

CDR & PLT							HIGH DENSITY FOOD ITEMS															SPT				
H1	H2	H3	H4	H5	H6	H7		H1	H2	H3	H4	H5	H6	H7	H8	H9		H1	H2	H3	H4	H5	H6	H7	H8	H9
2	2	2	2	2	2	2	Choc. Chip Bar	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	Crispy Bar	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	Flake Bar	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	Apricots																			
0	1*	1	1*	1	1	1	Sausage																			
1	1	1	1	1	1	1	Spaghetti	0	1	1	1	1	1	1	1	1		0	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	G.F. Drink	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	Chicken & Gravy	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
1	0	1	1	1	0	0	Mashed Potatoes	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	0
1	1+	1	1	1	1	0	Pork & Potatoes	1	1	1	1	1	1	1	1	1		1	1	1	1	0	1	1	0	1
1	0	0	1	1	0	1	Veal	1	1	1	1	1	1	1	1	1		1	1	1	1	0	1	0	1	1
							Cocoa	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
							Eggs	1	0	0	1	1	1	1	1	1		1	1	1	1	0	1	1	1	1
			1+				Chicken & Rice	1	0	0	0	1	1	1	1	1		1	1	1	1	1	1	1	1	1
							Peanut Butter	1	0	0	0	1	1	1	1	1		1	1	1	1	1	1	1	1	1
1	1						Pork Loin	1																		
	1						Peanuts																			
	1						Bread																			
							Salmon		1	1															1	
		1					B.S. Pudding																			
		1					Beef Hash				1															
							Chili																			
							Turkey R. Soup																			1
							Turkey & Gravy																			
							Peas				1															
							Corn				1															
							Strawberries																			
							Rice Krispies																			
							Vanilla Wafers																			
							Prime Rib																			
							Potato Soup																			
							Potato Salad																			
							Coffee +																			
							Coffee w/s*																			
							CDR																			
2	2	3	2	2	3	3	Potato Soup																			
2	1	1	1	1	1	1	Potato Salad																			
							Coffee +																			
							Coffee w/s*																			
9.0	6.5	0	8.5	2.5	0	2.5	CDR																			
11.0	12.5	0.5	7.0	4.5	0	4.5	PLT																			
Key: CDR only							Salt Packets Scheduled Usage							3	9	2	3	2	5	1	2	1				

	2	8	4	7	1	2	4	Salt Packets Scheduled Usage	3	9	2	3	2	5	1	2	1
	2	8	4	7	1	2	4	Coffee w/s*	CDR	PLT							
9.0	6.5	0	8.5	2.5	0	2.5											
11.0	12.5	0.5	7.0	4.5	0	4.5			5.5	10.0	9.0	0	5.0	0	14.0	0	6.5

Condiments consisting of liquid pepper, liquid garlic and Tabasco sauce were supplied in special purpose polyethylene dispensers. Dehydrated horseradish was supplied in Apollo spoon-bowl packages and dry salt was packaged in Apollo beverage packages. Both the horseradish and salt were rehydrated in-flight prior to use. A syringe with an adapter that interfaced with the one-way water valve on the package was used to measure and dispense the salt solution as required to account for sodium and chloride intake.

Prior to launch, the Skylab-3 crewmembers evaluated foods which had been subjected to the same temperature profile as the onboard food. During this evaluation it was demonstrated that, although there was decrement in food quality, the crew felt all items could be tolerated. The crew not only tolerated this reduced food quality, but they appear to have thrived on their diets as evidenced by medical findings reported elsewhere in this report.

Table 2.3.1-I. Mean Daily Nutrient Consumption (SL-4).

3/15/74

Crewman	Experimental Period	No. Days	Total Water ^b ml	Kcal	N ₂ g	Fat g	CHO g	Crude Fiber g	Ash g	Ca mg	Phos mg	Iron mg	Na mg	K mg	Mg mg	Cl mg	I ₂ ^c mcg	MACRONUTRIENTS, MINERALS AND ELECTROLYTES ^a																																																																																									
Recommended Daily Allowance ^d																																																																																																											
CDR	Preflight	27	2887.9	3153	19.32	108.1	363.4	5.8	21.7	855	1660	15.81	4748	3820	300	6509	5000																																																																																										
	In-flight	84		3200	18.86	99.4	397.8	6.8	22.5	896	1709	15.85	5044	3880	300	6697	5280																																																																																										
	Postflight	19																																																																																																									
	Minimum Tolerance Level ^e																																																																																																										
SPT	Preflight	27	3325.2	3090	18.02	107.5	358.2	5.1	21.0	884	1705	15.96	4909	3292	279	6632	4700																																																																																										
	In-flight	84		3082	17.81	91.8	395.0	5.2	22.5	925	1754	15.57	5481	3485	284	7455	4944																																																																																										
	Postflight	19																																																																																																									
	Minimum Tolerance Level ^e																																																																																																										
PLT	Preflight	27	3667.3	3195	20.28	113.3	347.9	7.7	24.2	900	1757	17.56	5131	4229	330	6975	5555																																																																																										
	In-flight	84		3276	20.46	108.1	383.4	6.5	24.5	985	1853	16.64	5618	3848	325	7554	5564																																																																																										
	Postflight	19																																																																																																									
	Minimum Tolerance Level ^e																																																																																																										
																		800																		1450																		4200																		3500																		290																	

^aOne vitamin tablet was consumed each day which contained the following: Ash 0.3 g, Ca 56 mg, Na 45 mg, K 5 mg, and Iron 0.03 mg. The vitamin tablet is not included in the mean daily nutrient consumption.

^bTotal water includes water in food, water used for rehydration, and drinking water.

^cIodine from food only. Iodine from water not included.

^dRecommended Daily Dietary Allowances, Revised 1973, for males 23-50 years of age, are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined.

^eIndividual minimum tolerance level for Skylab experiment.

^dRecommended Daily Dietary Allowances, Revised 1973, for males 23-50 years of age, are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined.

^eIndividual minimum tolerance level for Skylab experiment.

Table 2.3.1-II Mean Daily Nutrient Consumption (SL-4)

3/15/74

TRACE MINERALS AND VITAMINS ^a																		
Crewman	Experimental Period	No. Days	Copper mg	Cobalt mcg	Zinc mg	Thiamine mg	Ribo- flavin mg	Niacin mg	B ₁₂ mcg	V I T A M I N					Caro- tene mg	Fola- cin mg	Bio- tin mg	Pyri- doxine mg
										C mg	K mg	E IU	D IU	A IU				
Recommended Daily Allowance ^b			2.0 ^c		15	1.4	1.6	18	3.0	45	15		5000		0.400	0.3 ^c	2.0	
CDR	Preflight	27	1.52	445	14.18	1.65	2.19	33.8	6.07	318	0	0	0	5536	0.036	0.044	2.98	
	In-flight	84	1.62	408	13.07	1.63	2.05	35.5	6.70	491	0	0	0	7814	0.031	0.046	2.87	
	Postflight	19																
SPT	Preflight	27	1.56	430	12.59	1.85	2.12	30.5	6.00	556	0	0	0	10390	0.042	0.039	2.76	
	In-flight	84	1.57	462	11.75	1.71	1.93	31.2	6.15	574	0	0	0	10227	0.043	0.037	2.53	
	Postflight	19																
PLT	Preflight	27	1.56	458	14.84	1.48	2.05	36.1	6.71	353	0	0	0	6482	0.041	0.052	3.18	
	In-flight	84	1.55	424	13.18	1.57	2.17	39.0	7.33	557	0	0	0	8997	0.032	0.054	3.00	
	Postflight	19																

^aOne vitamin tablet was consumed each day which contained the following trace minerals in addition to the specified vitamins: Cobalt 9 mcg and Zinc 0.01 mg. Neither the minerals nor the vitamins from the vitamin tablet is included in the mean daily nutrient consumption.

^bRecommended Daily Dietary Allowances, Revised 1973, for males 23-50 years of age, are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined.

^cProposed USA Government Recommended Daily Allowance Federal Register 1/19/73.

2.3.2 Taste and Aroma Testing

Norman D. Heidelbaugh, V.M.D., M.P.H., Ph.D.; Donald E. Wescott, Ph.D.;
Morely R. Kare, Ph.D.; Charles T. Bourland, Ph.D.;
Malcolm C. Smith, Jr., D.V.M.; and Rita Rapp, B.S.

Introduction

The purpose of this experiment was to objectively quantitate taste and aroma responses of the SL-4 crew by measuring their in-flight taste thresholds and aroma identification ability, and comparing these to pre-flight and postflight measurements. The preflight and postflight measurements were taken under the same conditions as in-flight except for the presence of weightlessness.

The three Skylab crews were the first individuals to subsist for long flight periods (29, 59, and 84 days) on fixed menus during a space flight. These periods, in general, lasted not only for the time in orbit but an additional 21 days preflight and 14 days postflight (approximately). Total duration on the fixed menus for the SL 1/2, SL-3, and SL-4 flights were respectively 63, 91, and 119 days (approximately). The SL 1/2 crew reported a significant shift in food flavors when comparing the food consumed on the ground to that which was consumed in-flight. This difference was attributed to the inadvertent elevated Skylab temperatures experienced by the foods shortly following launch (figure 2.3.2-1).

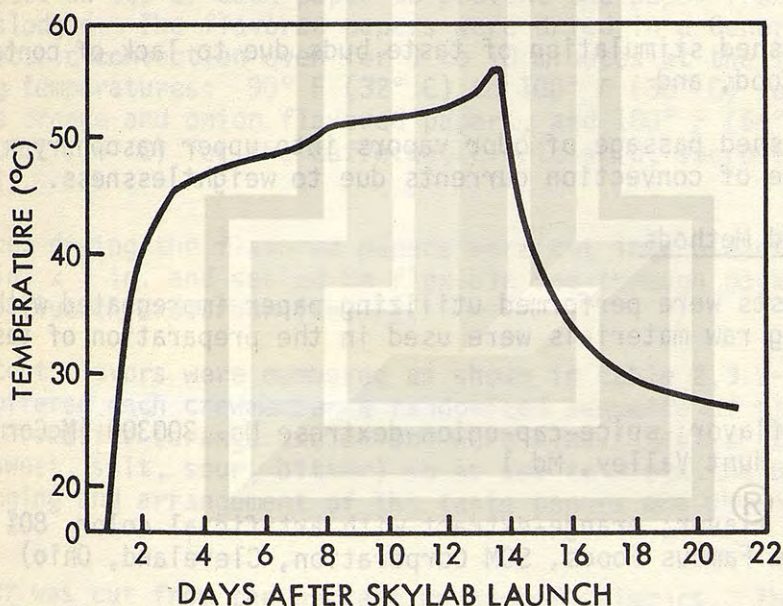


Figure 2.3.2-1. - Heat Profile to which Skylab Foods Were Exposed Due to Loss of Vehicle Heat Shield Following Launch.

In order to better define these changes, the SL 1/2 crew returned to Earth with samples of foods selected for taste evaluation. Upon examining these foods, the SL 1/2 crew reported that they did not taste the same as those which had been consumed in-flight.

Comparable reports of unfamiliar food tastes were recorded throughout the Mercury, Gemini, and Apollo programs. Most of these comments were judged in the light of the very unfamiliar eating modes enforced on those crews. Most of these Mercury, Gemini, and Apollo foods were consumed directly from plastic bags with little accommodation for the esthetics which normally account for the significant part of the oropharyngeal responses to foods. The unfamiliar taste responses reported by those earlier crews were, therefore, attributed largely to these unfamiliar eating modes.

Skylab crews gave the first controlled indication that there may be actual changes in the physiological response to taste or smell during weightless flight. Such changes might be due to intrinsic factors such that man would respond differently due to such factors as diminished nasopharynx sensitivity to odors due to passive congestion resulting from lack of blood pooling in lower extremities. Indeed, this phenomenon of nasopharynx "congestion" had been frequently reported on Skylab. This situation might be considered comparable to tasting food during periods of nasal congestion resulting from a "head cold". Extrinsic factors which might be hypothesized to cause such taste and/or aroma shifts in weightlessness were:

- ° diminished stimulation of taste buds due to lack of contact with food, and
- ° diminished passage of odor vapors into upper nasopharynx in absence of convection currents due to weightlessness.

Materials and Methods

The taste tests were performed utilizing paper impregnated with flavors. The following raw materials were used in the preparation of taste test papers.

- ° Onion flavor; spice-cap-onion-dextrose No. 300300 (McCormick & Co., Hunt Valley, Md.)
- ° Orange flavor; orange-extract with artificial color, 80% (Durkee Famous Foods, SCM Corporation, Cleveland, Ohio)
- ° Bitter; caffeine anhydrous (Sigma Chemical Co., St. Louis, Mo.)
- ° Sour; citric acid granules (Mallinkrodt Chemical Works, N.Y.)

