

CHAPTER I
ANTHROPOMETRIC CHANGES IN WEIGHTLESSNESS

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Man's body has been shaped by the constant force of gravity for the majority of his existence, both as a species and as an individual. His muscles, skeleton, and nervous and cardiovascular systems have all adapted to counter this force. It is not surprising that marked changes occur in such a body when forces of gravity are effectively removed, as in orbital flight. Significant changes in posture, size, shape, fluid quantity, and fluid distribution did occur during space flight (Thornton et al., 1977). Loss of strength, muscle, and body mass and changes in body composition will also occur in the absence of countermeasures (Thornton and Rummel, 1977). Such changes are summarized in table 1.

In addition, man has become dependent upon gravity for many of his actions. Virtually all of his furniture and many of his tools, appliances, and workspace designs are dependent upon gravity's action, both on the devices and on the man.

Placing the human body in such a changed force environment as weightlessness generates a new area of anthropometric study and application and provides a challenge to man/machine designers. The small amount of anthropometric data available from space flight has already been sufficient to indicate the major impact of such data on the design of apparatus for use in space, as well as to redirect many efforts of life scientists. With a new generation of spacecraft, equipment, and space systems now in progress, there is an immediate need to allow for changes due to weightlessness in the initial stages of design. Such changes in the human body must be accommodated if designs are to be efficient.

The primary purpose of this chapter is to document and explain, as fully as possible, the anthropometric data currently available on the human body in weightlessness. Although these data are far from complete and often lacking in rigor, they are virtually all that are available. Where possible, explanations of physiological mechanisms are included in an effort to provide as much understanding as possible of the interaction of the body with this new environment. A few comments on potential applications have been made. Other chapters also address the application of this material and existing one-g data to space-related problems. In many cases, imagination and creativity will be required to combine existing techniques with these data for optimum results.

TABLE 1.- ANTHROPOMETRIC CHANGES IN WEIGHTLESSNESS

<u>Change</u>	<u>Time required for change to occur</u>
<u>May be progressive</u>	
Weight loss	Small initial loss first 1 to 2 days; final course depends on diet, exercise, and other factors.
Trunk and limb girth	Immediate in some areas; slow in others; depends on diet, exercise, and other factors
Loss of muscle mass and strength	Days to weeks; depends on diet, exercise, and other factors
Body composition and density	Days to weeks; depends on diet, exercise, and other factors
<u>Constant and persists throughout flight</u>	
Height increase	2 phases: immediate step; then, hours to days for slower component
Posture	Immediate
Fluid shifts	Hours to 1 or 2 days
Center-of-mass shifts	Days

Some indications of changes caused by weightlessness can be gleaned from anecdotal information supplied by astronauts; stuffy noses, low-back fatigue, blood rushing to the head, the thin "bird legs of space," and suit-donning difficulties all provide hints.

Specific anthropometric measurements made during the American space program prior to Skylab consisted of preflight and postflight weight, a few

handgrip measurements, and stereophotogrammetric photographs taken on Apollo 16.¹ Preflight and postflight measurements of leg circumferences and volumes are available from other Apollo studies.²

On the Skylab 2 mission (SL-2), strength and fatigue measurements and segmental girth measurements of upper and lower extremities were made before and after flight.³ Also, in-flight mass measurements (Thornton and Ord, 1977) and one set of in-flight facial photographs were obtained, and preflight and postflight stereophotography and analysis⁴ were performed.

On SL-3, the aforementioned measurements were continued and a few body-girth measurements added. Whole-body photographs of the crewmen in anatomical positions were made during flight.⁵

On SL-4, the previously accumulated data were augmented by a set of photographs illustrating free-floating posture. Measurements of segmental limb girths, truncal girths, and heights were obtained throughout the flight (Thornton et al., 1977).

On the Apollo-Soyuz Test Project (ASTP) mission, in-flight height and leg-girth measurements were made.^{6,7} Followup one-g studies and analysis are still in progress. Insofar as possible, all of these data are included here and will be described.

In the Russian space program, anthropometric measurements, including postflight strength and limb girths, were made as early as 1968 on Soyuz 4 (Kakurin, 1971). In-flight handgrip forces were measured on the Soyuz 9 and 11 flights; static muscle forces and limb girths were measured on Soyuz 9 and probably on other flights. Preflight and postflight studies of walking were made on Soyuz 9 to 12 (Parin et al., 1974). Additional studies were probably performed. All Russian data available will be presented here.

¹P. Rambaut et al.: Nutritional Studies. Ch. 6 of Biomedical Results of Apollo. NASA SP-368, 1975.

²W. Hoffler and R. Johnson: Apollo Flight Crew Cardiovascular Evaluations. Ch. 4 of Biomedical Results of Apollo. NASA SP-368, 1975.

³W. Thornton and J. Rummel: Measurement of Crew Somatic and Functional Changes in Skylab 1/2. Skylab 1/2 Preliminary Biomedical Report, JSC-08439, 1973, pp. 77-94.

⁴M. Whittle and R. Herron: Stereophotogrammetry. Skylab 1/2 Preliminary Biomedical Report, JSC-08439, 1973.

⁵W. Thornton, W. Hoffler, and J. Rummel: Anthropometric and Functional Changes on Skylab. JSC-08439, 1973, sec. 2-4.

⁶J. W. Brown: Zero-g Effects on Crewman Height. JSC IN 76-EW-3, 1976.

⁷W. Hoffler et al.: Inflight Lower Limb Volume Measurements. JSC ASTP DTO C, 8, D, 1975.

WEIGHT CHANGES

SUMMARY

Weight loss has been an apparent constant side effect of space flight. It has ranged from 0 to 8 percent of body weight and has borne no fixed relation to mission duration, individual crewman, mission, or vehicle. On Skylab, the causes of such losses were demonstrated. Other than a small initial fluid loss, there is no obligatory weight loss associated with space flight if proper countermeasures are used during flight. On exposure of a person to weightlessness, a shift of fluid from the more dependent portions of the body occurs and 2 percent or less of body weight is lost through diuresis and/or decreased thirst over the first day or two. In a person with a caloric (food) intake which matches his energy expenditures, there will be no further loss. On the person's return to a one-g environment, the fluid lost will be replaced by retention for the first day or two.

It now appears that most of the losses in space flight were caused by inadequate diet. Energy costs on Skylab were surprisingly high - 203 to 212 kJ per kilogram (22 to 23 kcal per pound) of body weight per day - and

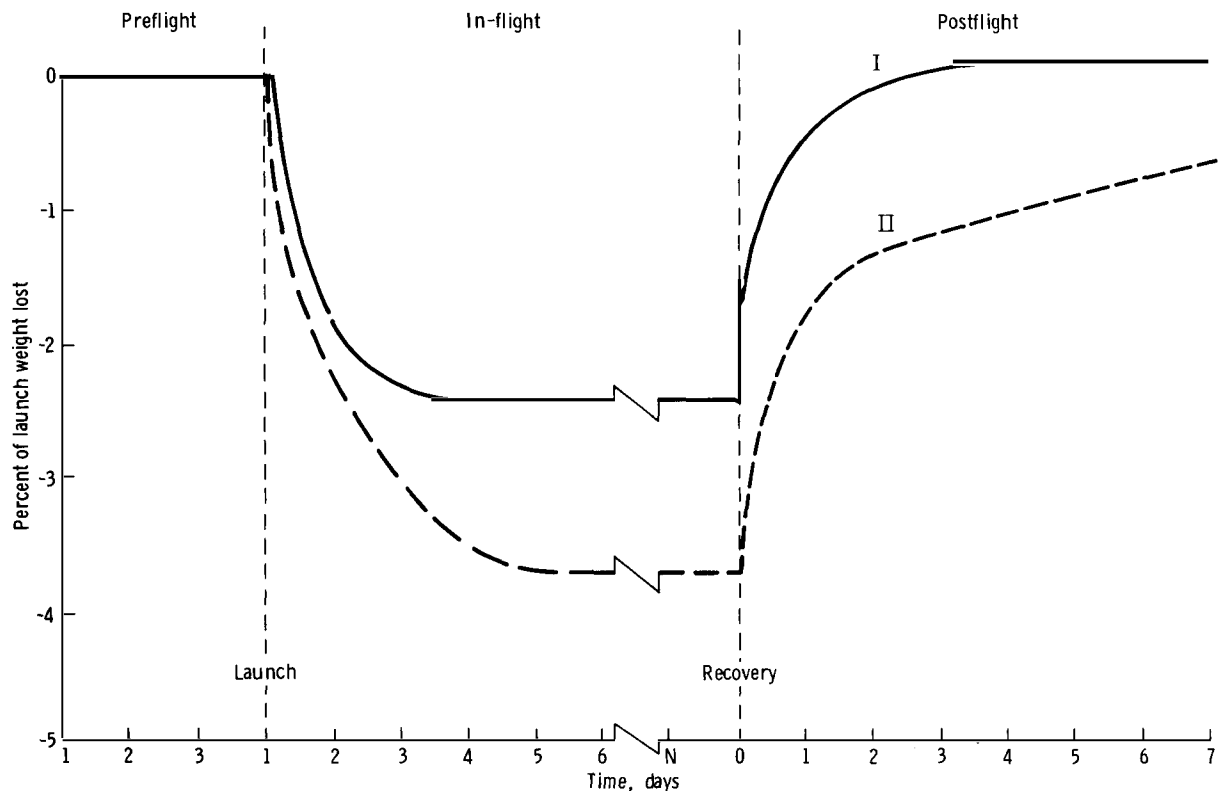


Figure 1.- Typical loss of body weight during weightlessness and gain after recovery.

reflect the pace of crew activity. It also appears that crewmen on most missions will require as much food as they do on Earth; and in some cases, considerably more. On the basis of Skylab data, curve I in figure 1 shows a typical loss that might be expected from normal crewmen in caloric balance. Curve II shows what might be expected from a crewman with a transient decreased intake resulting from a vestibular upset (inner ear disturbance causing vertigo, nausea, or vomiting), an occurrence that will probably affect 30 percent of all astronauts. After the fluid and caloric losses of the first 5 days, crewman II remains in balance until he returns to a one-g environment, at which time the fluid loss is replaced and an increased diet initiates replacement of the tissue loss incurred in the first day or two of flight. Any further caloric excess or deficit would be superimposed on these curves as a loss or gain at approximately 36 mg/kJ (1 lb/3000 kcal) in crewmen with normal body fat. Such losses may be chronic if caused by an inadequate diet, or acute if caused by a transiently increased workload.

Weight Change Data

Virtually every astronaut and cosmonaut has lost weight during space flight. These losses are tabulated in appendix A, tables A-1 and A-2. This potential problem of weight loss is intimately associated with problems discussed in the section on the musculoskeletal system.

On Mercury, Gemini, Apollo, and ASTP missions, astronauts were measured in the nude after voiding with calibrated clinical scales (platform with balance arm) which typically have a resolution of 0.1 kg (0.25 lb). These measurements are given in tabular form in appendix A and plotted against the logarithm of flight duration in figure 2.

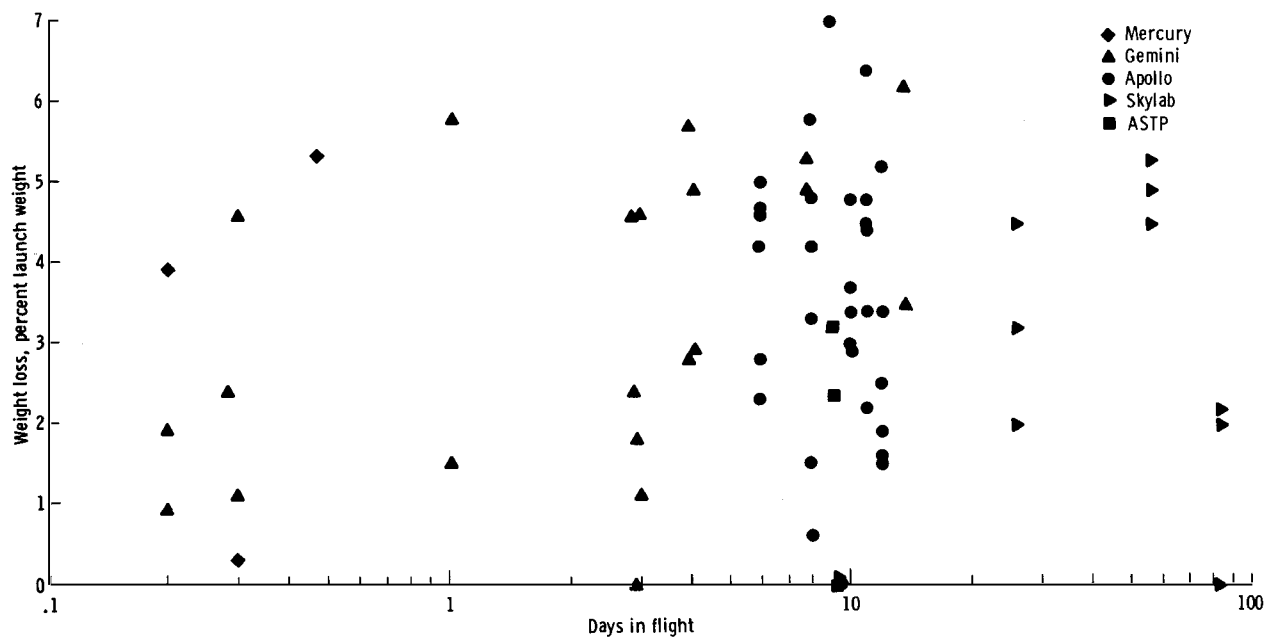


Figure 2.- Weight loss as a function of mission and duration.

On Skylab missions, daily measurements were made before and after flight with calibrated clinical scales each morning; the astronauts were measured in the nude immediately after arising and voiding. Body mass was measured in flight under the same constraints with a nongravimetric mass-measuring device (Thornton and Ord, 1977) which had a repeatability of ± 50 g (± 0.1 lb) and an absolute error of 0.1 to 0.45 kg (0.25 to 1 lb), with the lower figure more probable.

Data for all Skylab flights are plotted as 3-day sliding averages (i.e., data from each day of measurements are averaged with the preceding and following days' values) against time in figures 3 to 5. Daily weights without averaging are given in appendix A, tables A-3(a) to A-3(c).

Available Russian weight data are given in appendix A, table A-2. The techniques used to determine these data are unknown. It should be noted that many of the Russian weight measurements were made up to 24 hours after recovery.

Results and Comments

On the basis of the data in figure 2 and in table A-1 of appendix A, weight loss would seem to be a consequence of space flight. The amounts of loss were extremely variable even in the same subject. For example, in Stafford, the following variations were observed: 1 day, -5.8 percent on Gemini-Titan 6 (GT-6); 3 days, -1.1 percent on GT-9; 8 days, -1.5 percent on Apollo 10; and 9 days, +0.9 percent on the ASTP mission. Several attempts to show a relationship between weight loss and mission duration (Verigo, 1976) have been unconvincing and break down completely in the face of Skylab results.

Prior to Skylab, the necessary data on food intake, in-flight stresses, and other factors required to understand the losses were simply not available. On Skylab, the in-flight mass measurement plus the knowledge of food intake provided the data for understanding loss mechanisms. Further, the rigidly controlled diet was generally increased on each flight, producing in effect a series of three in-flight experiments. This mass measurement and diet control, plus individual variation and a 56-day one-g chamber simulation (Thornton, 1973) with use of the same restricted diet, provided proof of the primary cause of the losses.

In virtually all of the flights, including most of the Skylab missions, a calorically inadequate basic diet was supplied as a result of the assumption that in-flight requirements were less than those for a one-g environment.⁸ Figures 3 to 6 show the opposite to be true. Figure 6 is a plot of normalized weight loss as a function of energy intake. Extrapolation to zero loss shows the surprisingly high energy requirements of 203 to 212 kJ per kilogram (22 to 23 kcal per pound) of body weight per day, or approximately 15 503.1 kJ (3700 kcal) per day for a 77.1-kg (170 lb) man.

⁸See footnote 1 on p. I-3.

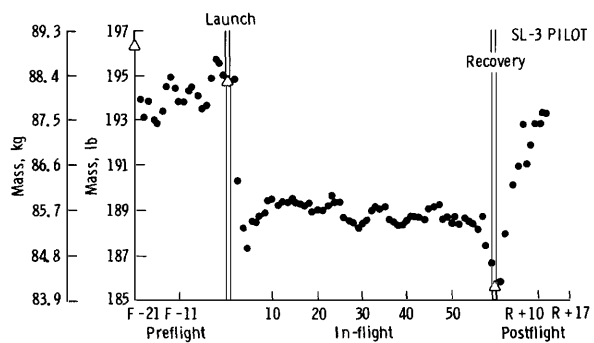
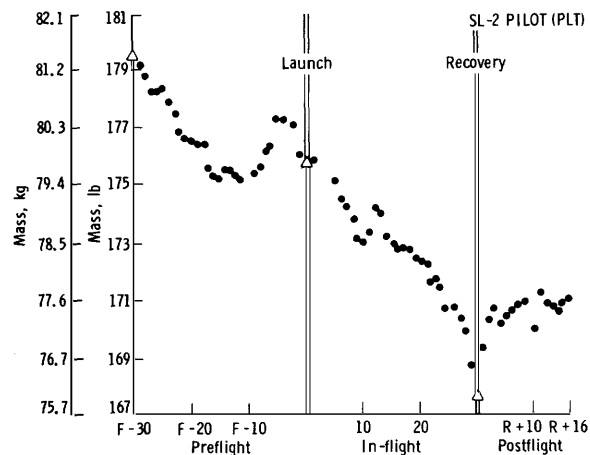
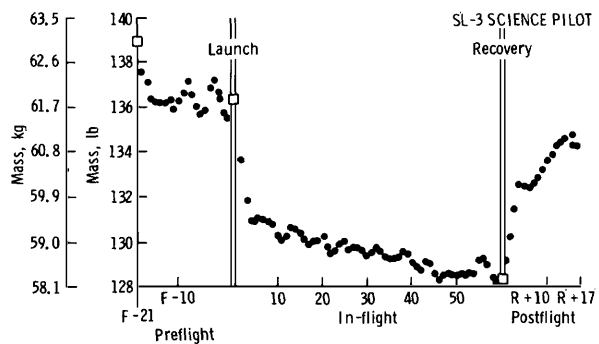
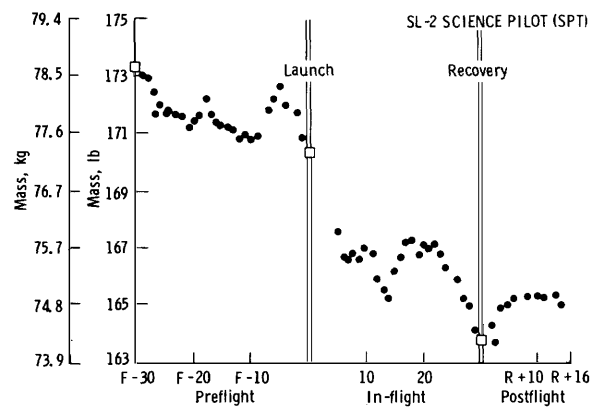
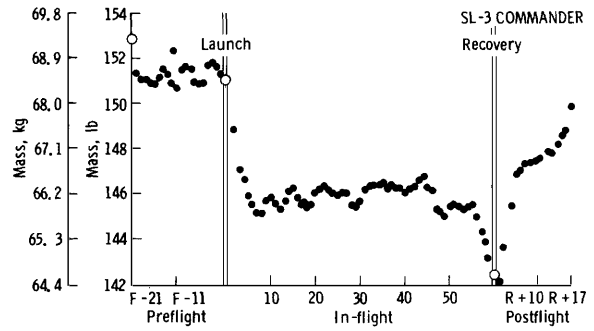
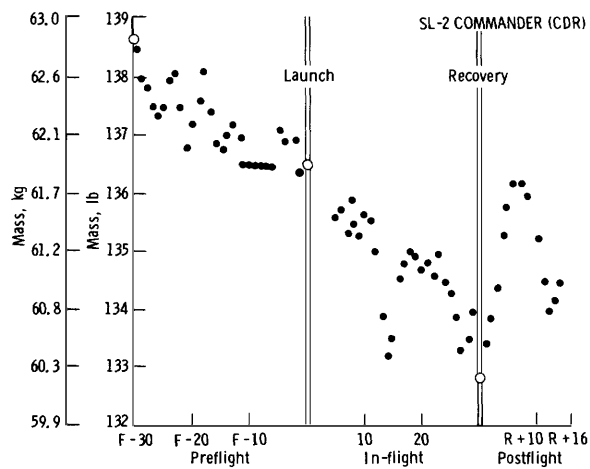


Figure 3.- Changes in body mass of SL-2 crewmen, where F - 10 is 10 days before lift-off, R + 10 is 10 days after recovery, etc.

Figure 4.- Changes in body mass of SL-3 crewmen.

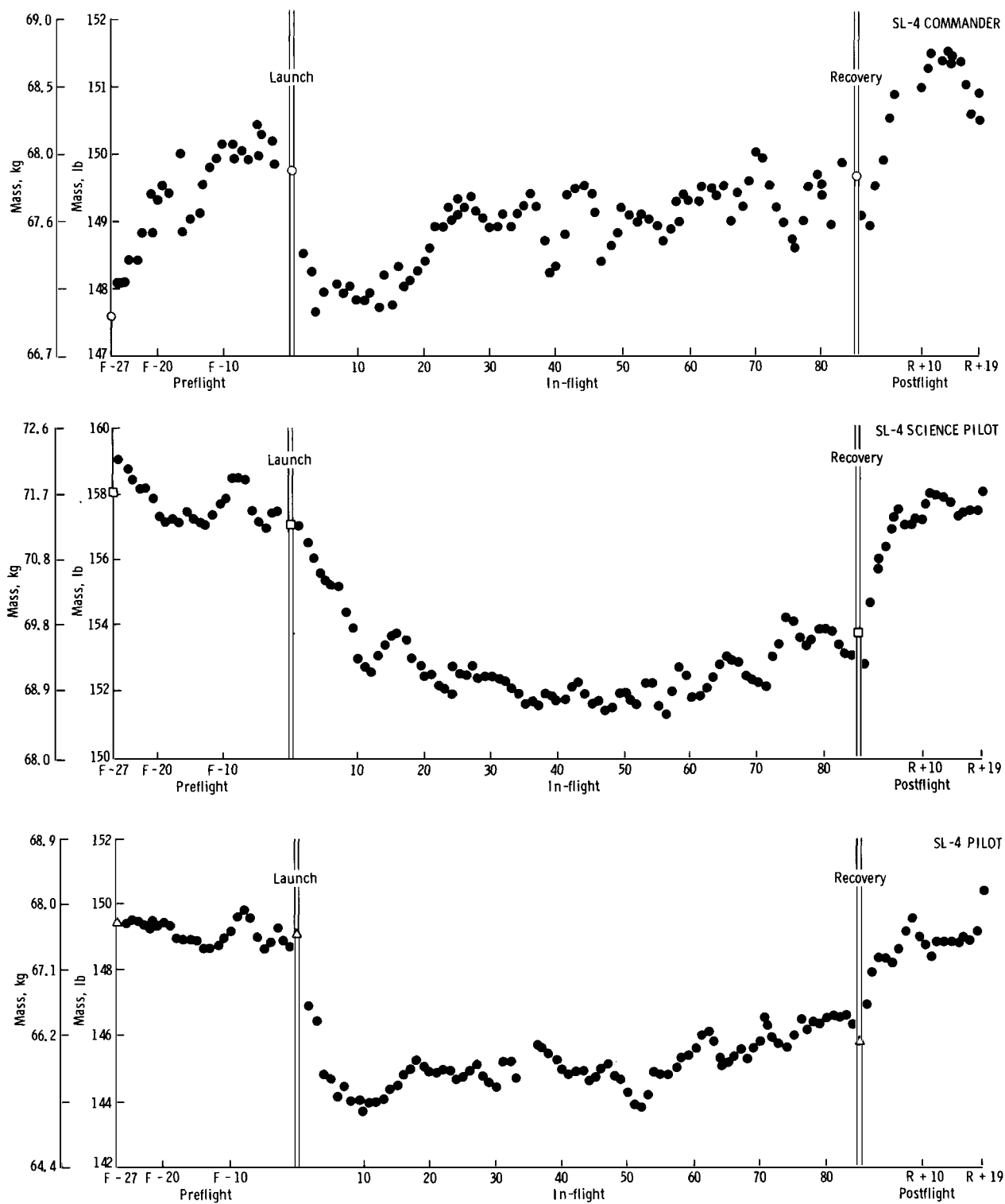


Figure 5.- Changes in body mass of SL-4 crewmen.

These values apply only to the Skylab missions, in which performance requirements were generally scheduled to the minute for hard driving crewmen who often worked well into sleep and other off duty periods. Other flights may have different requirements.

On the basis of the results from Skylab simulation and from Skylab flights, there can be little doubt that the major losses of weight in space have been caused by inadequate caloric intake. Examples of this correlation can be seen in the results for all three crewmen on SL-2 (fig. 3), whose losses started with the controlled diet and continued throughout the mission. A similar pattern was seen preflight in a 56-day Skylab simulation in one subject on an inadequate diet (Thornton, 1973).

It was observed that temporary weight decreases can be caused by periods of increased activity such as reentry preparations - as in the case of all three SL-2 crewmen (fig. 3) and the SL-3 commander and pilot (fig. 4). Smaller, long-term losses may be superimposed on other changes, as in the case of the science pilot on SL-3 (fig. 4), who had small preflight losses which continued throughout the flight. Another major consideration is poor intake during the first portion of the mission due to vestibular upset. This upset, which may range from nausea and vomiting to poor appetite, played a role in the sharp initial losses observed in SL-3 and SL-4 (figs. 4 and 5).

A second significant source of weight loss is caused by fluid redistribution. On initial exposure of a person to weightlessness, blood and other fluids are shifted from the lower, normally dependent portions of the body to the upper body, with an increase in central blood volume. The body probably attempts a reduction of this volume by diuresis in accord with the hypothesis of Gauer and Henry (1963). The initial loss of approximately 2 percent in the first few days of flight and the same rapid gain for the first few days of recovery are consistent with this theory. Figures 3 and 4 are good examples of such loss and gain.

In summary, the only obligatory weight loss associated with space flight is that associated with fluid redistribution. Major losses to date have been caused by inadequate caloric intake from diets too low in calories or by inadequate food consumption in flight, especially during the first days of flight.

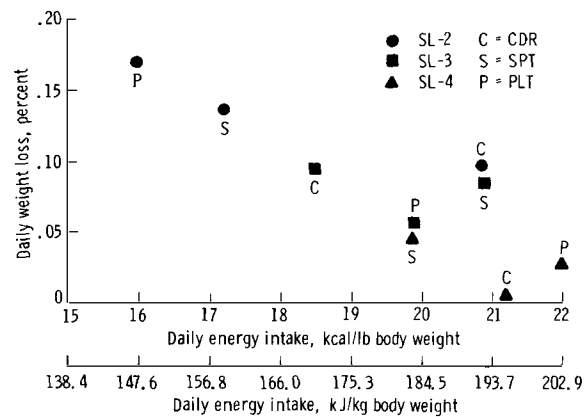


Figure 6.- Average weight loss as a function of average energy intake of Skylab crewmen. The SL-2 CDR, the SL-3 SPT, and the SL-4 PLT had very low body fat and a higher rate of weight loss.

Applications

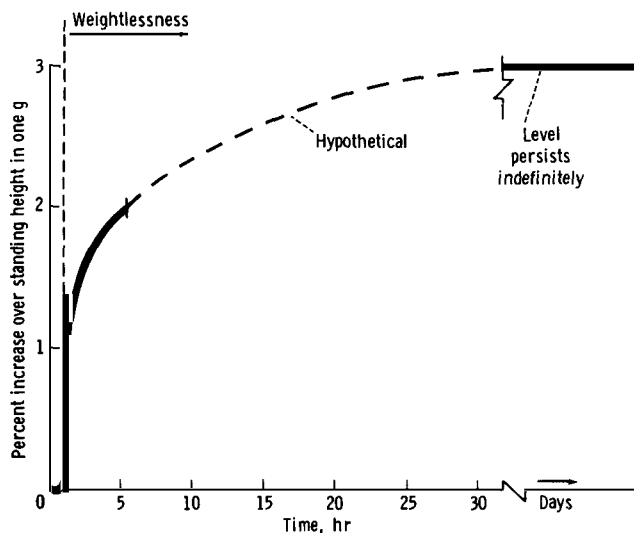
If diet is adequately controlled, weight losses should cause no difficulty to spacecraft design or operations. There are some center-of-mass shifts involved, but these will be treated elsewhere. Indirectly, this problem will be reflected in the necessity for provision of adequate amounts of food and oxygen.

HEIGHT CHANGES

SUMMARY

Astronauts will "grow" approximately 3 percent in height (typically about 5 cm (2 in.)) during the first day or two of weightlessness and then retain this increase throughout the mission until reexposure to one g, when the process is reversed. It appears that virtually all of this increase is caused by a lengthening of the spinal column; thus, the change is limited to the trunk and neck. Any man/machine interface which is affected by such changes in height and truncal length will be impacted. Potential design problems include pressure suits, clothing, and work stations and control stations with critical eye levels.

These changes which occur in weightlessness are simply the full expression of daily changes on Earth which result from loading and unloading of the spinal column. Figure 7 is a curve typical of height changes which occur in an individual on exposure to weightlessness. The intervertebral disks are



viscoelastic structure responsible for the changes, which occur in two phases. When the column load is changed, as - for example - when a person moves from lying to standing or vice versa, there is an immediate change in height, ΔH_1 , on the order of 1 percent. Changes in height are inversely related to changes in axial load (e.g., height increases when one changes from the vertical to the horizontal under one-g conditions and vice versa).

If the change in load is maintained, such as during sleep at night, a second, slower exponential change in height, ΔH_2 , occurs according to

$$H = H_0 \pm \Delta H_2(1 - e^{-t/T})$$

Figure 7.- Typical curve of height changes on exposure to weightlessness.

where

H = height at time t

H_0 = height at time of load change

ΔH_2 = maximum change in height under changed load

t = time since load was changed

T = subject's characteristic response time

On Earth, ΔH_2 typically amounts to some 1+ percent in adults. The magnitude and time response of change is usually reduced with age and is somewhat higher in females. There is considerable individual variation amounting to ± 30 to ± 40 percent in values of ΔH_1 and ΔH_2 . There are also considerable individual differences in response under one-g conditions as compared to maximum change under zero-g conditions. Some crewmen showed virtually the same changes under both conditions, whereas most added another 0.5 to 1.0 percent of height in weightlessness over the maximum changes on Earth.

The following factors should be considered in making one-g height measurements for weightlessness operations: (1) horizontal rather than vertical subject positions are more appropriate; (2) an even closer approximation to height in space can be obtained immediately after the subject has had a night's sleep or been in another horizontal position for a prolonged time; (3) during transition to and from weightlessness, height will change rapidly, especially under added g-loads; and (4) all measurements must be carefully made with the subjects in standard positions (0.16 cm (0.06 in.) is a practical working resolution), with use of a rigid, carefully calibrated jig.

Height Change Data

Height is a fundamental anthropometric parameter of particular importance in space flight. Aside from data developed in annual physical examinations, no records of pre-postflight height can be found prior to SL-3 or in Russian data. A study of in-flight height changes on SL-4 and the ASTP mission was done by Brown.⁹ Isolated height measurements were also made in flight on SL-4 as a part of an anthropometric package (Thornton et al., 1977). Followup one-g studies on the SL-4 and ASTP crewmen and other subjects are underway. Pertinent data from these studies are included here.

Most of the preflight height measurements of SL-4 crewmen were obtained by using standard clinical techniques. In flight, the Skylab crewmen anchored themselves with restraint shoes against a wall and were measured from

⁹See footnote 6 on p. I-3.

vertex to sole of the shoe with a square and calibrated tape. Four series of measurements were made. Conventional clinical methods were used after flight, but more attention was paid to measurement technique and all scales were calibrated and read to closer limits. Similar techniques were used in the ASTP mission except that in-flight vertex height was marked on a bulkhead and this mark was measured from the "floor."

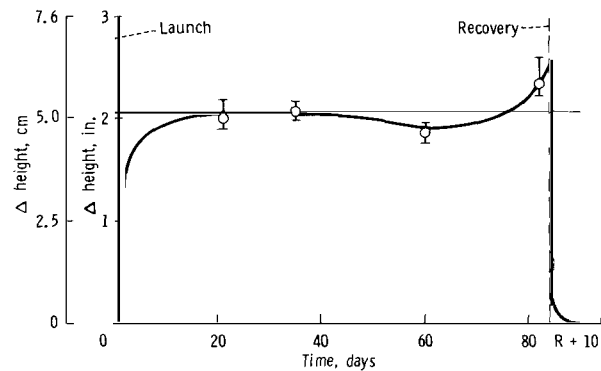


Figure 8.- Graph of mean in-flight SL-4 height measurements.

Initial heights of all astronauts who have flown in space are given in appendix A, table A-1, and pre-flight, in-flight, and postflight heights of SL-4 astronauts are shown in appendix B, tables B-1 to B-3.

Figure 8 is a graph of mean in-flight ΔH measurements of SL-4 crewmen. Skylab 4 crewmen were very similar to each other in height in the one-g environment (± 0.25 cm (0.1 in.)). They also showed similar in-flight changes and the data seem consistent, although the author is suspicious of a small systematic error on the last day of in-flight measurement. Postflight measurements were not adequately controlled in terms of time, and the exact course of postflight change is unknown. There was an obvious rapid decrease during the first few hours after recovery in all three crewmen. Two crewmen (CDR and PLT) quickly returned to original height, whereas the SPT followed a more gradual course. Changes in height on going from horizontal to vertical posture were not determined on the day of recovery; but by the second day, such changes were in the expected range (~ 2 cm (0.8 in.)) and remained there. Studies of one-g height changes in SL-4 and ASTP crewmen are underway but incomplete at this time.

The ASTP in-flight data¹⁰ had some obvious inconsistencies; but if these points are removed and the maximum increases taken, the data are consistent with Skylab results (see table 2).

Comment and Analysis

Analysis of height changes on Earth provides an understanding of height changes in weightlessness. Although anecdotal information on such changes on Earth is relatively common, there is surprisingly little on the subject in the literature. DePuky (1935) did a study of maximum daily changes in height in a large population and presented a theoretical basis for such changes, but he did not follow their time courses.

¹⁰See footnote 6 on p. I-3.

