sweden, 1961, pp. 186.

16-308. Solomon, P., Kubzansky, P. E., Leiderman, P. H., et al., (eds.), Symposium on Sensory Deprivation, Harvard Medical School, Cambridge, Mass, June 20-21, 1958, Harvard Univ. Press, 1965.

16-309. Spady, A. A. Jr., Krasnow, W. D., Exploratory Study of Man's Self-Locomotion Capabilities with a Space Suit in Lunar Gravity, NASA-TN-D-2641, July 1966.

16-310. Staples, M. L., A Bibliographical Survey and Critical Review of the Role of Anthropometry in the Sizing of Clothing and Personal Equipment, DRB-EP-10, Defence Research Board, Environmental Protection Section, Ottawa, Canada, June 1966.

16-311. Steinkamp, G. R., Hawkins, W. R., Hauty, G. T., et al., Human Experimentation in the Space Cabin Simulator: Development of Life Support Systems and Results of Initial Seven-Day Flights, SAM-TR-59-101, School of Aviation Medicine, Brooks AFB, Texas, Aug. 1959.

16-312. Stern, R. M., Electrophysiological Effects of Short-Term Sensory Deprivation, Rep. 9, Indiana Univ., Bloomington, Ind., Nov. 1963. (AD-437-810).

16-313. Stevenson, S. A., Trygg, L. E., Bibliography of Reports Issue by the Behavioral Sciences Lab., Engineering Psychology, Training Psychology, Environmental Stress, Simulation Techniques, and Physical Anthropology, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, June 1966.

16-314. Strughold, H., The physiological Clock in Aeronautics and Astronautics, Ann. N. Y. Acad. Sci., 134 Art. I: 413-422, Nov. 22, 1965.

16-315. Strughold, H., The Physiological Day-Night Cycle in Global Flights, SAM-SR-9, School of Aviation Medicine, Brooks AFB, Texas, Oct. 1952.

16-316. Suedfeld, P., Grissom, R. J., Vernon, J., The Effects of Sensory Deprivation and Social Isolation on the Performance of an Unstructured Cognitive Task, Amer. J. Psychol., 77(1): 111-115, 1964.

16-317. Suh, S., Time Domain Identification of Human Operator Dynamic Response, GAEC-RM-392, Grumman Aircraft Engineering Corp., Bethpage, N. Y., Dec. 1967.

16-318. Swearingen, J. J., McFadden, E. B., Garner, J. D., et al., Human Voluntary Tolerance to Vertical Impact, Aerospace Med., 31: 989-998, 1960.

16-319. Swearingen, J. J., Wheelwright, C. D., Garner, J. D., An Analysis of Sitting Areas and Pressures of Man, CARI-62-1, Federal Aviation Agency, Oklahoma City, Okla., Jan. 1962.

16-320. Tepas, D. I., Evoked Brain Response as a Measure of Human Sleep and Wakefulness, Aerospace Med., 38: 148-153, Feb. 1967.

16-321. Tewell, J. R., Murrish, C. H., Engineering Study and Experiment Definition for an Apollo Applications Program Experiment on Vehicle Disturbances due to Crew Activity, NASA-CR-66277, Mar. 1967.

16-322. Tieber, J. A., Lindemuth, R. W., An Analysis of the Inertial Properties and Performance of the Astronaut Maneuvering System, AMRL-TR-65-216, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Dec. 1965.

16-323. Titov, G., Caidin, M., I Am Eagle, The Bobbs-Merrill Co., Inc., Indianapolis, Ind., - New York, N. Y., 1962.

16-324. Treisman, M., Psychology of Time, Discovery, 26: 40-45, 1965.

16-325. Trumbull, T., Research Director, Office of Naval Research, Washington, D. C., personal communicztion, 1968.

16-326. Trumbull, R., Diurnal Cycles and Work-Rest Scheduling in Unusual Environments, Human Factors, 8(5): 385-398, Oct. 1966.