- Sweet; sucrose
- Salt; sodium chloride
- Colorless-tasteless paper; professional brand odor testing paper cards 3 in. x 5-1/2 in. (Frank Orlandi, Inc., N.Y.)

The taste test papers were prepared by the following procedure:

- Aliquots of caffeine, citric acid, sucrose, and salt were dissolved in separately measured amounts of distilled water, and appropriate dilutions of each were made with distilled water.
- An aliquot of orange extract was dissolved in a measured amount of 95% ethyl alcohol, and appropriate dilutions were made with 95% ethyl alcohol.
- An aliquot of spice-cap onion was dissolved in a measured amount of distilled water, and appropriate dilutions were made with 95% ethyl alcohol.
- Sufficient odorless-tasteless paper was immersed in each solution for 5 to 10 minutes, then drained and placed horizontally across the top of glass beakers. A glass rod was placed on top of each paper to prevent the paper from being dislodged. The flavored papers were dried in a General Electric convection oven for 9 to 10 minutes at the following temperatures: 90° F (32° C) to 100° F (38° C) for the orange and onion flavored papers, and 180° F (64° C) to 200° F (76° C) for the caffeine, citric acid, sucrose and salt.
- After drying the flavored papers were cut into pieces measuring 1 in. x 1 in. and sealed in flexible see-through packages of polyfluorohydrocarbon (Kel-F).

The six test flavors were numbered as shown in table 2.3.2-I. This pattern offered each crewmember a randomized sequence of flavors except that the aromatics (orange and onion) were always tasted after the basics (sweet, salt, sour, bitter) so as not to block the basic flavors. The packaging and arrangement of the taste papers are shown in figure 2.3.2-2.

Each paper was cut from the package by use of scissors. The lowest intensity (A) was placed on the tongue first and allowed to wet for about 10 seconds. The flavor response was then reported in accordance with instructions as defined on the flight cue card reproduced in table 2.3.2-II.

TABLE 2.3.2-I. TASTE TEST NUMBERING SYSTEM AND CONCENTRATIONS

RED VELCRO	1					2					3				
	INTENSITY		FLAVOR			CONC. (%)			FLAVOR			CONC. (%)			
Sheet No. 1	A		Caffeine			0.005			Citric Acid			0.05		Salt	
	B		Caffeine			0.05			Citric Acid			0.1		Salt	
	C		Caffeine			0.1			Citric Acid			0.25		Salt	
	D		Caffeine			0.3			Citric Acid			0.5		Salt	
	E		Caffeine			0.6			Citric Acid			1.0		Salt	
Sheet No. 2	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 3	A		Salt			0.06			Citric Acid			0.05		Caffeine	
	B		Salt			0.15			Citric Acid			0.1		Caffeine	
	C		Salt			0.3			Citric Acid			0.25		Caffeine	
	D		Salt			0.6			Citric Acid			0.5		Caffeine	
	E		Salt			1.2			Citric Acid			1.0		Caffeine	
Sheet No. 4	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 5	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 6	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 7	A		Salt			0.06			Citric Acid			0.05		Caffeine	
	B		Salt			0.15			Citric Acid			0.1		Caffeine	
	C		Salt			0.3			Citric Acid			0.25		Caffeine	
	D		Salt			0.6			Citric Acid			0.5		Caffeine	
	E		Salt			1.2			Citric Acid			1.0		Caffeine	
Sheet No. 8	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 9	A		Salt			0.06			Citric Acid			0.05		Caffeine	
	B		Salt			0.15			Citric Acid			0.1		Caffeine	
	C		Salt			0.3			Citric Acid			0.25		Caffeine	
	D		Salt			0.6			Citric Acid			0.5		Caffeine	
	E		Salt			1.2			Citric Acid			1.0		Caffeine	
Sheet No. 10	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 11	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	
Sheet No. 12	A		Sucrose			0.1			Orange			0.25		Onion	
	B		Sucrose			0.25			Orange			1.0		Onion	
	C		Sucrose			0.5			Orange			2.5		Onion	
	D		Sucrose			1.25			Orange			5.0		Onion	
	E		Sucrose			2.5			Orange			10.0		Onion	

0.1
0.25
0.5
1.25
2.5

Sucrose
Sucrose
Sucrose
Sucrose
Sucrose

Orange
Orange
Orange
Orange
Orange

0.02
0.1
0.5
1.0
2.0

Onion
Onion
Onion
Onion
Onion

TABLE 2.3.2-I. TASTE TEST NUMBERING SYSTEM AND CONCENTRATIONS (concluded)

WHITE VELCRO

	INTENSITY	13		14		15	
		FLAVOR	CONC. (%)	FLAVOR	CONC. (%)	FLAVOR	CONC. (%)
Sheet No. 5	A	Sucrose	0.1	Citric Acid	0.05	Salt	0.06
	B	Sucrose	0.25	Citric Acid	0.1	Salt	0.15
	C	Sucrose	0.5	Citric Acid	0.25	Salt	0.3
	D	Sucrose	1.25	Citric Acid	0.5	Salt	0.6
	E	Sucrose	2.5	Citric Acid	1.0	Salt	1.2
Sheet No. 6		16		17		18	
	A	Caffeine	0.005	Orange	0.25	Onion	0.02
	B	Caffeine	0.05	Orange	1.0	Onion	0.1
	C	Caffeine	0.1	Orange	2.5	Onion	0.5
	D	Caffeine	0.3	Orange	5.0	Onion	1.0
	E	Caffeine	0.6	Orange	10.0	Onion	2.0

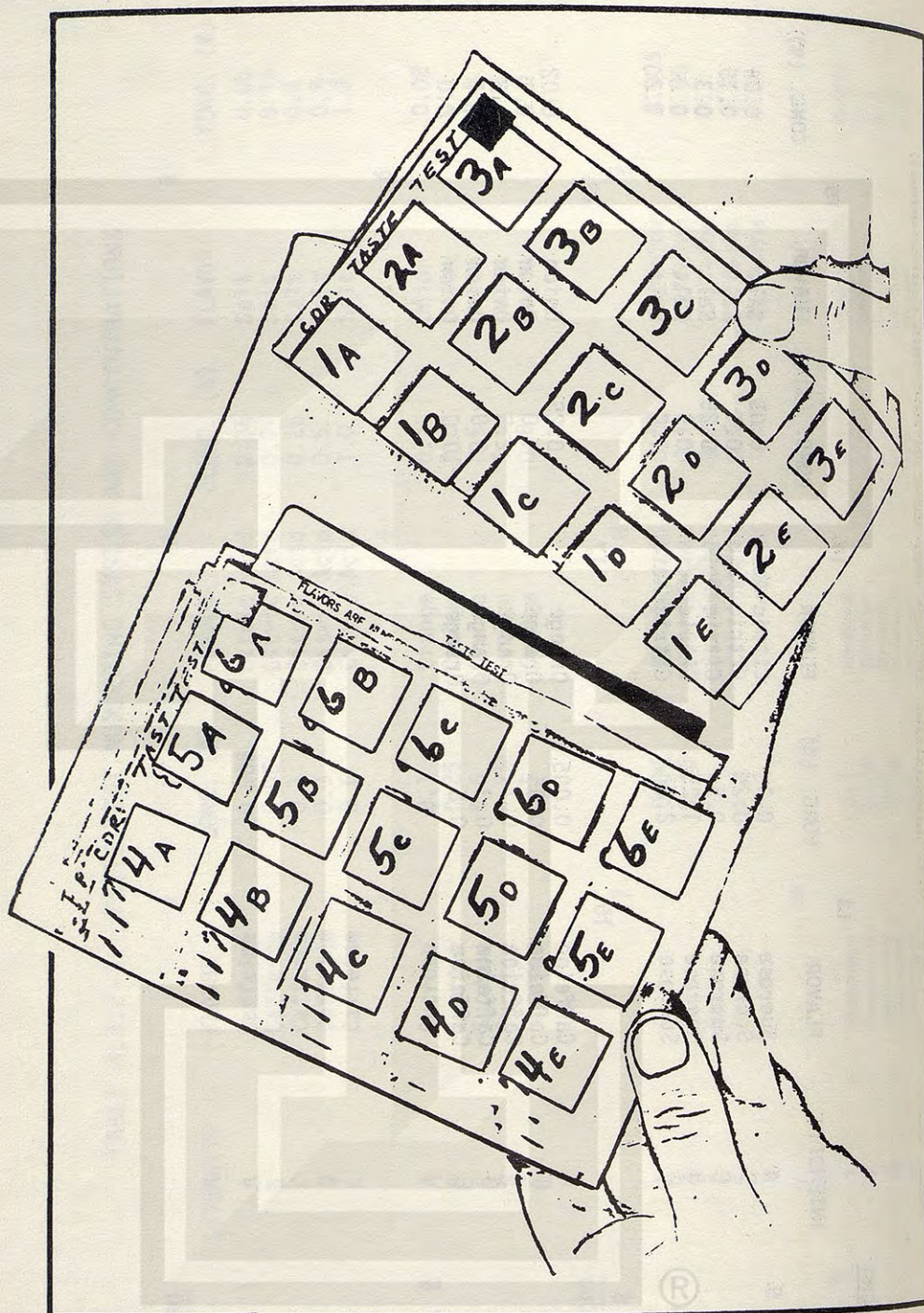


Figure 2.3.2-2.- Skylab Taste Test Flavors In-Flight Packages
(Identical to Preflight and Postflight Packages).

TABLE 2.3.2-II. SKYLAB IN-FLIGHT CUE CARD USED FOR TASTE TEST DIRECTION

Taste Test

Flavors are numbered. Intensities are lettered.

Flavors are sweet, sour, salt, bitter, orange, onion.

Procedures (Before noon meal)

1. Start with lowest number and taste in alphabetical order, starting with "A"
2. Place disk on tongue for about 10 seconds.
3. Spit out, rinse mouth, and try next sequential letter.

Report

1. Number, letter, and flavor when first detected.
2. Number, letter, and flavor when definitely confirmed.
3. Report during evening status report.

The aroma test strips were manufactured by microencapsulation of aromas and impregnating these on cards. The aromas used were: Lemon, Orange, Onion, Pepper, Chicken, Control (blank), Wintergreen, Chocolate, Clove, Spearmint, and Cinnamon. These test strips were packaged as shown in figure 2.3.2-3.

The aroma test procedure was to scratch the complete surface of the aroma bearing surface (white section) of the card and place the card against both nostrils. The crew was to inhale, and report the identified aroma. The concept of this test was to measure ability of crew to identify the various aromas.

Preflight tests were conducted at F-10 days, in-flight tests, near the midpoint, on day 42 of the flight, and the postflight tests were carried out on R+12 days. The preflight and postflight tests were near the midpoint of the controlled diet periods for each of these phases. Thus, the crew acted as their own controls.

Prior to initial testing, the crews were briefed as to the rationale and mechanics of the test. In addition, the crews were given taste paper and aroma cards for training. Each crewman practiced until he could readily identify each flavor and odor as determined by a series of preflight testings.

Results and Discussion

The results of the aroma tests are given in table 2.3.2-III. They gave no evidence that there was any change in the ability of any crewmember to identify aromas tested.

The results of the taste test are presented in table 2.3.2-IV. Results of the taste test were more varied than the aroma tests and were largely unexpected. These results indicate that a shift occurred in the threshold levels for detection of certain taste sensations and the shifts were highly individualized. This individualization of reaction has significant implications for future flight food systems. The most significant finding is that weightlessness had no measurable effect on the taste threshold.

The Commander had no change in his threshold to the four basic flavors (sweet, sour, salt, bitter). He significantly increased his ability to detect the aromatic flavor - orange, but remained unchanged in threshold for the aromatic flavor of onion. These data suggest that the Commander would experience no overall dramatic change in flavor response to foods when comparing in-flight to preflight responses.