TABLE 2.- COMPARISON OF HEIGHT CHANGES IN CREWMEN OF

SL-4 AND ASTP

Crewman	Height, cm (in.)			Height change	
	Preflight	^a _{MD-9}	MD-21	cm (in.)	Percent
		SL-4			
1 (CDR)	173.0 (68.1)	--	177.3 (69.8)	4.3 (1.7)	2.5
2 (SPT)	173.2 (68.2)	--	177.8 (70.0)	4.6 (1.8)	2.6
3 (PLT)	173.2 (68.2)	--	178.8 (70.4)	5.6 (2.2)	3.2
			Mean	4.8 (1.9)	2.8
		ASTP			
1 (ACDR)	181.4 (71.4)	188.0 (74.0)	--	6.6 (2.6)	3.6
2 (docking module pilot (DMP))	179.1 (70.5)	^b _{182.9 (72.0)}	--	3.8 (1.5)	2.1
3 (command module pilot (CMP))	180.3 (71.0)	186.4 (73.4)	--	6.1 (2.4)	3.4
			Mean	5.5 (2.2)	3.0

^a_{MD} = mission day.

^b_{MD-8}.

There are two components of change in height when one goes from one-g to zero-g conditions or otherwise changes the vertical load on the body.¹¹ The first component is an immediate change (ΔH_1), such as that which occurs when a person stands up after lying. A second, slower change (ΔH_2) also occurs. This change is observed on Earth after a person has experienced prolonged horizontal posture, such as in sleeping. Although both components may be larger in weightlessness than they are on Earth, there is evidence that it is primarily the slow component that increases.

Several explanations for these height changes might be considered. The rapid component (ΔH_1) could be caused by simple deformation of the soles of the feet, the closing of joint spaces, or changes in anatomical geometry such as spinal curvature or intervertebral disk compression. cursory observation shows insufficient change in spinal curvature to account for this effect. Measurements of tissue deformation or leg joint changes also show these to be negligible. It thus appears that essentially all of these changes occur in the spinal column from contraction and expansion of the intervertebral disks. For example, when changes in height throughout the day are measured with the subject in standing and seated positions, these changes are identical.

This result is entirely consistent with the results of studies of the characteristics of the intervertebral disks by Kazarian (1975) and others. These viscoelastic disks occupy approximately 35 percent of the total length of the spinal column and, under load, show an immediate elastic deformation, followed by a slower creep. The process is reversed on removal of load. Figure 9 illustrates three ΔH curves for a 14- to 16-hour period after a normal 8-hour sleep period. Subject J. T. (represented by the upper curve), immediately after awakening, "lost" 0.7 percent of his previous height on standing. This change, in going from lying to standing or vice versa, typically remains about the same throughout the day in all subjects as it did here. During the day, there was an approximately exponential loss of height (ΔH_2) which reached a total of some 1.8 percent in this younger subject. This shape is typical of the response curve of all normal subjects. The rate and amount of change varies from individual to individual and with age and sex (see table 3). The characteristic or response time of the exponential component also varies, typically becoming shorter with increasing age. Such behavior under load is consistent with the mechanical analog shown in figure 10.

On the basis of a few cursory measurements made by adding weights to a standing subject, S_1 appears to be a linear elastic element described by Force = Constant x Displacement. This spring constant of S_1 provides the rapid changes (ΔH_1) which occur in changing posture. It has considerable individual variation.

¹¹Changes in height are inversely related to changes in axial load (e.g., height increases when one changes from the vertical to the horizontal and vice versa under one g).

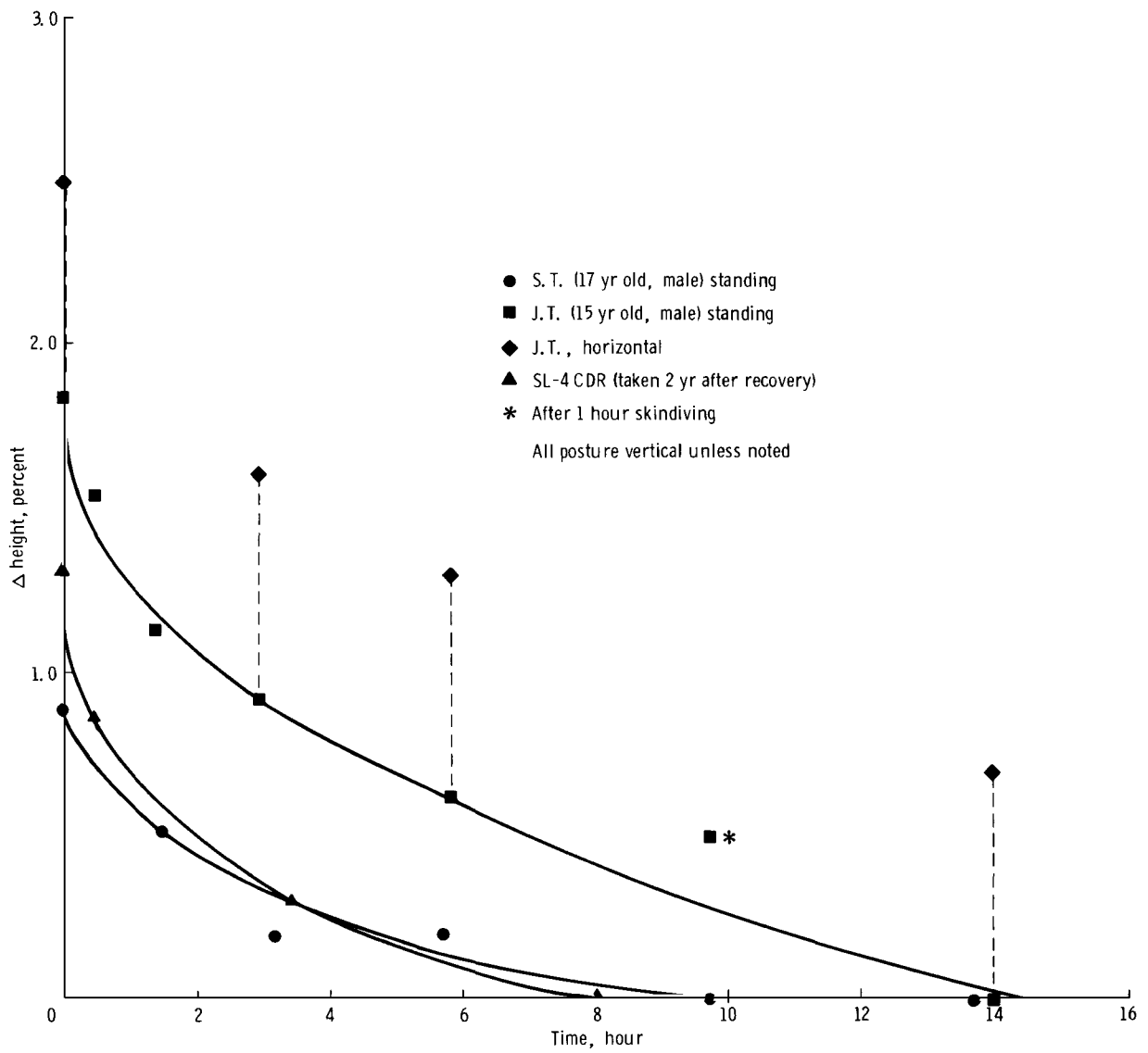


Figure 9.- An illustration of change in height in one g over an 8- to 14-hour period after a normal 8-hour sleep period.

TABLE 3.- CHANGES IN HEIGHT IN ONE g; STANDING AFTER RECLINING, AND
STANDING AFTER NORMAL SLEEP PERIOD

Subject	Sex	Age, yr	Measurement day	Normal standing height, cm (in.)	Δ height, horizontal to vertical		Δ height, standing after 8 hr sleep	
				cm (in.)	Percent	cm (in.)	Percent	
SL-4 CDR	M	--	^a R + 1	172.7 (68)	--	1.27 (0.5)	0.73	--
			R + 5	--	--	2.29 (.9)	1.32	--
			R + 17	--	--	2.03 (.8)	1.18	--
SL-4 SPT	M	--	R + 1	172.7 (68)	--	2.03 (.8)	1.18	--
			R + 5	--	--	1.78 (.7)	1.03	--
			R + 17	--	--	2.03 (.8)	1.18	--
SL-4 PLT	M	--	R + 1	172.7 (68)	--	1.52 (.6)	.88	--
			R + 17	--	--	1.52 (.6)	.88	--
ASTP CMP	M	--	--	180.3 (71)	0.89	1.60 (.63)	.89	0.89
W.T.	M	47	--	185.4 (73)	.77	1.42 (.56)	.77	.68
J.B.	F	30	--	157.5 (62)	1.11	--	--	1.21
J.T.	F	48	--	170.2 (67)	.94	1.60 (.63)	.94	0.94
J.T.	M	15	--	154.9 (61)	.72	1.12 (.44)	.72	1.95
S.T.	M	17	--	157.5 (62)	.90	1.42 (.56)	.90	.90

^aR + 1 = 1 day after recovery etc.

As noted in the summary, the second component of change appears to be of the form

$$H = H_0 \pm H_2(1 - e^{-t/T})$$

where

H = height at time t

H_0 = height before change in load

H_2 = slow component of height change

t = time since change in load

T = time constant characteristic of individual; may also be expressed in terms of elastic and viscous elements

A typical individual might have the following characteristics.

$$H_0 = 177.8 \text{ cm (70 in.)}$$

$$T = 30 \text{ minutes}$$

If this individual were placed in weightlessness, then 30 minutes later,

$$\begin{aligned} H &= 70 + 0.8 \left(1 - e^{-\frac{30}{30}} \right) \\ &= 70 + 0.8(1 - e^{-1}) \\ &= 70 + 0.5 \\ &= 179.1 \text{ cm (70.5 in.)} \end{aligned}$$

and after 3 hours (180 minutes) of weightlessness,

$$\begin{aligned} H &= 70 + 0.8 \left(1 - e^{-\frac{180}{30}} \right) \\ &= 70 + 0.8(1 - e^{-6}) \\ &= 70 + 0.8(0.997) \\ &= 179.8 \text{ cm (70.8 in.)} \end{aligned}$$

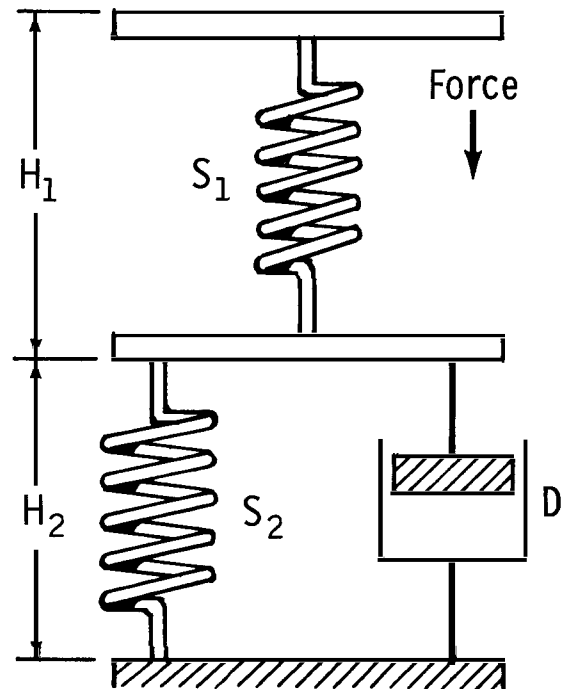


Figure 10.- First-order mechanical analog consistent with changes in axial mechanical loading and unloading. The symbol S_1 represents an elastic component in series with a second elastic component S_2 , which is paralleled by a viscous resistance D .

This expression means that if an astronaut's preflight base height is 177.8 cm (70 in.), he will gain approximately 2 cm (0.8 in.) in the second phase of weightlessness "growth." This result is consistent with the behavior of a parallel spring S_2 and a damper D with a response $\text{Force} = \text{Velocity} \times \text{Constant}$, shown in figure 10. A preliminary study of a few male and female subjects shows that females have greater elasticity and that age reduces both elasticity and damping (or viscosity). Such a model is not inconsistent with the anatomy and histology of the disks. One-g height changes in a few subjects, expressed in terms of each of the two components of height change, are given in table 3.

In weightlessness, the changes were greater. The author suspects that the increases were caused by some relaxation of the anterior spinal ligament, which appears to be the limiting element of intervertebral space. Another conceivable explanation of this greater change is the relative increase in tissue fluids that is known to occur in the upper body under a condition of weightlessness. Still other considerations are possible, such as a flattening of normal spinal curvature or a relaxation of ligaments and muscles with an attendant opening of joint spaces of the hips and legs.

At this time, it does not appear possible to predict the total height change in weightlessness from one-g studies. One crewman showed the same amount of change but, in most of the crewmen, weightlessness produced a height increase on the order of an additional 1 percent over that seen on the ground.

Design Applications

The first area of consideration is the problem of closely fitting garments such as space suits, especially in view of some of the difficulties experienced in donning the suits in weightlessness and in view of the planned use of a hard torso suit. If, as appears probable, a change in torso length of 5+ cm (2+ in.) occurs, such a change must be allowed for in this suit.

Other areas for consideration are eye heights in critical work station design and in cockpit seating. On Shuttle reentry with a prolonged period of g-load, one can expect a loss of 2.5+ cm (1+ in.) prior to landing. Although this loss would probably not be critical, seat adjustments should be allowed for. The temptation to simply transfer one-g dimensions to zero-g situations must be resisted.

In making one-g height measurements for space operations, several considerations should be observed: (1) horizontal rather than vertical subject positions are more appropriate; (2) an even closer approximation to height in space can be obtained immediately after the subject arises from a night's sleep or other prolonged horizontal position; (3) during transition to and from weightlessness, height will change rapidly; and (4) all measurements must be carefully made with the subjects in standard positions (0.16 cm (0.06 in.) is a practical working resolution).

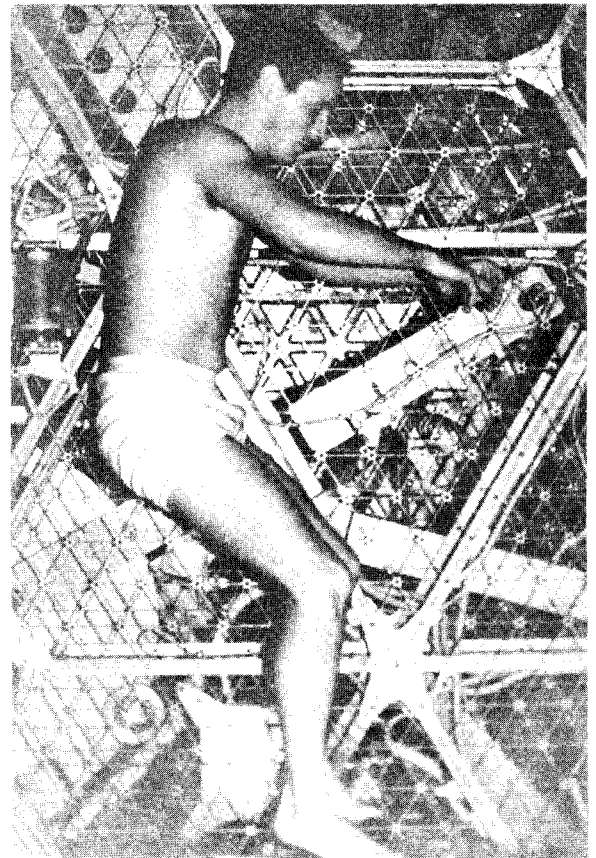
POSTURE

SUMMARY

In weightlessness, the relaxed, unrestrained human body automatically assumes and indefinitely maintains a single characteristic posture (see fig. 11). To force other postures on the body, either by the subject himself or through external constraint, frequently leads to discomfort, fatigue, and inefficiency. Characteristics of this weightless posture include plantar flexion of the feet and flexion of hips and knees with slight abduction of the legs. The thoraco-lumbar spine is straightened or even slightly flexed anteriorly. Although the cervical spine (neck) is straightened, it is also angled anteriorly, a positioning forcing the head inferiorly and anteriorly and thus lowering the normal angle of vision. Arms and shoulders are elevated, arms are abducted, and there is moderate elbow flexion.



(a) Front view.



(b) Side view.

Figure 11.- An SL-4 crewman in a relaxed, unrestrained posture that the human body automatically assumes and indefinitely maintains in weightlessness.

Many one-g positions such as sitting or bending, which depend upon gravity for loading forces, are particularly incompatible with this natural weightlessness posture since active muscle forces or heavy external constraints are required to maintain them and rapidly result in fatigue and pain. On Earth, gravity is also depended upon for stabilization, and some substitute stabilizing mechanism must be provided in flight for many tasks. Foot restraints appear to be the most satisfactory means; but for many tasks, additional body restraints should be available.

All the considerations for design interface with the weightlessness posture cannot be detailed here, but the reader is urged to consult the documentation by Gundersen and Bond¹² and by Jackson et al.¹³ and similar detailed considerations as they become available.

Design areas in which this posture must be considered are as follows: work stations and workspace, including equipment; operating and observation stations; any temporary work area in which tasks of even a few minutes in length must be undertaken; rest, sleep, exercise, and eating areas; and virtually every area where man must interface with a vehicle or system in space. Changes in posture must also be integrated with changes in height and shape for proper design.

Postural Changes

The human body in weightlessness naturally assumes and maintains a posture as characteristic of the species and environment as the more upright stance is characteristic of posture on Earth. The weightless posture differs greatly from any normal one-g posture, and the body rebels with fatigue and discomfort against any attempts to force it into one-g postures or appliances consistent with one-g postures. Chief characteristics of the weightless posture, as described in the summary, are shown in figure 11. For comfortable, efficient design, these features must be accommodated. The design engineer must study each situation carefully, thinking in terms of weightlessness rather than one-g. Gundersen and Bond¹² and Jackson et al.¹³ have made excellent beginnings in this area.

In the one-g environment, large parts of man's musculoskeletal and neurological systems are dedicated to maintaining a stable position under the forces of gravity. The human body has developed a series of natural positions - standing, squatting, sitting, and lying, among others - dependent upon the amount of support available and upon many other factors, including ethnic history. Most of these resting postures are attained by bringing the various body parts into positions that can be equilibrated against gravity

¹²Robert T. Gundersen and Robert L. Bond: Zero-g Work Station Design. JSC IN 76-EW-1, 1976.

¹³John Jackson, Robert Bond, and Robert Gundersen: Neutral Body Posture in Zero g. JSC-09551, 1975.

with a minimum expenditure of energy. These positions are dynamic, not static, and depend upon a host of sensor-nerve-muscle loops to constantly apply small corrections. If forces on the body are changed, posture changes accordingly. Development of a large belly, for example, produces lordosis.

Under weightlessness, the body is faced with a totally new situation. Not only are the large antigravity muscles and associated servoloops unopposed by gravity, but the various positions which depend upon gravity for stabilizing forces are now inappropriate. Designs of furniture, machines, and the like which depend upon gravity are usually inappropriate in space (e.g., chairs or a "bicycle" ergometer with a standard seat).

It is not surprising that the body finds a new, entirely different single position of equilibrium, a position usually incompatible with one-g designs. Also, not surprisingly, this new posture caused low-back discomfort in a few crewmen, who found that they could obtain relief by wedging themselves against a structure and pushing to apply force to the back, simulating gravitational forces on Earth. Many astronauts have described some of the design inadequacies and some of the difficulties of working in the weightless environment. Following are typical comments.¹⁴

"And so the upshot was that, at the food table and at the ATM panel, you had to hunch down in order to get a decent level . . ."

". . . your abdomen and your muscles tensed up and you just got tired of it. What we need to do is remember the postural situation up there and the fact that it is quite natural to be standing up; so you might as well get all of your work surfaces and . . . your eating surfaces up here (indicating chest height)."

"But one of the things that really bothers you is that you have to remain in a crouch position in order to take these observations. This requires continual muscle tension. I don't mean to be critical. I'm saying it just doesn't work right."

"When you are adapting things to conform to the human body in zero gravity, you've got to be careful. We found that the body normally wants to assume a more or less erect, slightly arched attitude, and holding yourself in a chair was difficult. The seatbelt helped, although it was hard to adjust."

"Body posture is one of your big problems."

". . . a crouching action is very difficult in zero g; so if you design a foot restraint where there's a posture requiring a crouching action, then you're not helping us at all."

¹⁴See footnote 13 on p. I-20.

"Your legs tend to come up a little bit so that they're partially bent. I estimate 30° from being in a straight line with your spine, both at the hip joint and at the knee joint. Your shoulders tend to shrug a little bit because you don't have gravity holding them down. Your muscles will tend to pull them up a little bit."

Documentation of this postural configuration was not obtained until SL-4 (Thornton et al., 1977). Photographs were made on the SL-3 flight¹⁵ with the subjects in the erect anatomical position (an example of one-g thinking on the author's part); but on the following mission, preflight, in-flight, and postflight photographs were made with the crewmen in relaxed as well as anatomical posture. Typical photographs from SL-3, with the PLT in forced erect posture, are shown in figures 12 and 13. These photographs added little to existing anthropometric knowledge. The thoraco-lumbar lordotic curve is still present. There is a slight tendency to lean back and incline the head, but this observation was not properly appreciated until the SL-4 photographs with relaxed crewmen were seen. Figure 11 is from this latter series and shows the subject in typical weightless, relaxed posture with eyes closed. Figures 14 and 15 are tracings of such photographs. This posture was seen from the first through the last photographs, showing that such posture was quickly acquired and maintained throughout the mission. Tracings of the segment angles were made from the entire series¹⁶ and are shown in figure 16.

Once documented, this position was easy to recognize in many unposed work situations, such as that shown in figure 17. Further evidence that this postural response is natural to weightlessness was obtained when underwater photographs¹⁶ were made with subjects in the relaxed position (see fig. 18). As can be seen in figure 18(b), the position more closely approximated that assumed in weightlessness when visual cues were removed by blocking vision through the mask.

Mechanisms Leading to Weightlessness Posture

The weightlessness posture adopted in space appears to be inherent and relatively unchanging since it is quickly assumed and showed no significant change in 84 days of weightlessness. This observation was further supported by crew comments. Further, this posture is assumed in water immersion.

Reasons for this posture should provide a fascinating subject of study for anthropometrists, anatomists, neurologists, and physiologists. A full discussion of the subject is beyond the purview of this document, but a few comments are irresistible. Elevation and abduction of the arms might be explained on the basis of increased muscle mass/strength in the abductor-elevator-flexor area, but this argument cannot apply to the legs, where the situation is reversed. Kennedy, at the U.S. Air Force Aerospace Medical

¹⁵See footnote 5 on p. I-3.

¹⁶See footnote 12 on p. I-20.

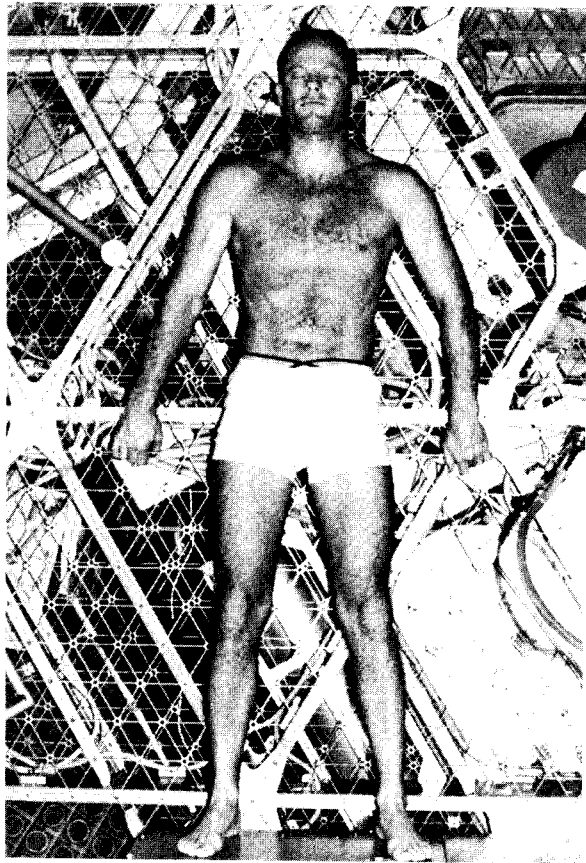


Figure 12.- The SL-3 PLT in a forced erect posture in weightlessness.

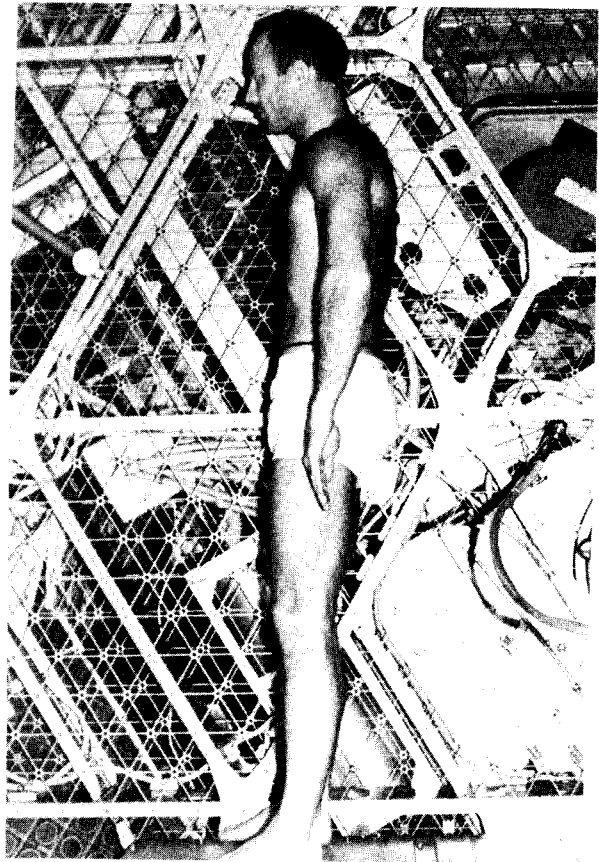
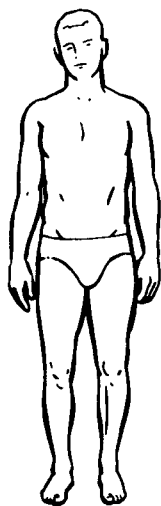
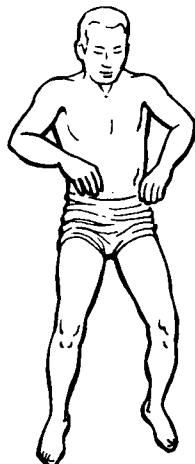


Figure 13.- Side view of the SL-3 PLT in forced erect posture in flight.



Preflight, standing



In-flight, relaxed



Preflight



In-flight



Postflight

Figure 14.- A front-view comparison of one-g and weightless posture in the SL-4 SPT (tracings from photographs).

Figure 15.- A side-view comparison of one-g and weightless posture in the SL-4 SPT (tracings from photographs).

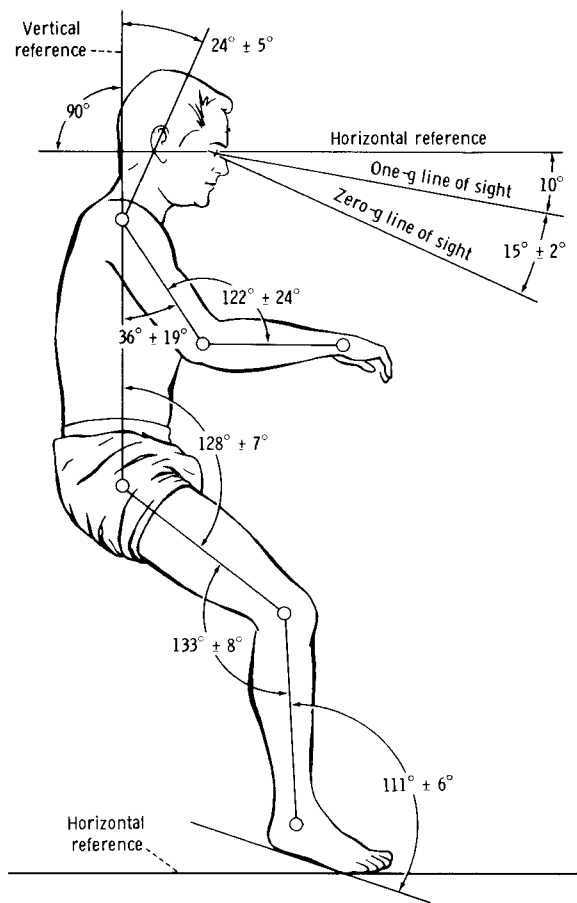


Figure 16.- The segment angles of the weightless neutral body position.



Figure 17.- The body position of the SL-3 PLT while loading film illustrates the relaxed posture in an unposed work situation.

Research Laboratory (AMRL), made a surprisingly good prediction of weightless posture by simply placing links and segments in their midrange (Simons, 1964). Although the link positions in weightlessness must be the result of muscle forces, such forces are not simply the product of available muscle mass/tension. Rather, the tension is controlled by a series of feedback loops which begin with force transducers in muscles and tendons and are modified by a host of other secondary and tertiary inputs. Could the position of limbs then be caused simply by completely unloaded myotatic loops which have their predominant action against gravity? If similar loops are active in the neck region, such a mechanism, plus spinal straightening, might account for cervical angulation. Reasons for straightening of the thoracolumbar spine are not obvious; the pelvis has obviously rotated, but whether this rotation is cause or effect is not yet clear. Much more data will be needed to completely characterize and understand posture and actions under weightlessness conditions.



(a) With unblocked vision.



(b) With blocked vision, resulting in a posture more closely approximating that assumed in null gravity.

Figure 18.- Underwater photographs of subject in a relaxed, neutral buoyancy posture.

Implications and Applications

For efficient man/machine design for space flight, this weightless posture must be taken into account. Space limitations preclude a detailed discussion of design criteria here, but a few general considerations are offered. Insofar as possible, one should start with an absolutely clean slate as regards carryover of one-g design to weightlessness design. Each element of design must be examined only in the light of weightless considerations. Every feature must be examined to see if gravity or one-g orientation influenced the design. If so, the feature must be suspect. The following facts must always be considered.

1. There is no up or down or preferred orientation. Crewmen reset their reference frames at will and without difficulty. There is no reason not to utilize the relative ease of positioning in any reference frame ("up," "down," or "sideways") so long as surrounding spaces are clear.

2. There is no weight to support. Chairs, couches, beds, and other devices to reduce fatigue are useless in this respect. On Skylab, the seat at the Apollo telescope mount console was little used by the first crew and discarded entirely by the second and third crews.

3. Absence of gravity removes body stabilization, which must be provided by alternatives. The primary alternative is a foot restraint, which in many situations appears to be adequate. Both experience and theoretical considerations lead to the conclusion that additional stabilization at the thigh and waist, and perhaps at other points, would be desirable for many tasks.

4. This basically single posture associated with weightlessness must be accommodated if fatigue and discomfort are to be avoided. Having to maintain some positions in weightlessness may produce much more stress than an equivalent position on Earth since muscles might be called on to supply forces which were normally supplied by gravity. Stooping and bending are examples of positions which always caused abdominal fatigue. The natural heights and angles of weightlessness posture must be accommodated. Although more information is needed in many of these areas, available data still provide a point of departure. Some of the areas to be considered are as follows.

a. Since the feet are plantar-flexed at approximately 25 percent, sloping rather than flat shoes or restraint surfaces should be considered.

b. The weightlessness stance is not vertical since hip/knee flexion displaces the torso backward, away from the footprint. Height is now located at a point between sitting and standing; so a work surface must be higher than one designed for normal sitting tasks. The feet are also positioned somewhere between a location directly below the torso (as in standing) and a point well out in front of the torso (as in sitting).

c. Elevation of the shoulder girdle and arm flexion also make elevation of the work surface desirable. Although in weightlessness the head is angled forward and down, a positioning which depresses the line of sight, eye-to-work level may remain practically the same.

d. Under weightlessness, there is no reason to keep work surfaces flat, and they should probably be tilted to accommodate the visual angles.

5. Reference should be made to the publications listed, and to others as they become available, when any weightlessness design is attempted.

The preceding considerations represent only the most rudimentary beginning approach to zero-g design problems. Each case must be approached freshly and with imagination.

SHAPE AND CENTER OF MASS

SUMMARY

The human body has large elastic and fluid components that must change in shape when subjected to change in forces such as occur in going from a one-g environment to weightlessness and vice versa. Other changes in shape may occur through loss or gain of fat and muscle. These changes experienced

on exposure to weightlessness may be classified in three categories according to their time course and origin.

1. Immediate - seconds to minutes, caused by elasticity and plasticity of the body

2. Rapid - minutes to days, caused by fluid shifts

3. Slow - days to months, caused by atrophy of fat and muscle or replacement of muscle by fat

There are immediate changes in height (which also had a slower component, as already described) and in abdominal girth with the subject in anatomical position (standing erect with arms at sides). The latter change may amount to 10 cm (4 in.) or more. In the next day or two, approximately 1 liter of fluid is lost from each leg, much of which goes to the head and supracardiac region where it produces puffiness in the face and mucosal congestion. Both of these changes persist, apparently indefinitely, until the subject returns to a one-g environment.

Slow changes through loss or gain of fat and muscle may be superimposed on the aforementioned changes (i.e., loss of fat will usually further reduce abdominal girth). The time course and magnitude of such changes are entirely dependent upon diet and exercise. An inadequate diet will result in fat and muscle losses, with the ratio depending on individual body-fat percentages. If this diet inadequacy is coupled with inadequate exercise, even more rapid muscle loss occurs. An adequate diet and inadequate exercise will result in an increase of fat and a decrease in muscle. In short, these slow changes are no different from everyday one-g experience.

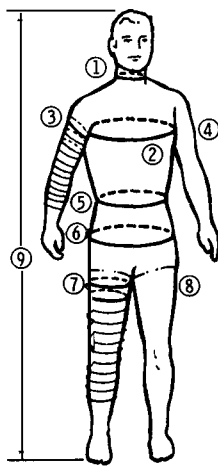
Without proper exercise, crewmen will lose muscle primarily from their legs. On flights to date, there have been significant losses of body fat and muscle through inadequate diet and lack of proper exercise. Such losses can only hurt crew performance on return to the one-g environment, especially that of the well-conditioned crewman with minimal body fat. Most importantly, with adequate diet and exercise, such tissue changes will be either negligible or nonexistent.

All these changes tend to shift the center of mass cephalad more than can be accounted for by height increases. These changes typically amount to 3 to 4 cm, measured from the soles of the feet.

Although the previously described changes are primarily of interest to the life scientists, accommodations in clothing and other personal gear must be made. Above all, prevention of tissue (fat and muscle) changes must always be considered in system design.

Changes in Shape

Seventy percent of the body is water, with some 30 percent of this being outside the cells. In addition, several body areas mechanically behave as



- ① Neck circumference at larynx
- ② Chest circumference at nipple (inspiratory (insp.) and expiratory (exp.))
- ③ Arm volume (girth every 3 cm)
- ④ Arm volume (girth every 3 cm)
- ⑤ Abdominal circumference at umbilicus
- ⑥ Hip circumference at greatest diameter
- ⑦ Leg volume (girth every 3 cm)
- ⑧ Leg volume (girth every 3 cm)
- ⑨ Height

Figure 19.- Anthropometric measurements made on the Skylab crewmen.