16-327. Tufts College Laboratory, Fatigue Tests: Three Day Test of Fatigue Effects under Conditions of Long Hours on Duty, Limited Sleep, National Defense Research Comm. Report, Contract OEMsr-581, No. 3, 1947.

16-328. Tyler, D. B., The Fatigue of Prolonged Wakefulness, Fed. Proc., 6: 218, 1947. (Abstract).

16-329. Tyler, D. B., Goodman, J., Rothman, T., The Effect of Experimental Insomia on the Rate of Potential Changes in the Brain, Amer. J. Physiol., 149: 185-193, 1947.

16-330. U. S. Air Force, AFSC Design Handbook, System Safety, DH-1-6, Headquarters, Air Force Systems Command, Andrews AFB, Washington, D. C., July 25, 1967. (Includes Rev. 1, Jan. 20, 1968).

16-331. U. S. Air Force, Handbook of Instructions for Aerospace Personnel Subsystem Designers, AFSCM-80-3, Air Force Systems Command, Headquarters, Andrews AFB, Washington, D. C., 1962.

16-332. U. S. Air Force, Handbook of Instructions for Aerospace Systems Design, Vol. III. Reduced Gravity, AFSCM-80-9, Air Force Systems Command, Headquarters, Andrews AFB, Washington, D. C., 1962-1967.

16-333. U. S. Air Force, Human Engineering Design Criteria for Aerospace Systems and Equipment, Part III. Aerospace Vehicle Equipment, MIL-STD-803A, Washington, D. C., 1966. (Draft).

16-334. U. S. Public Health Service, Weight, Height, and Selected Body Measurements of Adults, United States, 1960-62, Publication No. 1000-Series 11 - No. 8, Government Printing Office, Washington, D. C., 1965.

16-335. Utterback, R. A., Ludwig, G. D., A Comparative Study of Schedules for Standing Watches Aboard Submarines Based on Body Temperature Cycles, Proj. No. NM-004.003-1, Naval Medical Research Institute, Bethesda, Md., 1949.

16-336. Van Dyke, W. J., Performance/Design and Product Configuration Requirements, Extravehicular Mobility Unit for Apollo Block II Missions, Master End Item Specification, NASA-EMU-CSD-A-096, Manned Spacecraft Center, Houston, Texas, Jan. 1966.

16-337. Veydner-Dubrovin, L. A., Matyushkina, N. A., Acute Disruptions of the Diurnal Rhythm of Vital Functions and Their Effect on Professional Efficiency of Humans, FTD-TT-64-1188, Foreign Technology Div., Wright-Patterson AFB, Ohio, Apr. 1965. (AD-615-234). (Translation of Voprosy Psikhologii, No. 4: 61-68, 1964).

16-338. Viaud, G., Sleep, J. Psychol. Norm. Path. (Paris), 40: 195-231, 1947.

16-339. Volynkin, Yu. M., Akulinichev, I. T., Vasil'yev, P. V., et al., Some Data on the Condition of Cosmonauts during the Flight of the Voskhod-1 Spacecraft, Kosmicheskiye Issledovaniya, 4(5): 755-767, 1966. (Abstracted in Soviet Biotechnology and Bioastronautics, Jan. - June 1966, LC-ATD-67-13, Library of Congress, Aerospace Technology Div., Washington, D. C., Mar. 1967, p. 156).

16-340. Voskresenskiy, A. D., Venttsel', M. D., The Use of Correlation Analysis Methods for Studying the Human Cardiovascular Reaction to the Space Flight of Voskhod-1, *Kosmicheskiye Issledovaniya*, *3(6)*: 927-934, 1965. (Abstracted in *Soviet Biotechnology and Bioastronautics*, Jan-June 1966, LC-ATD-67-13, Library of Congress, Aerospace Technology Div., Washington, D. C., Mar. 1967, p. 153).

16-341. Walter, D. O., Kado, R. T., Rhodes, J. M., et al., Electroencephalographic Baselines in Astronaut Candidates Estimated by Computation and Pattern Recognition Techniques, NASA-CR-82506, 1967.