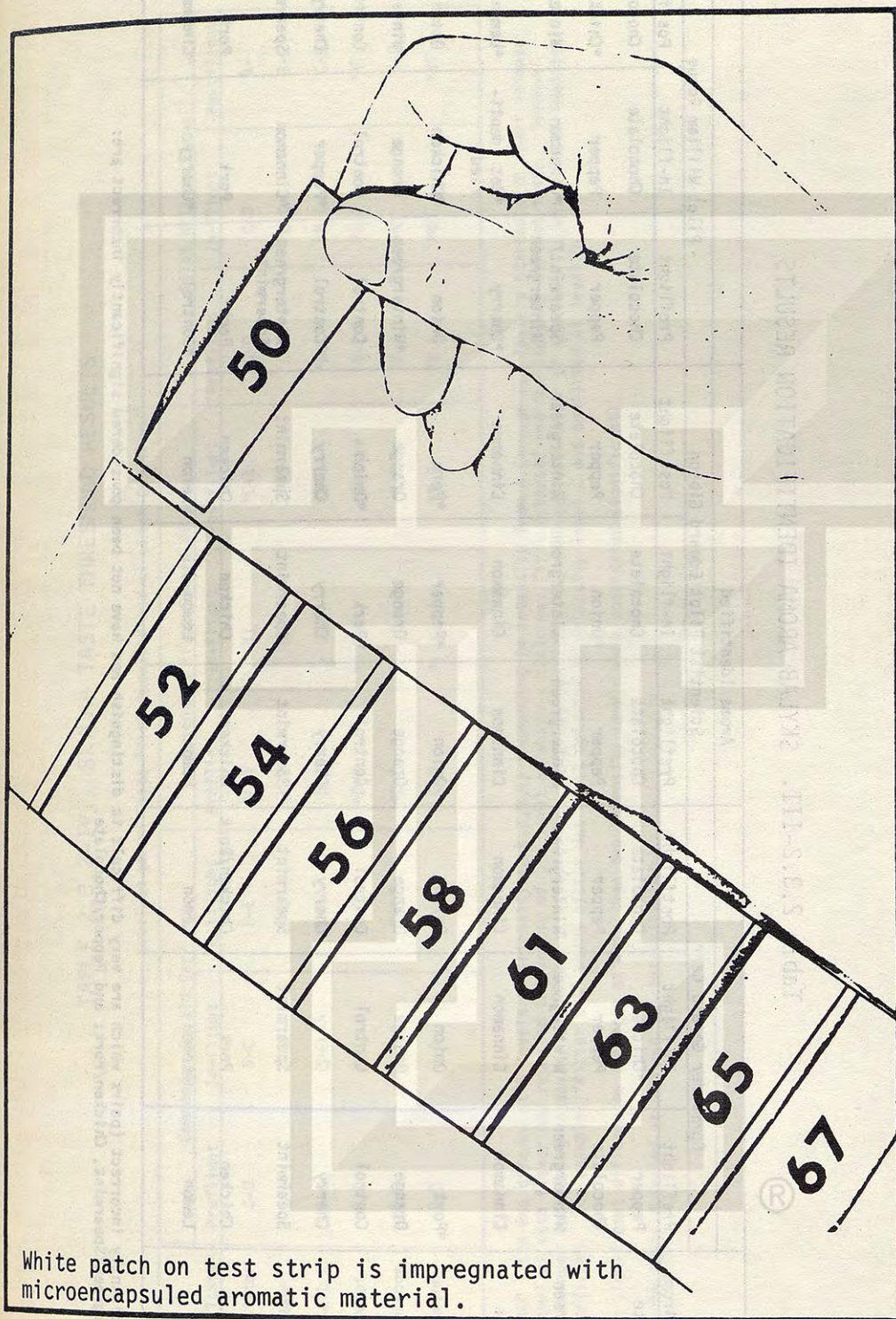


Figure 2.3.2-3. - Aroma Test Strips.

Table 2.3.2-III. SKYLAB AROMA IDENTIFICATION RESULTS

Actual Aroma	Commander Gerald Carr			Aroma Identified			Pilot William Pogue			
	Preflight	In-flight	Postflight	Preflight	In-flight	Postflight	Preflight	In-flight	Postflight	
Chocolate	Pepper	*Chicken	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate
Pepper	Chocolate	Pepper	Pepper	Pepper	*Onion	Pepper	Pepper	Pepper	*Chicken	*Chicken
Wintergreen	Wintergreen	Wintergreen	Wintergreen	Wintergreen	Wintergreen	Wintergreen	Spearmint/ Wintergreen	*Cinnamon	Wintergreen	Wintergreen
Cinnamon	Cinnamon	Cinnamon	Cinnamon	Cinnamon	Cinnamon	Cinnamon	*Cherry	*Not Identifed	*Lemon	*Lemon
Onion	*Pork	Onion	Onion	Onion	*Pepper	*Pork	Onion	*Chicken	Onion	Onion
Orange	Orange	Orange	Orange	Orange	Orange	Orange	*Wintergreen	Orange	*Wintergreen	*Wintergreen
Control	Control	Control	Control	Control	*Pork	*Onion	Control	Control	Control	Control
Cherry	Cherry	Cherry	Cherry	Cherry	Cherry	Cherry	*Control	*Pepper	Cherry	Cherry
Spearmint	Spearmint	Spearmint	Spearmint	Spearmint	Spearmint	Spearmint	Wintergreen/ Spearmint	*Cinnamon	Spearmint	Spearmint
Chicken	Chicken	Pork	Chicken/Pork	Chicken	Chicken	Chicken	Pork	Pork	Pork	Pork
Lemon	Lemon	Lemon	Lemon	Lemon	Lemon	Lemon	*Control	*Cherry	*Cinnamon	*Cinnamon

*Significantly incorrect (pairs which are very difficult to distinguish and have not been considered significantly incorrect are: Wintergreen/Spearmint; Chicken/Pork; and Pepper/Chocolate).

Chicken Lemon	Chicken Lemon	PORK Lemon	Chicken/PORK Lemon	Chicken Lemon	Chicken Lemon	Chicken Lemon	*Control	*Cherry	*Cinnamon
------------------	------------------	---------------	-----------------------	------------------	------------------	------------------	----------	---------	-----------

*Significantly incorrect (pairs which are very difficult to distinguish and have not been considered significantly incorrect are: Wintergreen/Spearmint, Chicken/Pork; and Pepper/Chocolate).

TABLE 2.3.2-IV. SKYLAB TASTE THRESHOLD RESULTS

Level at which Taste First Detected and at which Confirmed¹

Taste	Commander Gerald Carr			Scientist Pilot Edward Gibson			Pilot William Poque		
	Preflight	In-flight	Postflight	Preflight	In-flight	Postflight	Preflight	In-flight	Postflight
Bitter	C-D	B-C	D-E	*A-B	*NT	*C-E	C-D	C-D	B-
Sour	C-D	C-D	B-C	C-D	B-D	C-D	C-D	C-D	B-C
Salt	B-C	B-C	B-C	B-C	- D-E	D-E	*D-E	*B-C	C-D
Sweet	B-D	B-C	B-C	*D-E	*+ B-C	+Bitter	D-E	*D-E	*NT
Orange	+*D-E	*B-C	C-C	*C-D	*+ B	C-D	*B-C	*+NT	C-D
Onion	D-D	C-D	D-D	C-D	*- C	*D-E	*D-E	*NT	*NT

¹Each taste was offered at 5 levels of intensity (A,B,C,D,E) increasing in intensity from A through E. Tasters started with least intense level of each flavor and reported the letter of the level at which a taste was first detected and the identity of that taste. Tasters continued increasing intensity until the identity of the taste was confirmed; he reported the letter of the level at which taste identity confirmed. For example, "Bitter C-D" means bitter was first detected at intensity level C and confirmed at level D.

*+ = Significant differences (changes of more than two intensity levels were considered significant).

NT = No taste detected at highest (E) intensity level.

The Scientist Pilot showed a marked enhancement in ability to detect sweet flavor with a concomitant loss in ability to detect bitter. This was coupled with enhanced ability to detect orange flavor. His salt threshold shifted upwards. These results suggest that foods might generally taste sweeter to the Scientist Pilot in-flight compared to preflight test.

The Pilot exhibited an in-flight increased sensitivity to salt and a very diminished sensitivity to both aromatic flavors tested (orange and onion). The other flavors (bitter, sour, sweet) remained essentially unchanged. These tests suggest that food taste responses by the Pilot would tend to shift so that aromatic senses were diminished. The Pilot complained more about nasal "congestion" than the other crewmen, but the inability to detect onion at the highest intensity in the postflight test would suggest that such "congestion" was not zero-g related.

Prior to these tests, there was a wealth of conflicting opinions concerning the effects of weightlessness on flavor and aroma of foods. There is no evidence in any of these data that weightlessness, *per se*, is a significant factor influencing food flavor or aroma.

These findings are considered highly significant since they show that taste thresholds do change when individuals subsist on 6-day menu cycles for relatively lengthy periods independent of weightlessness. These findings support the conclusion that in-flight condiments should be provided so that an individual can season food to his taste preference. In addition, in longer term space flights, real-time menu selection is indicated in order to counteract shifts in individual taste responses.

Acknowledgements

The Principal Investigator would like to thank Drs. Clayton S. Huber, Herbert L. Meiselman, Richard L. Doty, and Robert H. Cagan for their scientific consultations.

2.4 Anthropometric Changes and Fluid Shifts on Skylab 4

W. E. Thornton, M.D., G. W. Hoffler, M.D., and J. A. Rummel, Ph.D.

Introduction

It was predicted that subjecting the human body to weightlessness would produce changes in its size, shape, and composition. Shifts of fluid, particularly blood, are everyday experiences on Earth and were expected to be more pronounced with total removal of gravitational forces. The loss or gain of tissue, either through changes in nutrition or from changed work or exercise, was another common and expected phenomenon. Changes in posture from removal of large gravity loads from body segments were also predicted.

Many of these changes had been described by astronauts and some measurements were made. In the later Apollo flights Drs. G. W. Hoffler and R. L. Johnson performed leg girth measurements every three centimeters over the length of the limb, allowing calculation of volumes. On Skylab the direct leg measurements (sec. 2.17) were continued, and body mass measurements (sec. 3.3) were made preflight, in-flight, and postflight. Very indirect inferences were possible from the balance studies described in sections 3.1, 3.2, and 3.4. Radioisotope measurements of some body spaces were scheduled preflight and postflight as were stereophotogrammetric studies (sec. 2.8). Although stereophotogrammetry is theoretically capable of being used for comprehensive and detailed mensuration, it was only done preflight and postflight. The sum of these studies was neither sufficiently comprehensive nor integrated to allow adequate documentation of changes.

In an attempt to obtain a coherent picture of anthropometric changes under weightlessness, the most comprehensive series of measurements possible under the operational and other restraints of Skylab was initiated on Skylab 1/2 (1). The initial anthropometric studies were done in conjunction with functional muscle testing preflight and postflight and included use of the direct leg measurements already described and of arm measurements done in the same way, of trunk girths, and of height. A single set of facial photographs was obtained on SL 1/2 to document the puffy facies and engorged veins. It was intended that all other relevant information that was available be integrated with these measurements such that the most complete picture possible be derived.

On SL-3 the same measurements were made with additional in-flight facial photographs and near the end of the mission a series of limb and trunk girths were made in-flight by the crew.

By the end of SL-3 there was much indirect evidence for rapid and large fluid shifts from the normally dependent portions of the body when leaving or entering Earth's gravity. For this reason a maximum effort was made to document these changes in-flight and in a timely fashion on SL-4. A series of measurements were added including taking limb volume measurements as early as possible in-flight as well as preflight and postflight. To further document fluid shifts, a series of preflight, in-flights, and postflight center of mass and IR augmented photographs of the crew in space were added. The latter photographs enhanced visualization of superficial venous patterns.

In addition to allowing studies of fluid shifts, these measurements also allowed more complete documentation of anthropometric changes. A second series of in-flight photographs were made with the crewmen completely relaxed in a "free float" to document anatomical changes.

Although a good deal of data was lost from technical and other problems the yield was significant. It should be pointed out that the crew did a superb job with the anthropometric measurements, a task for which they had not been trained and which cost them heavily in terms of schedule.

For the first time many postural and anatomical changes have been documented. The most important changes documented was the surprising large shift of fluid from the legs¹ during the early exposure to weightlessness. A description of the measurements and some preliminary results and interpretation follow. These will be described under two overlapping headings: Anthropometric, which includes postural changes and Fluid Shifts.

2.4.1 Anthropometric Changes

Methodology

Anthropometric measurements, as shown in figure 2.4.1-1, were made with calibrated non-stretch fabric tapes. Preflight and postflight, the limb girths were made with a jig to insure uniformity. It consisted of a longitudinal tape which was attached to the leg or arm with Velcro straps at anatomical landmarks. Sewn to this tape every three centimeters were circumferential tapes to allow rapid girth measurements at precise locations. In-flight the longitudinal tape was attached in the same fashion, but it was only marked every three centimeters such that a single tape was used to make the girth measurements. In one-g, leg measurements were made with the subjects supine and legs extended. Arm measurements were made with the subject seated and arms outstretched, and trunk height measurements taken with the subject upright. In-flight the same positions were used as relevant.