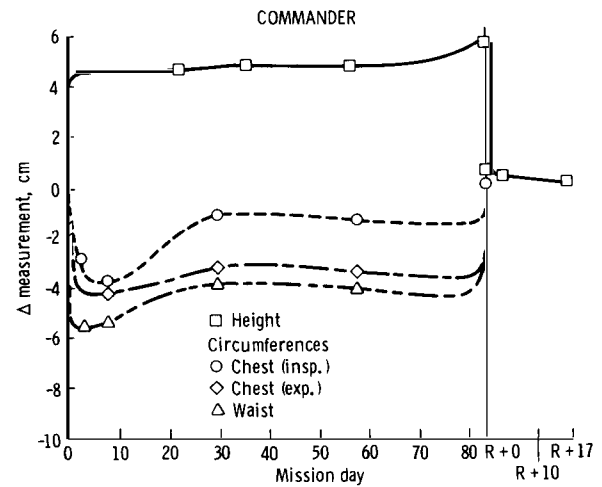


Figure 20.- Truncal girth changes of SL-4 crewmen in an anatomical position in weightlessness with one-g measurements as a baseline.

fluids in elastic compartments, whereas other body components have elastic and plastic properties. It should not be surprising that changes in shape occur as the body is moved from a one-g environment to weightlessness and vice versa. Although these changes probably have more implications for the biomedical researcher than for the man/machine designer, there are several changes that could affect clothing and personal equipment. Such changes in shape also overlap and reflect changes in other anthropometric areas, such as muscle function.

Shape variations can be placed in three categories, based on time course and mechanism.

1. Immediate - seconds to minutes, caused by elasticity and plasticity of the body

2. Rapid - minutes to days, caused by fluid shifts

3. Slow - days to months, caused by atrophy of fat and muscle or replacement of muscle by fat

Immediate Changes

Immediate changes occur in areas of the body containing elastic elements¹⁷ that would be under load in the one-g environment, such as the

¹⁷Muscle tone is included for present purposes.

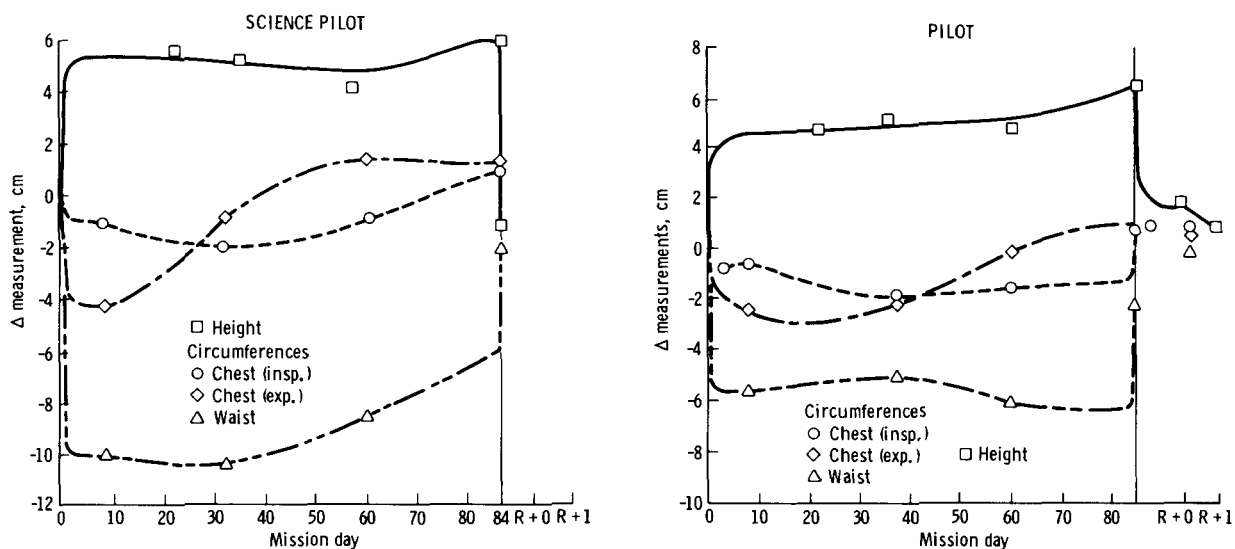


Figure 20.- Concluded.

intervertebral disks (see the section on height) and the abdominal region. In the absence of tissue changes such as fat or muscle loss, these changes will disappear on reexposure of the body to one g. Figure 19 depicts measurements made before and after flight on SL-2, SL-3, and SL-4 and in flight on SL-4. Truncal measurements are tabulated in appendix C, tables C-1(a) to C-1(c). Plots of the immediate changes seen in SL-4 crewmen are shown in figure 20.

Unfortunately, the area of most interest here, the first minutes of weightlessness, must remain a subject of speculation until future flights. The early portions of the curves shown in figure 20 are based on theoretical considerations and one-g measurements. Changes in height have already been discussed. The large waistline reductions may be explained by elimination of equivalent hydrostatic force on the abdominal contents, which may be considered semiliquid here. This liquid column is normally constrained anteriorly and laterally by the abdominal muscles. Under weightlessness, unbalanced forces from these muscles move the contents inward and upward until they are counterbalanced by other elastic forces. In both the United States (Sawin, 1977) and the Russian (Kakurin, 1971) programs, a loss of vital capacity in weightlessness has been documented that probably is in part a reflection of increased visceral pressure against the diaphragm. Another portion of the shift in abdominal volume is accounted for by the general elongation of the trunk through height expansion.

Changes in chest dimensions are smaller and less easy to explain but appear to be consistent. The reduced dimensions could be due to an increase in the costo-vertebral angles secondary to the elongation of the spine, possibly

followed by some in-flight adaptation of costo-vertebral ligaments and intercostal and other musculature. There were no significant changes detected in neck and hip girth on SL-4.

Another area in which immediate and probably rapid change is to be expected is the female breast, but there has not yet been an opportunity to make the pertinent studies in this area.

Rapid Changes

The rapid changes that occur over a matter of hours to days are caused by fluid redistribution. Again, the full expression of mechanisms that are active to a lesser degree under one-g conditions is being seen. For example, everyone is familiar with slightly swollen ankles after standing, puffy eyelids after a night's sleep, and similar one-g manifestations of fluid shifts. When the normal adult stands, there is an unbroken column of blood in veins and arteries from heart to foot, with a linearly increasing hydrostatic pressure from the heart downward that reaches 90 mm Hg and more in the foot.¹⁸ The head and neck veins are empty until they reach a level just above the heart. Arterial pressure to head and neck is linearly reduced by the height of its hydrostatic column; that is, portions of the body below the heart have increased fluid pressures, whereas those above the heart have relatively lower pressures. This increased pressure is partially offset by an increased number of elastic elements in the lower body. On exposure of the body to weightlessness, all hydrostatic forces vanish and the venous pressures are essentially equal everywhere, with the tissues below the heart at relatively lower fluid pressures than "normal" and those above the heart at higher fluid pressures. Fluid now tends to move out of the areas below the heart which have increased elasticity and pressures and into those above with less tissue pressure.

Among the first and most consistent "symptoms" of weightlessness were stuffy noses and a feeling of head fullness secondary to increased pressure and fluid shifts. The first evidence of the extent of these fluid shifts was obtained from a set of SL-2 in-flight "mug shots" at the end of the mission showing puffy faces, edematous eyelids, and full head and neck veins. These changes are now well documented (but not measured) and appear to persist as long as one is in weightlessness.

It was not until SL-4 that the magnitudes of the fluid shifts were documented, with in-flight segmental girth measurements of the arms and legs¹⁹ (Thornton et al., 1977). Volumes were calculated from limb girths every 3 cm by assuming that the arms and legs consisted of a series of regular truncated cones. Repeatability was on the order of 100 ml for legs of 70-kg subjects.

¹⁸This hydrostatic pressure is added to any existing arterial or venous pressure.

¹⁹Postflight volume measurements could not show the magnitude of changes, for the volumes change toward normal quite rapidly.

Left-limb volume changes of SL-4 crewmen are graphed in figure 21, and volumes of both legs are tabulated in table 4. Note that volume changes of 1+ liters per leg occurred in all crewmen. It was not possible to follow the right-leg volume changes as closely as those in the left leg because of schedule problems. There were differences between the two, but it was not possible to determine significant differences from available data. However, a total volume of approximately 2 liters was lost from the legs and shifted elsewhere in the body through the elastic forces described. Preflight and postflight measurements were made with the crewman in a supine position to minimize errors from gravitational pooling of blood. This fluid then was tissue fluid, which could have been lost as urine, through inadequate replacement, etc.; however, simultaneous body weight changes could account for only one-half or less of this quantity.

It is also obvious from figure 21 that the arms did not play a significant role. Hips showed a small in-flight loss in circumference (appendix C, tables C-2(a) to C-2(c)), and there was no significant change in the neck. The author suspects that the hip loss was fluid, for, in the one-g environment, there is still appreciable hydrostatic pressure at this level. This previous account leaves only the head and upper torso as possible areas for absorbing the 1 liter or more of fluid. There is no question that the tissues of the head were "wet" (i.e., relatively edematous), but this condition should account for only 100 to 200 ml at most. The remainder must have been distributed within the upper torso but obscured by other changes in this area.

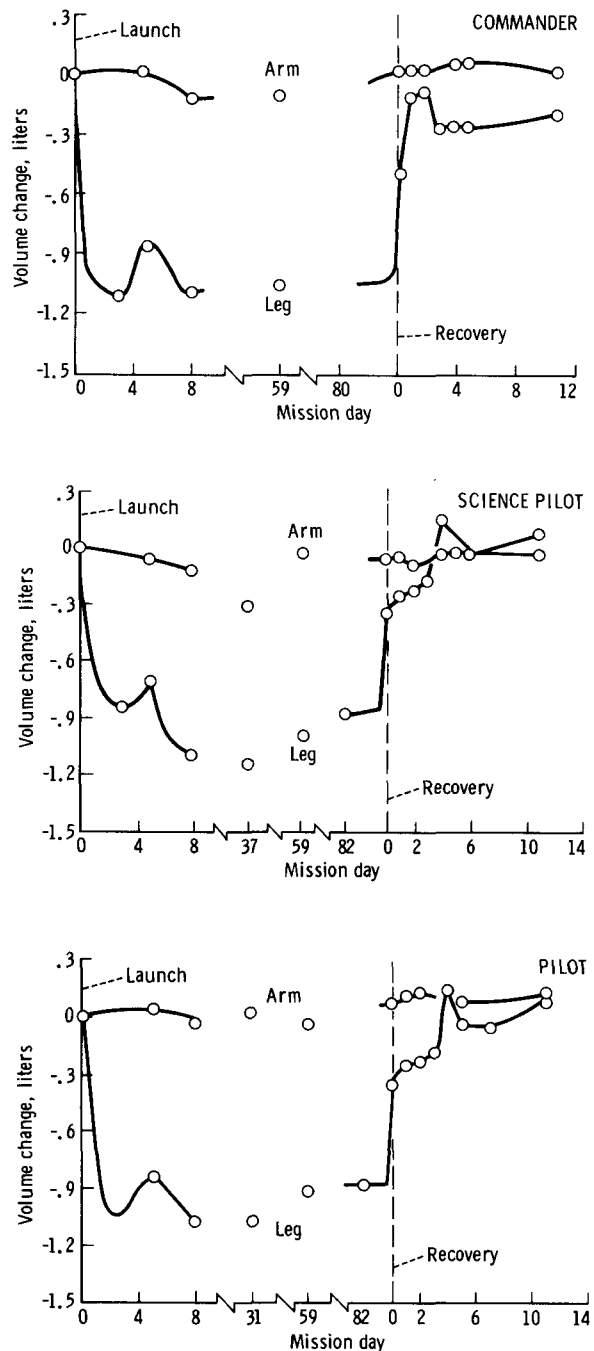


Figure 21.- Changes in left-limb volumes of SL-4 crewmen.

TABLE 4.- LEG-VOLUME MEASUREMENTS OF SL-4 CREWMEN

(a) CDR

Day (a)	Right leg			Left leg		
	Vol., ml	Δ vol., ml	Δ vol., percent	Vol., ml	Δ vol., ml	Δ vol., percent
F - 35	7531.9	56.3	0.75	7445.7	-50.9	-0.68
F - 20	7746.5	270.9	3.62	7573.4	76.8	1.02
F - 9	7455.7	-19.9	-.27	7515.7	19.1	.25
F - 5	7475.6	--	--	7496.6	--	--
MD-3	6671.6	-804.0	-10.75	6370.3	-1126.3	-15.02
MD-5	--	--	--	6625.4	-871.2	-11.62
MD-8	6646.4	-829.2	-11.09	6389.5	-1107.1	-14.77
MD-31	6388.7	-1086.9	-14.54	6294.6	-1202.0	-16.03
MD-57	6295.9	-1179.7	-15.78	6152.2	-1344.4	-17.93
R + 0	6967.1	-508.5	-6.80	6984.9	-511.7	-6.83
R + 1	7220.2	-255.4	-3.42	7354.1	-142.5	-1.90
	6989.1	-486.5	-6.51	6926.5	-570.1	-7.60
R + 2	7225.6	-250.0	-3.34	7412.3	-84.3	-1.12
R + 3	7143.4	-332.3	-4.44	7213.8	-282.8	-3.77
R + 4	7431.8	-43.8	-.58	7228.0	-268.6	-3.58
R + 5	7347.2	-128.4	-1.72	7227.9	-268.7	-3.58
R + 7	7432.8	-42.8	-.57	7261.3	-235.3	-3.14
R + 11	7629.1	153.5	2.05	7405.4	-91.2	-1.22
R + 17	7455.1	-20.5	-.27	7664.6	168.0	2.24
R + 31	7317.7	-157.9	-2.11	7359.8	-136.8	-1.82
R + 68	7747.8	272.2	3.64	7622.3	125.7	1.68

^aF - 35 is 35 days before flight; MD is mission day on-orbit; and R + 1 is 1 day after recovery.

TABLE 4.- Continued

(b) SPT

Day	Right leg			Left leg		
	Vol., ml	Δ vol., ml	Δ vol., percent	Vol., ml	Δ vol., ml	Δ vol., percent
F - 35	8244.9	300.9	3.8	8237.8	301.9	3.80
F - 30	8120.3	176.3	2.2	7829.1	-106.8	-1.34
F - 19	8374.8	430.8	5.4	7995.1	59.2	.74
F - 9	8192.6	248.6	3.1	8085.5	149.6	1.88
F - 5	7944.0	--	--	7935.9	--	--
MD-3	7106.3	-837.7	-10.5	7100.7	-835.2	-10.5
MD-5	--	--	--	7239.1	-696.8	-8.8
MD-8	7168.6	-775.4	-9.8	6834.5	-1101.4	-13.9
MD-37	--	--	--	6793.6	-1142.3	-14.4
MD-59	--	--	--	7026.0	-909.9	-11.5
MD-81	--	--	--	7039.8	-896.1	-11.3
R + 0	7300.7	-643.3	-8.1	7579.2	-356.7	-4.5
R + 1	7457.9	-486.1	-6.1	7689.4	-246.5	-3.1
R + 2	7747.6	-196.4	-2.5	7710.7	-225.2	-2.8
R + 3	7684.1	-259.9	-3.3	7762.6	-173.3	-2.2
R + 4	8124.3	180.3	2.3	8085.9	150.0	1.9
R + 5	7912.8	-31.2	-.4	7902.5	-33.4	-.4
R + 7	7999.8	55.8	.7	7885.9	-50.0	-.6
R + 11	7976.4	32.4	.4	8015.2	79.3	1.0
R + 17	7985.1	41.1	.5	7966.2	30.3	.4
R + 31	8265.9	321.9	4.0	8522.0	586.1	7.4
R + 68	8375.5	431.5	5.4	8342.4	406.5	5.1

I-34

I-34

Day	Right leg			Left leg		
	Vol., ml	Δ vol., ml	Δ vol., percent	Vol., ml	Δ vol., ml	Δ vol., percent
F - 35	7466.2	138.8	1.9	7717.1	-177.0	-2.2
F - 30	7521.6	194.2	2.7	7768.0	-126.1	-1.6
F - 19	7777.5	450.1	6.1	7948.1	54.0	.7
F - 9	7475.5	148.1	2.0	7881.6	-12.5	-.2
F - 5	7327.4	--	--	7894.1	--	--
MD-3	--	--	--	--	--	--
MD-5	--	--	--	7120.2	-773.9	-9.8
MD-8	6508.7	-818.7	-11.2	6832.7	-1061.4	-13.4
MD-31	6668.1	-659.3	-9.0	6805.9	-1088.2	-13.8
MD-59	6804.7	-522.7	-7.1	6518.3	-1375.8	-17.4
MD-81	--	--	--	6795.4	-1098.7	-13.9
R + 0	7032.2	-295.2	-4.0	7175.4	-718.7	-9.1
R + 1	7084.2	-243.2	-3.3	7431.3	-462.8	-5.9
R + 2	7233.2	-94.2	-1.3	7574.2	-319.9	-4.1
R + 3	7091.5	-235.9	-3.2	7467.8	-426.3	-5.4
R + 4	7250.6	-76.8	-1.0	7594.8	-299.3	-3.8
R + 5	7335.2	7.8	.1	7465.0	-429.1	-5.4
R + 7	7201.6	-125.8	-1.7	7547.3	-346.8	-4.4
R + 11	7523.8	196.4	2.7	7879.9	-14.2	-.2
R + 17	7493.5	166.1	2.3	7777.2	-116.9	-1.5
R + 31	7547.9	220.5	3.0	8043.8	149.7	1.9
R + 68	8097.2	769.8	10.5	7964.8	70.7	.9

If the leg and arm volumes are subdivided, it will be seen that, on a percentage basis, the lower legs lost relatively less fluid than the thighs. This difference may be explained by the greater amount of fluid-containing tissue found in the thighs compared to that found in the relatively bony lower legs. Conversely, the lower arms lost slightly more fluid than the upper arms, a difference which may be explained by the increased elasticity in the lower arms, which have a tissue/bone ratio more nearly approaching unity. The exact time course of these fluid volume shifts remains to be determined, but it is probably exponential and may have some initial oscillations. Fluid redistribution apparently follows a reciprocal course over a time span of 2 or 3 days on return of the body to a one-g environment.

The results of an ASTP in-flight study of leg volumes done by using segmental girth measurements²⁰ appear to be consistent with the data from Skylab. The detailed data are unpublished, but figure 22 is drawn from the preliminary report.

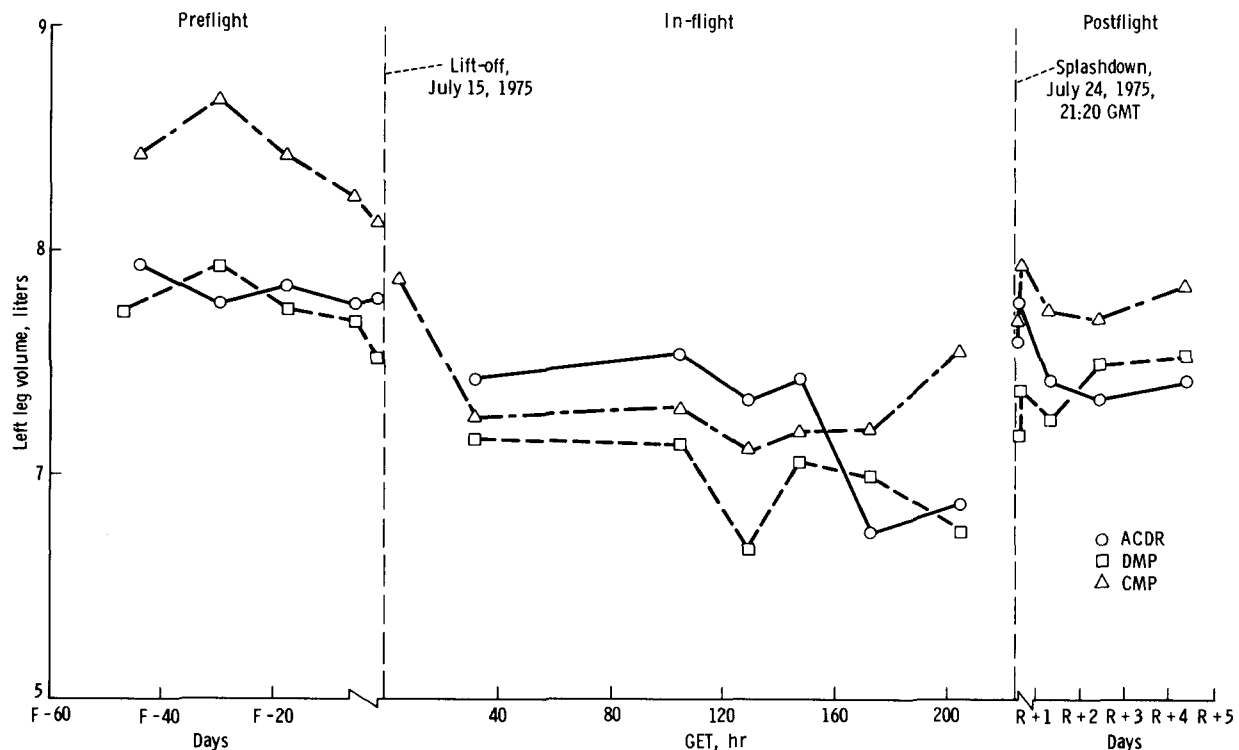


Figure 22.- Left-leg volumes of ASTP crewmen calculated from segmental girth measurements; DMP is docking module pilot, CMP is command module pilot. (Data supplied by Hoffler et al.; see footnote 7, p. I-3.)

²⁰See footnote 7 on p. I-3.

It must be recognized that volumes also will be changed by tissue atrophy or hypertrophy. This slower process with a different basis will be discussed next.

One could manipulate the raw leg-girth data in innumerable ways to meet specific needs or curiosity; and for this reason, the raw data on SL-4 limb girths are included in appendix C, tables C-3 to C-5.

Slow Changes

Slow changes over days to weeks, secondary to the disturbance of fat and muscle masses, may be caused by inadequate or excessive diet and exercise. As fluid redistribution appears to be relatively complete in 2 or 3 days after a change from one-g to weightlessness conditions or vice versa, any remaining volume changes are probably tissue changes. If a diet is calorically inadequate, then fat and muscle must be consumed to make up the difference. In subjects with normal body fat, losses will be in both muscle and fat, with most of the initial loss occurring in areas where fat is deposited (abdomen, buttocks, and subcutaneous areas); but if the percentage of body fat is initially low or becomes low, then muscle will be consumed. If exercise to a muscular area is inadequate at a time of inadequate diet, additional local muscle loss will occur. With diet adequate to maintain body mass but insufficient exercise, the muscles will atrophy and fat will be deposited in the usual areas.²¹ Available Russian data in this area are given in table 5. These measurements were taken 2 days after flight and should primarily reflect tissue changes. As will be seen, these data are generally consistent with the United States experience. Changes seen in flights of short duration were hardly significant. Both Soyuz and Salyut contained several exercise devices, the scheduled use of which was apparently adequate to maintain upper limbs but not lower. The legs show the major losses of tissue, presumably muscle.

The next available data are from preflight and postflight calf circumference measurements on all Apollo flights and leg volume measurements on two Apollo flights made by Hoffler and Johnson²² as part of the cardiovascular evaluation. Table C-6 in appendix C, a summary of these data, shows a consistent postflight decrease in calf and total leg volume that persists after the time for fluid redistribution. This decrease represents an appreciable muscle and/or fat loss for relatively short missions.

From the Skylab missions, several sources of data on such changes are available. Postflight leg and arm volumes and in-flight calf circumferences were measured on all Skylab missions, and in-flight leg and arm volumes were measured on SL-4. Herron's preflight and postflight stereophotogrammetry provided an overall survey of body changes (Herron, 1972; Whittle and Herron,

²¹There is obviously great individual variation in areas of body-fat deposition.

²²See footnote 2 on p. I-3.

TABLE 5.- POSTFLIGHT CHANGES IN CIRCUMFERENCE FOUND IN U.S.S.R. COSMONAUTS

Spacecraft	Flight duration, days	Circumference change on R + 2					
		Calf, mm	Hips, mm	Shoulder, mm	Upper arm, percent	Thigh, percent	Calf, percent
Soyuz 3 to 8	2 to 5	-2	-7	-5	--	--	--
Soyuz 9	18	-12	-27	-2	-0.3	-3.3	-4.9
Salyut	24	--	--	--	a-1.1	a-4.4	a-5.4

^aChanges measured post mortem.

1977). Although the data cannot be examined in detail here, when they are considered in view of the following flight conditions, there is a consistent picture that is compatible with current one-g experience and knowledge. All data must be interpreted in view of wide variations in individual and mission diets and exercise.

The SL-2 crewmen clearly had a calorically inadequate diet, and only the CDR exercised at reasonably adequate levels - albeit with the bicycle ergometer which was proven inadequate for maintenance of legs consistent with one-g conditions (see section on strength).

The SL-3 diet was inadequate (see weight section) for the SPT and marginal for the CDR and the PLT. Good arm exercise equipment was available, and this activity was undertaken vigorously; all crewmen used the bicycle at adequate levels on this flight.

The SL-4 diet was adequate to slightly positive for the CDR, inadequate for the SPT until augmented in the middle of the mission, and marginal for the PLT. Arm exercise equipment was available and used; the bicycle ergometer and a makeshift treadmill provided fair protection against leg atrophy.

Table 6 is a summary of values from three areas that should reflect diet and exercise effects on Skylab.²³ Changes in abdominal girth should be a rough gauge of changes in body fat. This supposition appears to be valid

²³Preflight and postflight arm and leg volumes on SL-2, SL-3, and SL-4 are in appendix C, tables C-3 to C-5 and C-7.

TABLE 6.- CHANGES IN ARM AND LEG VOLUME
AND WAIST GIRTH OF SKYLAB CREWMEN

Measurement	Change, percent				Change, percent/day
	CDR	SPT	PLT	Mean	
SL-2 (28 days)					
Arm volume ^a	1.4	-1.9	-0.4	-0.3	-0.0107
Leg volume ^b	-5.3	-4.8	-6.7	-5.6	-.2
Waist girth ^a	-.9	-5.7	-5.1	-3.9	-.139
SL-3 (59 days)					
Arm volume ^a	-11.7	-4.6	1.5	-4.9	-0.083
Leg volume ^b	-7.2	-6.4	-4.6	-6.1	-.1033
Waist girth ^a	-4.1	-3.8	-1.6	-3.2	-.0542
SL-4 (84 days)					
Arm volume ^a	1.05	-2.49	3.83	0.797	0.0095
Leg volume ^b	-2.2	-2.6	-2.7	-2.5	-.030
Waist girth ^a	1.2	-2.1	-2.4	-1.1	-.013

^aMeasured on R + 1.

^bMeasured on R + 2.

here, both collectively and individually. For example, the SL-4 CDR, who was close to caloric balance, gained in abdominal girth (the only crewman to do so); and normalized flight averages of girth change (percent change per day) also agree with the general increase of food on each mission. Leg changes appear to reflect effects of both food and appropriate exercise, with a ten-fold improvement observed on rate of loss during the last mission as compared to the first. This effect is seen better in figure 23, in which average postflight changes in leg volume for each Skylab crew are plotted.

Note that after fluid redistribution should have been complete, 2 or 3 days after a return to one-g conditions, crewmen of the 28-day mission still had a deficit in leg volume of 5+ percent, which persisted until the end of the measurement period. It is impossible to tell how much of this deficit was

due to fat loss and how much was due to muscle loss; but on the basis of strength studies, much of it must have been due to muscle loss. The following 59-day mission, with an increased amount of food intake and exercise scheduled, resulted in essentially the same loss and pattern as that for a mission approximately half as long. The final 84-day mission resulted in less than half the loss, and that was rapidly regained after flight. Somewhat more food and a means of heavy leg exercise were available on this flight wherein a sharp reduction in loss was seen. Losses on all three flights were consistent with strength changes found after flight.

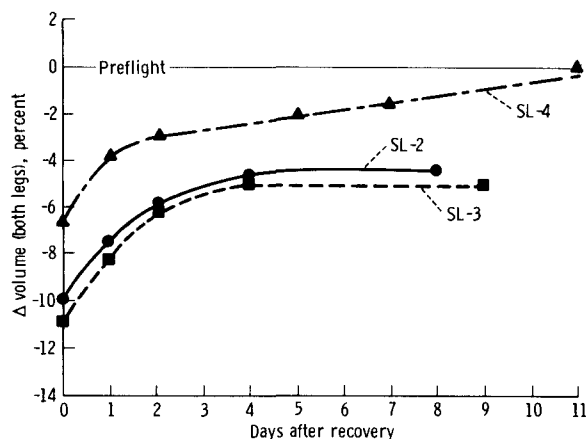


Figure 23.- Average postflight leg-volume changes on Skylab missions.

The results of all of these studies of leg mass are consistent with the following observations. Without protective, heavy exercise, there will be a rapid loss of leg tissue even on relatively short flights, such as Russian Soyuz and American Apollo flights. The rate of loss is greater with inadequate diet, as on the Apollo and SL-2 missions, and is related to the amount and type of exercise. (This subject will be dealt with further in the next section.) A positive view is that such loss of muscle may be prevented by an adequate diet and a proper amount and type of exercise.

Upper Limbs

Arm volumes derived from segmental girth measurements during Skylab missions are tabulated in appendix C, tables C-7(a) to C-7(c). Russian data from the Soyuz 9 to Salyut missions show a relatively greater postflight decrease in leg girth than in arm girth. This result was observed on SL-2 and SL-4 also; but when one looks at average arm volume changes from mission to mission, the volume changes do not correlate with food or exercise or postflight strength changes. Arm volume changes are relatively small and may be lost in the noise of the measurement apparatus, but this possibility is doubtful. Even in the absence of arm exercise devices, the ordinary activities in a spacecraft place moderate demands on upper limbs in contrast to the unused legs.

Center of Mass

With increases of height and shifts of liquid cephalad, the center of mass must change. Such changes were documented on SL-4 (Thornton et al., 1977).

Preflight baseline and postflight center-of-gravity measurements were obtained with a balance board, as shown in figure 24. In flight, a similar balance point was found without the complication of a board by looping a thin cord around the subject, who was "floating" freely, and then pulling the cord at right angles to the body's longitudinal axis to accelerate the crewman. If the cord were off the center of mass, the crewman would "tilt" during the acceleration. It was claimed by the crew that the null point, or center of mass, could be determined within a few millimeters. The use of skin tattoo as a reference is open to question, but it was felt that in practice this tattoo would be as stable as some skeletal landmark. The results shown in figure 25 for the PLT of SL-4 were typical. A slight increase occurred in the later part of the mission, which may represent a slower shift of fluid still further cephalad, a loss of leg tissue that was not obvious, or simply an error. Otherwise, the data seem to be reasonable in direction and magnitude.

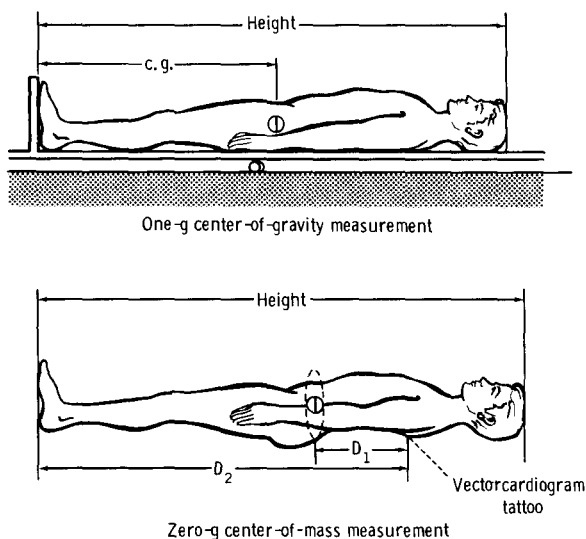


Figure 24.- Measurements used in center-of-gravity and center-of-mass determinations.

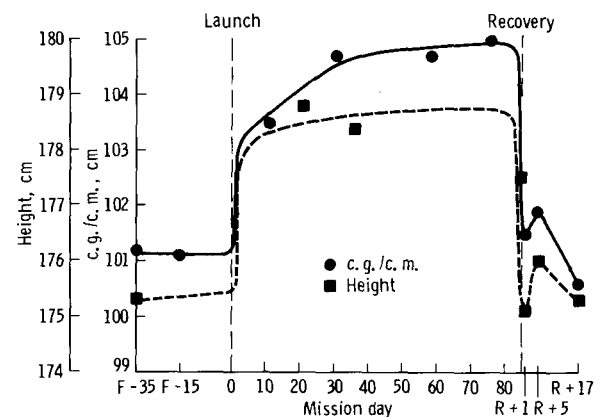


Figure 25.- Preflight (baseline) and postflight center-of-gravity measurements of SL-4 PLT obtained with a balance board. The c.g./c.m. distances were measured from soles of crewman's feet.

Methodology of Anthropometric Measurements for Space Flight

Collection of anthropometric data by conventional direct measurements has many liabilities, especially for space flight. The methodology is tedious, cumbersome, and time-consuming. Exact shapes cannot be determined by girth and similar measurements. Stereophotogrammetry, as applied to the body

by Herron et al., appears to be a most attractive alternative, and its utility and accuracy were successfully demonstrated on Skylab. The technique is fully described elsewhere (Herron, 1972; Whittle and Herron, 1977). Briefly, it consists of taking two pairs of photographic plates of the subject, from which - in the laboratory - a rather involved and complex data reduction process yields as many spatial points on the body as desired. From this matrix of points, a computer may generate a variety of data. Some examples are seen in figures 26 and 27. Figure 26 is a single transverse section of the body generated by the computer from points derived from stereophotogrammetry, and figure 27 is a composite of such points. Quantitative areas and volumes may be computed, as may surface areas. A curve of volume as a function of height may be calculated.

Preflight and postflight studies with the use of this technique were done in all Skylab missions. Figure 28 shows a plot of volume as a function of longitudinal axis level for the SL-3 CDR before and after flight. This plot shows the losses in abdominal area that, when taken with weight losses and other data, confirm the loss of adipose tissue. Smaller losses of leg volume may also be seen. Data obtained by using this technique were repeatedly compared to directly measured volumes and girths and other quantities and found to be within their error limits.