16-342. Walter Reed Army Institute of Research, Symposium on Medical Aspects of Stress in the Military Climate, Washington, D. C., Apr. 22-24, 1964.

16-343. Wargo, M. J., Kelley, C. R., Mitchell, M. B., et al., Human Operator Response Speed, Frequency, and Flexibility: A Review, Analysis and Device Demonstration, NASA-CR-874, Sept. 1967.

16-344. Warren, N., Clark, B. C., Blocking in Mental and Motor Tasks during a 65-Hour Vigil, *J. Exp. Psychol.*, *21*: 97-105, 1937.

16-345. Wasicko, R. J., McRuer, D. T., Magdaleno, R. E., Human Pilot Dynamic Response in Single-Loop Systems with Compensatory and Pursuit Displays, AFFDL-TR-66-137, Flight Dynamics Lab., Wright-Patterson AFB, Ohio, Dec. 1966.

16-346. Webb, P., Annis, J. F., The Principle of the Space Activity Suit, NASA-CR-973, Dec. 1967.

16-347. Webb, W. B., Sleep: Effects of a Restricted Regime, *Science*, *150(3709)*: 1745-1746, Dec. 1965.

16-348. Weinstein, S., The Effects of Isolation, Sensory Deprivation, and Sensory Rearrangement on Visual, Auditory and Somesthetic Sensation, Perception, and Spatial Orientation, NASA-CR-90498, 1965.

16-349. Weinstein, S., Richlin, M., Weisinger, M., et al., The Effects of Sensory Deprivation on Sensory, Perceptual, Motor, Cognitive and Physiological Functions, NASA-CR-727, Mar. 1967.

16-350. Welch, B. L., Psychophysiological Response to the Mean Level of Environmental Stimulation: A Theory of Environmental Integration, *in* Symposium on Medical Aspects of Stress in the Military Climate, Washington, D. C., Apr. 22-24, 1964, pp. 39-99.

16-251. Welford, A. T., Brown, R. A., Gabb, J. E., Two Experiments on Fatigue as Affecting Skilled Performance in Civilian Air Crew, Brit. J. Psychol., 40(4): 195-211, 1950.

16-352. West, L. J., et al., The psychosis of Sleep Deprivation, Ann. N. Y. Acad. Sci., 96: 66-70, 1962.

16-353. Wever, R., The Duration of the Re-Entrainment of Circadian Rhythms after Phase-Shifts of the Zeitgeber, A Theoretical Investigation, J. Theoret. Biol., V13: 187-201, 1966.

16-354. Wever, R., A Mathematical Model for Circadian Rhythms, in Circadian Clocks, Aschoff, J., (ed.), North-Holland Publishing Co., Amsterdam, 1965, pp. 47-63.

16-355. Wever, R., Mechanism of Biological Diurnal Cycles. Part II. Influence of the Oscillation Level on the Properties of a Self-Induced Oscillation, Kybernetik, 1(6): 213-231, May 1963. (Text in German).

16-356. Wever, R., Mechanism of Biological Diurnal Cycles. Part III. Use of an Equation Model, Kybernetik, 2 (3): 127-144, Sept. 1964. (Text in German).

16-357. Weybrew, B. B., Bibliography of Sensory Deprivation Isolation and Confinement, NMRL-Memo-60-1, Naval Medical Research Lab., New London, Conn., Jan. 1960. (Also in U. S. Armed Forces Med. J., 11: 903-911, Aur. 1960).

16-358. Whitsett, C. E., Jr., Some Dynamic Response Characteristics of Weightless Man, AMRL-TDR-63-18, Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio, Apr. 1963.

16-359. Wilbur, R. L., Electrical Anesthesia Techniques, BNWL-317, Battelle-Northwest Lab., Richland, Wash., Nov. 1966.

16-360. Wilkins, W. L., Group Behavior in Long-Term Isolation, NMNRU-65-22, Navy Medical Neuropsychiatric Research Unit, San Diego, Calif., 1967. (AD-646-817).