¹The preflight and postflight leg volume measurements were a part of the experiment M092 protocol and the results were shared for this study. The measurements were extended to include arm measurements in-flight for purposes of this study.

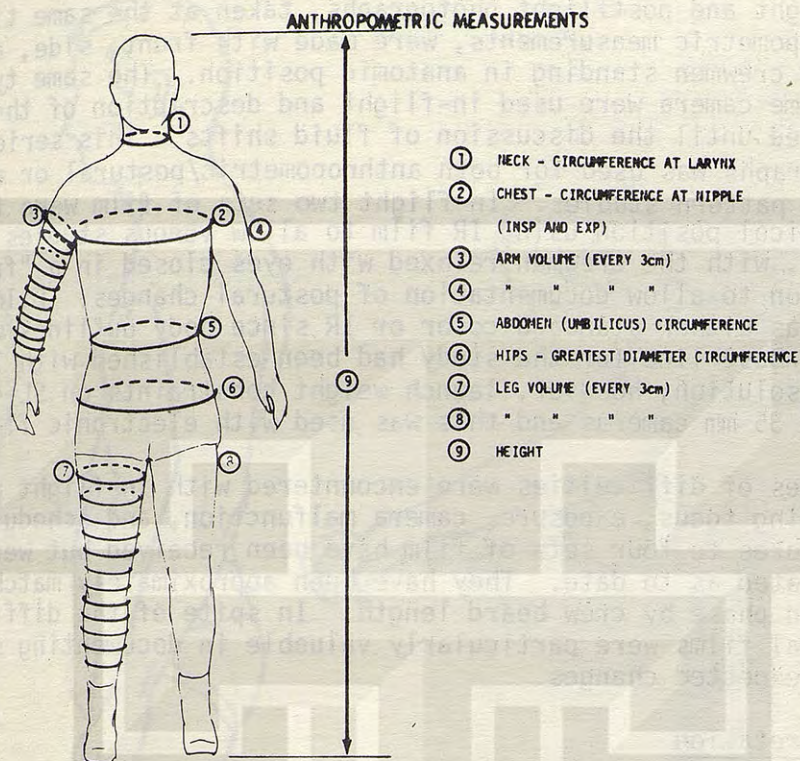


Figure 2.4.1-1. - Measurements taken preflight and post-flight on SL 1/2 and SL-3, and preflight, in-flight and postflight on SL-4.

Front, side and rear photographs were taken of the subject standing preflight and postflight and completely relaxed and "free floating" in-flight.

Results

With bold changes, MD 3 was the earliest that the direct anthropometric measurements could be scheduled. Even then this time-consuming procedure had such an impact that only two of three crewmen could complete it. Repeated measurements were made on mission days 5, 8, 31, and 60 and a partial measurement was made on two crewmen on MD 80. Measurements were made preflight and postflight on days F-30, -15 and -5 and on R+1, +2, +5 and +17. The accuracy and repeatability of these measurements performed by the crew in flight were impressive by any standards, but especially so when done under the circumstances.

Preflight and postflight photographs, taken at the same time as the anthropometric measurements, were made with front, side, and back views of the crewmen standing in anatomic position. The same type film and the same camera were used in-flight and description of these will be deferred until the discussion of fluid shifts. This series of in-flight photographs was used for both anthropometric/postural or anthropometric/venous pattern studies. In-flight two sets of film were taken, one, anatomical position using IR film to allow venous studies and, the second, with the crewman relaxed with eyes closed in a "free floating" position to allow documentation of postural changes. Film in the latter case was either standard color or IR since body outlines were the concern. Base line for the study had been established with 70 mm cameras for resolution; however, launch weight constraints on SL-4 dictated the use of 35 mm cameras and this was used with electronic flash.

A series of difficulties were encountered with in-flight photography including focus, exposure, camera malfunction, and scheduling problems. Some three to four sets of film have been received but were not correlated as to date. They have been approximately matched as to mission phase by crew beard length. In spite of the difficulties, the postural films were particularly valuable in documenting some large and unexpected changes.

Interpretation

Shown in figures 2.4.1-2 profile views a, b and c, and 2.4.1-3 front views of the SPT preflight, in-flight and postflight are changes which were typical of all the crewmen. Figure 2.4.1-4 graphically depicts these changes in truncal and height measurements with mission duration. Although there are the expected individual variations, there are common changes in size and shape when gravitational loads are removed. Large and probably most immediate of the changes was the marked reduction in abdominal girth. This is consistent with the elastic support of fluid-like viscera by abdominal musculature under one-g. When weight is removed, these elastic forces are unopposed and force the viscera in and presumably "upward". This same mechanism was encountered in fluid shifts from the legs. Also noted were reductions in chest girth in inspiration and expiration, a change interrelated with heights, and postural changes. Figures 2.4.1-2 views a, b, and c and 2.4.1-3 views a and b are tracings from photos of the SPT of SL-4 standing preflight, postflight, and "free floating" and relaxed in-flight. Scale is approximately the same. When comparison of the shape of the spinal column, as outlined by the back, is made between views a and b to c, the most striking difference is the absence of normal thoracolumbar (lordotic) curvature while thoraco/cervical curvature remains. This has several effects. In all cases, height is increased in weightlessness and apparently continues to increase for some time. Two mechanisms

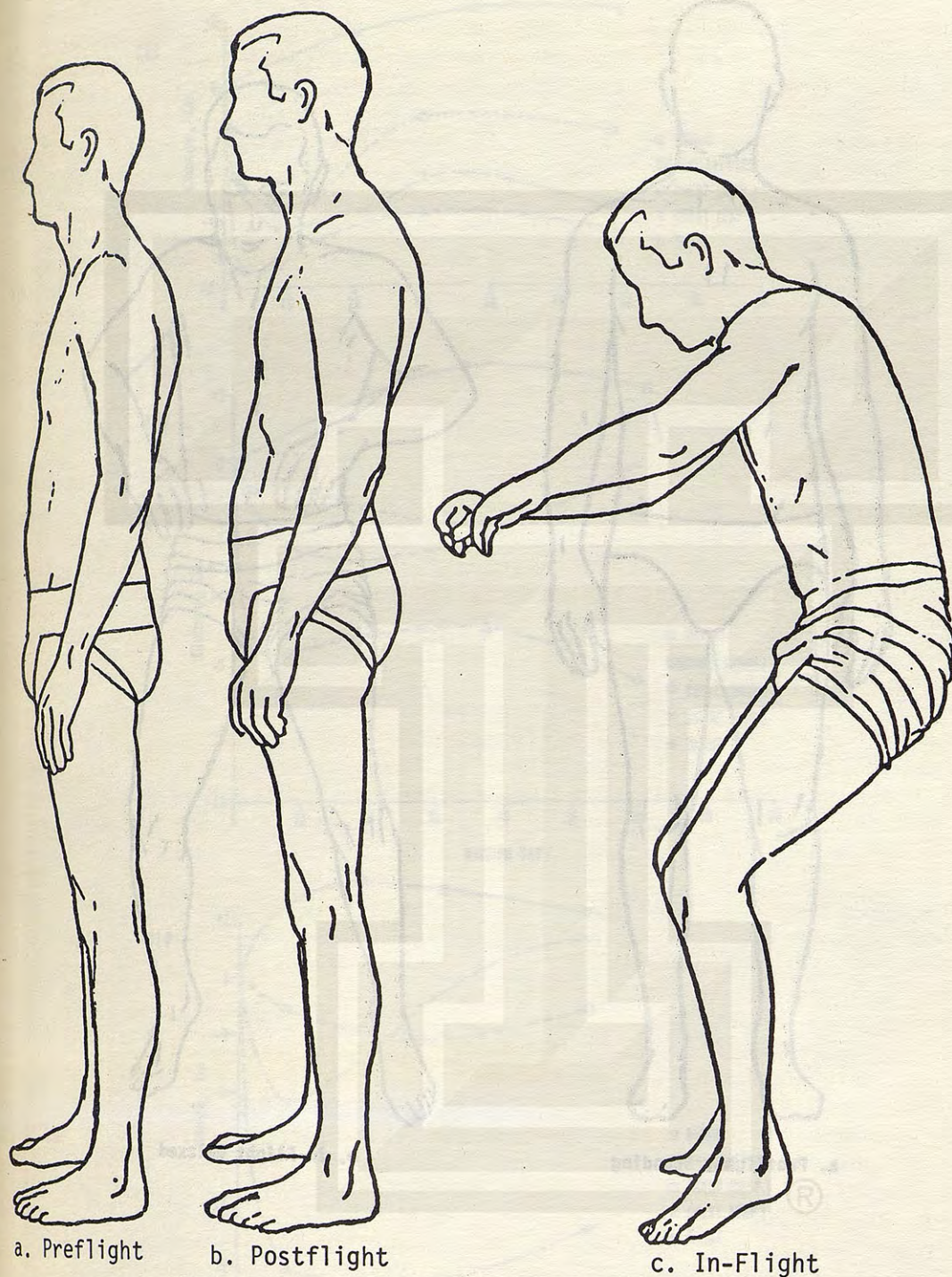
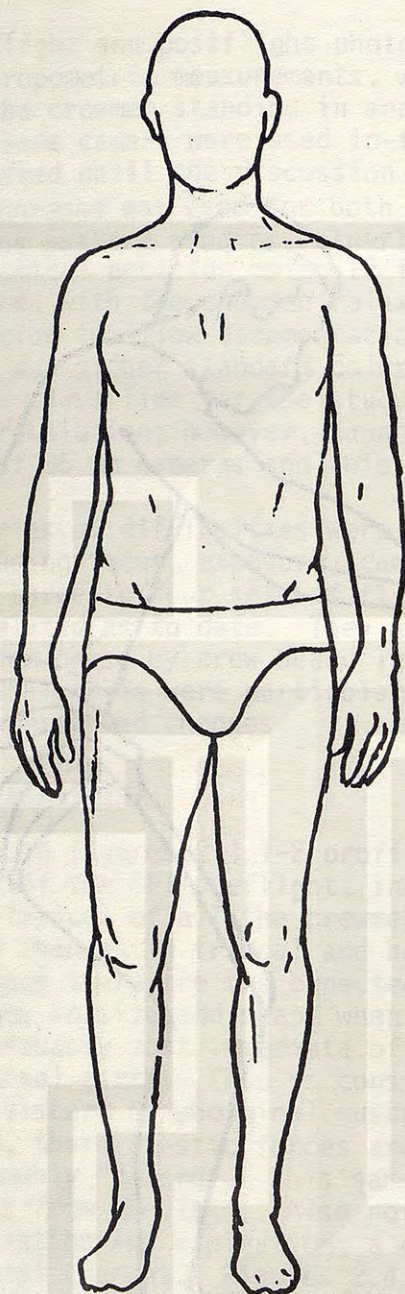
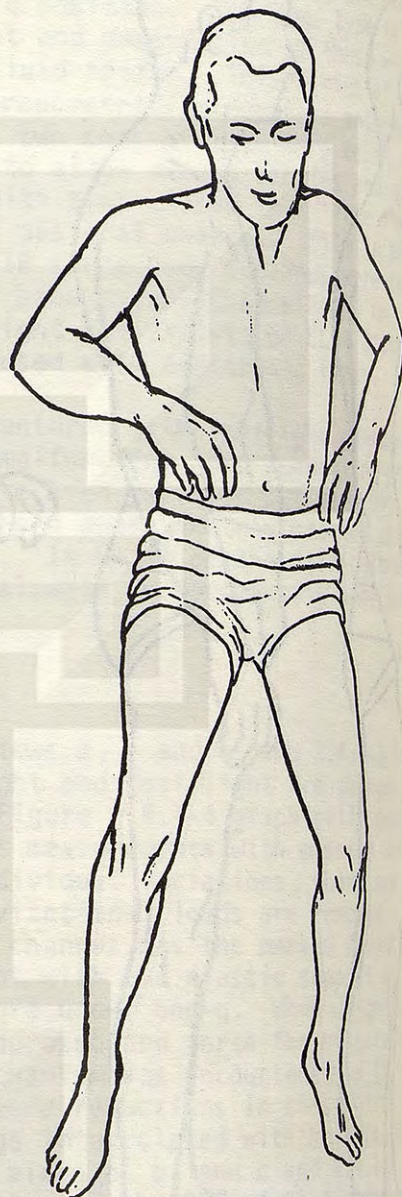


Figure 2.4.1-2. - Truncal and Height Measurement Changes With Mission Duration, SPT (SL-4).



a. Preflight, Standing



b. In-Flight Relaxed

Figure 2.4.1-3. - Postural Changes, SPT (SL-4).