The simplicity of obtaining the photographs and the huge amount of data they contain more than offset the time, complexity, and cost of their analysis. This method, with suitable modifications for in-flight usage, is probably the method of choice for dimensional studies of size, volume, and shape

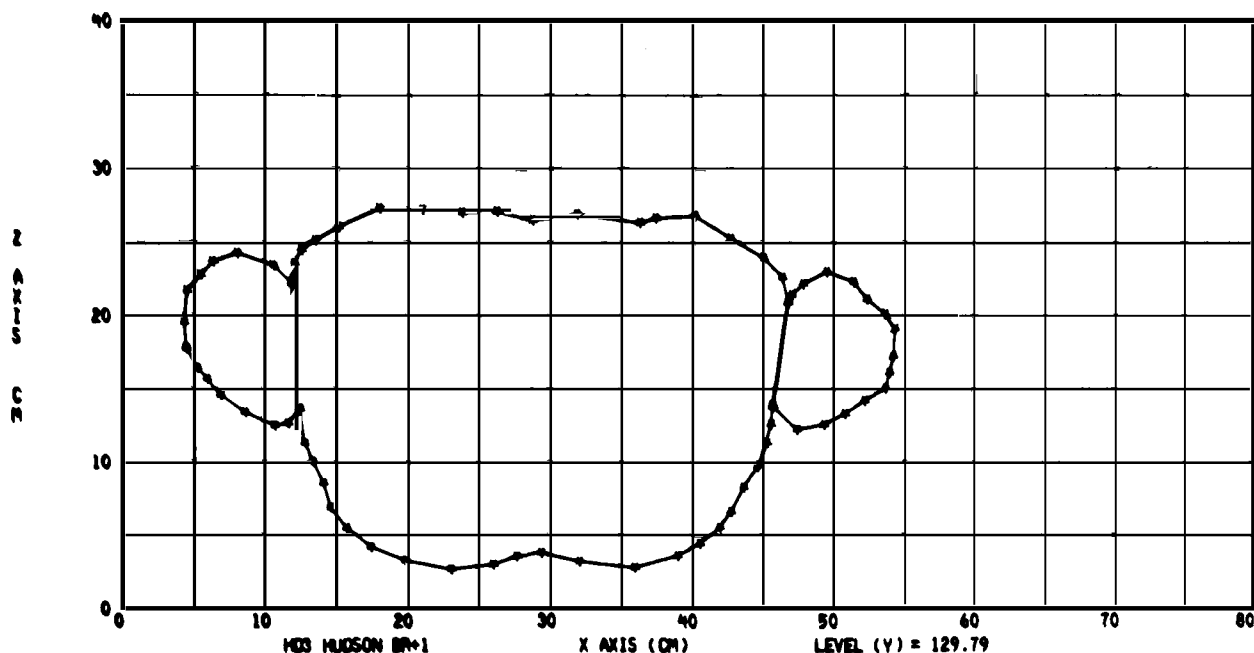


Figure 26.- A single transverse section of the body at shoulder level generated by a computer from points derived from stereophotogrammetry.

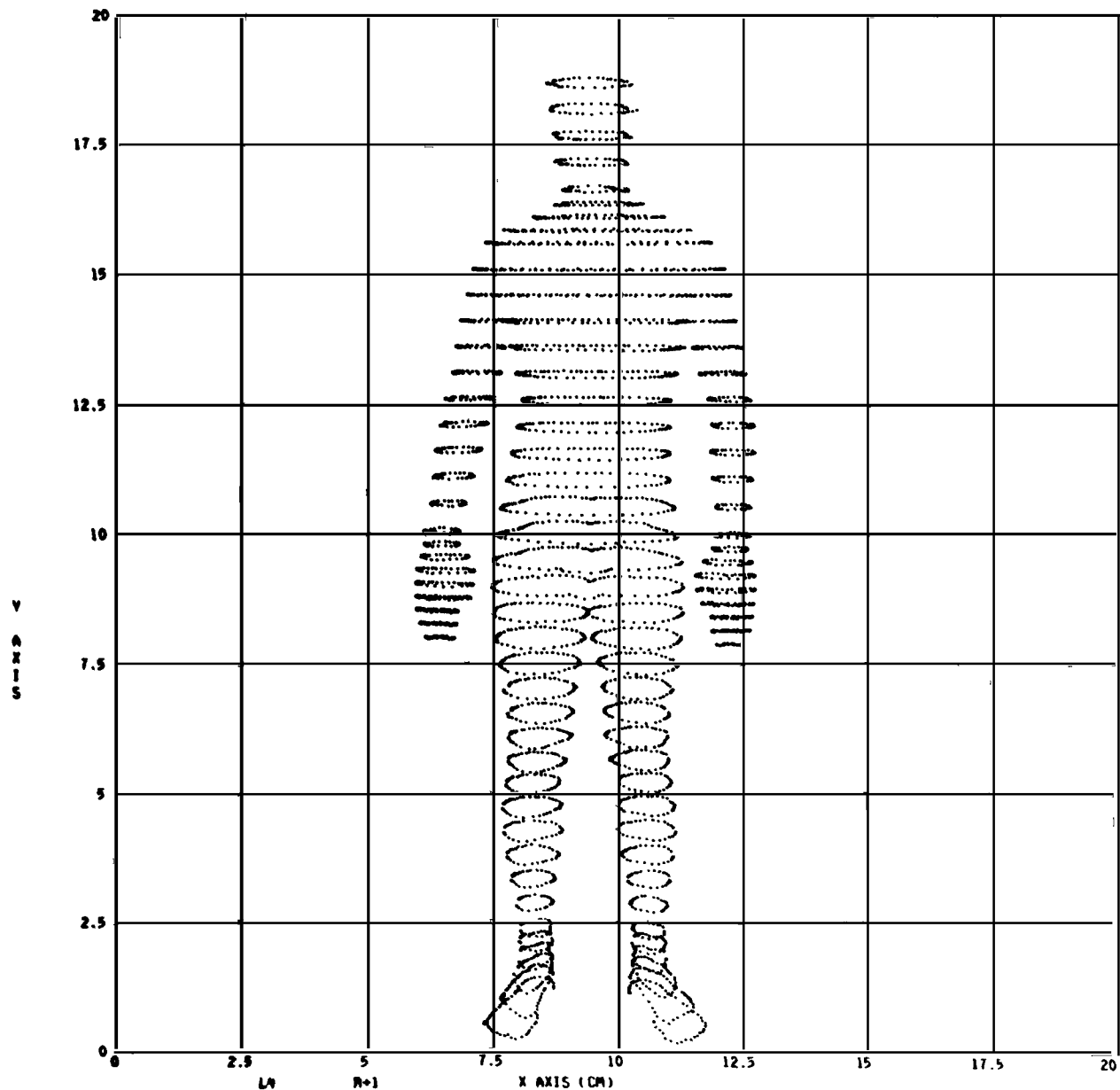


Figure 27.- A composite of transverse body sections made from stereo-photogrammetry.

in the future. The only reservation the author has concerns the attempted usage of this method for obtaining precise volumetric assessments for density (specific gravity) determinations; however, continued refinements may make such precise assessments possible.

Applications

Height is discussed in the second section of this chapter. Although abdominal changes of this magnitude would be serious on Earth for clothing fit, in space the normal posture will tend to increase abdominal girth and clothing will be weightless. However, adjustments should be available in clothing. There will be changes in the female breast area that may also require consideration for comfort and fit.

Except in unusual, closely fitted garments or equipment, the reduction in leg size should cause no problem. Facial puffiness and stuffy noses will probably remain a part of space flight, and a probably insignificant reduction in field of view may occur. The medical scientist should be primarily concerned in this area.

The magnitude of slow tissue changes should be small. Indeed, slow changes should be largely regarded as a warning that diet and/or exercise is not at the correct level.

Although there will be a significant cephalad shift of center of mass, this effect should cause no concern except with respect to maneuvering units should they have critical balance and control moments.

STRENGTH AND BODY COMPOSITION

SUMMARY

This area is one of the more critical areas for manned space operations of appreciable duration. Large areas of the body, especially back and legs, are composed of antigravity muscles normally subjected to loads of up to several hundred pounds, several thousand times a day.

In weightlessness, these muscles become virtually unused, and disuse atrophy will occur rapidly. There were significant changes in strength and muscle mass following short flights, such as the Apollo and Soyuz flights. Unprotected, the legs can be expected to atrophy to some level consistent with in-flight forces but below that required for supporting or transporting the body under one-g conditions. This loss of strength would cause no problems in weightlessness but would necessitate special reentry considerations and a period of rehabilitation after recovery.

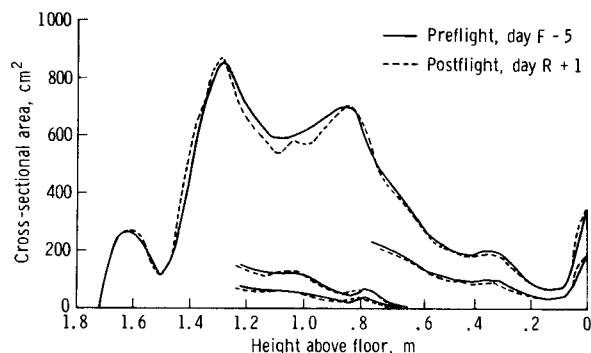


Figure 28.- Volume as a function of longitudinal axis level of SL-3 CDR before and after flight.

An inadequate diet will increase the deconditioning effects through direct loss of muscle mass, especially in well-conditioned subjects. To prevent such leg muscle losses, an adequate diet and relatively short periods of heavy exercise are required. Any muscle must be exercised at or above its one-g working stress level to prevent loss of function. On the basis of Russian and Skylab experience, a treadmill with axial body loading to body weight levels appears to be the best exercise device. Optimum protocols remain to be demonstrated.

A second undesirable aspect of leg muscle deconditioning is a reduction in gravity tolerance of the cardiovascular system.

Arms will also suffer some atrophy under weightlessness, but this loss will be limited because of the relatively heavier workloads they encounter in weightlessness, where arms must often assume the legs' role in stabilization as well as their usual role of manipulation. Handgrip strength is little affected because of the grasping of loads required in space.

Changes in legs begin immediately on exposure to weightlessness; and as an optimum countermeasure, exercise should begin as early as possible. Although these changes are potentially serious, there is every reason to believe that they can be prevented by proper diet and exercise.

Strength and Composition Changes

From one-g experience, it could be predicted that placing the human body in weightlessness would produce a marked decrease in strength and mass of several major muscle groups, especially major antigravity groups, and would probably affect neuromuscular function. In an active individual, some 40 percent or more of the body is devoted to opposing gravity in standing and walking. Large masses of muscle in legs, hips, and back are normally required to generate forces of hundreds of pounds, thousands of times a day. Unless engaged in manual labor or rigorous training, the hands, arms, and shoulders do much less work, which is reflected in their smaller mass. In weightlessness, the legs become virtually useless and unused except for "perching" and, occasionally, for pushing off in movement. In contrast, the hands and arms remain in use, increasingly in some cases, for grasping and stabilization of the body, as well as for manual manipulations. However, arm and hand forces in weightlessness are usually much smaller than corresponding forces on Earth. Under such circumstances, one would expect a relatively rapid (days to weeks) loss of strength in legs and lower back, followed by atrophy of these areas, with a relative sparing of strength and mass in arms and shoulders. Loss of muscle may be further affected by diet. If the diet is inadequate (see the section on weight changes), especially in crewmembers with low body fat, the caloric deficit will be made up with body fat and muscle (Vanderveen and Allen, 1972). Conversely, if the diet is adequate to maintain body weight, any muscle lost will be replaced with fat deposited in the areas of the body usually subject to such deposition.

Loss of muscle mass and function will cause little difficulty during a flight, for no tasks that require maximum strength of legs and back would be included in on-orbit operations. It is during reentry and after recovery that such reductions in function would be noted. Cardiovascular effects of this loss of leg muscle²⁴ cannot be covered here but may become critical under gravitational forces in reentry. Should the crew have to make emergency ground exits after, say, an Orbiter landing, such reductions in muscle function could also be serious. If preventive measures are not taken in flight, the crew must expect several days or more of reduced function in the one-g environment after landing; the time factor will depend upon individual characteristics and flight duration. Flights as short as 18 days have caused difficulty in the Russian program (Kakurin, 1971; Parin et al., 1974).

Study and documentation of such changes are far from complete. For one thing, neither Russian nor American programs have been planned to allow deconditioning to follow its normal course, and for good reason. Although the Russians have placed a great deal of emphasis on this aspect of space physiology and operations and have had active programs of investigation and prevention, there was little effort in this area in American programs until Skylab. The following three subsections are a resume of programs and data obtained to date, including Russian data available to the author at this time.

Strength

The state of the art of the study of strength is such that reiteration of a few fundamental considerations is in order. All measurement conditions, including angles, velocities, and types of opposing forces, affect measured muscle forces. Unless otherwise stated, it is assumed that all Russian measurements were of static maximum-effort forces; but nothing else is known about them. American handgrip forces were static, but Skylab measurements were of voluntary maximum-effort isokinetic exertions at a rate of 45°/sec, which produced forces just below maximum-effort static levels.

Equally important to proper interpretation is knowledge of the subject's previous and current training program. Russian Soyuz missions had an unknown exercise regimen that was expanded on Soyuz 9 to include simulated weights, with exercise periods of approximately 2 hours a day. Exercises included "running, walking, jumping, squatting" - but only at simulated weights of 20 kg²⁵ - and exercise "of the hands, neck, etc., for purposes of coordination" (Kakurin, 1971). The Soyuz 11/Salyut mission had an even more vigorous program - 3 hours a day with loads of up to 50 kg of body weight and a motor-driven treadmill that enabled walking. These exercise factors must be used in interpretation of results. Exercise protocols on Skylab are discussed later.

²⁴See footnote 5 on p. I-3.

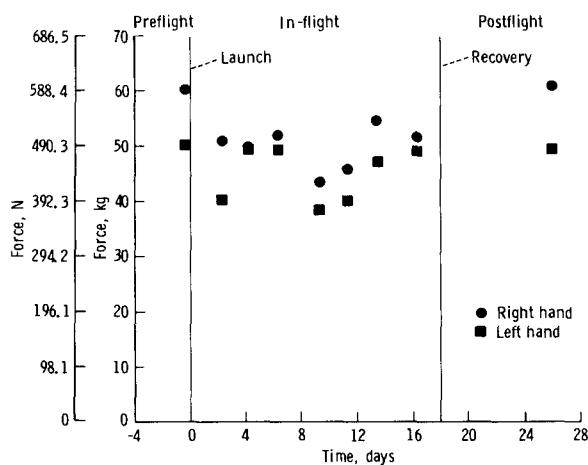
²⁵This simulated weight was apparently increased in flight.

The earliest, easiest to make, and probably least important strength measurements are those of the static handgrip forces. Figures 29(a) and 29(b) contain a series of measurements from Soyuz 9. Apparently, Russian investigators felt that neurological inhibition from weightlessness played a part in the reduction of forces seen in flight here, for on the Soyuz 11/Salyut mission, they compared forces with the man restrained as opposed to "free" and found no significant differences (Parin et al., 1974). American Skylab data are summarized in table 7 and show no consistent change except a slight bilateral loss in the PLT on SL-3, who was an unusually powerful man accustomed to heavy one-g work.

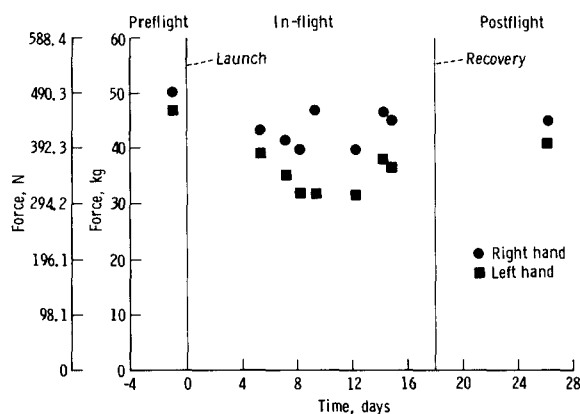
These results would be consistent with the view that the hands are probably less affected by space flight than any other muscle group, as a great deal of grasping and other hand functions are performed in flight. All other major muscle groups, and especially the lower limbs, suffer rapid disuse atrophy. This fact was demonstrated in Russian programs and during the Skylab program, which will be described next.

In the Skylab program, a minimum-impact postflight muscle function test was first instituted; later, according to mission demands, exercises and exercise devices were added, and the testing was expanded. The result was a different exercise environment on each flight such that there were three experiments, with the results of each flight affecting the next. The flights will be described chronologically.

Evaluation of the right arm and leg was done before and after flight on all missions with the Cybex Isokinetic Dynamometer. This dynamometer may be rotated in either direction without resistance until an adjustable limit speed is reached. Speed cannot be increased above this limit by forces of



(a) Nikolayev.



(b) Sevast'yanov.

Figure 29.- Handgrip forces as a function of time in weightlessness for Soyuz 9 crewmen.

TABLE 7.- GRIP STRENGTH MEASUREMENTS OF SKYLAB CREWMEN

Crew- man	Hand	Preflight, N (lb)		Postflight, N (lb)									
		F - 30	F - 4	R + 0	R + 1	R + 2	R + 4	R + 5	R + 11				
		SL-2											
CDR	Right	427.0	(96.0)	385.2	(86.6)	397.2	(89.3)	387.0	(87.0)	--	--	--	--
	Left	424.8	(95.5)	383.9	(86.3)	380.8	(85.6)	373.6	(84.0)	--	--	--	--
SPT	Right	556.0	(125.0)	520.4	(117.0)	--		538.2	(121.0)	--	--	--	--
	Left	538.2	(121.0)	462.6	(104.0)	--		478.6	(107.6)	--	--	--	--
PLT	Right	547.1	(123.0)	474.2	(106.6)	458.2	(103.0)	483.1	(108.6)	--	--	--	--
	Left	507.1	(114.0)	444.8	(100.0)	478.6	(107.6)	467.1	(105.0)	--	--	--	--
SL-3													
CDR	Right	418.1	(94.0)	409.2	(92.0)	416.3	(93.6)	--		--	418.1	(94.0)	--
	Left	385.2	(86.6)	403.0	(90.6)	401.7	(90.3)	--		--	387.0	(87.0)	--
SPT	Right	453.7	(102.0)	444.8	(100.0)	459.5	(103.3)	458.2	(103.0)	434.1	(97.6)	432.8	(97.3)
	Left	449.3	(101.0)	475.9	(107.0)	434.1	(97.6)	458.2	(103.0)	468.4	(105.3)	460.8	(103.6)
PLT	Right	634.3	(142.6)	650.8	(146.3)	582.7	(131.0)	566.3	(127.3)	547.1	(123.0)	551.6	(124.0)
	Left	598.7	(134.6)	607.6	(136.6)	587.2	(132.0)	576.5	(129.6)	573.8	(129.0)	523.1	(117.6)
SL-4													
CDR	Right	390.1	(87.7)	387.0	(87.0)	397.2	(89.3)	387.0	(87.0)	388.3	(87.3)	394.6	(88.7)
	Left	375.0	(84.3)	364.7	(82.0)	369.2	(83.0)	351.4	(79.0)	351.4	(79.0)	366.1	(82.3)
SPT	Right	502.6	(113.0)	458.2	(103.0)	439.0	(98.7)	452.4	(101.7)	418.1	(94.0)	403.5	(90.7)
	Left	499.5	(112.3)	451.5	(101.5)	412.3	(92.7)	410.6	(92.3)	382.5	(86.0)	369.2	(83.0)
PLT	Right	441.7	(99.3)	462.6	(104.0)	430.1	(96.7)	431.5	(97.0)	415.0	(93.3)	431.5	(97.0)
	Left	401.7	(90.3)	432.8	(97.3)	427.0	(96.0)	427.0	(96.0)	419.5	(94.3)	418.1	(94.0)

any magnitude; that is, the constant speed-maximum force of isokinesis is achieved. Input or muscle forces are continuously recorded at a constant angular rate.

The arrangement used on Skylab missions is shown in figure 30. A crewman, after thorough warmup, made 10 maximum-effort full flexions and extensions of the arm at the elbow and of the hip and knee at an angular rate of $45^\circ/\text{sec}$. A continuous force record was made of each repetition at a rate of 25 mm/sec, and the integral of force - or, under these conditions, work - was recorded on a second channel (see fig. 31).

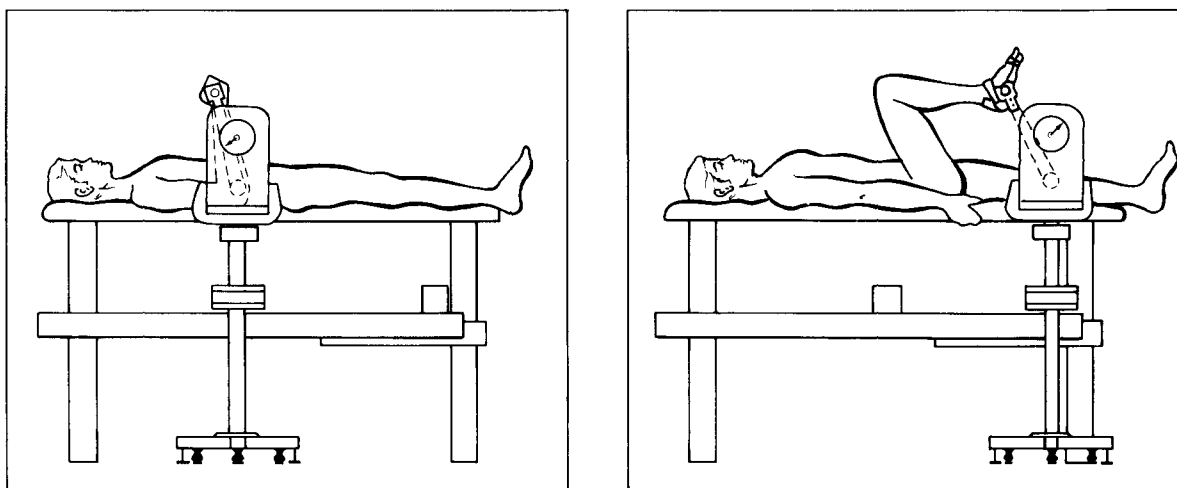


Figure 30.- Arrangement used for Skylab postflight muscle function test.

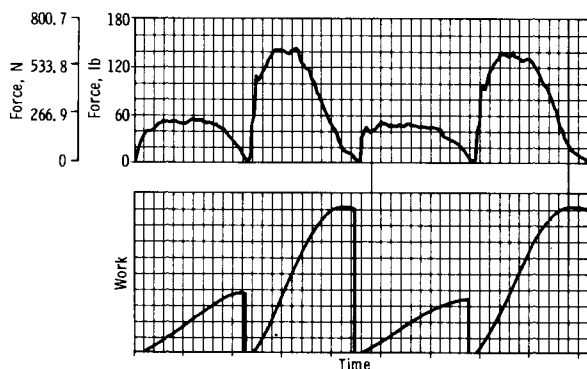


Figure 31.- Recording of right-leg muscle forces of the SL-3 backup PLT.

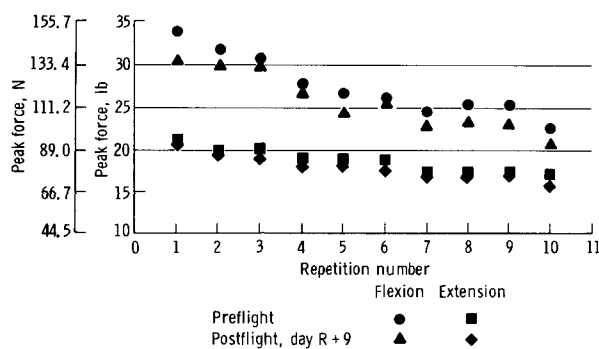


Figure 32.- A plot of peak arm forces of the SL-3 CDR from preflight and postflight curves.

Machine errors are small, 2 to 3 percent or less. At lower angular rates, the test gives a measurement of strength comparable to that achieved in the more commonly used isometric testing but has the advantage of recording this force throughout the whole range of motion, as well as allowing a number of repetitions for statistical purposes. It is sensitive enough to show small changes in performance which may occur in days.

A great deal of information is contained in the recordings made, but only one quantity will be used, the peak force of each repetition. Use of a single point on the tension curve to represent the entire curve may be open to criticism, especially for the leg, in which a number of muscles are involved. However, for the investigators' purposes, the author believes that this method provides a valid measure of strength of the muscles tested.

A plot of such peak points from a preflight and a postflight curve is shown in figure 32. The strength for a given movement is taken as the average of 10 repetitions. As can be seen, a fatigue decrement is present and may vary. It is included in the strength figure by virtue of averaging the 10 repetitions.

On SL-2, only the bicycle ergometer was used for in-flight exercise. The CDR used it in the normal fashion and was the only person on Skylab to use it in the hand-pedal mode. He also was the only person in this crew to exercise at rates comparable to those of later missions.

On this mission, testing was performed 18 days before launch and 5 days after flight. It was recognized that these testing times were too far removed from the time of flight, but it was the best that could be done under schedule constraints.

By the time muscle testing was done on day 5, there had been a significant recovery in function; however, a marked decrement remained. The decrement in leg extensor strength approached 25 percent; the arms had suffered less but also had marked losses (see figs. 33 and 34). The CDR's arm extensors had no loss (fig. 33) since he presumably used these muscles in hand-pedaling the bicycle. This result illustrates a crucial point in muscle conditioning: to maintain the strength of a muscle, it must be stressed to or near the level at which it will have to function. Leg extensor muscles must develop forces of hundreds of pounds, whereas arm extensor forces are measured in tens of pounds. Forces developed in pedaling the bicycle ergometer are typically tens of pounds and are totally incapable of maintaining leg strength. The bicycle ergometer is an excellent machine for aerobic exercise and cardiovascular conditioning, but it simply cannot develop either the type or level of forces required to maintain strength for walking under one-g conditions.

Immediately after SL-2, work was started on devices to provide adequate exercise to arms, trunk, and legs. A mass-produced commercial device, called Mini Gym (designated MK-I), was extensively modified. A centrifugal brake arrangement approximated isokinetic action on this device. Only exercises which primarily benefited arms and trunk were available from this device, as

shown in figure 35. Forces transmitted to the legs were higher than those from the ergometer, but they were still limited to an inadequate level since forces could not exceed the maximum strength of the arms, a fraction of leg strength.

A second device, designated MK-II, consisted of a pair of handles between which up to five extension springs could be attached. By using this device with its full complement of accessories, a maximum force of 364.8 N per meter (25 lb per foot) of extension could be developed.

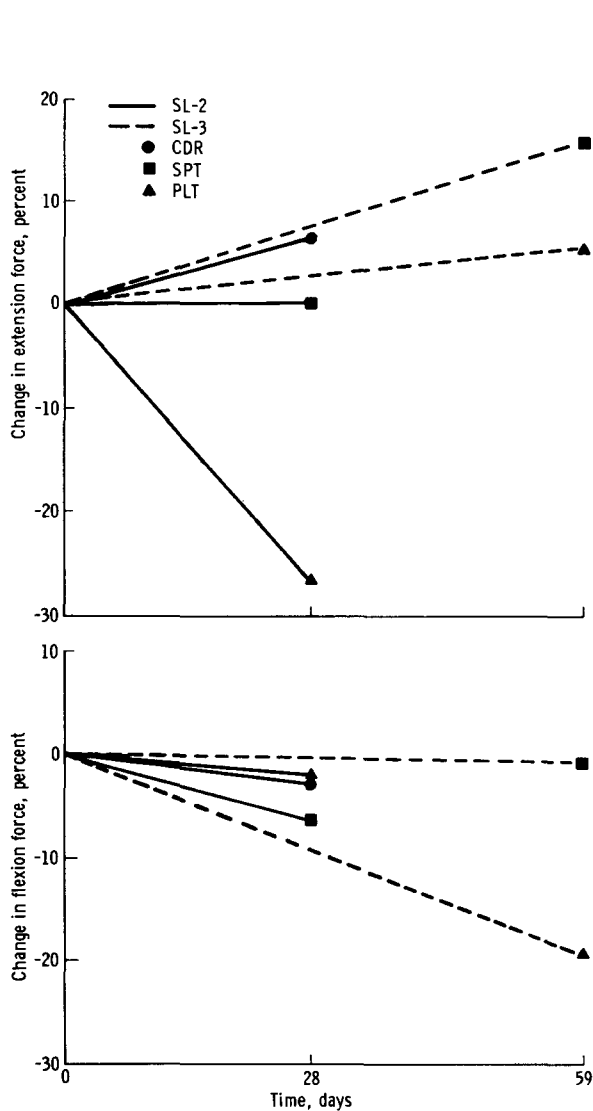


Figure 33.- A plot of the postflight changes in arm forces on SL-2 and SL-3. Positive values represent gain; negative values, loss.

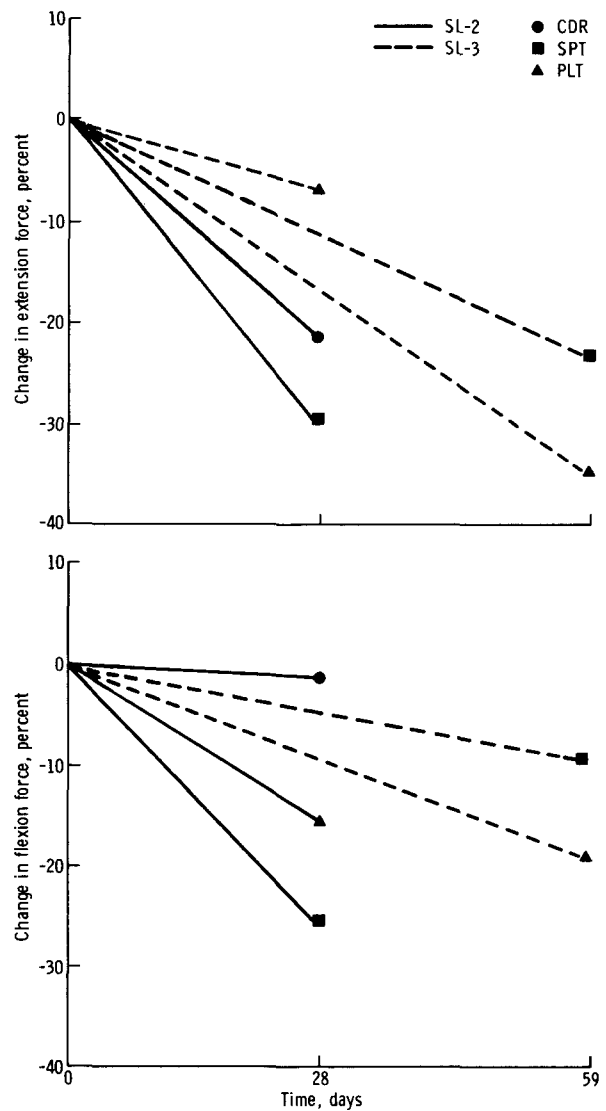


Figure 34.- A plot of the postflight changes in leg forces on SL-2 and SL-3. Positive values represent gain; negative values, loss.

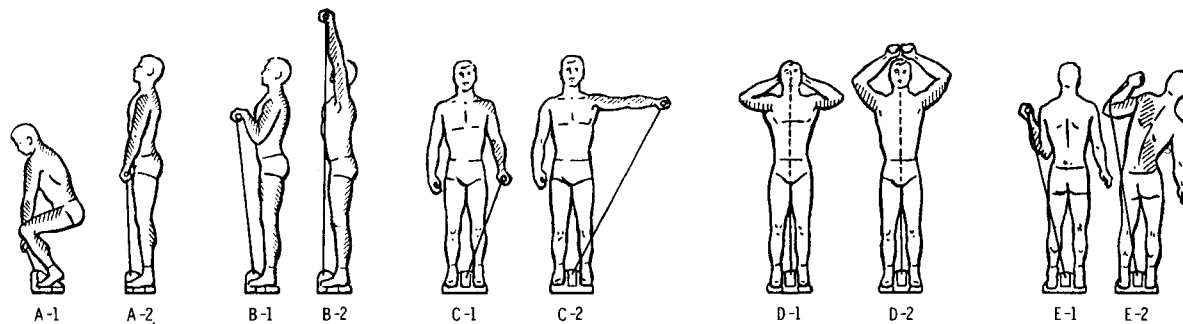


Figure 35.- MK-I exerciser positions.

These two devices were flown on SL-3, and food and time for exercise were increased in flight. The crew performed many repetitions per day of their favorite maneuvers on the MK-I and, to a lesser extent, on the MK-II. Also, the average amount of work done on the bicycle ergometer was more than doubled on SL-3, with all crewmen participating actively.

The results of muscle testing of SL-3 crewmen were markedly different from the results for the SL-2 crew.

Looking at changes in arm forces on SL-3, one sees complete preservation of extensor function, in contrast to SL-2 results (see fig. 33). The SPT showed a marked gain in arm strength. This consequence is the result of putting a good distance runner, which he was, on the equivalent of a weight-lifting program.

Looking now at changes in leg function, in figure 34, one sees a different picture. Results for only two SL-3 crewmen are shown since the CDR suffered a recurrence of a back strain from a lurch resulting from a roll of the recovery ship - possibly another demonstration of the hazard of muscle deconditioning.

Some device which would enable walking and running under forces equivalent to gravity appeared to be the ideal answer to this problem. This need had long been recognized; and immediately after SL-2, work was started on a treadmill for SL-4. As mission preparation progressed, the launch weight of the SL-4 vehicle became crucial; so the final design was simulation of a treadmill in response to weight constraints. The final weight of the device was 1.6 kg (3.5 lb).

The "treadmill," shown in figure 36, consisted of an aluminum-Teflon walking surface attached to the isogrid floor. Four rubber bungees, providing an equivalent weight of approximately 80 kg (175 lb), were attached to a shoulder and waist harness. By angling the bungees, an equivalent to a slippery hill is presented to the subject, who must climb it. High loads were placed on some leg muscles, especially in the calf, and fatigue occurred rapidly; so the device could not be used for significant aerobic work.

On SL-4, the crew used the bicycle ergometer at essentially the same rate as on SL-3, as well as the MK-I and MK-II exercisers. In addition, they typically performed 10 minutes per day of walking, jumping, and jogging on the treadmill. Food intake had again been increased.

Even prior to muscle testing, it was obvious that the SL-4 crew was in surprisingly good condition. They stood and walked for long periods without apparent difficulty on the day after recovery, in contrast to the experience of the other crews after the earlier missions. Results of the testing confirmed that a surprisingly small loss in leg strength occurred after almost 3 months in weightlessness. A summary of the exercise and strength testing, shown in averaged values for the three missions, is depicted in figures 37 and 38. One point to be noted is the relatively small loss in arm strength as compared to legs in all missions. This result is reasonable, for in space ordinary work provides relatively greater loads for the arms; the legs receive virtually no effective loading. With the MK-I and MK-II exercisers, SL-4 arm strength increased in flexion and was minimal in extension.

Size is another common measure of muscle condition and has been discussed in the preceding section (see fig. 25).

There was a 4.7- to 9-fold reduction in the rate of loss of leg extensor strength, leg volume, lean body mass, and total body mass from SL-2 to SL-4. One might argue that this reduction simply represents some kind of equilibrium with increasing mission duration, but this conclusion is not consistent with the data in table 8, which show absolute losses.

As shown in figure 39, SL-4 crewmen demonstrated a marked improvement over previous Skylab crews with regard to losses of weight, leg strength, and leg volume. There can be little doubt that use of the added MK-I and MK-II improved the arm performance of the crewmen on SL-2 and SL-3 and equally little doubt that use of the SL-4 treadmill sharply reduced loss of leg strength and mass, since there was negligible increase in leg exercise with other devices on SL-4.