16-361. Wilkins, W. L., Group Behavior in Long-Term Isolation, in Psychological Stress, Issues in Research, Appley, M. H., Trumbull, R., (eds), Appleton-Centruy-Croft, N. Y., 1966, pp. 278-296.

16-362. Wilkinson, R. T., Interaction of Noise with Knowledge of Results and Sleep Deprivation, J. Exp. Psychol., 66(4): 332-337, 1963.

16-363. Wilkinson, R. T., The Effect of Lack of Sleep on Visual Watch-Keeping, Quart. J. Exp. Psychol., 12(1): 36-40, 1960.

16-364. Wilkinson, R. T., Rest Pauses in a Task Affected by Lack of Sleep, Ergonomics, 2(4): 373-380, 1959.

16-365. Williams, H. L., Problem of Defining Depth of Sleep, University of Oklahoma School of Medicine, Oklahoma City, 1966.

16-366. Williams, H. L., Signal Uncertainty and Sleep Loss, J. Exp. Psychol., 69(4): 401-407, 1965.

16-367. Williams, R. L., Agnew, H. W. Jr., Webb, W. B., Effects of Prolonged Stage Four and 1-REM Sleep Deprivation, EEG Task Performance, and Psychologic Responses, SAM-TR-67-59, School of Aerospace Medicine, Brooks AFB, Texas, 1967.

16-368. Wilmor, T. L., Ritch, T. G., Report on the General Health and Morale of the Officers and Crew during a 30-Day Simulated War Patrol Aboard a Snorkel Submarine, NMRL-140-a, Naval Medical Research Lab., New London, Conn., 1948.

16-369. Wise, H. G. Jr., Analysis of Anticipated Problems, Part II. of Proceedings of the NASA Symposium on the Effects of Confinement on Long Duration Manned Space Flights, NASA-Office of Manned Space Flight, Washington, D. C., Nov. 17, 1966.

16-370. Wolstenholme, G. E. W., O'Connor, M., (eds.), The Nature of Sleep, CIBA Foundation Symposium, Little, Brown and Co., Boston, 1961.

16-371. Woodson, W. E., Human Engineering Guide for Euqipment Designers, University of California Press, Berkeley, Calif., 1954. (Rev. 1964).

16-372. Wortz, E. C., Browne, L. E., Shreck, W. H., et al., Study of Astronaut Capabilities to Perform Extravehicular Maintenance and Assembly Functions in Weightless Conditions, NASA-CR-859, Sept, 1967.

16-373. Young, L. R., Li, Y. T., Studies of Human Dynamic Space Orientation Using Techniques of Control Theory, NASA-CR-89978, June 1967.

16-374. Zheltakov, M. M., Skripkin, Yu. K., Somov, B. A., Methods Used in Administration of Electrically Induced Sleep, JPRS-23524, Joint Publications Research Service, Washington, D. C., Mar. 1964. (Translation of Elektroson i Gipnoz Dermatologii, 1963, Chapt. VI, pp. 99-113, 307, 308).

16-375. Ziskind, E., Augsburg, T., Hallucinations in Sensory Deprivation-Method or Madness?, Science, 137: 992, Sept. 21, 1962.

16-376. Zubek, J. P., Behavioral and EEG Changes after 14 Days of Perceptual Deprivation, Psychon. Sci., 1: 57-58, 1964.

16-377. Zubek, J. P., Behavioral Changes after Prolonged Perceptual Deprivation (No Intrusions), Percept. Motor Skills, 18: 413-420, Jan-June, 1964.

16-378. Zubek, J. P., Bibliography of Studies on Sensory Deprivation and Related Conditions, Rep. 65-10, Manitoba, Univ., Winnipeg, Canada, Oct. 1965. (AD-475-872).

16-379. Zubek, J. P., Electroencephalographic Changes after Prolonged Sensory and Perceptual Deprivation, Science 139: 1209-1210, 1963.

16-380. Zuckerman, M., Stress Response in Total and Partial Perceptual Isolation, Psychosomatic Med., 26(3): 250-260, 1964.