relaxed

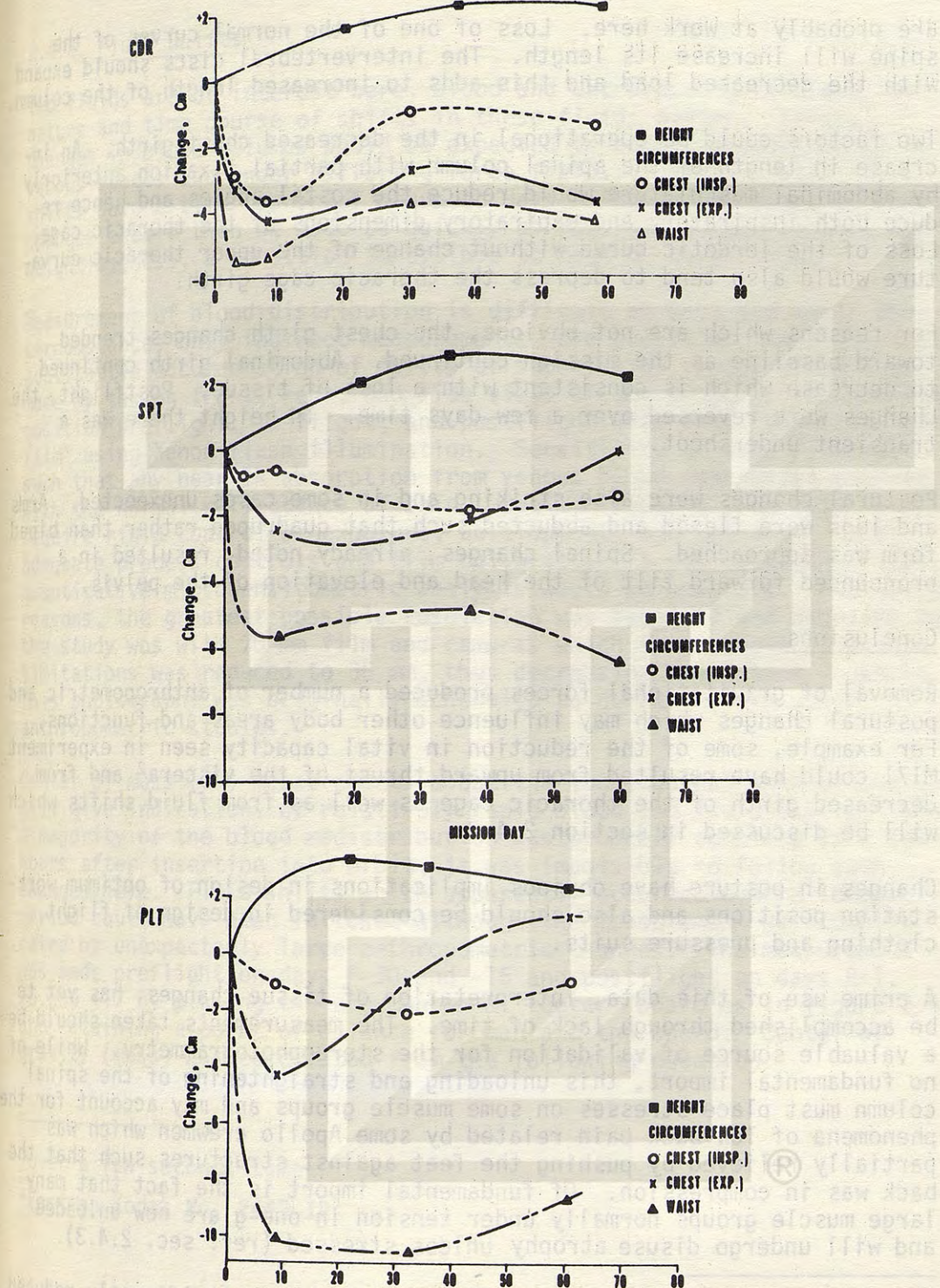


Figure 2.4.1-4. - Anthropometric Changes SL-4.

are probably at work here. Loss of one of the normal curves of the spine will increase its length. The intervertebral discs should expand with the decreased load and this adds to increased length of the column.

Two factors could be operational in the decreased chest girth. An increase in length of the spinal column with partial fixation anteriorly by abdominal musculature would reduce the costal angles and hence reduce both inspiratory and expiratory dimensions of the thoracic cage. Loss of the lordotic curve without change of the upper thoracic curvature would also tend to depress the thoracic cage girth.

For reasons which are not obvious, the chest girth changes trended toward baseline as the mission continued. Abdominal girth continued to decrease which is consistent with a loss of tissue. Postflight, changes were reversed over a few days time. In height there was a transient undershoot.

Postural changes were also striking and in some cases unexpected. Arms and legs were flexed and abducted such that quadruped rather than biped form was approached. Spinal changes, already noted, resulted in a pronounced forward tilt of the head and elevation of the pelvis.

Conclusions

Removal of gravitational forces produced a number of anthropometric and postural changes which may influence other body areas and functions. For example, some of the reduction in vital capacity seen in experiment M171 could have resulted from upward thrust of the viscera² and from decreased girth of the thoracic cage as well as from fluid shifts which will be discussed in section 2.4.2.

Changes in posture have obvious implications in design of optimum workstation positions and also should be considered in design of flight clothing and pressure suits.

A prime use of this data, interpretation of tissue changes, has yet to be accomplished through lack of time. The measurements taken should be a valuable source of validation for the stereophotogrammetry. While of no fundamental import, this unloading and straightening of the spinal column must place stresses on some muscle groups and may account for the phenomena of low back pain related by some Apollo crewmen which was partially relieved by pushing the feet against structures such that the back was in compression. Of fundamental import is the fact that many large muscle groups normally under tension in one-g are now unloaded and will undergo disuse atrophy unless stressed (ref. sec. 2.4.3).

²It is an accepted fact that vital capacities are significantly reduced by changing the subject from seated to lying position under one-g.

2.4.2 Fluid Shifts

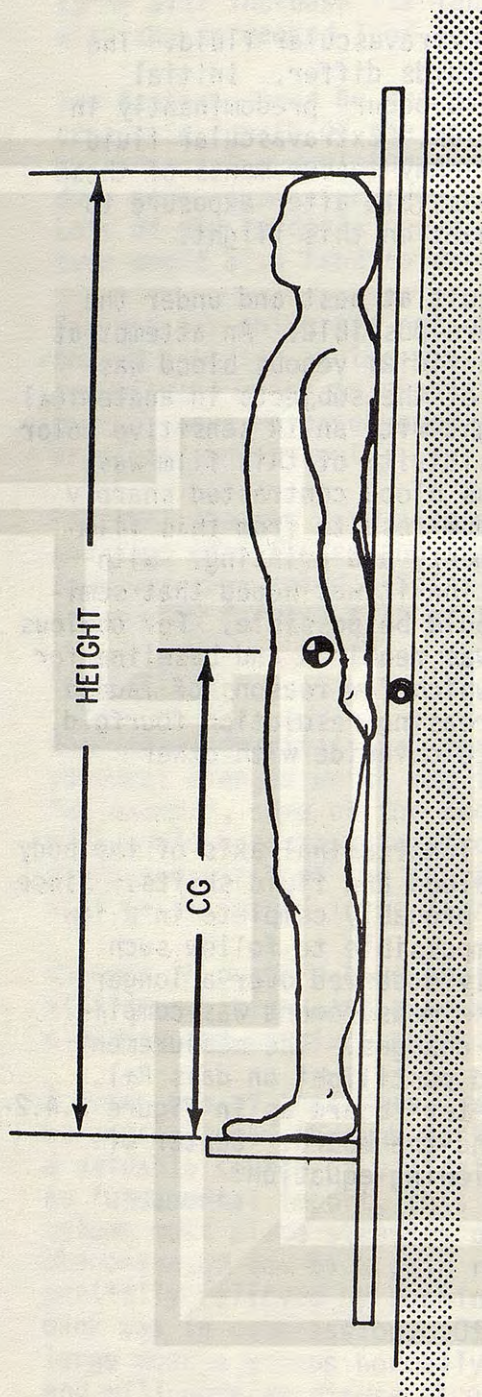
Two fluids are of interest here, blood and extravascular fluid. The nature and time course of shifts in these fluids differ. Initial changes in blood volumes would be expected to occur³ predominantly in venous spaces and under differing force fields. Extravascular fluid shifts have a time course of hours to days. Any measurements of these changes should then be made as quickly as possible after exposure to weightlessness, a condition impossible to meet on this flight.

Measurement of blood distribution is difficult at best and under the circumstances only indirect measurements were possible. An attempt at qualitative documentation of shifts of superficial venous blood was made by taking front, rear, and side views of the subjects in anatomical position preflight, in-flight, and postflight with an IR sensitive color film⁴ using Xenon flash illumination. Sensitivity of this film was such that any near IR absorption from venous blood contrasted sharply with the normal reflectance of skin. Optimum results from this film require rigid control of exposure, development, and printing. With adequate process controls and film calibration it was hoped that semi-quantitative microdensitometric analysis would be possible. For obvious reasons, the greatest possible resolution was required and baseline for the study was with 70 mm film and cameras which for reasons of launch limitations was reduced to 35 mm, thus decreasing resolution fourfold. This photography was originally scheduled to coincide with other anthropometric studies.

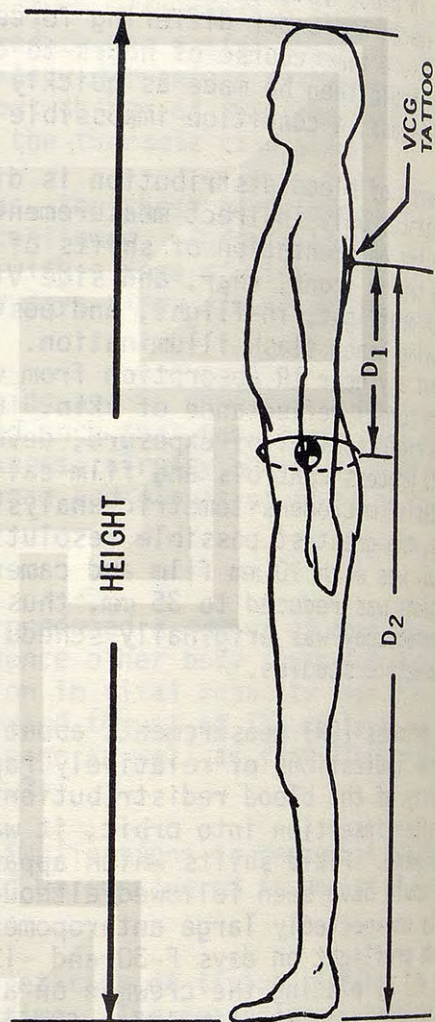
Center of mass (CM) measurements about the longitudinal axis of the body will give indications of relatively rapid blood and fluid shifts. Since a majority of the blood redistribution was probably complete in a few hours after insertion into orbit, it was impossible to follow such changes here. Fluid shifts which apparently occurred over a longer period could have been followed although the measurement was complicated by unexpectedly large anthropometric changes. The measurement was made preflight on days F-30 and -15 and postflight on days R+1, +5 and +17 by placing the crewman on a "teeter" board as in figure 2.4.2-1 and obtaining a point of balance for man and the board. Center of gravity (mass) was calculated from the following equation:

³over a few seconds time

⁴Eastman Kodak No. 2443 IR



1-g CENTER OF GRAVITY MEASUREMENT



200-g CENTER OF MASS MEASUREMENT

$$\frac{(W_m + W_b) CG_{mb} - W_b CG_b}{W_m} = CG_m$$

- W_m = Weight of man
 W_b = Weight of board
 CG_{mb} = Center of gravity of man and board*
 CG_b = Center of gravity of board
 CG_m = Center of gravity of man

*Measurements referred to soles of feet of subject.

Heights were also taken during this measurement.