However, it must be recognized that food was another variable present. Virtually all nutritionists recognize that metabolic losses in normal subjects are mixed; i.e., both fat and muscle are lost. Vanderveen and Allen

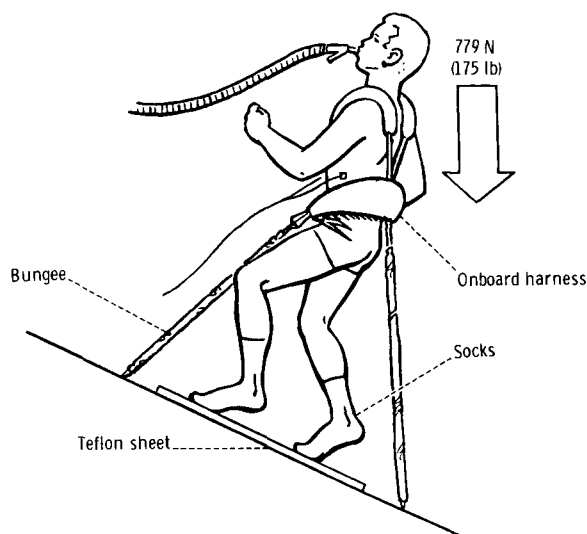


Figure 36.- Skylab treadmill arrangement used to test muscle function.

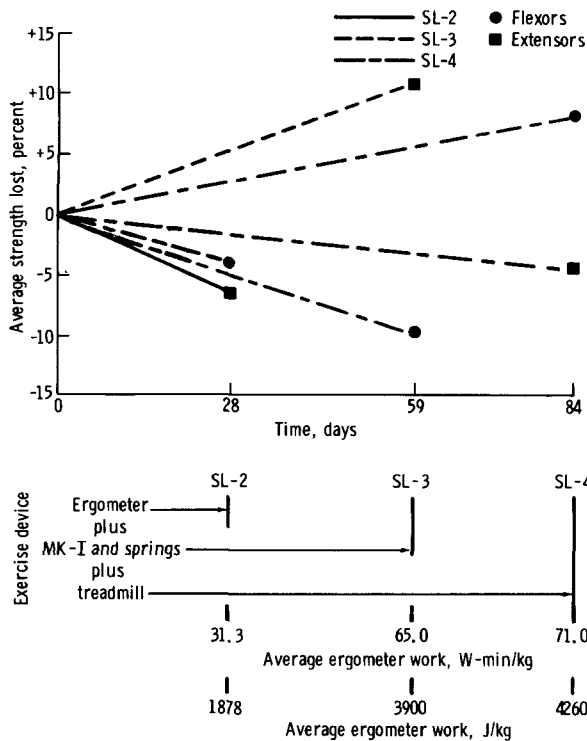


Figure 37.- A plot of the average arm strength changes on Skylab missions.

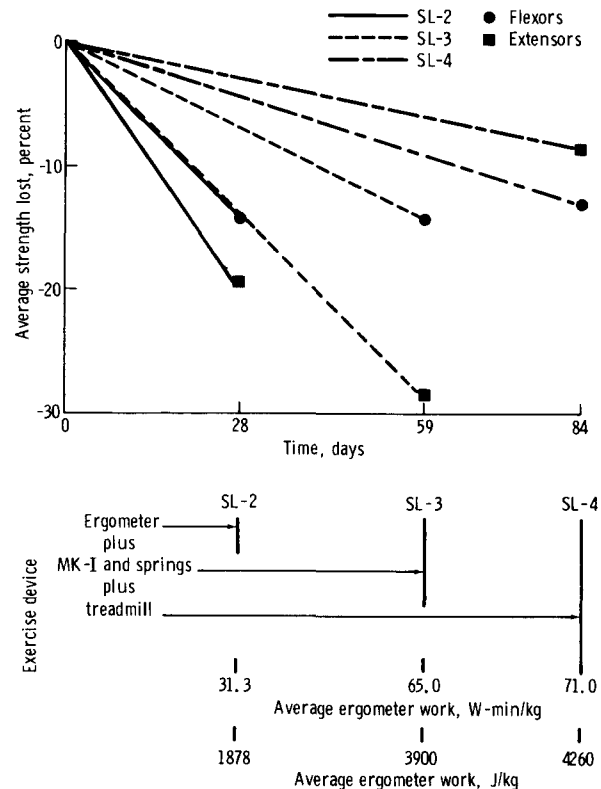


Figure 38.- A plot of the average leg strength changes on Skylab missions.

(1972) deliberately reduced caloric intake during a one-g chamber test simulation of space-flight conditions, using subjects chosen on the basis of being as equivalent as possible to the astronaut population. They found an almost pure muscle loss.

The Russian experience followed similar but much more elaborate lines, which included prolonged bed rest and supine tests on a motor-driven mill flown on Soyuz 11/Salyut, with elaborate force-loading suits to simulate gravity. Hours per day were spent on the treadmill, but at a load of only 50 kg of equivalent weight, in contrast to the 80 kg on Skylab with 70-kg crewmen for 12 to 15 minutes a day.

Some measured parameters from Russian missions are shown in table 9. According to these data, there is a consistent increase in loss of "tone" and strength in the legs, as compared to small arm losses, even on the 3- to 5-day missions. This loss increased sharply on the 18-day Soyuz 9 flight, in spite of prolonged, lightly loaded exercises. Again, such exercise was apparently sufficient for arms, which showed an increase in tone and negligible loss in girth and in wrist strength. It is interesting to note that the right, presumably dominant, wrist lost strength, whereas the left wrist

TABLE 8.- SUMMARY OF SKYLAB CREW AVERAGES OF EXERCISE-RELATED DATA

Skylab mission	Change in leg extension forces (F - 15 to R + 1), percent/day	Change in leg volume (F - 15 to R + 5), percent/day	Change in lean body mass (LBM) (F - 15 to R + 1), percent/day	Change in body weight (F - 1 to R + 0), percent/day	Average daily ergometer exercise, J/kg (W-min/kg) body weight
^a ₂	^b -0.75	-0.160	-0.089	-0.13	1878 (31.3)
^c ₃	-0.50	-0.088	-0.019	-0.08	3900 (65.0)
^d ₄	-0.10	-0.023	-0.011	-0.02	4260 (71.0)

^aExercise available - bicycle ergometer.^bMeasured at R + 5 on this flight.^cExercise available - bicycle ergometer, MK-I and MK-II exercisers.^dExercise available - bicycle ergometer, MK-I and MK-II exercisers, treadmill.TABLE 9.- SOME AVERAGE CHANGES IN MUSCLE PARAMETERS^a

[From Kakurin (1971) and Parin (1974)]

Flight duration, days	Number of subjects	Change, percent preflight				Δ circumference							
		Tone		Strength		mm				percent			
		Tibialis anterior	Quadriceps	Biceps brachii	Standing	Left wrist	Right wrist	Shin level	Hip level	Shoulder level	Upper arm	Thigh	Calf
2 to 5	12	-7.5	-10.4	-5.4	-17	1.7	-1.5	-2	-7	-5	--	--	--
		Soyuz 3 to 8											
18	2	-11.2	-13.4	5.5	-29.9	5.7	-6.1	-12	-27	-2	-0.3	-3.3	-4.9
		Soyuz 9											
24	3	--	--	--	--	--	--	--	--	--	b -1.1	b -4.4	b -5.4
		Soyuz 11/Salyut											

^aMeasured 2 days after recovery except as noted otherwise.^bMeasured post mortem.

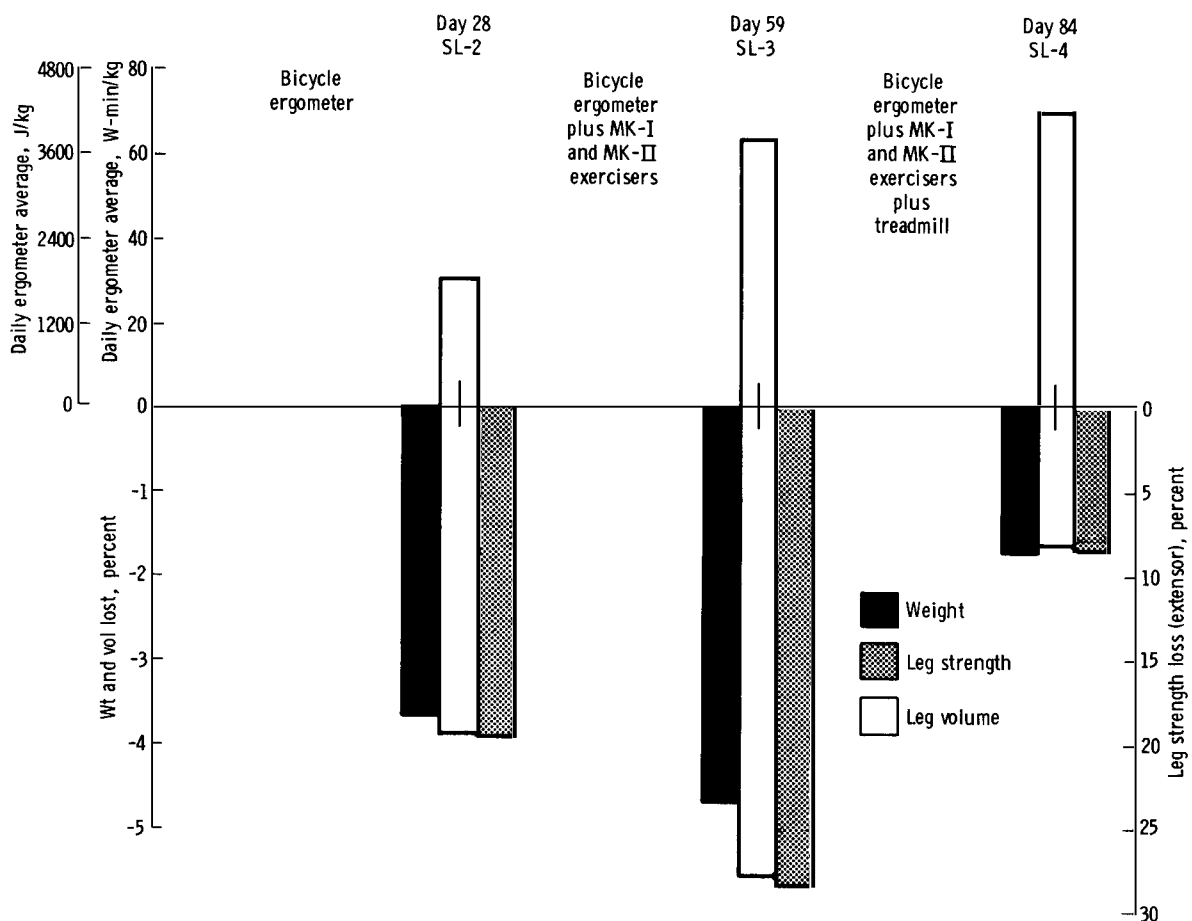


Figure 39.- Exercise-related quantities on Skylab missions.

gained. Although it did not appear statistically significant, one had the impression from Skylab handgrip measurements that the same thing happened there. The author suspects that the nondominant hand was used for grasping and stabilization, whereas the dominant hand was used for manipulation. The in-flight death of the Salyut crew makes functional comparisons impossible.

Another single data point on muscle change was obtained on the ASTP, a 9-day mission (see table 10). It may be a coincidence that crewman 2 lost no leg volume, but he was provided with a shoulder harness which enabled high-force leg exercises to be performed with a rope/capstan device.

Walking

Changes in muscle function were also reflected in postflight gait and posture. There was a general tendency toward hunched posture with slightly lowered head and a "shuffling" gait, with a marked aversion to the upright

TABLE 10.- LEFT-LEG VOLUME CHANGES OF ASTP CREWMEN

Crewman	Preflight volume, liters	Postflight (R+2) volume, liters	Δ volume, liters	Δ volume, percent
1 (ACDR)	7.8	7.40	-0.40	-5.1
2 (DMP)	7.5	7.50	0	0
3 (CMP)	8.1	7.75	-.35	-4.3

posture, especially in the first two Skylab crews. The last crew tolerated upright posture without apparent difficulty just 18 hours after recovery. Unfortunately, the gait and posture were not documented in the American program; but Russian cinephotographic documentation (Parin et al., 1974) showed a marked slowing of all phases of the walking gait (and especially the time with both feet on the ground), an effect which would be consistent with American observations. This result indicates reduced strength in the trunk and legs, possibly complicated by neuromuscular changes.

Body Composition Changes

Other indicators of muscle (and fat) changes are lean body mass determinations. These values were obtained on Skylab missions by means of standard radioisotopic dilution studies.²⁶ Results are tabulated in table 11. As these studies were made on recovery day (R + 0), before fluid redistribution and replacement were complete, some degree of dehydration was present, which would have the effect of decreasing both lean body mass and lean body mass percentage. Data taken on day R + 2 would have been more representative here, but the R + 0 data are consistent with other muscle data.

The data show a consistent loss of lean body mass but a rate of loss reduced with each mission. Lest someone interpret this result as some kind of adaptation, note that the crew of the shortest mission had the greatest lean body mass loss and the last crew had the least strength loss. Only one individual gained lean body mass (SL-3 SPT). He was the lightest individual; and he used the in-flight arm exercise devices enough to increase his arm strength by 15 percent, in contrast to his one-g regimen of running only.

In spite of this loss of lean body mass, the percentage of lean body mass increased in all crewmen but two, a result indicating the inadequacy of the diet to maintain fat levels even in individuals with body-fat percentages as low as 9 percent.

²⁶Data from studies done by Phil Johnson, Baylor Medical College, and Carolyn Leach, Lyndon B. Johnson Space Center.

TABLE 11.- CHANGES IN LEAN BODY MASS

ON SKYLAB MISSIONS

[By isotopic determination]

(a) By crewman

Crewman	LBM, kg, on -		Δ LBM		LBM, percent, ^a on -		Δ LBM, percent
	F - 1	R + 0	kg	percent	F - 1	R + 0	
SL-2							
CDR	56.6	55.9	-0.7	-1.2	91.9	92.7	0.8
SPT	67.4	65.7	-1.7	-2.5	87.0	^b 88.9	1.9
PLT	71.5	68.5	-3.0	-4.2	88.3	90.1	1.8
SL-3							
CDR	58.2	57.4	-0.8	-1.4	85.0	88.7	3.7
SPT	53.6	54.2	.6	1.1	87.0	92.2	5.2
PLT	73.4	71.1	-2.3	-3.1	84.6	83.1	-1.5
SL-4							
CDR	57.4	56.2	-1.2	-2.1	84.3	82.5	-1.8
SPT	62.3	61.5	-.8	-1.3	87.4	87.8	.4
PLT	63.0	61.8	-1.2	-1.9	91.3	93.9	2.6

(b) By mission

Mission	Duration, days	Mean Δ LBM			
		kg	kg/day	percent	percent/day
SL-2	28	-1.80	6.43×10^{-2}	-1.50	-5.36×10^{-2}
SL-3	59	-.83	1.41×10^{-2}	-2.47	-4.19×10^{-2}
SL-4	84	-1.07	1.27×10^{-2}	-.40	$-.48 \times 10^{-2}$

^aLBM divided by body weight times 100.^bMeasured on R + 1.

The crewmen maintaining body fat are notable. The SL-4 CDR was the only crewman not losing body weight, a result indicating that some lost muscle was replaced with fat. Although the SL-3 PLT lost body weight, he was large and unusually well muscled and obviously lost this muscle at a rate greater than the rate of loss of body weight and thereby maintained his body fat.

Each succeeding mission showed an improvement in rate of loss of lean body mass and rate of change in lean body mass percentage, which can only be attributed to generally improved nutrition and exercise on each succeeding flight.

Applications

This subject of loss of strength and muscle mass is one of the more important aspects of manned space flight, especially for the prolonged missions of the future requiring numerous personnel for manual tasks such as structure assembly and similar operations. The concern is not with operations in space - for there is no reason to think that even unprotected muscle function will ever fall below that routinely required in space flight - but with capabilities on Earth after a return from space flight. Without protection, serious muscle disuse atrophy will begin in the first few days of weightlessness in the major antigravity groups and continue to a functional equilibrium far below that compatible with erect stance and locomotion on Earth. Although this aspect is not discussed, such atrophy will seriously degrade gravity tolerance as well. Thus, unless one is prepared to accept special reentry precautions, followed by an extensive rehabilitation program on return to a one-g environment, adequate in-flight diet and exercise force levels compatible with those required for walking must be provided. This problem of prevention is primarily one for the life scientists; however, the measurements and assessments of muscle condition required are much more familiar to the anthropometrist. A cooperative effort by the anthropometrist, the exercise physiologist, and the industrial physician may be in order.

FUTURE

Unfortunately, the role of anthropometrics, other than when forced to the surface by a specific problem such as suit fit or cockpit layout, has been largely ignored. This neglect cannot be continued unless a long, painful, and inefficient period of trial and error can be afforded in the space program as man expands his time and efforts in space. The pitifully incomplete data informally gathered and presented here should be enough to stimulate better future efforts. Even this small amount of data has been enough to show the potential impact of weightlessness on man/machine design. It was also enough to redirect the efforts and thinking in several life science areas, especially the cardiovascular area.

For this reason, a few NASA investigators are redoubling their efforts in several areas. Most urgent, these investigators believe, is development of improved methods of data collection, especially with regard to time and simplicity, particularly for dynamic data such as strength measurements. A series of developments is underway that, hopefully, will enable rapid, automatic recording and analysis of size, shape, and motion on Earth or in space, of nude or space-suited crewmen. These data will be stored and automatically interfaced with computational facilities so that man may be synthetically interfaced with any desired machine or situation.

The optimum interface may then be tested in space by this improved data gathering and instrumentation, and both models and machines will be improved. Several pioneers have been at work for some time now, showing alternatives to the complications and limitations of tapes, goniometers, static weights, and mockups, including "Combiman" at AMRL, Herron with his application of stereophotogrammetry to the body, and Perrine with isokinetic strength testing, as well as many others. The NASA investigators hope to follow and possibly aid their trailblazing and sincerely hope to be joined by professional anthropometrists more experienced than themselves in investigating this new area of weightlessness, for it is an exciting place to be - and there is both need and opportunity aplenty.

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ADDITIONAL DATA SOURCES

It was originally intended to include all anthropometric data available from space flight in this chapter and the accompanying appendixes, but it soon became obvious that more had been collected than originally allowed for. Although the bibliographic references contain additional data, a good number of known sources were not included. Investigators with appropriate requirements and NASA clearance are directed to the following sources for further information.

1. The Life Sciences Directorate, code DA, NASA Lyndon B. Johnson Space Center, Houston, Texas 77058, which has an archival section in which all zero-g data will eventually be assembled.

2. William Thornton, M.D., code CB, NASA Lyndon B. Johnson Space Center, Houston, Texas 77058, who has most of the raw data, including all anthropometric photographs, complete strength measurement curves, and some related one-g records.

3. Dr. R. E. Herron, Biostereometrics Laboratory, Texas Institute for Rehabilitation and Research, 1333 Moursund Ave., Houston, Texas 77025, who has the original stereophotogrammetric work.

4. Dr. Wycliff Hoffler, code DB53, NASA John F. Kennedy Space Center, Kennedy Space Center, Florida 32899, who has ASTP and other leg-girth data.

5. John Jackson and Jeri Brown, code EW5, NASA Lyndon B. Johnson Space Center, Houston, Texas 77058, who have a variety of data, including zero-g and water-immersion studies.

APPENDIX A

WEIGHT CHANGES OF SPACE-FLIGHT CREWMEN

In table A-1, anthropometric weight changes of U.S. crewmen of the Mercury-Redstone (MR), Mercury-Atlas (MA), Gemini-Titan (GT), Apollo-Saturn (AS), and Apollo-Soyuz Test Project (ASTP) missions are listed. The nude weight of the designated pilot (PLT), command pilot (CP), commander (CDR), command module pilot (CMP), lunar module pilot (LMP), Apollo commander (ACDR), or docking module pilot (DMP) was taken immediately before and after each mission.

In table A-2, weight changes of U.S.S.R. cosmonauts are shown for the Vostok 1 to 6, Voskhod 1 and 2, Soyuz 3 to 9, and Soyuz 11/Salyut missions.

In table A-3, body weights of all Skylab crewmen measured daily during the Skylab 2 (SL-2), Skylab 3 (SL-3), and Skylab 4 (SL-4) missions are presented, together with a range of preflight and postflight measurements. The day of year (DOY), calendar date, and mission day (MD) are listed for convenience. The designator F - 30 represents 30 days before lift-off, R + 0 represents recovery day, R + 16 represents 16 days after recovery, and so forth. The crewman designators are CDR, PLT, and science pilot (SPT). Except for first shipboard weights or as otherwise noted, all ground-based measurements were made of the nude crewmen after the first urination of the day and before breakfast.

In-flight mass measurements were made with use of the body mass measuring device (BMMD). A fifth-order curve fit was used on DOY 151 calibration data for SL-2, a second-order curve fit on DOY 211 calibration data for SL-3, and a fourth-order curve fit on DOY 211 calibration data for SL-4. Where appropriate, corrections have been made for clothing weight and one-g conditions.

TABLE A-1.-- WEIGHT CHANGES OF U.S. ASTRONAUTS

Flight	Crewman	Age, yr	Height, cm(in.)	Weight, kg(lb)		Weight change	
				Preflight	Postflight	kg(lb)	percent
MR-3	PLT	37	180.3 (71)	--	--	--	--
MR-4	PLT	35	170.2 (67)	--	--	--	--
MA-6	PLT	40	179.1 (70.5)	--	--	--	--
MA-7	PLT	37	179.1 (70.5)	69.8 (154)	67.1 (148.0)	-2.7 (-6.0)	-3.9
MA-8	PLT	39	177.8 (70)	80.2 (176.8)	80.0 (176.3)	-.2 (-.5)	-.3
MA-9	PLT	36	172.7 (68)	66.7 (147)	63.3 (139.5)	-3.5 (-7.75)	-5.3
GT-III	CP	38	170.2 (67)	71.7 (158)	70.3 (155)	-1.4 (-3)	-1.9
	PLT	34	175.3 (69)	74.4 (164)	73.8 (162.8)	-.6 (-1.5)	-.9
GT-IV	CP	36	180.3 (71)	71.0 (156.5)	68.9 (152)	-2.0 (-4.5)	-2.9
	PLT	34	180.3 (71)	78.5 (173)	74.6 (164.5)	-3.8 (-8.5)	-4.9
GT-V	CP	38	172.7 (68)	68.9 (152)	65.5 (144.5)	-3.4 (-7.5)	-4.9
	PLT	35	168.9 (66.5)	69.8 (154)	66.1 (145.8)	-3.7 (-8.2)	-5.3
GT-VI	CP	42	177.8 (70)	80.0 (176.3)	78.8 (173.7)	-1.2 (-2.6)	-1.5
	PLT	35	182.9 (72)	77.6 (171.0)	73.0 (161.0)	-4.5 (-10)	-5.8
GT-VII	CP	37	177.8 (70)	73.7 (162.5)	69.2 (152.5)	-4.5 (-10)	-6.2
	PLT	37	180.3 (71)	76.9 (169.5)	74.2 (163.5)	-2.7 (-6.0)	-3.5
^a GT-VIII	CP	35	180.3 (71)	73.8 (162.7)	--	--	--
	PLT	33	182.9 (72)	78.5 (173.0)	--	--	--
GT-IX	CP	35	182.9 (72)	78.9 (174.0)	78.0 (172.0)	-.9 (-2.0)	-1.1
	PLT	32	182.9 (72)	78.2 (172.5)	74.6 (164.5)	-3.6 (-8)	-4.6
GT-X	CP	35	175.3 (69)	73.9 (163.0)	72.1 (159)	-1.8 (-4)	-2.4
	PLT	35	180.3 (71)	74.2 (163.5)	70.8 (156)	-3.4 (-7.5)	-4.6
GT-XI	CP	36	168.9 (66.5)	69.3 (152.7)	68.0 (150)	-1.2 (-2.7)	-1.8
	PLT	36	170.2 (67)	68.5 (151.0)	68.5 (151.0)	0 (0)	0
GT-XII	CP	38	180.3 (71)	77.1 (170.0)	72.7 (160.3)	4.4 (-9.7)	-5.7
	PLT	35	177.8 (70)	75.3 (166.0)	73.2 (161.3)	-2.1 (-4.7)	-2.8

^aMission aborted.

TABLE A-1.- Continued

Flight	Flight duration, days:hr:min	Crewman	Age, yr	Height, cm(in.)	Weight, kg(lb)		Weight change	
					Preflight	Postflight	kg(lb)	percent
AS-7	10:20:09	CDR	45	177.8 (70)	88.0 (194.0)	86.1 (189.8)	-1.9 (-4.2)	-2.2
		CMP	38	175.3 (69)	71.2 (157)	66.7 (147.0)	-4.5 (-10)	-6.4
		LMP	36	177.8 (70)	70.8 (156)	67.6 (149)	-3.2 (-7)	-4.5
AS-8	06:03:00	CDR	40	177.8 (70)	76.6 (169)	72.8 (160.5)	-3.8 (-8.5)	-5.0
		CMP	40	180.3 (71)	78.0 (172)	74.4 (164)	-3.6 (-8)	-4.7
		LMP	35	172.7 (68)	64.4 (142)	62.6 (138)	-1.8 (-4)	-2.8
AS-9	10:01:00	CDR	39	180.3 (71)	72.1 (159)	69.6 (153.5)	-2.5 (-5.5)	-3.5
		CMP	36	182.9 (72)	80.7 (178)	78.2 (172.5)	-2.5 (-5.5)	-3.1
		LMP	33	182.9 (72)	72.1 (159)	69.4 (153)	-2.7 (-6)	-3.8
AS-10	08:00:03	CDR	38	182.9 (72)	77.5 (171)	76.4 (168.5)	-1.1 (-2.5)	-1.5
		CMP	38	175.3 (69)	74.8 (165)	72.3 (159.5)	-2.5 (-5.5)	-3.4
		LMP	35	182.9 (72)	78.5 (173)	73.9 (163)	-4.5 (-10)	-5.8
AS-11	08:03:18	CDR	38	180.3 (71)	78.0 (172)	74.4 (164)	-3.6 (-8.0)	-4.7
		CMP ^b	38	180.3 (71)	75.3 (166)	72.1 (159)	-3.2 (-7.0)	-4.2
		LMP	39	177.8 (70)	75.7 (167)	75.3 (166)	-.4 (-1.0)	-.6
AS-12	10:04:36	CDR	39	168.9 (66.5)	67.7 (149.3)	65.8 (145)	-1.9 (-4.3)	-2.9
		CMP ^b	40	170.2 (67)	70.4 (155.3)	67.1 (148)	-3.3 (-7.3)	-4.8
		LMP	37	176.5 (69.5)	69.2 (152.5)	63.5 (140)	-5.7 (-12.5)	-8.2
AS-13	05:22:54	CDR	42	180.3 (71)	80.5 (177.5)	74.2 (163.5)	-6.3 (-14.0)	-7.9
		CMP	38	181.6 (71.5)	89.3 (197.0)	84.4 (186.0)	-4.9 (-11.0)	-5.6
		LMP	36	176.5 (69.5)	70.8 (156.0)	67.8 (149.5)	-3.0 (-6.5)	-4.2

^bDesignated crewmen spent period at 1/6 g; all other crewmen remained in weightlessness throughout mission.

TABLE A-1.- Concluded

Flight	Flight duration, days:hr:min	Crewman	Age, yr	Height, cm(in.)	Weight, kg(lb)		Weight change	
					Preflight	Postflight	kg(lb)	percent
AS-14	09:00:01	CDR	47	180.3 (71)	76.2 (168.0)	76.6 (169.0)	0.4 (1.0)	0.6
		CMP ^b	37	177.8 (70)	74.8 (165.0)	69.4 (153.0)	-5.4 (-12.0)	-7.3
		LMP	40	180.3 (71)	79.8 (176.0)	80.3 (177.0)	.4 (1.0)	.6
AS-15	12:07:11	CDR	38	182.9 (72)	80.2 (176.8)	78.9 (174.0)	-1.3 (-2.8)	-1.6
		CMP ^b	39	179.1 (70.5)	73.5 (162.0)	72.1 (159.0)	-1.4 (-3.0)	-1.9
		LMP	41	172.7 (68)	73.2 (161.5)	70.7 (156.0)	-2.5 (-5.5)	-3.4
AS-16	11:01:51	CDR	41	175.3 (69)	78.9 (174.0)	75.5 (166.5)	-3.4 (-7.5)	-4.3
		CMP ^b	36	177.8 (70)	61.4 (135.5)	58.5 (129.0)	-2.9 (-6.5)	-4.8
		LMP	36	181.6 (71.5)	73.0 (161.0)	70.5 (155.5)	-2.5 (-5.5)	-3.4
AS-17	12:13:51	CDR	38	182.9 (72)	80.3 (177.0)	76.1 (167.8)	-4.2 (-9.2)	-5.2
		CMP ^b	39	181.6 (71.5)	75.7 (167.0)	74.6 (164.5)	-1.1 (-2.5)	-1.5
		LMP	37	175.3 (69)	74.8 (165.0)	72.9 (160.8)	-1.9 (-4.2)	-2.5
ASTP	09:01:28	ACDR	44	182.9 (72)	76.9 (169.5)	77.6 (171.1)	.7 (1.6)	.9
		CMP	51	179.1 (70.5)	74.8 (165)	72.8 (160.5)	-2.0 (-4.5)	-2.7
		DMP	44	180.3 (71)	80.2 (176.8)	77.6 (171.1)	-2.6 (-5.7)	-3.2

^bDesignated crewmen spent period at 1/6 g; all other crewmen remained in weightlessness throughout mission.

TABLE A-2.- WEIGHT CHANGES OF U.S.S.R. COSMONAUTS

Flight	Flight duration, days:hr	Crewman	Weight, kg		Weight change	
			Preflight	Postflight	kg	Percent
Vostok 1	00:02	Gagarin	NA ^a	NA	NA	b,c-0.7
Vostok 2	01:01	Titov	NA	NA	NA	b,c-3.9
Vostok 3	03:22	Nikolayev	NA	NA	NA	b,c-2.5
Vostok 4	02:23	Popovich	NA	NA	NA	b,c-2.7
Vostok 5	04:23	Bykovskiy	NA	NA	NA	c-3.5
Vostok 6	02:23	Tereshkova	NA	NA	NA	c-3.2
Voskhod 1	00:24	Komarov et al.	NA	NA	b,d-2.5 to -3	NA
Voskhod 2	01:02	C-Belyayev	NA	NA	b-1.0	NA
		A-Leonov	NA	NA	b-.9	NA
^e Soyuz 3	03:23	Beregovoy	NA	NA	-2.4	NA
^e Soyuz 4	02:23	Shatalov	NA	NA	-4.0	NA
	^f 02:00	Yeliseyev	NA	NA	-2.0	NA
	^f 02:00	Krunov	NA	NA	-2.0	NA
^e Soyuz 5	03:46	Volynov	NA	NA	-2.4	NA
^e Soyuz 6	04:23	Shonin	NA	NA	-2.4	NA
		Kubasov	NA	NA	-2.1	NA
^e Soyuz 7	04:23	Filipchenko	NA	NA	-3.9	NA
		Gorbatko	NA	NA	-2.0	NA
		Volkov	NA	NA	-2.4	NA
^e Soyuz 8	04:23	Shatalov	NA	NA	-2.2	NA
		Yeliseyev	NA	NA	-3.6	NA
Soyuz 9	17:16	Nikolayev	65.0	62.3	-2.7	^g -4.15
	17:16	Sevast'yanov	68.0	64.5	-3.5	^g -5.14
Soyuz 11/Salyut	24:00	Dobrovol'skiy	81.0	77.1	-3.9	^g -4.8
		Volkov	83.3	80.56	-2.74	^g -3.3
		Patsayev	74.6	70.87	-3.73	^g -5.0

^aNA = not available.^bMeasured 24 hours after flight.^cSource: unpublished report.^dRange of losses.^eSource: Kakurin (1971).^fCrewmen launched on Soyuz 5 and returned on Soyuz 4.^gSource: Parin et al. (1974).

TABLE A-3.- DAILY BODY WEIGHTS OF SKYLAB CREWMAN

(a) SL-2

DOY	Date, 1973	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			Preflight		
^a 115	Apr. 25	F - 30	62.8 (138.5)	78.6 (173.3)	81.4 (179.5)
116	Apr. 26	F - 29	62.5 (137.8)	78.5 (173.0)	81.3 (179.3)
117	Apr. 27	F - 28	62.5 (137.8)	78.4 (172.8)	81.0 (178.5)
118	Apr. 28	F - 27	62.5 (137.8)	78.4 (172.8)	81.0 (178.5)
119	Apr. 29	F - 26	62.1 (137.0)	77.8 (171.5)	80.7 (178.0)
120	Apr. 30	F - 25	62.1 (137.0)	77.9 (171.8)	80.9 (178.3)
121	May 1	F - 24	62.8 (138.5)	77.8 (171.5)	80.9 (178.3)
122	May 2	F - 23	62.8 (138.5)	78.0 (171.9)	80.3 (177.0)
123	May 3	F - 22	62.3 (137.3)	77.8 (171.5)	80.3 (177.0)
124	May 4	F - 21	62.0 (136.8)	77.6 (171.0)	80.2 (176.8)
125	May 5	F - 20	61.8 (136.3)	77.5 (170.9)	79.9 (176.3)
126	May 6	F - 19	62.8 (138.5)	78.2 (172.5)	80.2 (176.8)
127	May 7	F - 18	62.6 (138.0)	77.8 (171.5)	79.9 (176.3)
128	May 8	F - 17	62.5 (137.8)	78.2 (172.5)	79.8 (176.0)
129	May 9	F - 16	61.9 (136.5)	77.5 (170.8)	79.2 (174.5)
130	May 10	F - 15	61.9 (136.5)	77.9 (171.8)	79.6 (175.5)
131	May 11	F - 14	62.3 (137.3)	77.6 (171.0)	79.6 (175.5)
132	May 12	F - 13	62.3 (137.3)	77.5 (170.8)	79.7 (175.8)
133	May 13	F - 12	62.1 (137.0)	77.8 (171.5)	79.4 (175.0)
134	May 14	F - 11	62.0 (136.8)	77.6 (171.0)	79.4 (175.0)
135	May 15	F - 10	61.6 (135.8)	77.2 (170.3)	N.D. ^b
136	May 16	F - 9	62.0 (136.8)	77.6 (171.0)	79.6 (175.5)
137	May 17	F - 8	62.1 (137.0)	N.D.	79.7 (175.8)
138	May 18	F - 7	61.6 (135.8)	77.8 (171.5)	79.7 (175.8)
139	May 19	F - 6	62.0 (136.8)	78.4 (172.8)	80.3 (177.0)
140	May 20	F - 5	62.0 (136.8)	78.1 (172.3)	80.1 (176.5)
141	May 21	F - 4	62.5 (137.8)	78.4 (172.8)	81.0 (178.5)
142	May 22	F - 3	N.D.	N.D.	N.D.
143	May 23	F - 2	61.7 (136.0)	77.5 (170.8)	80.3 (177.0)
144	May 24	F - 1	62.0 (136.8)	77.7 (171.3)	79.7 (175.8)
145	May 25	1	61.9 (136.5)	77.2 (170.3)	79.7 (175.8)

^aStart controlled diet.^bN.D. = not done.