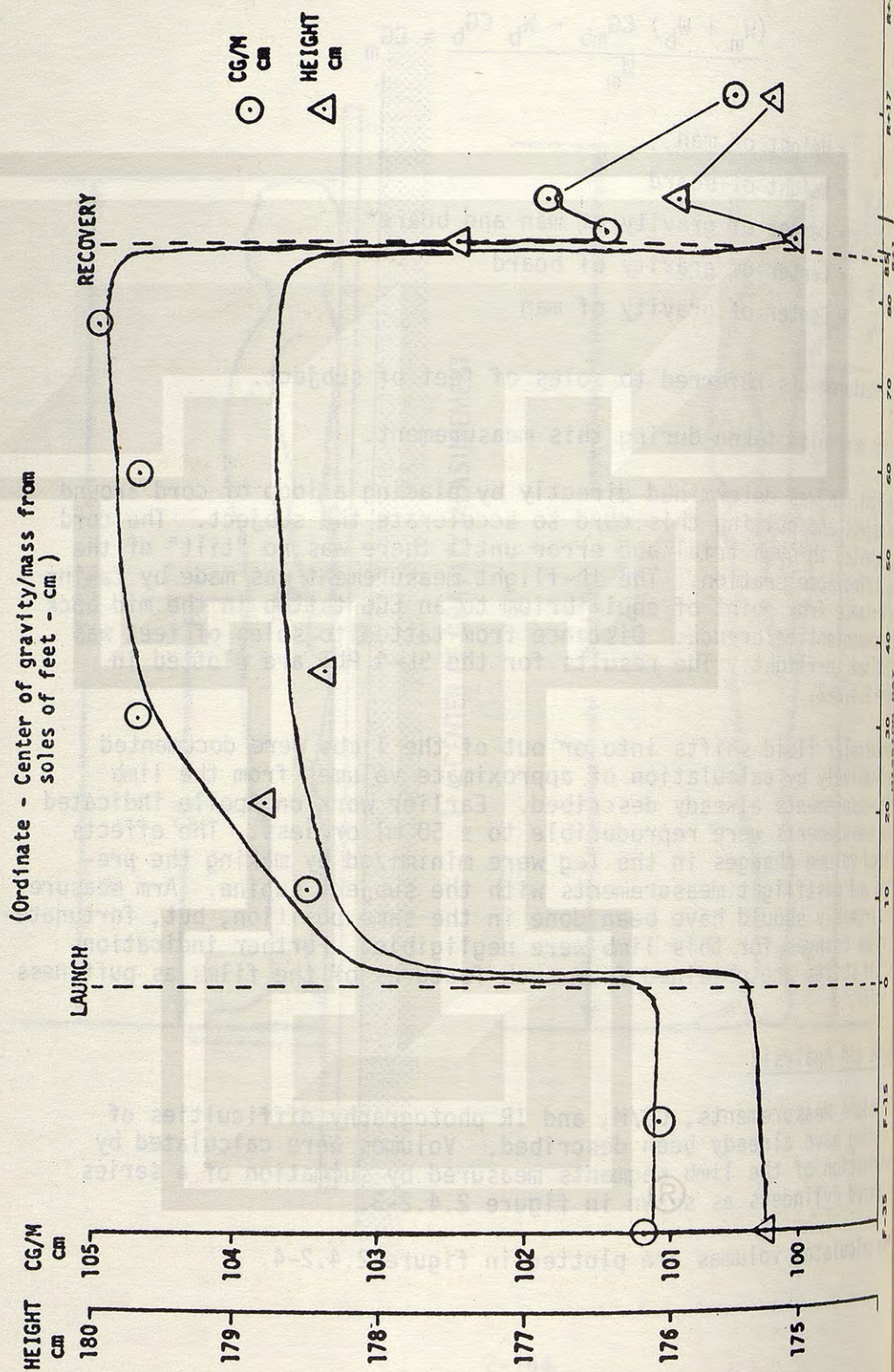
In-flight, CM was determined directly by placing a loop of cord around the subject and pulling this cord to accelerate the subject. The cord was adjusted through trial and error until there was no "tilt" of the body during acceleration. The in-flight measurement was made by taking the distance from point of equilibrium to an ECG tattoo in the mid back as a convenient reference. Distance from tattoo to soles of feet was determined in-flight. The results for the SL-4 PLT are plotted in figure 2.4.2-2.

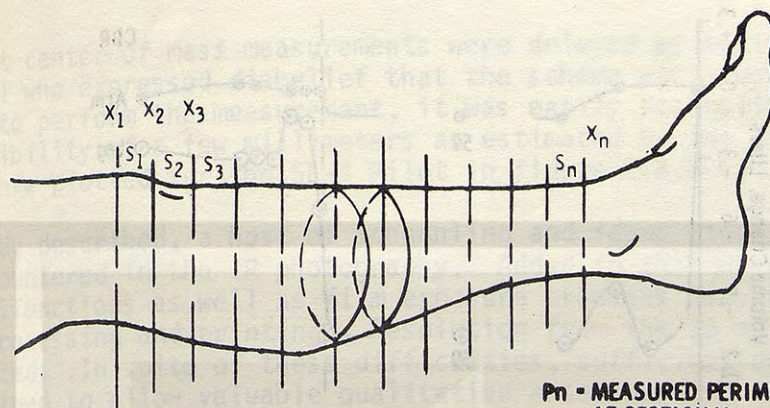
Extravascular fluid shifts into or out of the limbs were documented quantitatively by calculation of approximate volumes from the limb girth measurements already described. Earlier work on Apollo indicated these measurements were reproducible to ± 50 ml or less. The effects of blood volume changes in the leg were minimized by making the pre-flight and postflight measurements with the subject supine. Arm measurements probably should have been done in the same position, but, fortunately volume changes for this limb were negligible. Further indications of fluid shifts are obtained from such features of the films as puffiness or facies.

Results and Analysis

Limb Volume Measurements, CG/M, and IR photography difficulties of scheduling have already been described. Volumes were calculated by approximation of the limb segments measured by summation of a series of tapered cylinders as shown in figure 2.4.2-3.

These calculated volumes are plotted in figure 2.4.2-4.





P_n - MEASURED PERIMETER
AT SECTION X_n

X - CROSS-SECTION LOCATION

v - SEGMENT VOLUME

V - TOTAL VOLUME

CROSS SECTIONS ARE ASSUMED
CIRCULAR IN SHAPE

$$v = \left(\frac{P_1^2 + P_2^2}{8\pi} \right) (X_n - X_{n-1})$$

SEGMENT	P_1	P_2	$X_n - X_{n-1}$	v
S_1				
S_2				
S_3				
"				
"				
"				
"				
"				
S_n				

$$V = \sum v$$

Figure 2.4.2-3. - Calculations of Limb Volumes by Approximation of the Limb Segments Measured by Summation of a Series of Segment Volumes.

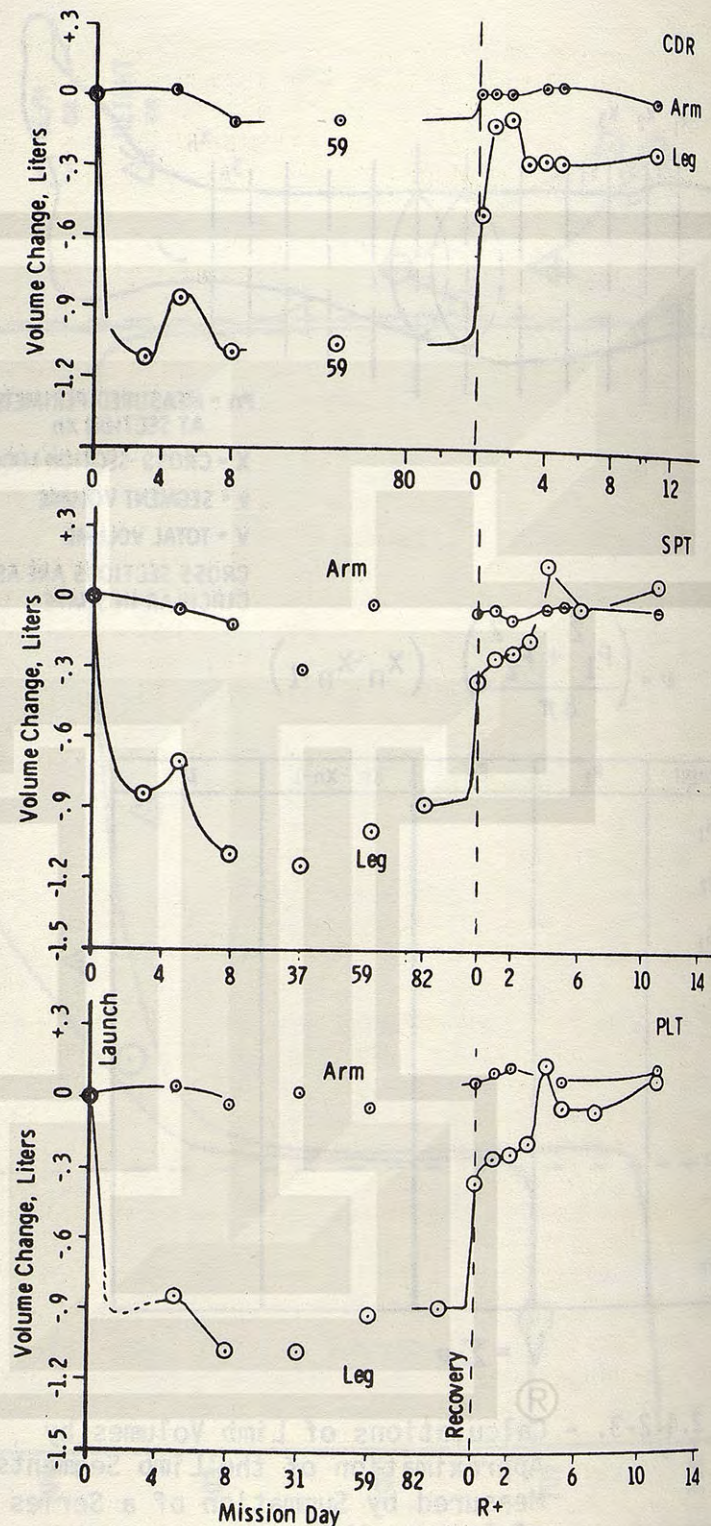


Figure 2.4.2-4. - Change in Left Limb Volumes, SL-4.

CDR
Arm
Leg
In-flight center of mass measurements were delayed by medical scheduling personnel who expressed disbelief that the scheme would work. When allowed to perform the measurement, it was easily accomplished with a reproducibility of a few millimeters as estimated by the crewmen. The results are plotted for the SL-4 Pilot in figure 2.4.2-4.

As already described, a host of scheduling and identification problems were encountered in the IR photography. Added to this were camera and other malfunctions as well as film exposure problems and lack of quantitative processing and printing. Resolution from the 35 mm film was poor as expected. In spite of these difficulties, sufficient usable film was obtained to allow valuable qualitative assessment.

12
SPT
In addition to the measurements described, the crew's observations provide another valuable source of information. They frequently develop keen insight into the problems. For example, long before Skylab, we have had repeated descriptions of puffy facies, stuffy nose, "full" heads, engorged head veins, and transient conjunctival injection. Skylab crew observations also included a transient ruddiness of the skin for the first week or so, "bird legs" of space, and improvement of nasal stuffiness and head fullness following exercise and lower body negative pressure. In addition, SL-4 crew comments regarding vestibular problems while in-flight were both pertinent to and consistent with the findings from these studies.

Interpretation and Conclusions

14
PLT
Probably most striking and significant of the findings was the documentation, for the first time, of the time course and magnitude of the fluid shifts. These are shown in figure 2.4.2-4. It would have been most desirable to have had earlier and more frequent measurements, but we are indeed fortunate to get these. It is reasonable to infer that these changes in volume are primarily extravascular fluid since the preflight measurements were made with the crew supine, a maneuver which should remove the majority of venous blood from the legs. It is thought that this shift in fluid is well under way in a matter of hours and was probably completed before the three days which elapsed prior to the first in-flight measurement. Such a time course would be consistent with the crew's observations on time of onset of head fullness and nasal stuffiness which also occurred within hours and with the rapid shifts seen on recovery. It would also be consistent with the rapid, apparently inverse change seen on return to one-g when the majority of the change had occurred by the time of the initial measurement on day R+0, a matter of hours. In the SPT and PLT one might argue that these were a continuing upward drift, but I had rather attribute this to tissue anabolism. Note that the arms take no appreciable part in these transient changes. The loss in arm volume of the SPT at mid-mission

14
mes, SL-4.

is most likely tissue loss for he had an appreciable rate of mass loss during the first part of the mission which was reversed before the measurement at MD 59.

The explanation of the small increase in volume from the legs of the two crewmen measured at MD 5 is not obvious, but no source of error can be found to account for it. It is conceivably related to start of in-flight exercise between the times of measurement on MD 3 and MD 5 but may also be a distribution transient.

Two questions are immediately raised by such volume changes:

- ° What is the driving force?
- ° Where does the fluid go?