TABLE A-3,- Continued

(a) Concluded

DOY	Date, 1973		MD	Weight, kg (lb)		
				CDR	SPT	PLT
				In-flight		
145	May	25	1	61.9 (136.5)	77.2 (170.3)	79.7 (175.8)
146	May	26	2	N.D.	N.D.	N.D.
147	May	27	3	N.D.	N.D.	N.D.
148	May	28	4	N.D.	N.D.	N.D.
149	May	29	5	61.4 (135.4)	75.6 (166.6)	79.4 (175.1)
150	May	30	6	61.2 (135.0)	75.2 (165.9)	79.2 (174.6)
151	May	31	7	62.1 (136.8)	76.1 (167.7)	78.9 (173.9)
152	June	1	8	61.1 (134.8)	75.3 (166.1)	79.0 (174.2)
153	June	2	9	61.7 (136.0)	75.5 (166.4)	78.6 (173.2)
154	June	3	10	61.6 (135.8)	75.9 (167.2)	78.0 (172.0)
155	June	4	11	61.2 (134.9)	75.9 (167.3)	78.8 (173.8)
156	June	5	12	61.6 (135.8)	75.3 (166.0)	79.1 (174.5)
157	June	6	13	60.5 (133.4)	74.7 (164.6)	79.1 (174.4)
158	June	7	14	60.1 (132.4)	75.3 (166.1)	78.5 (173.0)
159	June	8	15	60.7 (133.7)	74.9 (165.1)	78.1 (172.2)
160	June	9	16	61.0 (134.4)	76.0 (167.5)	78.6 (173.4)
161	June	10	17	61.4 (135.3)	76.0 (167.6)	78.4 (172.9)
162	June	11	18	61.1 (134.7)	75.7 (166.9)	78.0 (172.0)
163	June	12	19	61.2 (134.9)	75.9 (167.4)	78.6 (173.2)
164	June	13	20	61.3 (135.2)	75.4 (166.2)	78.2 (172.4)
165	June	14	21	60.7 (133.9)	76.1 (167.7)	77.9 (171.8)
166	June	15	22	61.3 (135.2)	75.7 (167.0)	78.3 (172.6)
167	June	16	23	61.1 (134.7)	75.6 (166.6)	77.3 (170.5)
168	June	17	24	61.3 (135.1)	75.7 (166.9)	77.7 (171.2)
169	June	18	25	N.D.	N.D.	N.D.
170	June	19	26	60.6 (133.6)	75.0 (165.3)	77.3 (170.3)
171	June	20	27	60.4 (133.1)	75.0 (165.4)	77.4 (170.6)
172	June	21	28	60.5 (133.3)	74.9 (165.2)	77.2 (170.3)
173	June	22	R + 0	60.8 (134.0)	74.5 (164.2)	76.5 (168.7)
Postflight						
173	June	22	^c R + 0	60.2 (132.8)	74.3 (163.8)	76.0 (167.5)
174	June	23	R + 1	60.6 (133.5)	73.8 (162.8)	76.4 (168.5)
175	June	24	R + 2	60.7 (133.8)	75.1 (163.5)	78.1 (172.3)
176	June	25	R + 3	61.0 (134.5)	N.D.	77.1 (170.0)
177	June	26	R + 4	61.2 (135.0)	74.6 (164.5)	77.3 (170.5)
178	June	27	R + 5	61.9 (136.5)	74.8 (165.0)	77.1 (170.0)
179	June	28	R + 6	61.7 (136.0)	75.1 (165.5)	77.6 (171.0)
180	June	29	R + 7	61.9 (136.5)	N.D.	77.5 (170.8)
181	June	30	R + 8	61.7 (136.0)	75.1 (165.5)	77.5 (170.8)
182	July	1	R + 9	N.D.	N.D.	N.D.
183	July	2	R + 10	61.5 (135.5)	74.8 (165.0)	77.7 (171.3)
184	July	3	R + 11	60.8 (134.0)	75.2 (165.8)	77.6 (171.0)
185	July	4	R + 12	60.8 (134.0)	N.D.	77.8 (171.5)
186	July	5	R + 13	60.8 (134.0)	75.0 (165.3)	77.2 (170.3)
187	July	6	R + 14	61.0 (134.5)	74.8 (165.0)	77.5 (170.8)
188	July	7	R + 15	N.D.	N.D.	77.5 (170.8)
^d 189	July	8	R + 16	N.D.	N.D.	77.6 (171.0)

^cFirst shipboard weights.^dStop controlled diet.

TABLE A-3.- Continued

(b) SL-3

DOY	Date, 1973	MD	Weight, kg (lb)		
			CDR	SPT	PLT
Preflight					
^a 188	July 7	F - 21	69.3 (152.8)	62.9 (138.8)	89.0 (196.3)
189	July 8	F - 20	68.4 (150.8)	62.5 (137.8)	86.7 (191.3)
190	July 9	F - 19	68.2 (150.3)	61.7 (136.0)	88.1 (194.3)
191	July 10	F - 18	68.8 (151.8)	62.1 (137.0)	87.9 (193.8)
192	July 11	F - 17	68.5 (151.0)	61.7 (136.0)	87.7 (193.3)
193	July 12	F - 16	68.0 (150.0)	61.5 (135.5)	87.1 (192.0)
194	July 13	F - 15	68.6 (151.3)	62.1 (137.0)	87.7 (193.3)
195	July 14	F - 14	68.9 (152.0)	61.6 (135.8)	88.5 (195.0)
196	July 15	F - 13	68.6 (151.3)	61.7 (136.0)	88.6 (195.3)
197	July 16	F - 12	68.3 (150.6)	61.5 (135.5)	88.1 (194.3)
198	July 17	F - 11	68.5 (151.0)	62.4 (137.5)	87.8 (193.5)
199	July 18	F - 10	68.7 (151.5)	62.0 (136.8)	87.8 (193.5)
200	July 19	F - 9	68.9 (152.0)	62.1 (137.0)	88.2 (194.5)
201	July 20	F - 8	68.6 (151.3)	61.6 (135.8)	88.3 (194.8)
202	July 21	F - 7	68.6 (151.3)	61.3 (135.3)	88.1 (194.3)
203	July 22	F - 6	68.0 (150.0)	61.7 (136.0)	87.4 (192.8)
204	July 23	F - 5	68.5 (151.0)	61.9 (136.5)	87.7 (193.3)
205	July 24	F - 4	68.8 (151.8)	62.5 (137.8)	88.5 (195.0)
206	July 25	F - 3	69.1 (152.3)	62.3 (137.3)	89.0 (196.3)
207	July 26	F - 2	68.6 (151.3)	61.1 (134.8)	88.8 (195.8)
208	July 27	F - 1	68.6 (151.3)	61.2 (135.0)	88.2 (194.5)
209	July 28	1	68.5 (151.0)	61.8 (136.3)	88.3 (194.8)
In-flight					
209	July 28	1	68.5 (151.0)	61.8 (136.3)	88.3 (194.8)
210	July 29	2	67.1 (147.8)	60.5 (133.5)	^e 86.5 (190.6)
211	July 30	3	66.9 (147.5)	59.5 (131.2)	^e 84.2 (185.5)
212	July 31	4	66.3 (146.1)	59.4 (130.9)	^e 85.6 (188.6)
213	Aug. 1	5	66.4 (146.3)	59.4 (131.0)	85.3 (188.0)
214	Aug. 2	6	65.9 (145.4)	59.5 (131.2)	85.7 (189.0)
215	Aug. 3	7	65.7 (144.8)	59.5 (131.2)	85.3 (188.1)
216	Aug. 4	8	65.9 (145.3)	59.4 (131.0)	85.8 (189.1)
217	Aug. 5	9	66.1 (145.6)	59.3 (130.8)	86.0 (189.7)
218	Aug. 6	10	66.3 (146.2)	59.3 (130.7)	85.8 (189.3)
219	Aug. 7	11	66.0 (145.6)	58.7 (129.4)	85.8 (189.1)
220	Aug. 8	12	65.7 (144.8)	59.1 (130.3)	85.8 (189.3)
221	Aug. 9	13	66.1 (145.6)	59.4 (130.9)	86.1 (189.9)
222	Aug. 10	14	66.5 (146.6)	59.4 (130.9)	85.6 (188.8)
223	Aug. 11	15	66.3 (146.2)	59.0 (130.1)	86.0 (189.7)
224	Aug. 12	16	66.1 (145.8)	59.2 (130.4)	85.8 (189.3)
225	Aug. 13	17	66.0 (145.5)	59.1 (130.2)	85.8 (189.3)
226	Aug. 14	18	65.8 (145.1)	58.7 (129.4)	85.8 (189.1)
227	Aug. 15	19	66.1 (145.7)	59.2 (130.6)	86.0 (189.5)
228	Aug. 16	20	66.2 (146.0)	59.1 (130.3)	85.4 (188.3)
229	Aug. 17	21	66.4 (146.4)	58.9 (129.9)	85.6 (188.8)
230	Aug. 18	22	66.4 (146.3)	58.6 (129.3)	86.1 (189.8)
231	Aug. 19	23	66.5 (146.6)	58.7 (129.3)	85.8 (189.1)
232	Aug. 20	24	65.9 (145.3)	59.1 (130.4)	86.3 (190.2)
233	Aug. 21	25	66.3 (146.2)	59.1 (130.2)	85.6 (188.8)

^aStart controlled diet.^eBMMD readings very scattered; measurements unreliable.

TABLE A-3.- Continued

(b) Continued

DOY	Date, 1973	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			In-flight		
234	Aug. 22	26	66.5 (146.5)	58.8 (129.6)	85.7 (188.8)
235	Aug. 23	27	66.1 (145.7)	58.6 (129.3)	85.5 (188.6)
236	Aug. 24	28	66.1 (145.7)	59.2 (130.5)	85.3 (188.1)
237	Aug. 25	29	65.8 (145.1)	58.7 (129.5)	85.6 (188.6)
238	Aug. 26	30	66.0 (145.6)	58.6 (129.2)	85.2 (187.8)
239	Aug. 27	31	66.4 (146.4)	58.9 (129.9)	85.7 (188.8)
240	Aug. 28	32	66.5 (146.7)	58.8 (129.7)	85.9 (189.3)
241	Aug. 29	33	66.3 (146.1)	58.9 (129.9)	85.7 (189.0)
242	Aug. 30	34	66.6 (146.8)	58.6 (129.3)	85.9 (189.4)
243	Aug. 31	35	66.4 (146.3)	58.6 (129.1)	85.7 (188.8)
244	Sept. 1	36	66.4 (146.3)	58.7 (129.4)	85.7 (189.0)
245	Sept. 2	37	66.3 (146.1)	58.7 (129.3)	85.3 (188.1)
246	Sept. 3	38	66.6 (146.8)	58.8 (129.5)	85.3 (188.1)
247	Sept. 4	39	66.3 (146.1)	58.5 (128.9)	85.6 (188.7)
248	Sept. 5	40	66.4 (146.4)	59.0 (130.0)	85.4 (188.2)
249	Sept. 6	41	66.2 (145.8)	58.3 (128.5)	85.6 (188.7)
250	Sept. 7	42	66.4 (146.5)	58.3 (128.5)	85.9 (189.3)
251	Sept. 8	43	66.5 (146.7)	58.7 (129.4)	85.3 (188.1)
252	Sept. 9	44	^f 66.6 (146.8)	58.9 (129.8)	85.6 (188.7)
253	Sept. 10	45	66.7 (147.1)	58.1 (128.0)	85.7 (189.0)
254	Sept. 11	46	66.0 (145.4)	58.2 (128.2)	86.1 (189.9)
255	Sept. 12	47	66.3 (146.1)	58.6 (129.1)	85.7 (188.8)
256	Sept. 13	48	65.5 (144.5)	58.4 (128.6)	85.7 (188.8)
257	Sept. 14	49	65.8 (145.1)	58.3 (128.5)	85.4 (188.3)
258	Sept. 15	50	66.0 (145.5)	58.3 (128.6)	85.6 (188.8)
259	Sept. 16	51	66.2 (146.0)	58.3 (128.6)	85.3 (188.1)
260	Sept. 17	52	65.9 (145.4)	58.5 (129.0)	85.7 (188.8)
261	Sept. 18	53	65.8 (145.1)	58.2 (128.2)	85.3 (188.1)
262	Sept. 19	54	66.0 (145.6)	58.5 (129.0)	85.7 (189.0)
263	Sept. 20	55	66.2 (145.8)	58.5 (128.9)	85.5 (188.5)
264	Sept. 21	56	65.8 (145.0)	59.0 (130.0)	85.2 (187.7)
265	Sept. 22	57	65.4 (144.3)	58.6 (129.1)	85.3 (188.0)
266	Sept. 23	58	65.3 (143.9)	58.0 (127.9)	85.1 (187.7)
267	Sept. 24	59	65.0 (143.4)	58.2 (128.3)	84.7 (186.6)
268	Sept. 25	R + 0	64.6 (142.4)	58.2 (128.4)	84.1 (185.5)

^fMeasurement made after breakfast; mass of breakfast deducted.

TABLE A-3.- Continued

(b) Concluded

DOY	Date, 1973	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			Postflight		
268	Sept. 25	^c R + 0	64.6 (142.5)	58.7 (129.5)	84.1 (185.5)
269	Sept. 26	R + 1	64.2 (141.5)	58.3 (128.5)	84.1 (185.5)
270	Sept. 27	R + 2	64.5 (142.3)	58.9 (129.8)	84.6 (186.5)
271	Sept. 28	R + 3	N.D.	60.2 (132.8)	N.D.
272	Sept. 29	R + 4	^f 66.8 (147.3)	60.0 (132.3)	87.1 (192.0)
273	Sept. 30	R + 5	66.5 (146.5)	^f 60.2 (132.8)	87.0 (191.8)
274	Oct. 1	R + 6	66.7 (147.0)	60.0 (132.3)	87.1 (192.0)
275	Oct. 2	R + 7	67.0 (147.8)	60.1 (132.5)	87.2 (192.3)
276	Oct. 3	R + 8	66.8 (147.3)	60.4 (133.3)	86.2 (190.0)
277	Oct. 4	R + 9	66.8 (147.3)	60.3 (133.0)	86.7 (191.3)
278	Oct. 5	R + 10	66.9 (147.5)	60.6 (133.5)	87.8 (193.5)
279	Oct. 6	R + 11	67.1 (148.0)	61.0 (134.5)	87.8 (193.5)
280	Oct. 7	R + 12	67.0 (147.8)	60.7 (133.8)	87.5 (193.0)
281	Oct. 8	R + 13	67.1 (148.0)	61.1 (134.8)	87.7 (193.3)
282	Oct. 9	R + 14	67.1 (148.0)	61.1 (134.8)	87.8 (193.5)
283	Oct. 10	R + 15	67.4 (148.5)	61.0 (134.5)	88.1 (194.3)
284	Oct. 11	R + 16	67.6 (149.0)	61.1 (134.8)	88.7 (195.5)
285	Oct. 12	R + 17	67.5 (148.8)	60.8 (134.0)	88.2 (194.5)
^d 286	Oct. 13	R + 18	N.D.	61.0 (134.5)	N.D.
287	Oct. 14	R + 19	N.D.	N.D.	N.D.
288	Oct. 15	R + 20	N.D.	N.D.	N.D.
289	Oct. 16	R + 21	68.9 (152.0)	N.D.	N.D.
290	Oct. 17	R + 22	68.7 (151.5)	62.0 (136.8)	N.D.
291	Oct. 18	R + 23	68.5 (151.0)	61.6 (135.8)	N.D.
292	Oct. 19	R + 24	68.5 (151.0)	61.0 (134.5)	N.D.
293	Oct. 20	R + 25	68.4 (150.8)	60.9 (134.3)	N.D.
294	Oct. 21	R + 26	68.9 (152.0)	61.2 (135.0)	N.D.
295	Oct. 22	R + 27	68.9 (152.0)	61.8 (136.3)	N.D.
296	Oct. 23	R + 28	69.2 (152.5)	61.3 (135.3)	N.D.
297	Oct. 24	R + 29	69.4 (153.0)	61.8 (136.3)	88.0 (194.0)
298	Oct. 25	R + 30	69.3 (152.8)	N.D.	N.D.
299	Oct. 26	R + 31	69.6 (152.5)	61.0 (134.5)	N.D.
300	Oct. 27	R + 32	N.D.	61.6 (135.8)	N.D.
301	Oct. 28	R + 33	N.D.	61.8 (136.3)	N.D.
302	Oct. 29	R + 34	N.D.	61.9 (136.5)	N.D.

^cFirst shipboard weights.^dStop controlled diet.^fMeasurement made after breakfast; mass of breakfast deducted.

TABLE A-3.- Continued

(c) SL-4

DOY	Date	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			Preflight		
281	Oct. 8, 1973	F - 39	N.D.	70.5 (155.5)	N.D.
282	Oct. 9, 1973	F - 38	N.D.	70.3 (155.0)	N.D.
283	Oct. 10, 1973	F - 37	N.D.	71.4 (157.5)	N.D.
284	Oct. 11, 1973	F - 36	N.D.	71.2 (157.0)	N.D.
285	Oct. 12, 1973	F - 35	67.8 (149.5)	71.1 (156.8)	N.D.
286	Oct. 13, 1973	F - 34	66.7 (147.0)	71.3 (157.1)	67.2 (148.3)
287	Oct. 14, 1973	F - 33	66.5 (146.5)	71.8 (158.3)	67.4 (148.5)
288	Oct. 15, 1973	F - 32	66.2 (146.0)	72.3 (159.5)	67.5 (148.8)
289	Oct. 16, 1973	F - 31	67.8 (149.5)	71.9 (158.5)	67.6 (149.0)
290	Oct. 17, 1973	F - 30	67.2 (148.3)	71.0 (156.6)	67.6 (149.0)
291	Oct. 18, 1973	F - 29	66.6 (146.8)	71.3 (157.3)	67.8 (149.5)
292	Oct. 19, 1973	F - 28	66.3 (146.3)	71.0 (156.3)	68.0 (150.0)
^a 293	Oct. 20, 1973	F - 27	67.4 (148.5)	71.8 (158.3)	67.7 (149.3)
294	Oct. 21, 1973	F - 26	67.1 (148.0)	72.0 (158.8)	67.6 (149.0)
295	Oct. 22, 1973	F - 25	67.2 (148.3)	72.5 (159.8)	67.8 (149.5)
296	Oct. 23, 1973	F - 24	67.1 (148.0)	71.4 (157.5)	67.9 (149.8)
297	Oct. 24, 1973	F - 23	67.6 (149.0)	71.7 (158.0)	67.6 (149.0)
298	Oct. 25, 1973	F - 22	67.2 (148.3)	72.0 (158.8)	67.6 (149.0)
299	Oct. 26, 1973	F - 21	67.6 (149.0)	71.4 (157.5)	67.8 (149.5)
300	Oct. 27, 1973	F - 20	67.6 (149.0)	71.2 (157.0)	67.8 (149.5)
301	Oct. 28, 1973	F - 19	68.0 (150.0)	71.4 (157.5)	67.7 (149.3)
302	Oct. 29, 1973	F - 18	67.8 (149.5)	71.1 (156.8)	67.6 (149.0)
303	Oct. 30, 1973	F - 17	67.5 (148.8)	71.3 (157.3)	67.4 (148.5)
304	Oct. 31, 1973	F - 16	67.7 (149.3)	71.3 (157.3)	67.7 (149.3)
305	Nov. 1, 1973	F - 15	67.2 (148.3)	71.6 (157.8)	67.6 (149.0)
306	Nov. 2, 1973	F - 14	67.7 (149.3)	71.0 (156.5)	67.2 (148.3)
307	Nov. 3, 1973	F - 13	67.9 (149.8)	71.2 (157.0)	67.4 (148.5)
308	Nov. 4, 1973	F - 12	67.7 (149.3)	71.4 (157.5)	67.6 (149.0)
309	Nov. 5, 1973	F - 11	68.2 (150.3)	71.4 (157.5)	67.4 (148.5)
310	Nov. 6, 1973	F - 10	68.0 (150.0)	71.7 (158.0)	67.7 (149.3)
311	Nov. 7, 1973	F - 9	68.0 (150.0)	71.7 (158.0)	67.8 (149.5)
312	Nov. 8, 1973	F - 8	68.2 (150.3)	72.2 (159.3)	68.0 (150.0)
313	Nov. 9, 1973	F - 7	67.7 (149.3)	71.7 (158.0)	67.9 (149.8)
314	Nov. 10, 1973	F - 6	68.2 (150.3)	71.6 (157.8)	67.5 (148.8)
315	Nov. 11, 1973	F - 5	68.0 (150.0)	71.0 (156.5)	67.1 (148.0)
316	Nov. 12, 1973	F - 4	68.5 (151.0)	71.2 (157.0)	67.6 (149.0)
317	Nov. 13, 1973	F - 3	68.0 (150.0)	71.3 (157.3)	67.8 (149.5)
318	Nov. 14, 1973	F - 2	67.8 (149.5)	71.7 (158.0)	67.6 (149.0)
319	Nov. 15, 1973	F - 1	68.0 (150.0)	71.2 (157.0)	67.0 (147.8)
320	Nov. 16, 1973	1	67.9 (149.8)	71.2 (157.0)	67.6 (149.0)

^aStart controlled diet.

TABLE A-3.- Continued

(c) Continued

DOY	Date	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			In-flight		
321	Nov. 17, 1973	2	N.D.	N.D.	N.D.
322	Nov. 18, 1973	3	66.7 (147.1)	70.8 (156.0)	65.7 (144.8)
323	Nov. 19, 1973	4	67.0 (147.8)	70.5 (155.4)	65.9 (145.4)
324	Nov. 20, 1973	5	67.1 (147.9)	70.5 (155.5)	65.4 (144.2)
325	Nov. 21, 1973	6	67.1 (147.9)	70.4 (155.3)	65.5 (144.4)
326	Nov. 22, 1973	7	67.1 (147.9)	70.2 (154.7)	65.3 (144.0)
327	Nov. 23, 1973	8	67.3 (148.3)	70.1 (154.6)	65.8 (145.1)
328	Nov. 24, 1973	9	66.9 (147.5)	69.8 (153.8)	64.9 (143.0)
329	Nov. 25, 1973	10	67.1 (147.9)	69.5 (153.3)	65.6 (144.6)
330	Nov. 26, 1973	11	67.2 (148.1)	69.0 (152.0)	65.1 (143.6)
331	Nov. 27, 1973	12	66.8 (147.3)	69.3 (152.7)	65.2 (143.7)
332	Nov. 28, 1973	13	67.3 (148.4)	69.4 (153.0)	65.6 (144.6)
333	Nov. 29, 1973	14	66.9 (147.5)	69.6 (153.5)	65.3 (144.0)
334	Nov. 30, 1973	15	67.4 (148.6)	69.7 (153.6)	65.6 (144.6)
335	Dec. 1, 1973	16	67.2 (148.1)	69.9 (154.1)	65.7 (144.8)
336	Dec. 2, 1973	17	67.2 (148.2)	69.6 (153.4)	65.9 (145.4)
337	Dec. 3, 1973	18	67.0 (147.7)	69.5 (153.3)	65.8 (145.0)
338	Dec. 4, 1973	19	67.3 (148.4)	69.0 (152.2)	66.0 (145.6)
339	Dec. 5, 1973	20	67.3 (148.4)	69.4 (153.0)	65.7 (144.8)
340	Dec. 6, 1973	21	67.3 (148.4)	69.1 (152.3)	65.6 (144.7)
341	Dec. 7, 1973	22	67.4 (148.7)	69.1 (152.3)	65.9 (145.3)
342	Dec. 8, 1973	23	67.4 (148.7)	68.9 (151.9)	65.8 (145.0)
343	Dec. 9, 1973	24	67.7 (149.2)	69.0 (152.2)	65.6 (144.6)
344	Dec. 10, 1973	25	67.6 (149.1)	68.7 (151.5)	65.6 (144.6)
345	Dec. 11, 1973	26	67.9 (149.7)	69.8 (153.8)	65.9 (145.3)
346	Dec. 12, 1973	27	67.5 (148.8)	69.0 (152.2)	65.8 (145.0)
347	Dec. 13, 1973	28	67.8 (149.5)	69.1 (152.4)	65.9 (145.2)
348	Dec. 14, 1973	29	67.5 (148.9)	69.3 (152.7)	65.4 (144.2)
349	Dec. 15, 1973	30	67.4 (148.6)	69.1 (152.3)	65.7 (144.8)
350	Dec. 16, 1973	31	67.7 (149.2)	69.1 (152.4)	65.5 (144.5)
351	Dec. 17, 1973	32	67.5 (148.8)	69.1 (152.4)	65.5 (144.3)
352	Dec. 18, 1973	33	67.7 (149.3)	69.1 (152.4)	65.7 (144.8)
353	Dec. 19, 1973	34	67.4 (148.7)	68.8 (151.6)	66.0 (145.4)
354	Dec. 20, 1973	35	67.8 (149.4)	69.0 (152.0)	66.0 (145.6)
355	Dec. 21, 1973	36	67.7 (149.4)	68.6 (151.3)	66.1 (145.7)
356	Dec. 22, 1973	37	67.7 (149.4)	68.8 (151.7)	66.2 (146.0)
357	Dec. 23, 1973	38	67.5 (148.8)	68.9 (151.9)	65.8 (145.0)
358	Dec. 24, 1973	39	67.1 (148.0)	69.2 (152.5)	65.9 (145.4)
359	Dec. 25, 1973	40	67.0 (147.8)	68.6 (151.3)	66.0 (145.6)
360	Dec. 26, 1973	41	67.6 (149.1)	68.6 (151.2)	65.9 (145.3)
361	Dec. 27, 1973	42	67.7 (149.4)	69.4 (153.0)	66.0 (145.4)
362	Dec. 28, 1973	43	67.9 (149.6)	69.1 (152.4)	66.2 (146.0)
363	Dec. 29, 1973	44	67.8 (149.4)	68.7 (151.5)	65.7 (144.9)
364	Dec. 30, 1973	45	67.9 (149.6)	68.9 (151.9)	65.9 (145.3)
365	Dec. 31, 1973	46	67.7 (149.2)	68.6 (151.3)	66.1 (145.8)

TABLE A-3.- Continued

(c) Continued

DOY	Date	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			In-flight		
1	Jan. 1, 1974	47	67.3 (148.4)	68.9 (151.8)	65.7 (144.9)
2	Jan. 2, 1974	48	67.0 (147.6)	68.6 (151.3)	65.4 (144.2)
3	Jan. 3, 1974	49	67.9 (149.8)	68.8 (151.7)	65.4 (144.2)
4	Jan. 4, 1974	50	67.5 (148.9)	69.4 (153.0)	65.6 (144.6)
5	Jan. 5, 1974	51	67.5 (148.9)	68.6 (151.2)	65.2 (143.7)
6	Jan. 6, 1974	52	67.8 (149.5)	68.6 (151.3)	65.1 (143.5)
7	Jan. 7, 1974	53	67.4 (148.6)	69.0 (152.2)	65.6 (144.5)
8	Jan. 8, 1974	54	67.7 (149.2)	69.6 (153.5)	65.8 (145.0)
9	Jan. 9, 1974	55	67.7 (149.3)	68.6 (151.3)	66.0 (145.4)
10	Jan. 10, 1974	56	67.3 (148.3)	68.0 (150.0)	65.4 (144.2)
11	Jan. 11, 1974	57	67.4 (148.6)	69.3 (152.7)	65.9 (145.4)
12	Jan. 12, 1974	58	68.0 (149.8)	69.7 (153.6)	66.0 (145.6)
13	Jan. 13, 1974	59	67.8 (149.4)	69.0 (152.2)	65.8 (145.2)
14	Jan. 14, 1974	60	67.6 (149.0)	68.8 (151.6)	66.1 (145.8)
15	Jan. 15, 1974	61	67.8 (149.5)	68.8 (151.7)	66.2 (146.0)
16	Jan. 16, 1974	62	67.8 (149.5)	69.1 (152.3)	66.4 (146.5)
17	Jan. 17, 1974	63	67.8 (149.4)	69.2 (152.6)	66.3 (146.1)
18	Jan. 18, 1974	64	67.8 (149.5)	69.2 (152.6)	65.8 (145.2)
19	Jan. 19, 1974	65	67.7 (149.4)	69.6 (153.4)	65.7 (144.8)
20	Jan. 20, 1974	66	67.9 (149.6)	69.6 (153.4)	66.0 (145.6)
21	Jan. 21, 1974	67	67.6 (149.0)	69.0 (152.2)	66.1 (145.8)
22	Jan. 22, 1974	68	67.8 (149.5)	69.5 (153.1)	65.9 (145.3)
23	Jan. 23, 1974	69	67.7 (149.2)	69.0 (152.2)	65.7 (144.8)
24	Jan. 24, 1974	70	68.3 (150.6)	68.9 (151.8)	66.6 (146.9)
25	Jan. 25, 1974	71	68.1 (150.1)	69.3 (152.9)	66.3 (146.1)
26	Jan. 26, 1974	72	67.6 (149.1)	68.9 (152.0)	66.3 (146.1)
27	Jan. 27, 1974	73	67.7 (149.3)	70.0 (154.4)	66.2 (145.8)
28	Jan. 28, 1974	74	67.7 (149.2)	69.9 (154.2)	66.0 (145.5)
29	Jan. 29, 1974	75	67.3 (148.4)	70.0 (154.4)	66.1 (145.8)
30	Jan. 30, 1974	76	67.4 (148.6)	69.7 (153.6)	66.5 (146.7)
31	Jan. 31, 1974	77	67.4 (148.7)	69.3 (152.8)	66.2 (145.9)
32	Feb. 1, 1974	78	67.9 (149.8)	69.8 (153.9)	66.7 (147.1)
33	Feb. 2, 1974	79	68.1 (150.1)	69.9 (154.1)	66.2 (145.9)
34	Feb. 3, 1974	80	67.6 (149.1)	69.7 (153.7)	66.4 (146.4)
35	Feb. 4, 1974	81	67.5 (148.9)	69.8 (153.8)	66.6 (146.9)
36	Feb. 5, 1974	82	67.5 (148.8)	69.9 (154.0)	66.6 (146.9)
37	Feb. 6, 1974	83	67.4 (148.6)	69.3 (152.7)	66.4 (146.4)
38	Feb. 7, 1974	84	67.1 (147.9)	69.3 (152.8)	66.6 (146.9)
39	Feb. 8, 1974	R + 0	67.9 (149.7)	69.8 (153.8)	66.2 (145.9)

TABLE A-3.- Concluded

(c) Concluded

DOY	Date	MD	Weight, kg (lb)		
			CDR	SPT	PLT
			Postflight		
39	Feb. 8, 1974	^c R + 0	67.8 (149.5)	68.6 (151.3)	66.1 (145.8)
40	Feb. 9, 1974	R + 1	67.1 (148.0)	69.4 (153.0)	66.8 (147.3)
41	Feb. 10, 1974	R + 2	67.9 (149.8)	70.1 (154.5)	67.0 (147.8)
42	Feb. 11, 1974	R + 3	67.6 (149.0)	71.0 (156.5)	67.6 (149.0)
43	Feb. 12, 1974	R + 4	67.9 (149.8)	70.8 (156.0)	67.4 (148.5)
44	Feb. 13, 1974	R + 5	68.5 (151.0)	71.1 (156.8)	67.0 (147.8)
45	Feb. 14, 1974	R + 6	68.4 (150.8)	71.7 (158.0)	67.4 (148.5)
46	Feb. 15, 1974	R + 7	68.4 (150.8)	71.6 (157.8)	67.9 (149.8)
47	Feb. 16, 1974	R + 8	N.D.	71.0 (156.5)	67.7 (149.3)
48	Feb. 17, 1974	R + 9	68.4 (150.8)	71.1 (156.8)	67.9 (149.8)
49	Feb. 18, 1974	R + 10	68.3 (150.5)	71.8 (158.3)	67.0 (147.8)
50	Feb. 19, 1974	R + 11	68.8 (151.8)	71.7 (158.0)	67.5 (148.8)
51	Feb. 20, 1974	R + 12	68.6 (151.3)	71.6 (157.8)	67.6 (149.0)
52	Feb. 21, 1974	R + 13	68.6 (151.3)	71.8 (158.3)	67.5 (148.8)
53	Feb. 22, 1974	R + 14	68.7 (151.5)	71.4 (157.5)	67.6 (149.0)
54	Feb. 23, 1974	R + 15	68.8 (151.8)	71.3 (157.3)	67.5 (148.8)
55	Feb. 24, 1974	R + 16	68.5 (151.0)	71.2 (157.0)	67.6 (149.0)
56	Feb. 25, 1974	R + 17	68.6 (151.3)	71.7 (158.0)	67.7 (149.3)
57	Feb. 26, 1974	R + 18	68.4 (150.8)	71.4 (157.5)	67.2 (148.3)
^d 58	Feb. 27, 1974	R + 19	67.9 (149.8)	71.2 (157.0)	68.0 (150.0)
59	Feb. 28, 1974	R + 20	68.9 (152.0)	72.5 (159.8)	69.3 (152.8)
60	Mar. 1, 1974	R + 21	69.6 (153.5)	71.4 (157.5)	69.3 (152.8)
61	Mar. 2, 1974	R + 22	69.6 (153.5)	72.2 (159.3)	69.4 (153.0)
62	Mar. 3, 1974	R + 23	68.5 (151.0)	72.7 (160.3)	70.1 (154.5)
63	Mar. 4, 1974	R + 24	68.8 (151.8)	73.7 (162.5)	69.4 (153.0)
64	Mar. 5, 1974	R + 25	68.6 (151.3)	72.8 (160.5)	69.6 (153.5)
65	Mar. 6, 1974	R + 26	68.9 (152.0)	72.8 (160.5)	69.9 (154.0)
66	Mar. 7, 1974	R + 27	69.4 (153.0)	72.1 (159.0)	69.9 (154.0)
67	Mar. 8, 1974	R + 28	69.2 (152.5)	N.D.	69.6 (153.5)
68	Mar. 9, 1974	R + 29	68.9 (152.0)	N.D.	70.3 (155.0)
69	Mar. 10, 1974	R + 30	69.2 (152.5)	73.7 (162.5)	69.9 (154.0)
70	Mar. 11, 1974	R + 31	69.2 (152.5)	74.2 (163.5)	69.4 (153.0)
71	Mar. 12, 1974	R + 32	68.9 (152.0)	73.0 (161.0)	69.6 (153.5)
72	Mar. 13, 1974	R + 33	68.6 (151.3)	73.8 (162.8)	69.7 (153.8)
73	Mar. 14, 1974	R + 34	69.3 (152.8)	74.2 (163.5)	70.3 (155.0)
74	Mar. 15, 1974	R + 35	68.8 (151.8)	73.8 (162.8)	69.9 (154.0)
75	Mar. 16, 1974	R + 36	68.5 (151.0)	73.0 (161.0)	70.9 (156.3)
76	Mar. 17, 1974	R + 37	68.7 (151.5)	74.2 (163.5)	71.4 (157.5)
77	Mar. 18, 1974	R + 38	70.2 (154.8)	73.9 (163.0)	70.6 (155.8)
78	Mar. 19, 1974	R + 39	70.0 (154.3)	N.D.	69.9 (154.0)
79	Mar. 20, 1974	R + 40	69.3 (152.8)	N.D.	N.D.
80	Mar. 21, 1974	R + 41	69.2 (152.5)	N.D.	N.D.
81	Mar. 22, 1974	R + 42	68.5 (151.0)	N.D.	70.4 (155.3)
82	Mar. 23, 1974	R + 43	68.5 (151.0)	N.D.	70.3 (155.0)
83	Mar. 24, 1974	R + 44	69.5 (153.3)	N.D.	N.D.
84	Mar. 25, 1974	R + 45	70.4 (155.3)	N.D.	N.D.
85	Mar. 26, 1974	R + 46	69.2 (152.5)	N.D.	N.D.