These questions cannot be discussed without reference to the vascular system and especially the veins. Figure 2.4.2-5 is an attempt to portray the pressure volume relationships of the venous circulation with and without gravity. In quiet standing, the venous system of the legs rapidly develops a hydrostatic pressure that is directly proportional to the level of the vein with respect to a level just above the right atrium. Veins of the legs have several unique features to deal with these pressures. All of them have numerous heart directed one-way valves which makes muscle pumping possible. Deep veins are surrounded by muscles with intrinsic tension which in turn are frequently surrounded by inexpandible fascial sheaths. The superficial veins of the legs, and for that matter, of the arms are invested with musculature which is more or less proportional to the level of hydrostatic force in standing posture. All of these mechanisms insure a return of blood. The capillaries are subsequently subjected to similar hydrostatic forces which, if unopposed, would result in massive extravasation of vascular fluid and edema. It is postulated that large intrinsic tissue elasticities are present to oppose such hydrostatic pressures and these pressures which are completely unopposed⁵ in weightlessness cause shift of fluid into the circulation. These tissue forces plus those forces of the veins already described are thought to be more effective in removing blood from the veins, and indeed the photographs show a virtual absence of filling of any leg or foot veins under weightlessness in marked contrast to the preflight and postflight pictures.

Where does the blood and fluid go? Although we do not have quantitative evidence such as that from the legs, we have the crew's descriptions, photographs of facial puffiness, and photographic documentation of full head and neck veins which remained full throughout duration of the mission.

⁵Except for a few mm Hg pressure from the right atrium and hydrodynamic effects.

FLUID SHIFT

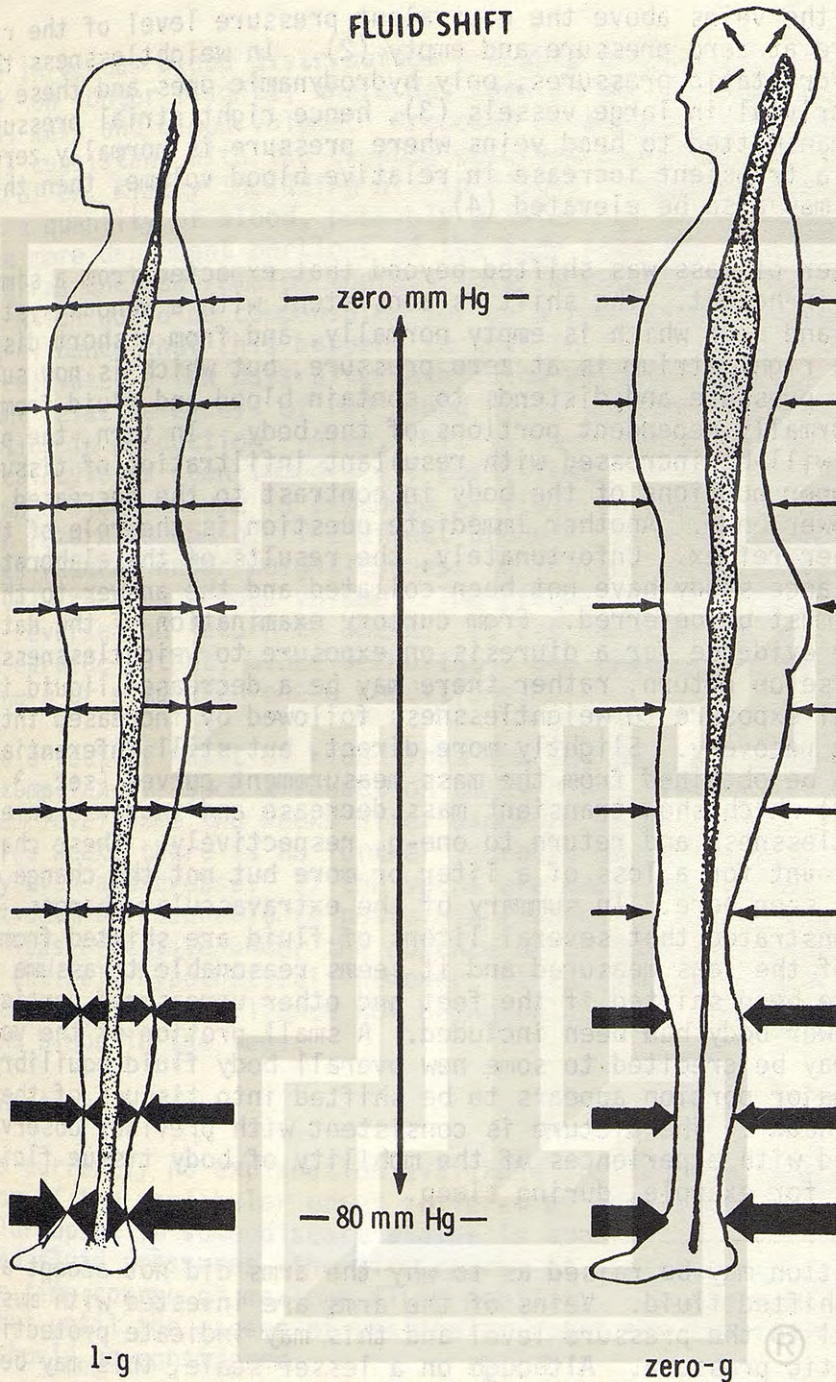


Figure 2.4.2-5. - Schematic of Proposed Fluid Pressure/Volume Changes Under Weightlessness. [The hydrostatic pressures under 1-g (internal arrows) are opposed by tissue pressures (external arrows) which shift venous blood and tissue fluid cephalad.]

Normally the veins above the equivalent pressure level of the right atrium are at zero pressure and empty (2). In weightlessness there are no hydrostatic pressures, only hydrodynamic ones and these are usually trivial in large vessels (3), hence right atrial pressure will not be transmitted to head veins where pressure is normally zero. If there is a transient increase in relative blood volume, then this pressure may also be elevated (4).

Also center of mass was shifted beyond that expected from a simple increase in height. The shift is consistent with a venous system of the head and neck which is empty normally, and from a short distance above the right atrium is at zero pressure, but which is now subjected to atrial pressure and distends to contain blood and fluid from the lower, normally dependent portions of the body. In turn, the pressure gradient will be increased with resultant infiltration of tissue fluids to the upper portions of the body in contrast to the decreased fluids in the lower body. Another immediate question is the role of the Henry Gauer reflex. Unfortunately, the results of the elaborate cardiovascular fluid balance study have not been collated and the answer to this question must be deferred. From cursory examination of the data, there is little evidence for a diuresis on exposure to weightlessness or the inverse on return, rather there may be a decreased liquid intake on initial exposure to weightlessness followed by increased intake following recovery. Slightly more direct, but still inferential, evidence can be obtained from the mass measurement curves (sec. 3.3 experiment M172) which show transient mass decrease and increase on exposure to weightlessness and return to one-g, respectively. These changes would account for a loss of a liter or more but not the change of several liters as seen here. In summary of the extravascular changes, it has been demonstrated that several liters of fluid are shifted from the portion of the legs measured and it seems reasonable to assume that it would have been shifted if the feet and other unmeasured portions of the lower body had been included. A small portion of the volume shifted may be credited to some new overall body fluid equilibrium while a major portion appears to be shifted into tissues of the upper body and head⁶. The picture is consistent with previous observations and indeed with experiences of the mobility of body tissue fluids on Earth, as for example, during sleep.

⁶The question may be raised as to why the arms did not accept a portion of the shifted fluid. Veins of the arms are invested with muscle proportional to the pressure level and this may indicate protection against hydrostatic pressure. Although on a lesser scale, this may be similar to anatomical conditions described for the legs.

Change
vious
red ce
which
studie
is tha
from t
venous
volem
is goo
sharpl
result
a redu
of ret
occurs
space
which
effect
rapidl
maximu
under

A seco
venous
a maxi
some t
possib
does n
become
late i
observ
fluid

Recomm

There
mechan
vestibu
increas
with th
dence,
factor

Many q
of data

⁷This c
moved

Changes in venous blood distribution probably affect many areas. Previously, on longer flights, there has been an unexplained reduction in red cell mass and blood volume. Proposed as a possible explanation, which is consistent with the changes observed and with the hematologic studies of Dr. Kimzey including his in-flight hemoglobin measurements, is that a quantity of blood, possibly a liter⁷ or more, is shifted from the more dependent portions of the body into the central upper venous areas and now remains there. This amounts to a relative hypervolemia which would be compensated for by a reduction in plasma. There is good evidence that this happens in that in-flight hemoglobin was sharply elevated a few days after achieving weightlessness. The resultant relative excess of red blood cells appeared to be reduced by a reduction in production. Also, this is consistent with the absence of reticulocytosis seen immediately postflight. A resulting anemia occurs when blood volume is expanded by fluid to fill the dependent space on return to one-g. The effect produced is of a blood volume which was reduced under weightlessness to fit the requirements for an effectively reduced venous volume. The process is self-limiting and rapidly reversed on return to one-g. It can be expected to reduce maximum cardiac output, hence orthostatic and ergometric tolerance under one-g or simulated one-g conditions.

A second effect of shift of blood from the leg may be a reduction of venous compliance. Such a reduction takes place (sec. 2.17) and reaches a maximum level some two weeks after exposure to weightlessness. After some three weeks there is no further increase of venous compliance and possibly even a decrease. If the veins are empty and remain so, it does not seem unreasonable to postulate changes in reflex activity that becomes less effective under the absence of stimulation. This postulate is entirely hypothetical; however, it is hard to imagine the observed changes in compliance not being related to the reduction in fluid and blood in the legs.

Recommendations

There is currently no explanation available for the fundamental mechanism of the vestibular upset suffered by some crewmen. While vestibular upset in some disease states is apparently accompanied by increased fluid pressures, the time course of the problem is compatible with the time course of maximum fluid mobility. This may be coincidence, but until the causes of vestibular upset are explained this factor should be considered.

Many questions are raised by these findings; however, interpretation of data from many areas should be done keeping these changes in mind.

⁷This quantity would not seem unreasonable since 700 ml of blood is removed from the legs of a man in standard upright position by lying down.

The effects of fluid changes in any study simulating weightlessness by bed rest or other means, should be considered and documented. To my knowledge, no such study had been done.

At every opportunity the exact time course and more exact magnitude of these changes in actual space flight should be measured.

Introd

Muscle
docume
antly,
to the

On SL
effort
very l
strate

On SL-3
were m
the cre
exercis
not pro
the leg
excelle
functio
losses
further
gias, a

A simpl
jogging
on SL-4
mell ca
Februar
in conj
by the
follow.
decondi

2.4.3 Measurement and Prevention of Muscular Deconditioning

W. Thornton, M.D. and J. Rummel, Ph.D.

Introduction

Muscle function measurements were continued and expanded on SL-4 to document physiological changes induced by the flight and, more importantly, to evaluate the effectiveness of several exercise devices added to the mission to prevent these previously documented changes.

On SL 1/2 a single preflight and postflight measurement of 10 maximum effort arm and leg flexion and extension forces was made (5). Though very limited from an experimental viewpoint, they nevertheless demonstrated several points including:

- ° Weightlessness produces large and rapid loss of muscle function and mass.
- ° Exercise of adequate force level and duration will prevent such loss, *e.g.*, hand cranking the ergometer prevented loss of elbow extensor function for the SL 1/2 CDR.
- ° Large amounts of work at low force levels such as those generated by the bicycle ergometer will not prevent loss of function and atrophy of large, powerful muscles such as the antigravity muscles of the legs and back.

On SL-3, two preflight and two postflight muscle function recordings were made. Additional in-flight exercise time was made available to the crew as were two additional exercise devices which permitted good exercise of the upper extremities, fair exercise of the trunk, but did not provide adequate force levels nor proper range of motion to protect the legs. This was confirmed postflight when the measurements showed excellent preservation of arm muscle function. Conversely, while leg function had been partially protected as compared to SL 1/2, major losses in leg strength and mass had occurred. Observations of the crew further confirmed this as did their complaints of unsteadiness, arthralgias, and myalgias.

A simple passive treadmill which permitted simulation of walking and jogging under approximately 175 pounds of simulated weight was flown on SL-4 (fig. 2.4.3-1). Operational discussion of this passive treadmill can be found in JSC-08668, *Skylab 3 Preliminary Biomedical Report*, February 1974, pp. 2.4.2-2, 2.4.2-5. The results of using this device in conjunction with the existing onboard devices were graphically shown by the crew's locomotive ability after splashdown; quantitative results follow. Each exercise device used on SL-4 and its effect on muscular deconditioning will be discussed individually.