^cFirst shipboard weights.^dStop controlled diet.

APPENDIX B

HEIGHT MEASUREMENTS OF SKYLAB 4 CREWMEN

Height and change-in-height (Δ height) measurements of the Skylab 4 (SL-4) crewmen are contained in tables B-1 to B-3. The crewman designations are commander (CDR), science pilot (SPT), and pilot (PLT). Preflight measurements were taken with the crewmen in an erect standing position, and postflight measurements were taken with the crewmen in both erect and supine positions. In-flight measurements were taken in the morning and afternoon on mission day (MD) 21, MD-35, MD-57, MD-60, and MD-82. Recovery day is designated R + 0, R + 1 is 1 day after recovery, and so forth.

TABLE B-1.- HEIGHT AND CHANGE-IN-HEIGHT MEASUREMENTS

OF SL-4 CDR

(a) Preflight measurements

Date	Erect height, cm (in.)
1966	172.2 (67.8)
1967	172.7 (68.0)
1968	172.5 (67.9)
1969	172.7 (68.0)
1970	172.7 (68.0)
1971	172.7 (68.0)
1972	173.0 (68.1)
^a 1972	^b 172.7 (68.0)

(b) In-flight measurements

Day	Height and Δ height					
	Morning			Afternoon		
	cm (in.)	Δ cm (Δ in.)	Δ percent	cm (in.)	Δ cm (Δ in.)	Δ percent
MD-21	177.3 (69.8)	4.6 (1.8)	2.7	177.5 (68.9)	4.8 (1.9)	2.8
MD-35	177.8 (70.0)	5.1 (2.0)	2.9	177.5 (69.9)	4.8 (1.9)	2.8
MD-57	177.8 (70.0)	5.1 (2.0)	2.9	176.8 (69.6)	4.1 (1.6)	2.4
MD-82	178.6 (70.3)	5.9 (2.3)	3.4	--	--	--
Mean	--	5.2 (2.03)	3.0	--	--	--

^aSuit fit; other preflight measurements were from annual physical examinations.

^bBaseline.

TABLE B-1.- Concluded

(c) Postflight measurements

Day	Height and Δ height					
	Erect			Supine		
	cm (in.)	Δ cm (Δ in.)	Δ percent	cm (in.)	Δ cm (Δ in.)	Δ percent
R + 0						
^c 01:42	--	--	--	176.8 (69.6)	4.1 (1.6)	2.4
^c 03:03	174.8 (68.8)	2.1 (0.8)	1.2	--	--	--
^c 05:43	174.0 (68.5)	1.3 (.5)	.7	--	--	--
R + 1						
Morning	175.3 (69.0)	2.6 (1.0)	1.5	--	--	--
Afternoon	173.4 (68.3)	.7 (.25)	.4	174.8 (68.8)	2.1 (.8)	1.2
R + 4	175.3 (69.0)	2.6 (1.0)	1.5	--	--	--
R + 5	173.7 (68.4)	1.0 (.4)	.6	176.0 (69.3)	3.3 (1.3)	1.9
R + 17	172.7 (68.0)	0 (0)	0	174.8 (68.8)	2.1 (.8)	1.2

^cTime after recovery, hours:minutes.

TABLE B-2.- HEIGHT AND CHANGE-IN-HEIGHT MEASUREMENTS

OF SL-4 SPT

(a) Preflight measurements

Date	Erect height, cm (in.)
1970	172.7 (68.0)
^a 1972	^b 173.0 (68.1)
1973	172.7 (68.0)
^c 1973	175.3 (69.0)

^aSuit fit.

^bBaseline.

^c35 days before lift-off.

TABLE B-2.- Concluded
(b) In-flight measurements

Day	Height and Δ height					
	Morning			Afternoon		
	cm (in.)	Δ cm (Δ in.)	Δ percent	cm (in.)	Δ cm (Δ in.)	Δ percent
MD-21	177.8 (70.0)	4.8 (1.9)	2.8	177.8 (70.0)	4.8 (1.9)	2.8
MD-35	178.6 (70.3)	5.6 (2.2)	3.2	178.8 (70.4)	5.8 (2.3)	3.4
MD-60	177.8 (70.0)	4.8 (1.9)	2.8	178.0 (70.1)	5.0 (2.0)	3.0
MD-82	179.8 (70.8)	6.8 (2.7)	4.0	--	--	--
Mean	--	5.5 (2.18)	3.2	--	--	--

(c) Postflight measurements

Day	Height and Δ height					
	Erect			Supine		
	cm (in.)	Δ cm (Δ in.)	Δ percent	cm (in.)	Δ cm (Δ in.)	Δ percent
R + 0						
^d 01:53	--	--	--	178.8 (70.4)	5.8 (2.3)	3.4
^d 03:08	176.5 (69.5)	3.5 (1.4)	2.1	--	--	--
^d 07:43	175.0 (68.9)	2.0 (.8)	1.2	--	--	--
R + 1						
Morning	175.3 (69.0)	2.3 (.9)	1.3	--	--	--
Afternoon	174.0 (68.5)	1.0 (.4)	1.0	176.0 (69.3)	3.0 (1.2)	1.8
R + 4	174.0 (68.5)	1.0 (.4)	1.0	--	--	--
R + 5	174.8 (68.8)	1.8 (.7)	1.0	176.5 (69.5)	3.5 (1.4)	2.1
R + 17	174.5 (68.7)	1.5 (.6)	.9	176.5 (69.5)	3.5 (1.4)	2.1

^dTime after recovery, hours:minutes.

TABLE B-3.- HEIGHT AND CHANGE-IN-HEIGHT MEASUREMENTS

OF SL-4 PLT

(a) Preflight measurements

Date	Erect height, cm (in.)
1966	173.0 (68.1)
1969	173.5 (68.3)
^a 1972	^b 173.2 (68.2)
^c 1973	173.5 (68.3)

(b) In-flight measurements

Day	Height and Δ height					
	Morning			Afternoon		
	cm (in.)	Δ cm (Δ in.)	Δ percent	cm (in.)	Δ cm (Δ in.)	Δ percent
MD-21	178.8 (70.4)	5.6 (2.2)	3.2	179.1 (70.5)	5.6 (2.3)	3.4
MD-35	178.6 (70.3)	5.4 (2.1)	3.1	178.6 (70.3)	5.1 (2.1)	3.1
MD-57	177.8 (70.0)	4.6 (1.8)	2.6	176.8 (69.6)	3.3 (1.4)	2.1
MD-82	179.3 (70.6)	6.1 (2.4)	3.5	--	--	--
Mean	--	5.4 (2.13)	3.1	--	--	--

^aSuit fit.^bBaseline.^c15 days before lift-off.

TABLE B-3.- Concluded

(c) Postflight measurements

Day	Height and Δ height					
	Erect			Supine		
	cm (in.)	Δ cm (Δ in.)	Δ percent	cm (in.)	Δ cm (Δ in.)	Δ percent
R + 0						
^d 01:26	--	--	--	177.5 (69.9)	5.9 (1.7)	2.5
^d 03:53	175.0 (68.9)	1.8 (0.7)	1.0	--	--	--
R + 1						
Morning	174.0 (68.5)	.8 (.3)	.4	--	--	--
Afternoon	173.5 (68.3)	.3 (.1)	.1	175.0 (68.9)	1.8 (.7)	1.0
R + 17	173.7 (68.4)	.5 (.2)	.3	175.3 (69.0)	5.8 (.8)	1.2

^dTime after recovery, hours:minutes.

APPENDIX C

TRUNCAL, NECK, AND LIMB GIRTH MEASUREMENTS OF U.S. SPACE-FLIGHT CREWMEN

Truncal, neck, and limb girth measurements of Skylab and Apollo crewmen made before, during, and after various flights are presented in this appendix. Table C-1 contains data on truncal, neck, and arm girth of the Skylab 3 (SL-3) commander (CDR), science pilot (SPT), and pilot (PLT) obtained before flight, in flight (on mission day (MD) 38 and MD-54), and after flight (on recovery day (R + 0) and on the 1st, 2nd, and 4th days after recovery (days R + 1, R + 2, and R + 4, respectively)). Change-in-girth values (Δ girth) (with the preflight measurement as the baseline value) are also provided. All measurements were made in the anatomical position.

In table C-2, truncal and neck girth measurements of SL-4 crewmen made 30 and 15 days before lift-off (days F - 30 and F - 15, respectively), during flight, and after flight are compared to the preflight measurement made 4 days before lift-off (day F - 4), the baseline value in each case.

Tables C-3 to C-5 contain detailed circumference measurements of the left (L) and right (R) legs of SL-4 crewmen. Daily volumes for both the left and the right leg of each crewman are given, together with preflight means and standard deviations.

Table C-6 contains data on individual calf circumference and lower-limb volume from preflight and postflight measurements of the CDR, the command module pilot (CMP), and the lunar module pilot (LMP) of selected Apollo missions, in a resting, supine position. Preflight individual means and standard deviations and preflight and postflight group means and standard deviations are given, together with other statistical indicators.

The upper-limb volumes and changes in upper-limb volumes of Skylab crewmen shown in table C-7 were computed from girth segments every 3 cm from wrist to shoulder of both arms.

All truncal and neck girth measurements were made in the anatomical position.

TABLE C-1.- TRUNCAL, NECK, AND ARM GIRTH MEASUREMENTS

OF SL-3 CREWMEN

(a) CDR

Measurement	Preflight	MD-38	MD-54	R + 0	R + 1	R + 2	R + 4
Left biceps, cm	30.8	28.1	29.0	28.2	29.8	29.8	30.2
Δ girth, cm		-2.7	-1.8	-2.6	-1.0	-1.0	-0.6
Δ girth, percent		-8.8	-5.8	-8.4	-3.2	-3.2	-1.9
Right biceps, cm	30.8	28.8	30.0	29.2	29.8	31.7	31.4
Δ girth, cm		-2.0	-0.8	-1.6	-1.0	-0.9	0.6
Δ girth, percent		-6.5	-2.6	-5.2	-3.2	2.9	1.9
Chest, inspiratory (insp.), cm	96.0	--	--	95.2	96.5	95.9	97.5
Δ girth, cm		--	--	-0.8	0.5	-0.1	1.5
Δ girth, percent		--	--	-0.8	0.5	-0.1	1.6
Chest, expiratory (exp.), cm	91.1	88.9	--	89.5	90.8	90.5	92.1
Δ girth, cm		-2.2	--	-1.6	-0.3	-0.6	1.0
Δ girth, percent		-2.4	--	-1.8	-0.3	-0.7	1.1
Abdomen, cm	82.1	76.3	76.3	78.7	79.7	79.7	--
Δ girth, cm		-5.8	-5.8	-3.4	-2.4	-2.4	--
Δ girth, percent		-7.1	-7.1	-4.1	-2.9	-2.9	--
Neck, cm	38.1	37.1	37.3	38.4	37.1	39.0	38.1
Δ girth, cm		-1.0	-0.8	0.3	-1.0	0.9	0
Δ girth, percent		-2.6	-2.1	0.8	-2.6	2.4	0

TABLE C-1.- Continued

(b) SPT

Measurement		Preflight	MD-38	MD-54	R + 0	R + 1	R + 2	R + 4
Left biceps, cm		28.7	26.1	28.0	27.0	27.6	27.9	27.3
Δ girth, cm			-2.6	-0.7	-1.7	-1.1	-0.8	-1.4
Δ girth, percent			-9.0	-2.4	-5.9	-3.8	-2.8	-4.9
Right biceps, cm		28.9	27.6	29.3	29.5	28.9	29.5	28.9
Δ girth, cm			-1.3	0.4	0.6	0	0.6	0
Δ girth, percent			-4.5	1.4	2.1	0	2.1	0
Chest, insp, cm		90.0	--	86.8	89.2	88.9	88.9	88.9
Δ girth, cm			--	-3.2	-0.8	-1.1	-1.1	-1.1
Δ girth, percent			--	-3.6	-0.9	-1.2	-1.2	-1.2
Chest, exp., cm		84.2	84.0	83.4	83.2	81.3	--	--
Δ girth, cm			-0.2	-0.8	-1.0	-2.9	--	--
Δ girth, percent			-0.2	-0.9	-1.2	-3.4	--	--
Abdomen, cm		79.2	71.1	72.0	74.9	76.2	75.9	--
Δ girth, cm			-8.1	-7.2	-4.3	-3.0	-3.3	--
Δ girth, percent			-10.0	-9.1	-5.4	-3.8	-4.2	--
Neck, cm		35.9	--	34.9	34.6	34.9	35.2	35.9
Δ girth, cm			--	-1.0	-1.3	-1.0	-0.7	0
Δ girth, percent			--	-2.8	-3.6	-2.8	-1.9	0

TABLE C-1.- Concluded

(c) PLT

Measurement	Preflight	MD-38	MD-54	R + 0	R + 1	R + 2	R + 4
Left biceps, cm	33.6	31.7	33.0	32.4	33.0	33.0	33.0
Δ girth, cm		-1.9	-0.6	-1.2	-0.6	-0.3	-0.6
Δ girth, percent		-5.6	-1.8	-3.6	-1.8	-0.9	-1.8
Right biceps, cm	34.4	32.8	33.5	32.4	34.3	34.6	33.3
Δ girth, cm		-1.6	-0.9	-2.0	-0.1	0.2	-1.1
Δ girth, percent		-4.6	-2.6	-5.8	-0.3	0.6	-3.2
Chest, insp. cm	107.2	--	104.8	106.7	106.7	106.7	107.0
Δ girth, cm		--	-2.4	-0.5	-0.5	-0.5	-0.2
Δ girth, percent		--	-2.2	-0.5	-0.5	-0.5	-0.2
Chest, exp., cm	100.8	--	97.6	97.5	100.9	101.9	--
Δ girth, cm		--	-3.2	-3.3	0.1	1.1	--
Δ girth, percent		--	-3.2	-3.3	0.1	1.1	--
Abdomen, cm	88.4	84.0	83.9	88.6	87.0	89.2	--
Δ girth, cm		-4.4	-4.5	0.2	-1.4	0.8	--
Δ girth, percent		-5.0	-5.1	0.2	-1.6	0.9	--
Neck, cm	40.6	41.0	40.9	41.6	41.3	41.9	41.3
Δ girth, cm		0.4	0.3	1.0	0.7	1.3	0.7
Δ girth, percent		1.0	0.7	2.5	1.7	3.2	1.7

TABLE C-2.- TRUNCAL AND NECK GIRTH MEASUREMENTS OF SL-4 CREWMEN

(a) CDR

Measurement	Preflight			In-flight			Postflight						
	F - 30	F - 15	F - 4	MD-3	MD-8	MD-31	MD-58	R + 0	R + 1	R + 2	R + 4	R + 5	R + 11
Abdomen, cm	83.8	82.5	83.5	78.0	78.0	79.6	79.1	81.7	84.5	83.6	83.1	82.3	82.9
Δ girth, cm	0.3	-1.0		-5.5	-5.5	-3.9	-4.4	-1.8	1.0	0.1	-0.4	-1.2	-0.6
Δ girth, percent	0.3	-1.2		-6.6	-6.6	-4.7	-5.3	-2.2	1.2	0.1	-0.5	-1.4	-0.7
Chest, insp., cm	103.5	100	102.2	99.3	98.5	101.2	100.8	101.6	101.6	103.5	102.6	102.0	102.7
Δ girth, cm	1.3	-2.2		-2.9	-3.7	-1.0	-1.4	-0.6	-0.6	1.3	0.4	-0.2	0.5
Δ girth, percent	1.3	-2.1		-2.8	-3.6	-1.0	-1.4	-0.6	-0.6	1.3	0.4	-0.2	0.5
Chest exp., cm	98.4	94.4	96.8	93.5	92.5	94.0	93.1	97.4	95.5	96.3	96.0	94.8	96.1
Δ girth, cm	1.6	-2.4		-3.3	-4.3	-2.8	-3.7	0.6	-1.3	-0.5	-0.8	-2.0	-0.7
Δ girth, percent	1.6	-2.5		-3.4	-4.4	-2.9	-3.8	0.6	-1.3	-0.5	-0.8	-2.1	-0.7
Neck, cm	37.1	37.4	37.5	36.8	38.1	37.5	37.5	36.8	37.9	37.9	38.1	38.9	36.9
Δ girth, cm	-0.4	-0.1		-0.7	0.6	0	0	-0.7	0.4	0.4	0.6	1.4	-0.6
Δ girth, percent	-1.1	-0.3		-1.9	1.6	0	0	-1.9	1.1	1.1	1.6	3.7	-1.6
Buttocks, cm	—	90.4	87.2	88.5	87.0	87.5	89.1	91.3	89.9	90.7	92	91.4	91.3
Δ girth, cm	—	3.2		1.3	-0.2	0.3	1.9	4.1	2.7	3.5	4.8	4.2	4.1
Δ girth, percent	—	3.7		-1.5	-0.2	0.3	2.2	4.7	3.1	4.0	5.5	4.8	4.7

(b) SPT

Measurement			Preflight			In-flight			Postflight				
	F - 30	F - 15	F - 4	MD-3	MD-8	MD-37	MD-61	R + 0	R + 1	R + 2	R + 4	R + 5	R + 11
Abdomen, cm	86.0	84.0	83.3	82.7	77.7	79.2	76.8	81.0	81.5	83.4	82.5	81.1	82.9
Δ girth, cm	2.7	0.7		-0.6	-5.6	-4.1	-6.5	-2.3	-1.8	0.1	-0.8	-2.2	-0.4
Δ girth, percent	3.2	0.8		-0.7	-6.7	-4.9	-7.8	-2.8	-2.2	0.1	-0.9	-2.6	-0.5
Chest, insp., cm	101.8	99.5	97.0	96.0	96.2	95.0	95.5	97.6	98.0	98.6	97.8	97.4	97.9
Δ girth, cm	4.8	2.5		-1.0	-0.8	-2.0	-1.5	0.6	1.0	1.6	0.8	0.4	0.9
Δ girth, percent	4.9	2.6		-1.0	-0.8	-2.1	-1.5	0.6	1.0	1.6	0.8	0.4	0.9
Chest, exp., cm	91.1	89.8	90.6	90.0	88.0	88.5	90.5	91.5	91.0	90.1	92.9	89.5	91.2
Δ girth, cm	0.5	-0.8		-0.6	-2.6	-2.1	-0.1	0.9	0.4	-0.5	2.3	-1.1	0.6
Δ girth, percent	0.5	-0.9		-0.7	-2.9	-2.3	-0.1	1.0	0.4	-0.5	2.5	-1.2	0.7
Neck, cm	38.3	39.0	37.5	38.5	38.1	37.4	38.0	38.5	39.4	39.2	38.1	39.0	38.4
Δ girth, cm	0.8	1.5		1.0	0.6	-0.1	0.5	1.0	1.9	1.7	0.6	1.5	0.9
Δ girth, percent	2.1	4.0		2.7	1.6	-0.3	1.3	2.7	5.1	4.5	1.6	4.0	2.4
Buttocks, cm	—	97	92.4	—	89.3	89.0	90.0	96.4	96.2	97.2	97.3	97.2	96.6
Δ girth, cm	—	4.6		—	-3.1	-3.4	-2.4	4.0	3.8	4.8	4.9	4.8	4.2
Δ girth, percent	—	5.0		—	-3.3	-3.7	-2.6	4.3	4.1	5.2	5.3	5.2	4.5

TABLE C-2.- Concluded
(c) PLT

Measurement	Preflight			In-flight			Postflight					
	F - 30	F - 15	F - 4	MD-8	MD-60	MD-31	R + 0	R + 1	R + 2	R + 4	R + 5	R + 11
Abdomen, cm	82.5	80.7	81.4	71.3	72.8	71	78.5	79.4	80.0	78.7	76.9	79.0
Δ girth, cm	1.1	-0.7		-10.1	-8.6	-10.4	-2.9	-2.0	-1.4	-2.7	-4.5	-2.4
Δ girth, percent . . .	1.3	-0.8		-12.4	-10.6	-12.8	-3.6	-2.4	-1.7	-3.3	-5.5	-2.9
Chest, insp., cm	101.6	99.4	99.1	98	98.2	97.0	99.0	98.9	99.1	99.3	99.1	—
Δ girth, cm	2.5	0.3		-1.1	-0.9	-2.1	-0.1	-0.2	0	0.2	0	—
Δ girth, percent . . .	2.5	0.3		-1.1	-0.9	-2.1	-0.1	-0.2	0	0.2	0	—
Chest, exp., cm	92.7	92.0	93.4	89.1	94.8	92.5	92.5	92.2	92.0	92.0	91.7	91.4
Δ girth, cm	-0.7	-1.4		-4.3	1.4	-0.9	-0.9	-1.2	-1.4	-1.4	-1.7	-2.0
Δ girth, percent . . .	-0.7	-1.5		-4.6	1.5	-1.0	-1.0	-1.3	-1.5	-1.5	-1.8	-2.1
Neck, cm	38.7	38.5	36.7	34.6	35.5	35.3	35.0	36.0	35.6	35.4	36.5	35.7
Δ girth, cm	2.0	1.8		-2.1	-1.2	-1.4	-1.7	-0.7	-1.1	-1.3	-0.2	-1.0
Δ girth, percent . . .	5.4	4.9		-5.7	-3.3	-3.8	-4.6	-1.9	-3.0	-3.5	-0.5	-2.7
Buttocks, cm	—	93.0	90.1	89.4	87.8	81.9	92.5	92.4	93.1	92.9	91.5	94.2
Δ girth, cm	—	2.9		-0.7	-2.3	-8.2	2.4	2.3	3.0	2.8	1.4	4.1
Δ girth, percent . . .	—	3.2		-0.8	-2.5	-9.1	2.7	2.5	3.3	3.1	1.5	4.5

TABLE C-3.- LEG MEASUREMENTS OF SL-4 CDR

(a) Preflight

Leg zone	F - 49 (Aug. 28, 1973)		F - 35 (Oct. 12, 1973)		F - 21 (Oct. 26, 1973)		F - 10 (Nov. 6, 1973)		F - 6 (Nov. 10, 1973)		Mean $\pm$ SD ^a	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	—	—	—	—	—	—	—	—	—	—	—	—
2	21.2	20.9	20.8	20.8	21.1	20.9	20.8	21.1	20.8	21.1	—	—
3	22.0	21.4	21.6	21.6	21.7	21.9	21.6	21.6	21.5	21.9	—	—
4	24.0	23.1	23.8	23.6	23.8	23.4	23.6	23.4	23.3	23.3	—	—
5	26.8	25.4	25.6	26.0	26.0	25.5	25.7	25.1	25.5	26.2	—	—
6	29.0	27.5	28.4	29.0	28.6	28.4	27.9	27.5	28.1	29.1	—	—
7	31.8	31.3	31.0	32.2	32.0	32.0	30.6	31.2	31.0	31.5	—	—
8	34.5	33.6	33.6	34.2	34.3	34.5	34.0	33.5	33.8	33.8	—	—
9	34.9	34.6	34.7	35.0	34.9	34.8	35.1	34.9	35.1	34.9	—	—
10	33.8	33.8	34.1	33.9	34.1	33.9	34.1	34.2	34.7	34.6	—	—
11	32.3	32.2	32.7	32.4	32.5	32.2	32.5	32.6	33.0	32.5	—	—
12	32.2	32.2	32.6	32.1	32.5	32.4	32.4	32.9	32.5	32.3	—	—
13	35.0	34.1	34.5	34.6	34.0	34.9	34.5	33.5	34.0	34.2	—	—
14	36.4	36.4	36.6	36.4	36.2	36.6	36.2	35.7	35.9	36.3	—	—
15	36.4	36.1	36.4	36.6	36.3	36.7	36.5	36.6	36.5	36.3	—	—
16	37.5	36.3	36.5	37.1	36.7	37.7	36.9	36.8	36.6	36.6	—	—
17	39.0	38.1	38.1	39.0	38.4	39.9	38.2	38.4	38.2	38.4	—	—
18	43.8	40.4	40.4	41.8	41.3	42.8	41.0	41.2	41.0	40.2	—	—
19	45.0	44.2	43.7	44.6	44.8	45.6	44.1	43.9	44.5	44.7	—	—
20	49.0	47.5	46.7	47.3	47.8	49.1	47.1	47.9	46.9	47.1	—	—
21	50.9	49.8	49.4	50.0	50.5	51.7	50.0	49.9	49.6	49.4	—	—
22	51.9	50.9	51.5	51.5	51.9	53.0	51.9	51.6	51.4	51.7	—	—
23	53.0	52.5	53.9	52.5	54.0	53.9	54.5	53.4	54.2	53.1	—	—
24	54.6	53.1	55.3	54.6	55.0	54.0	55.6	54.6	56.2	54.8	—	—
25	—	—	—	—	—	—	—	—	—	—	—	—
Volume, ml												
	7691.05	7346.29	7445.68	7531.90	7573.36	7746.47	7515.17	7455.70	7496.63	7475.62	7544.38	7511.20
											± 93.84	± 147.75

^aSD = standard deviation.

TABLE C-3.- Continued

(b) In-flight

Leg zone	MD-3 (Nov. 18, 1973)		MD-5 (Nov. 20, 1973)		MD-8 (Nov. 23, 1973)		MD-31 (Dec. 16, 1973)		MD-57 (Jan. 11, 1974)	
	L	R	L	R	L	R	L	R	L	R
Circumference, cm										
1	--	--	--	--	--	--	--	--	--	--
2	20.2	21.0	21.7	--	20.1	20.2	19.8	20.0	19.4	20.2
3	20.5	21.0	21.2	--	20.9	21.3	20.5	20.4	20.2	19.9
4	21.7	22.5	22.5	--	22.1	22.9	22.3	21.8	21.5	21.1
5	23.8	24.0	24.3	--	24.1	24.9	24.1	23.9	23.6	22.9
6	26.1	26.3	26.8	--	26.5	26.7	26.3	25.7	25.3	24.8
7	28.3	28.7	29.4	--	29.3	30.3	28.2	29.5	28.9	27.3
8	32.2	32.5	32.0	--	32.0	32.4	31.8	32.0	31.6	31.0
9	33.5	33.6	33.2	--	33.0	33.0	32.4	33.8	32.1	32.3
10	33.1	33.0	33.1	--	32.5	31.9	31.7	32.5	31.5	32.3
11	32.0	31.5	33.0	--	30.3	30.6	30.2	31.4	30.3	31.0
12	30.5	32.0	30.8	--	30.5	31.1	30.6	30.7	30.2	30.6
13	31.0	31.5	30.7	--	30.7	32.3	31.6	32.0	31.3	32.0
14	32.6	33.8	33.3	--	33.0	35.0	33.4	34.2	33.2	33.4
15	33.8	34.5	33.7	--	34.7	34.8	34.1	34.8	34.2	34.7
16	34.2	34.5	34.0	--	34.2	34.3	33.8	34.6	33.7	34.7
17	34.6	35.0	35.3	--	34.9	35.2	34.8	35.0	34.6	35.2
18	37.0	37.2	38.0	--	36.7	38.2	36.8	36.2	35.5	37.1
19	38.6	41.0	41.1	--	39.2	41.0	40.2	39.4	39.0	39.1
20	42.2	44.8	44.5	--	42.6	44.5	42.0	41.2	40.6	41.4
21	45.1	46.7	46.5	--	45.2	46.7	44.8	44.3	44.1	44.3
22	48.0	49.5	48.6	--	48.8	47.9	47.2	47.5	47.4	47.3
23	50.2	51.0	50.6	--	49.1	50.1	48.9	50.0	48.4	49.5
24	51.0	52.0	51.8	--	51.4	51.9	50.6	51.2	50.6	51.3
25	--	--	--	--	--	--	--	--	--	--
Volume, ml										
	6370.33	6671.57	6625.43	--	6389.47	6646.43	6294.55	6388.72	6152.23	6265.95

TABLE C-3.- Continued

(c) Postflight, R + 0 to R + 4

Leg zone	R + 0 (Feb. 8, 1974)		R + 1 (Feb. 9, 1974)		R + 1 (Feb. 9, 1974)		R + 2 (Feb. 10, 1974)		R + 3 (Feb. 11, 1974)		R + 4 (Feb. 12, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	—	—	—	—	—	—	—	—	—	—	—	—
2	20.2	20.2	21.2	21.0	20.5	20.7	21.0	21.2	20.8	20.6	20.7	20.9
3	20.8	20.8	21.8	21.5	21.5	20.9	21.8	21.7	21.4	21.4	21.5	21.4
4	22.3	22.3	23.8	23.0	22.6	22.3	24.0	23.3	23.3	22.5	23.1	23.1
5	24.1	23.9	25.6	24.6	24.4	24.4	26.1	25.2	25.3	24.6	24.7	25.4
6	26.1	26.4	28.0	27.5	27.0	26.3	28.6	26.4	28.0	27.3	27.6	27.6
7	29.3	29.6	31.2	30.2	29.4	29.8	32.7	30.5	30.6	29.5	30.2	30.8
8	31.6	32.3	33.7	32.6	32.5	32.2	33.7	33.0	32.9	32.1	32.7	33.4
9	32.8	32.8	34.1	33.3	33.2	32.6	34.5	34.3	33.9	33.4	34.0	34.3
10	32.2	32.1	33.2	32.6	32.8	31.8	33.8	33.5	33.4	33.0	33.8	32.6
11	31.3	31.2	32.1	31.5	32.7	31.1	32.4	32.0	32.4	31.8	32.8	32.3
12	31.3	31.4	32.2	31.5	31.7	31.7	32.5	31.8	32.1	31.6	32.2	32.1
13	32.9	33.4	34.2	33.8	33.5	34.2	34.3	33.8	33.7	33.5	33.5	35.4
14	35.3	35.7	36.1	36.2	35.5	35.7	36.9	36.5	36.2	36.2	36.0	36.6
15	36.0	36.7	36.6	36.5	35.7	35.8	37.1	37.2	36.7	36.9	36.6	37.1
16	35.9	35.7	36.8	36.7	35.3	35.5	37.0	37.0	36.4	36.4	36.7	37.2
17	37.7	36.9	37.7	38.0	36.4	36.7	37.6	38.0	37.4	37.5	37.6	38.7
18	39.5	39.2	40.4	40.5	38.6	38.8	40.0	37.8	39.4	40.5	37.7	40.5
19	42.4	42.6	43.1	44.2	41.5	42.6	43.2	43.1	42.3	42.8	42.7	44.0
20	45.4	45.7	46.1	46.6	44.4	45.4	46.2	45.4	45.3	45.5	45.7	46.4
21	48.0	48.6	48.9	48.8	47.0	47.6	48.7	48.6	48.1	49.0	48.3	47.8
22	50.1	49.9	51.0	50.6	49.5	51.2	51.2	50.6	51.0	50.8	51.3	51.5
23	53.1	51.9	53.8	52.9	52.7	52.8	53.2	52.5	53.2	52.4	53.0	53.4
24	55.6	54.3	56.0	54.0	54.5	54.6	55.0	54.1	55.8	54.5	55.0	54.6
25	—	—	—	—	—	—	—	—	—	—	—	—

Volume, ml

6984.87	6967.05	7354.09	7220.17	6926.50	6989.14	7412.26	7225.64	7213.81	7143.41	7228.04	7431.75
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TABLE C-3.- Concluded

(d) Postflight, R + 5 to R + 68

Leg zone	R + 5 (Feb. 13, 1974)		R + 7 (Feb. 15, 1974)		R + 11 (Feb. 19, 1974)		R + 17 (Feb. 25, 1974)		R + 31 (Mar. 11, 1974)		R + 68 (Apr. 17, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	20.7	20.9	20.3	20.9	21.0	20.8	20.9	21.1	20.5	20.5	20.5	20.8
3	21.4	21.9	22.3	21.5	21.4	21.7	21.7	21.5	21.6	21.3	21.2	21.6
4	22.8	23.0	22.7	23.0	23.3	23.4	23.8	22.9	23.2	22.5	23.3	23.0
5	24.9	25.3	25.4	25.4	25.0	26.2	26.6	24.7	25.1	24.5	25.6	25.2
6	27.0	28.0	27.4	27.9	27.5	28.3	28.4	27.8	27.3	27.2	27.7	27.8
7	27.7	30.9	29.6	31.6	31.2	31.8	31.3	30.9	30.8	30.0	31.4	31.0
8	32.8	33.5	32.6	33.5	33.2	33.9	33.9	32.9	32.9	32.7	34.0	34.2
9	33.9	34.2	33.7	33.0	34.4	34.4	34.6	34.4	34.0	34.0	34.6	35.0
10	33.8	33.3	33.4	33.4	33.8	33.4	33.7	33.9	33.6	33.4	33.8	34.3
11	32.6	32.4	32.1	32.4	32.7	32.2	32.5	32.7	32.0	32.0	32.3	32.7
12	32.1	32.0	32.2	32.3	32.1	32.1	32.2	31.9	32.0	31.9	32.4	32.5
13	33.2	33.2	33.7	34.6	33.5	35.0	39.3	34.2	33.7	34.5	34.4	34.5
14	36.0	36.0	36.1	36.5	36.1	36.6	36.6	36.6	36.0	36.4	36.6	36.4
15	36.5	36.9	36.3	36.9	36.8	36.8	37.0	36.5	36.6	36.5	36.6	37.2
16	36.5	36.6	36.5	37.0	36.7	37.6	37.3	37.2	36.7	36.7	37.2	37.6
17	37.5	37.9	37.8	39.3	38.0	39.4	39.0	38.5	38.3	38.4	39.0	39.2
18	39.6	39.9	40.8	40.6	40.8	41.7	41.7	41.0	40.4	40.5	41.6	42.1
19	43.0	44.2	43.8	44.5	44.0	45.7	44.4	44.6	43.7	44.2	45.0	45.5
20	46.3	46.5	46.0	46.8	47.1	48.5	48.2	47.6	47.1	48.0	47.8	48.3
21	48.7	49.5	48.8	49.9	49.7	50.1	50.2	50.9	49.3	49.5	50.5	51.4
22	51.3	51.5	50.8	50.8	51.0	52.0	52.3	51.2	51.3	50.9	52.7	53.4
23	53.2	53.0	53.1	52.6	53.7	53.7	55.2	52.6	54.1	52.6	54.9	54.9
24	55.3	55.5	55.6	55.4	55.8	55.6	57.4	55.4	55.5	54.5	56.2	56.4
25	--	--	--	--	--	--	--	--	--	--	--	--
Volume, ml												
	7227.94	7347.18	7261.31	7432.81	7419.02	7629.09	7664.57	7455.12	7359.80	7317.71	7622.30	7743.78

TABLE C-4.- LEG MEASUREMENTS OF SL-4 SPT

(a) Preflight

Leg zone	F - 46 (Aug. 31, 1973)		F - 35 (Oct. 12, 1973)		F - 21 (Oct. 26, 1973)		F - 10 (Nov. 6, 1973)		F - 6 (Nov. 10, 1973)		Mean $\pm$ SD	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	20.6	20.9	20.1	20.8	20.2	20.9	20.3	20.9	20.2	20.5	--	--
3	21.5	21.8	20.5	21.6	20.5	21.8	21.0	21.4	20.7	21.1	--	--
4	23.7	24.1	22.8	23.8	23.0	23.6	23.0	23.9	23.3	23.5	--	--
5	26.4	27.6	25.4	26.9	25.6	26.5	26.0	27.5	25.8	26.6	--	--
6	29.7	31.3	28.6	29.6	28.5	29.6	29.6	30.5	29.3	30.4	--	--
7	33.4	34.6	31.9	33.6	33.2	32.6	33.2	33.4	32.4	32.6	--	--
8	37.4	37.0	35.7	36.0	36.0	36.0	36.8	36.1	35.5	35.4	--	--
9	38.1	37.4	36.9	36.4	37.3	36.7	37.9	36.9	37.4	36.6	--	--
10	37.0	36.5	36.6	35.5	36.6	35.9	36.8	35.9	36.6	36.1	--	--
11	34.9	34.0	35.6	33.5	34.8	34.0	35.2	33.9	35.0	33.8	--	--
12	34.0	33.2	34.0	33.1	33.7	33.1	33.8	33.3	34.0	32.9	--	--
13	35.5	35.7	34.7	35.9	34.4	35.2	35.9	35.5	36.6	35.6	--	--
14	37.9	37.9	37.3	37.5	37.3	38.3	37.8	37.6	37.7	37.3	--	--
15	38.8	38.1	37.8	38.4	38.1	39.0	38.4	38.6	38.2	38.3	--	--
16	38.7	38.9	37.9	39.1	38.3	40.5	38.2	39.0	38.9	37.8	--	--
17	40.1	40.6	39.0	41.2	39.6	42.0	40.0	41.7	39.8	40.2	--	--
18	42.6	44.1	41.4	43.6	42.1	45.2	42.3	43.7	43.1	43.3	--	--
19	45.6	46.4	45.1	46.5	45.6	47.8	45.8	47.0	45.0	46.4	--	--
20	49.4	50.1	47.3	49.6	48.4	50.5	48.7	49.7	48.6	48.7	--	--
21	52.2	52.2	49.8	51.8	51.1	53.0	50.8	52.1	50.0	51.4	--	--
22	53.7	53.3	52.2	52.4	53.7	54.1	52.8	52.8	52.0	52.0	--	--
23	56.0	53.9	55.1	54.5	55.5	56.5	54.8	53.9	53.6	53.2	--	--
24	56.5	55.9	56.7	56.9	55.9	56.0	57.1	57.2	55.7	54.9	--	--
25	--	--	--	--	--	--	--	--	--	--	--	--

Volume, ml

8237.85	8244.90	7829.16	8120.34	7995.12	8374.84	8085.53	8192.67	7935.98	7944.06	8016.73	8175.36
										± 154.76	± 159.26

TABLE C-4.- Continued

(b) In-flight

Leg zone	MD-3 (Nov. 18, 1973)		MD-5 (Nov. 20, 1973)		MD-8 (Nov. 23, 1973)		MD-37 (Dec. 22, 1973)		MD-59 (Jan. 13, 1974)		MD-81 (Feb. 4, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	19.1	19.5	19.1	--	19.3	19.5	18.7	--	19.1	--	18.9	--
3	20.2	21.0	20.5	--	19.4	20.8	19.4	--	20.1	--	19.7	--
4	21.4	23.0	22.5	--	22.0	22.8	22.2	--	22.3	--	22.7	--
5	24.0	25.5	25.0	--	24.0	25.8	24.8	--	24.5	--	25.2	--
6	27.5	28.5	27.5	--	26.6	28.2	27.8	--	28.0	--	28.0	--
7	31.2	31.5	31.5	--	29.4	32.5	31.0	--	32.1	--	31.3	--
8	35.0	34.5	35.5	--	33.5	34.0	33.6	--	34.7	--	34.0	--
9	36.0	35.9	36.5	--	35.6	35.0	34.0	--	35.0	--	34.2	--
10	35.6	34.5	35.7	--	35.0	33.8	32.5	--	33.5	--	33.0	--
11	33.1	33.0	34.5	--	34.2	32.1	31.5	--	32.0	--	32.1	--
12	33.2	31.5	33.5	--	32.2	32.1	31.0	--	31.7	--	31.3	--
13	32.6	34.0	33.6	--	32.8	33.9	33.0	--	33.4	--	33.0	--
14	34.6	35.8	36.0	--	34.6	35.6	35.0	--	35.8	--	35.8	--
15	35.9	36.0	36.5	--	36.2	36.7	34.8	--	37.0	--	35.5	--
16	35.7	36.0	36.4	--	35.5	35.9	35.2	--	35.6	--	35.4	--
17	37.0	37.0	37.5	--	36.0	36.8	36.8	--	36.8	--	37.3	--
18	39.1	39.5	39.2	--	38.5	38.9	39.5	--	38.4	--	41.0	--
19	42.4	41.5	42.9	--	40.9	42.0	42.7	--	42.1	--	41.7	--
20	44.6	44.1	45.0	--	43.5	45.1	45.0	--	45.8	--	45.0	--
21	48.0	47.0	47.5	--	45.8	48.5	46.8	--	47.6	--	48.1	--
22	50.5	50.0	50.0	--	49.0	52.0	48.5	--	49.1	--	50.9	--
23	51.5	52.0	51.5	--	51.0	51.3	49.5	--	50.8	--	51.0	--
24	52.7	52.2	52.2	--	51.5	52.5	50.0	--	52.2	--	52.1	--
25	--	--	--	--	--	--	--	--	--	--	--	--
Volume, ml												
	7100.71	7106.30	7239.15	--	6834.52	7168.61	6793.60	--	7026.05	--	7039.81	--

TABLE C-4.- Continued

(c) Postflight, R + 0 to R + 4

Leg zone	R + 0 (Feb. 8, 1974)		R + 1 (Feb. 9, 1974)		R + 1 (Feb. 9, 1974)		R + 2 (Feb. 10, 1974)		R + 3 (Feb. 11, 1974)		R + 4 (Feb. 12, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	19.5	19.7	20.3	20.6	20.6	19.7	20.2	20.8	20.0	20.6	20.3	20.8
3	20.4	20.4	20.4	20.8	20.3	20.4	20.8	21.3	20.5	20.9	20.7	21.4
4	22.7	22.5	22.5	23.0	22.4	23.0	23.3	23.5	23.2	23.1	23.5	24.0
5	26.0	25.2	24.8	25.4	24.6	25.1	25.3	26.7	25.5	26.2	25.7	26.7
6	28.2	28.1	27.9	29.0	27.0	27.6	28.3	29.1	28.9	29.4	28.8	29.6
7	32.1	31.2	31.1	31.4	31.1	31.2	31.7	32.4	32.0	31.6	32.7	33.0
8	34.1	33.0	34.6	33.8	34.0	33.4	34.8	34.8	35.3	34.5	35.4	35.2
9	34.8	34.1	36.2	34.7	35.8	34.3	36.0	35.5	36.2	35.3	36.4	36.0
10	34.3	33.5	36.1	34.5	35.5	33.7	35.6	34.6	35.7	34.6	35.7	35.6
11	32.9	32.3	34.7	33.2	33.4	32.4	34.2	33.2	34.4	33.2	34.0	33.5
12	32.5	31.8	33.5	32.5	33.1	32.2	33.7	32.6	33.4	32.5	33.8	33.0
13	35.6	35.0	34.5	34.5	34.5	34.3	35.2	35.4	35.2	34.5	36.0	36.1
14	37.0	36.9	37.2	36.2	36.9	36.2	37.9	37.5	37.7	36.8	37.9	38.1
15	37.3	32.3	38.2	37.8	37.5	37.2	38.1	38.0	38.2	38.5	38.5	38.7
16	37.0	36.8	38.0	38.0	37.4	36.7	38.2	38.2	38.2	38.1	38.6	38.9
17	39.0	38.9	38.9	38.9	39.4	38.3	39.1	34.5	39.1	39.6	40.8	41.0
18	41.3	41.6	41.4	41.3	41.0	40.8	41.0	42.0	41.6	41.6	43.1	43.7
19	44.4	43.6	44.3	44.5	44.4	43.6	44.2	45.1	42.2	44.5	46.3	46.3
20	48.2	46.3	47.2	46.4	48.6	47.1	47.8	48.1	47.5	48.4	47.3	49.5
21	49.5	49.1	50.0	49.0	49.9	49.2	49.7	50.5	50.0	50.5	51.5	51.3
22	51.3	50.9	51.1	50.6	51.3	51.2	52.3	52.2	52.2	51.0	53.1	53.1
23	53.5	51.0	54.6	51.9	53.5	54.0	53.2	53.1	54.4	53.9	55.2	55.6
24	56.1	53.2	56.5	55.1	55.8	55.2	55.2	54.5	57.6	54.9	57.5	56.5
25	--	--	--	--	--	--	--	--	--	--	--	--

Volume, ml

7579.27	7300.78	7689.47	7457.96	7599.91	7394.23	7710.79	7747.60	7762.68	7684.15	8085.90	8124.33
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TABLE C-4.- Concluded

(d) Postflight, R + 5 to R + 68

Leg zone	R + 5 (Feb. 13, 1974)		R + 7 (Feb. 15, 1974)		R + 11 (Feb. 19, 1974)		R + 17 (Feb. 25, 1974)		R + 31 (Mar. 11, 1974)		R + 68 (Apr. 17, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	20.0	20.8	20.0	21.0	20.2	20.2	20.2	20.6	21.0	21.1	20.7	20.8
3	20.8	21.4	20.6	21.5	20.6	21.6	20.7	21.3	21.7	21.5	21.1	21.3
4	22.6	23.5	22.6	23.8	23.0	23.9	22.6	23.6	24.2	23.5	23.2	23.5
5	25.3	26.5	24.8	27.0	25.9	26.2	25.3	26.2	26.7	26.7	25.8	26.6
6	28.1	29.5	27.7	27.9	29.2	30.1	28.1	29.4	30.4	29.9	29.2	30.1
7	32.1	32.6	32.2	33.5	33.0	32.7	31.8	32.6	34.6	34.6	33.0	33.3
8	35.2	35.7	35.5	35.4	35.9	35.5	35.4	35.2	37.0	35.5	36.7	36.4
9	36.3	36.0	36.9	36.4	37.0	36.3	36.7	36.1	38.2	36.7	37.9	37.1
10	35.7	34.5	36.6	35.9	36.4	35.4	36.2	35.5	37.2	35.9	37.6	36.5
11	34.4	33.8	34.9	34.2	34.6	33.6	34.7	33.8	35.5	34.4	36.0	34.6
12	33.7	33.2	35.8	33.3	34.0	33.0	33.9	33.1	34.6	33.6	34.7	33.7
13	35.6	35.5	34.9	36.2	35.9	35.2	35.3	35.4	36.8	36.0	35.8	36.1
14	37.4	37.4	37.5	37.4	38.1	38.1	37.8	37.6	38.9	38.4	38.4	38.3
15	38.4	38.5	38.2	38.2	39.0	38.8	38.8	38.5	39.6	39.3	39.1	39.3
16	38.4	38.5	38.2	38.6	38.8	38.9	38.6	38.4	39.9	39.3	39.1	40.1
17	40.0	40.1	39.6	39.4	40.1	40.7	40.6	40.3	41.1	41.2	40.5	41.8
18	42.0	42.5	42.0	42.9	42.3	43.0	42.2	43.3	43.3	44.2	43.5	44.2
19	44.8	45.5	45.0	46.5	45.2	45.5	44.8	45.5	46.7	47.3	46.7	47.3
20	48.0	48.2	47.5	48.6	48.7	48.6	48.8	48.9	49.9	49.7	49.3	50.0
21	50.7	50.4	50.4	51.4	50.5	50.8	51.0	51.3	52.0	51.6	51.8	51.5
22	52.6	52.4	52.7	52.1	52.6	52.2	52.8	52.6	54.2	53.5	54.0	54.5
23	55.2	54.7	55.2	53.9	54.4	54.0	54.9	57.6	57.3	55.2	56.6	56.1
24	57.2	56.1	57.2	55.0	56.8	56.4	57.1	56.7	58.8	56.3	58.0	57.3
25	--	--	--	--	--	--	--	--	--	--	--	--

Volume, ml

7902.50	7912.85	7885.98	7999.82	8015.23	7976.42	7966.28	7985.16	8522.03	8265.90	8342.41	8375.52
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TABLE C-5.- LEG MEASUREMENTS OF SL-4 PLT

(a) Preflight

Leg zone	F - 46 (Aug. 31, 1973)		F - 35 (Oct. 12, 1973)		F - 21 (Oct. 26, 1973)		F - 10 (Nov. 6, 1973)		F - 6 (Nov. 10, 1973)		Mean $\pm$ SD	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	22.0	21.4	22.0	21.5	22.1	21.6	21.8	21.4	22.0	21.5	--	--
3	22.3	21.9	22.1	22.1	22.5	22.6	22.0	21.8	22.2	21.6	--	--
4	24.2	23.6	24.0	23.7	24.2	24.0	24.0	23.6	24.2	23.6	--	--
5	26.5	25.9	26.0	25.6	26.5	26.1	26.1	26.1	26.6	25.3	--	--
6	28.3	28.6	28.0	27.9	28.4	28.2	28.2	28.3	28.4	27.6	--	--
7	30.6	30.6	30.4	30.0	30.9	31.2	30.8	30.5	31.1	29.5	--	--
8	33.7	34.0	33.1	33.1	34.2	34.1	33.4	32.8	33.9	31.8	--	--
9	36.8	35.2	35.9	35.4	36.9	36.2	36.6	34.7	36.3	34.1	--	--
10	36.7	35.3	36.6	35.7	36.7	36.2	36.5	35.7	36.5	35.6	--	--
11	35.0	33.3	35.1	33.9	35.2	34.3	35.3	33.7	34.5	34.0	--	--
12	33.4	32.5	33.7	32.7	33.7	33.3	33.5	32.7	33.3	32.5	--	--
13	34.4	34.6	34.8	34.6	35.3	34.5	35.0	34.2	35.0	34.1	--	--
14	36.7	35.9	36.7	35.9	37.1	36.2	36.8	35.9	36.9	36.0	--	--
15	36.3	36.1	37.9	36.5	38.2	37.4	37.4	36.3	37.7	36.5	--	--
16	36.8	36.2	37.5	37.2	37.9	36.9	37.2	36.3	37.8	35.7	--	--
17	39.7	37.7	39.7	38.6	39.8	40.2	40.1	38.4	40.1	37.7	--	--
18	41.3	42.1	42.7	41.5	42.9	43.8	43.3	42.3	43.6	42.6	--	--
19	45.0	47.0	45.9	45.5	46.7	47.0	46.7	46.0	46.3	44.0	--	--
20	48.5	48.3	48.4	48.5	49.5	49.2	49.1	48.4	49.1	47.6	--	--
21	51.2	50.3	50.4	50.4	51.2	51.2	51.2	50.3	51.3	49.5	--	--
22	52.1	50.7	51.6	51.1	52.1	51.0	52.1	50.8	52.0	50.9	--	--
23	52.6	50.6	53.3	51.6	53.5	52.6	53.4	50.8	53.5	51.2	--	--
24	53.3	51.3	54.1	52.9	54.2	52	55.0	52.4	54.2	51.9	--	--
25	--	--	--	--	--	--	--	--	--	--	--	--
Volume, ml												
	7717.19	7466.25	7768.02	7521.66	7948.18	7777.57	7881.69	7475.53	7894.18	7327.43	7841.85 ± 95.69	7513.69 ± 164.39

TABLE C-5.- Continued

(b) In-flight

Leg zone	MD-5 (Nov. 20, 1973)		MD-8 (Nov. 23, 1973)		MD-31 (Dec. 16, 1973)		MD-58 (Jan. 12, 1973)		MD-81 (Feb. 4, 1974)	
	L	R	L	R	L	R	L	R	L	R
Circumference, cm										
1	—	—	—	—	—	—	—	—	—	—
2	26.0	—	20.5	21.6	20.2	20.2	20.2	20.0	20.0	—
3	21.6	—	21.6	21.3	21.2	20.4	20.5	20.8	20.9	—
4	23.2	—	23.6	23.0	23.3	22.5	22.4	22.8	22.4	—
5	25.4	—	25.6	24.6	25.5	24.6	24.1	24.8	24.8	—
6	27.4	—	28.0	27.4	27.9	27.6	26.0	26.9	26.3	—
7	29.2	—	30.0	29.2	29.9	29.4	28.2	29.1	28.5	—
8	32.9	—	33.5	31.2	32.6	31.1	30.6	31.6	31.5	—
9	36.1	—	35.0	34.5	34.0	33.5	34.0	33.2	33.8	—
10	34.6	—	33.7	33.4	33.1	33.5	33.6	32.1	32.8	—
11	32.6	—	32.3	32.0	31.0	33.0	32.3	31.1	31.5	—
12	31.2	—	31.9	31.5	31.3	31.2	31.2	31.4	31.8	—
13	32.4	—	33.8	32.7	32.6	32.5	32.7	33.8	33.8	—
14	35.3	—	34.9	34.4	35.0	34.5	34.0	34.3	34.3	—
15	35.0	—	34.5	34.5	34.6	34.2	34.1	34.0	34.1	—
16	35.2	—	34.5	33.5	34.3	33.7	34.1	35.6	34.6	—
17	38.7	—	36.3	34.2	37.5	36.2	35.4	36.7	36.4	—
18	41.6	—	38.5	36.3	38.6	38.1	38.9	39.2	40.7	—
19	45.1	—	43.5	40.6	42.2	42.8	40.9	43.2	43.8	—
20	46.8	—	45.3	42.8	45.7	45.1	45.0	47.0	45.5	—
21	47.5	—	46.6	46.8	46.8	47.1	45.4	47.2	47.3	—
22	48.9	—	47.9	46.9	48.5	47.9	46.8	48.8	48.7	—
23	50.1	—	48.4	48.9	49.8	48.6	48.9	49.6	49.7	—
24	49.9	—	49.2	49.6	50.7	49.9	49.6	51.2	50.3	—
25	—	—	—	—	—	—	—	—	—	—
Volume, ml										
	7120.24	—	6832.74	6508.76	6805.97	6668.12	6518.33	6804.72	6795.45	—

TABLE C-5.- Continued

(c) Postflight, R + 0 to R + 4

Leg zone	R + 0 (Feb. 8, 1974)		R + 1 (Feb. 9, 1974)		R + 1 (Feb. 9, 1974)		R + 2 (Feb. 10, 1974)		R + 3 (Feb. 11, 1974)		R + 4 (Feb. 12, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	20.8	20.5	21.5	20.8	21.4	20.5	21.8	21.4	21.3	20.9	21.9	21.4
3	21.2	20.9	21.3	21.1	21.2	20.8	22.0	21.7	21.5	21.1	21.9	21.7
4	23.0	23.8	23.2	22.6	22.8	22.9	23.9	23.2	23.3	22.9	23.6	23.5
5	24.5	24.8	25.2	24.5	24.8	24.4	25.4	25.3	25.2	24.8	25.4	25.0
6	26.6	27.1	27.2	26.7	26.6	26.0	27.4	27.4	27.0	27.3	27.0	27.6
7	28.7	28.9	29.4	28.7	29.4	28.3	29.8	29.8	29.3	29.6	29.6	29.7
8	31.5	31.4	31.9	31.0	31.9	31.2	32.5	33.0	32.2	31.9	32.5	32.2
9	33.9	33.0	34.5	33.2	33.9	33.6	35.2	33.9	34.8	33.3	35.1	34.5
10	33.3	32.9	34.8	34.0	34.2	32.9	35.2	34.6	34.8	34.0	35.7	34.5
11	32.7	31.9	33.9	33.2	33.0	31.8	33.9	33.3	33.7	32.5	34.3	33.0
12	32.1	31.4	32.7	32.1	32.3	31.3	32.8	32.7	32.5	31.8	33.3	32.3
13	33.3	33.7	34.3	33.4	33.3	33.3	34.6	34.6	34.0	33.6	34.7	34.4
14	35.7	35.1	36.4	35.5	35.6	34.9	37.1	35.7	36.4	35.5	37.0	35.8
15	36.6	35.7	37.5	36.4	36.2	35.4	37.6	36.5	39.7	36.2	37.9	36.5
16	36.3	35.4	37.6	35.9	36.5	35.4	37.1	36.7	36.8	36.1	37.7	36.3
17	38.6	37.6	39.7	38.2	38.5	37.5	39.9	37.7	38.9	38.1	40.0	38.2
18	41.2	40.8	41.5	40.2	42.3	39.8	42.3	41.2	42.8	40.1	41.7	41.0
19	44.2	44.6	44.9	43.6	44.0	45.2	45.4	43.9	44.9	44.5	45.4	44.1
20	46.8	46.8	41.8	46.8	46.9	46.8	48.2	47.5	47.6	47.0	48.0	46.7
21	49.2	48.6	49.5	49.5	48.8	49.0	50.0	49.0	49.3	48.7	49.9	49.0
22	50.2	49.6	50.9	49.9	50.0	49.6	51.2	49.6	51.2	49.7	51.6	50.2
23	51.5	50.8	51.6	50.7	50.9	49.9	52.3	50.7	52.5	49.9	52.1	51.5
24	53.2	51.8	53.0	57.9	52.6	50.4	53.0	51.3	54.9	51.9	53.6	51.9
25	--	--	--	--	--	--	--	--	--	--	--	--

Volume, ml

7175.40	7032.22	7431.37	7084.29	7194.36	6945.49	7574.22	7233.25	7467.87	7091.50	7594.82	7250.68
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TABLE C-5.- Concluded

(d) Postflight, R + 5 to R + 68

Leg zone	R + 5 (Feb. 13, 1974)		R + 7 (Feb. 15, 1974)		R + 11 (Feb. 19, 1974)		R + 17 (Feb. 25, 1974)		R + 31 (Mar. 11, 1974)		R + 68 (Apr. 17, 1974)	
	L	R	L	R	L	R	L	R	L	R	L	R
Circumference, cm												
1	--	--	--	--	--	--	--	--	--	--	--	--
2	21.7	21.1	21.4	21.1	21.8	21.4	21.7	21.4	22.2	21.7	22.2	21.3
3	21.8	21.6	21.8	21.5	22.3	22.1	21.9	21.9	22.3	22.5	22.0	22.0
4	23.0	23.1	23.4	23.2	24.2	24.7	23.5	23.6	24.2	23.6	23.6	23.8
5	25.2	25.4	25.2	24.9	26.2	25.4	25.9	25.5	26.3	24.9	25.4	26.0
6	26.9	27.6	27.3	27.3	28.0	27.6	27.6	28.1	28.4	27.4	27.5	28.2
7	29.2	29.5	29.6	29.1	30.6	29.8	30.1	29.9	30.7	29.4	30.4	31.2
8	32.3	31.9	33.0	31.4	33.8	32.7	33.4	32.5	33.9	32.2	32.9	33.5
9	34.8	34.3	35.1	34.1	36.4	34.9	36.0	35.0	36.3	35.0	36.0	36.5
10	35.4	35.5	35.5	34.0	35.8	35.0	35.8	35.3	36.5	35.9	37.4	36.9
11	34.1	33.1	34.1	32.8	34.3	33.5	34.3	33.9	35.0	34.8	35.9	35.2
12	32.9	32.2	33.0	31.9	33.4	32.4	33.1	32.7	33.7	33.1	34.2	33.7
13	34.2	34.1	34.6	33.6	35.3	35.0	34.5	34.2	35.7	34.3	34.5	35.0
14	36.7	35.7	36.6	35.4	37.3	35.8	36.7	35.9	37.4	36.3	37.3	37.0
15	37.3	36.4	36.9	35.8	37.7	36.8	37.4	36.7	38.2	37.2	38.3	37.7
16	37.0	36.9	37.2	36.4	37.7	37.0	37.5	36.7	38.2	36.5	38.4	38.0
17	38.7	38.6	38.8	38.2	40.0	39.2	40.1	39.2	40.3	38.2	39.6	40.0
18	41.0	41.5	41.7	41.2	43.2	42.4	43.4	41.6	43.2	41.6	43.0	44.0
19	44.6	45.0	45.6	44.7	47.4	46.0	46.3	45.4	47.2	45.6	47.2	47.8
20	47.6	47.3	48.6	47.4	49.4	48.6	48.8	48.1	49.8	48.4	49.5	50.7
21	49.9	49.9	49.7	49.8	50.9	50.1	50.9	50.5	52.0	50.2	51.3	52.9
22	51.6	50.5	51.3	50.3	52.0	51.1	52.2	51.0	53.0	51.6	53.1	53.6
23	52.8	50.9	52.5	51.1	52.9	51.7	53.2	51.9	54.2	52.6	54.1	54.4
24	53.2	53.1	53.8	51.4	55.0	52.4	54.8	53.0	55.2	53.6	55.1	55.2
25	--	--	--	--	--	--	--	--	--	--	--	--

Volume, ml

7465.08	7335.29	7547.38	7201.60	7879.95	7523.88	7777.29	7493.53	8043.86	7547.92	7964.81	8097.25
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TABLE C-6.- CALF-CIRCUMFERENCE AND LOWER-LIMB-VOLUME DATA FOR INDIVIDUAL
APOLLO CREWMEMBERS IN A RESTING, SUPINE POSITION^a

Apollo mission	Crew-member	Preflight evaluations			Preflight summary		Postflight evaluations ^b			
		F - 30	F - 15	F - 5	Mean	±SD	First	Second	Third	Fourth
Resting supine mean calf circumference, cm										
7	CDR	40.7	40.9	40.8	40.8	0.10	40.1 +	40.1 +	--	--
	CMP	35.9	35.9	35.9	35.9	.00	34.7	35.6	--	--
	LMP	36.6	36.9	36.1	36.5	.40	35.1 +	36.0	--	--
8	CDR	35.2	35.3	35.4	35.3	.10	34.9 +	35.2	34.4 +	--
	CMP	39.7	39.4	39.4	39.5	.17	39.1	39.1	39.1	--
	LMP	37.3	36.8	37.2	37.1	.26	36.8	36.7	37.2	--
9	CDR	37.0	37.0	36.8	36.9	.12	35.2 +	35.9 +	36.4 +	--
	CMP	40.5	40.2	40.1	40.3	.21	38.9 +	40.2	40.4	--
	LMP	36.4	--	36.2	36.3	.14	34.7 +	38.1 +	36.1	--
10	CDR	36.3	35.1	35.9	35.8	.61	34.6 +	35.6	--	--
	CMP	37.8	37.1	37.0	37.3	.44	36.2	37.1	--	--
	LMP	38.1	37.5	37.0	37.5	.55	35.6 +	36.5	--	--
11	CDR	36.6	36.0	36.2	36.3	.31	35.6	--	--	--
	CMP	37.2	36.8	38.1	37.4	.67	37.0	--	--	--
	LMP	37.9	38.3	37.6	37.9	.35	37.6	--	--	--
15	CDR	40.3	40.5	40.5	40.4	.12	39.3 +	39.4 +	40.1	40.8 +
	CMP	36.5	36.3	36.5	36.4	.12	35.6 +	35.1 +	35.9 +	35.9 +
	LMP	37.5	37.1	37.4	37.3	.21	36.0 +	36.5 +	36.7 +	36.3 +
18	CDR	38.1	37.9	38.0	38.0	.10	36.6 +	36.6 +	36.5 +	--
	CMP	34.4	34.4	34.8	34.5	.23	33.5 +	33.5 +	33.2 +	--
	LMP	36.3	36.3	36.3	36.3	.00	35.6	35.6	35.4	--
17	CDR	38.0	38.2	38.5	38.2	.25	37.3 +	36.6 +	38.1	37.3 +
	CMP	38.8	38.1	38.6	38.5	.36	37.0 +	37.0 +	38.1	37.0 +
	LMP	38.6	39.1	38.9	38.9	.25	37.4 +	37.5 +	38.1 +	37.6 +
Group mean		37.57	37.44	37.47	37.47		36.43	36.85	37.05	37.48
±SD		1.621	1.724	1.625	1.634		1.688	1.719	1.995	1.743
					t-test		p < 0.05	n.s. ^c	n.s.	n.s.
Lower limb volume, ml										
16	CDR	15 929	15 485	15 669	15 694	223	14 108 +	14 146 +	13 770 +	13 812 +
	CMP	12 577	12 492	12 798	12 622	158	12 150 +	11 898 +	12 005 +	12 146 +
	LMP	14 556	14 794	14 741	14 697	125	14 482	14 033 +	14 068 +	13 806 +
17	CDR	17 265	17 685	17 991	17 647	364	16 772	16 427 +	17 238	16 706 +
	CMP	17 426	17 132	17 357	17 305	154	15 964 +	16 366 +	17 028	16 424 +
	LMP	17 944	18 542	18 030	18 172	323	17 084 +	17 692	17 878	17 189 +
Group mean		15 950	16 022	16 098	16 023		15 093	15 094	15 331	15 014
±SD		2 059	2 218	2 089	2 113		1 873	2 116	2 371	2 035
					t-test		n.s.	n.s.	n.s.	n.s.

^aW. Höffler and R. Johnson: Apollo flight Crew Cardiovascular Evaluations. Ch. 4 of Biomedical Results of Apollo. NASA SP-368, in press.

^bArrows indicate probability p < 0.05.

^cn.s. - not significant.

TABLE C-7.- UPPER-LIMB VOLUMES AND CHANGES IN VOLUME OF SKYLAB CREWMEN

(a) SL-2

Day	Vol., ml	Right arm Δ vol., ml	Δ vol., percent Vol., ml	Left arm Δ vol., ml	Δ vol., percent
			CDR		
F - 6	^a 2209	--	--	--	--
F + 1	2236	27	1.2	24	1.0
R - 2	2294	85	3.8	-18	-0.8
			SPT		
F - 6	^a 2768	--	--	--	--
R + 1	--	--	--	--	--
R + 2	2698	-70	-2.5	-34	-1.3
			PLT		
F - 6	^a 2702	--	--	--	--
R + 1	2589	-113	-4.2	-60	-2.4
R + 2	2693	-9	-0.3	-9	-0.4

^aBaseline.

TABLE C-7.- Continued

(b) SL-3

Day	Right arm			Left arm		
	Vol., ml	Δ vol., ml	Δ vol., percent	Vol., ml	Δ vol., ml	Δ vol., percent
			CDR			
F - 6	^a 3228	--	--	^a 2831	--	--
F - 5	3182	-46	-1.4	2861	30	1.1
R + 1	2967	-261	-8.1	2710	-121	-4.3
R + 2	2874	-354	-11.0	2476	-355	-12.5
R + 3	2850	-378	-11.7	2550	-281	-9.9
R + 4	2807	-421	-13.0	2492	-339	-12.0
			CPT			
F - 6	^a 2745	--	--	^a 2672	--	--
F - 5	2774	29	1.1	2669	-3	-0.1
R + 1	2580	-165	-6.0	2543	-129	-4.8
R + 2	2521	-224	-8.2	2667	-5	-.2
R + 3	2675	-70	-2.6	2506	-166	-6.2
R + 4	2656	-89	-3.2	2544	-128	-4.8
			PLT			
F - 6	^a 3073	--	--	^a 3494	--	--
F - 5	3026	-47	-1.5	3482	-12	-0.3
R + 1	3013	-60	-1.9	3534	40	1.1
R + 2	3135	62	2.0	3509	15	.4
R + 3	3134	61	2.0	3580	86	2.5
R + 4	2992	-81	-2.6	3424	-70	-2.0

^aBaseline.

TABLE C-7.- Continued

(c) SL-4

Day	Vol., ml	Right arm		Left arm	
		Δ vol., ml	Δ vol., percent	Δ vol., ml	Δ vol., percent
			CDR		
F - 30	2498	65	2.7	2335	-2
F - 15	2430	-3	-.1	2393	56
F - 4	^a 2433	—	—	^a 2337	—
MD-5	—	—	—	2352	15
MD-8	2434	1	.04	2224	-113
MD-31	2367	-66	-2.7	2256	-81
MD-57	2439	6	.2	2234	-103
R + 0	2432	-1	.04	2348	11
R + 1	2467	34	1.4	2353	16
R + 2	2465	32	1.3	2362	25
R + 4	2511	78	3.2	2391	54
R + 5	2505	72	2.9	2401	64
R + 11	2442	9	.4	2344	7

^aBaseline.

TABLE C-7.- Continued

(c) Continued

Mission date	Vol., ml	Right arm		SPT	Left arm	
		Δ vol., ml	Δ vol., percent		Δ vol., ml	Δ vol., percent
F - 30	2786	81	3.0		-90	-3.3
F - 15	2681	-24	-.9		-99	-3.7
F - 4	^a 2705	—	—		—	—
MD-5	—	—	—		-58	-2.1
MD-8	2768	63	2.3		-128	-4.7
MD-31	—	—	—		-324	-12.0
MD-57	—	—	—		-22	-.8
R + 0	2659	-46	-1.7		-71	-2.6
R + 1	2628	-77	-2.8		-58	-2.1
R + 2	2718	13	.5		-84	-3.1
R + 4	2703	-2	-.1		-50	-1.9
R + 5	2693	-12	-.4		-11	-.4
R + 11	2740	35	1.3		-31	-1.1

^aBaseline.

(c) Concluded

^aBaseline.