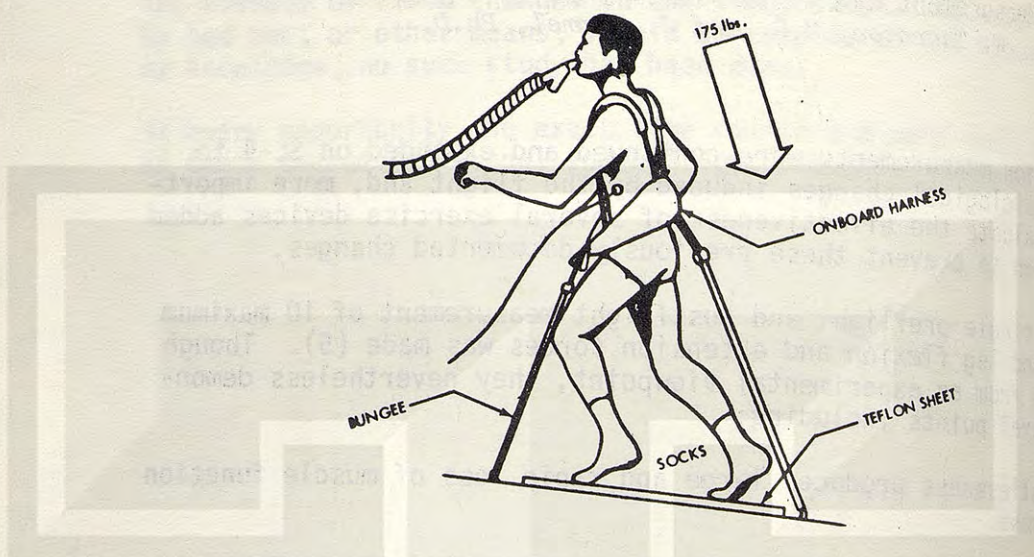


Figure 2.4.3-1. - Sketch of SL-4 Treadmill.

The isokinetic method of muscle testing was further investigated during and after flight. These plus an additional preflight and postflight crew measurement gave better understanding of this relatively new measurement technique. While several factors prevented this test from being as comprehensive as desired, it had been possible to delineate the major factors required to protect the muscular function of man on flights much longer than Skylab.

Equipment and Protocol (Method)

On SL-4 the CYBEX II¹ constant speed (isokinetic) dynamometer was used again. Ten maximum force flexions and extensions of elbow and hip/knee were made at a constant rate of 45°/sec. Although it would have been desirable to measure many other body segments and use a number of other rates, time allowed only for measurement of these two sites. Conversely, an additional session was scheduled both preflight and postflight on SL-4 which produced a far better characterization of the changes induced not only by the flight, but also during the preflight and post-flight periods.

The dynamometer head is mounted on a rolling stand and attached by a bar and clamp arrangement to a heavy physical therapy table as shown in figure 2.4.3-2. For leg measurements, a steel cable under tension, tying the dynamometer head to the table, was added to increase stability.

¹Manufactured by Lumex Corp., Long Island, N. Y.

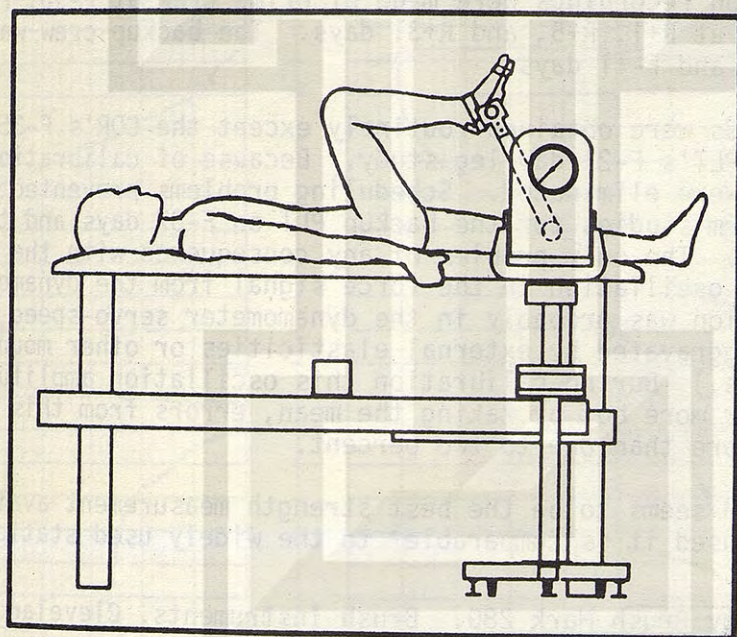
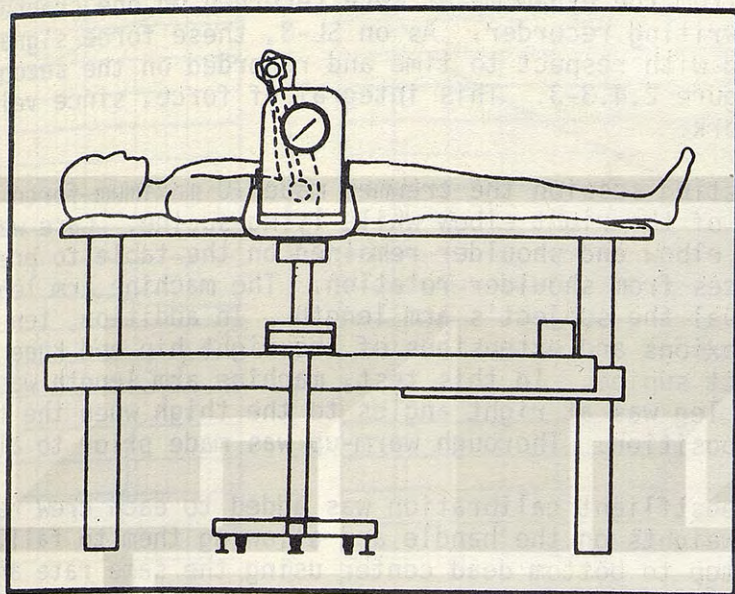


Figure 2.4.3-2.- Positions Used in Muscle Function Testing.
Both Arm and Leg were Carried through Full
Range of Flexion and Extension.

Force signals from the dynamometer were recorded on one channel of a Brush² direct-writing recorder. As on SL-3, these force signals were also integrated with respect to time and recorded on the second channel as shown in figure 2.4.3-3. This integral of force, since velocity is constant, is work.

During each testing session the crewmen made 10 maximum force full flexions and extensions of the right elbow while lying supine. Care was taken to insure that elbow and shoulder remained on the table to prevent additional forces from shoulder rotation. The machine arm length was adjusted to equal the subject's arm length. In addition, ten maximum effort full flexions and extensions of the right hip and knee were made with the subject supine. In this test, machine arm length was set such that the lower leg was at right angles to the thigh when the thigh was in a vertical position. Thorough warm-up was made prior to all testing.

Preflight and postflight calibration was added to each crew record by placing known weights on the handle and allowing them to fall, under gravity, from top to bottom dead center using the same rate and arm length as used for the crew record.

For this mission recordings were made of prime crew at F-35, F-21, and F-10 days, and at R+1, R+5, and R+31 days. The backup crew was measured at F-37, F-19, and F-11 days.

All crew records were obtained routinely except the CDR's F-35 day arm study and the PLT's F-21 day leg study. Because of calibration problems these studies were eliminated. Scheduling problems prevented the recording of arm studies for the backup PLT on F-37 days and the prime PLT on day R+1. The only problem of any consequence with the recording process was an oscillation in the force signal from the dynamometer. (This oscillation was probably in the dynamometer servo-speed control and possibly aggravated by external elasticities or other mounting characteristics.) During calibration this oscillation amplitude was five percent or more but by taking the mean, errors from this source should be no more than one to two percent.

The method used seems to be the best strength measurement available. At the speeds used it is comparable³ to the widely used static

²Manufactured by Brush Mark 280. Brush Instruments, Cleveland, Ohio

³Instantaneous forces of a slowly moving limb are a few percent higher than the maximum isometric force at the same limb angles (muscle length). There is a widely held misconception based on studies of excised muscle tissue, and until recently shared by the author, that maximum forces were an inverse function of the speed of the muscle contraction. In fact, maximum forces, as recorded, are virtually constant over the whole range of the contraction until some limiting velocity is reached after which the force is an inverse function.

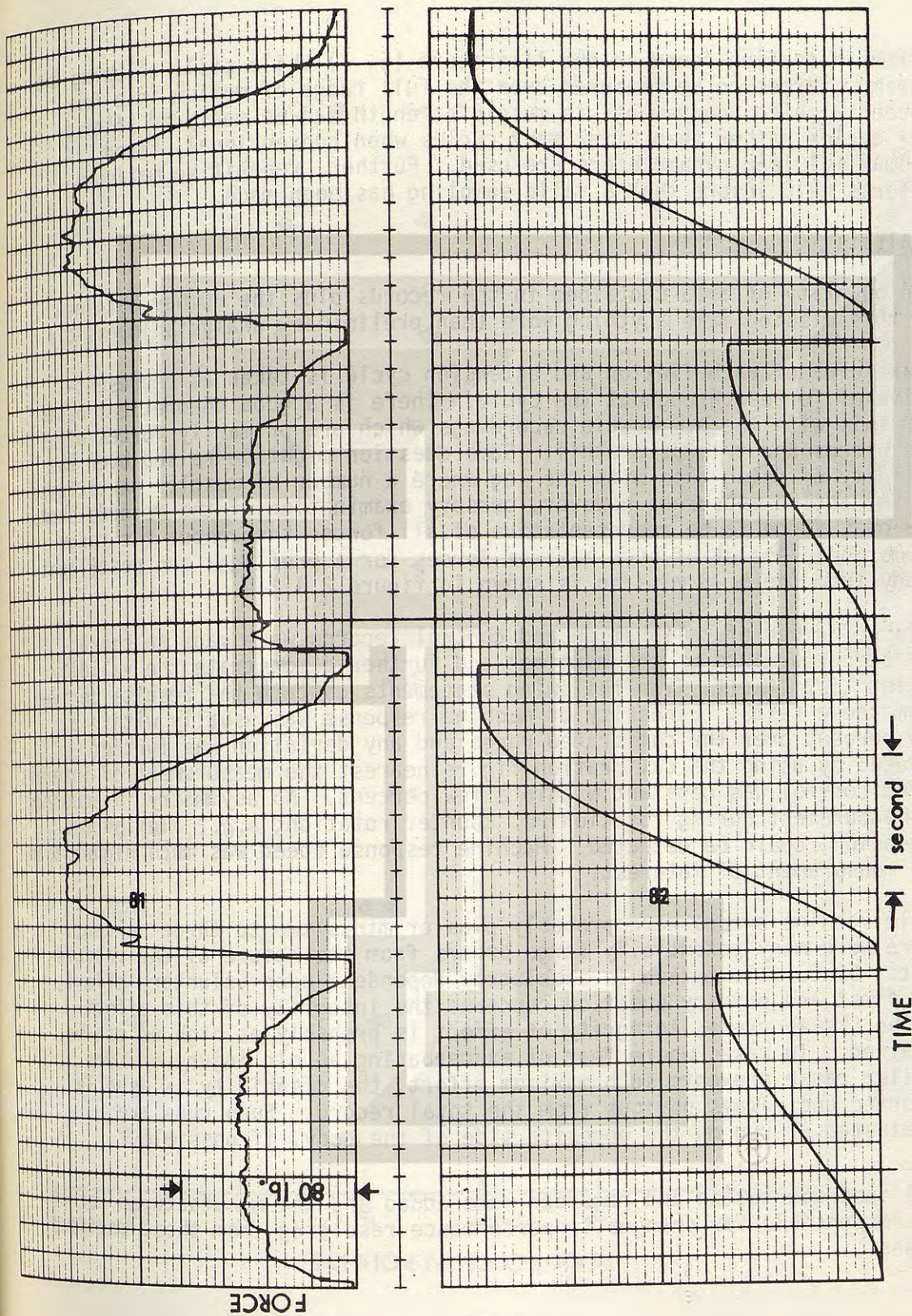


Figure 2.4.3-3.- Fast Recording of Right Leg, SL-3 Backup PLT. (Upper tracing is force and lower is integral of force at constant velocity; i.e., work.)

strength testing found in the literature (6, 7) while still allowing the maximum forces to be measured over the full range of motion in a few seconds. Also, decrements in muscle strength can be measured after a few cycles rather than after many cycles when conventional, fixed, submaximal load dynamometers are used. Further, repetitive maximum efforts help insure that a valid sampling has been made.

Analysis

The quantity of data contained in the records plus the number obtained on this mission make anything more than preliminary analysis impossible.

Peak force of each flexion and extension cycle is taken as representative of forces throughout the cycle. There is a good theoretical basis for this with the arm muscle recordings which are primarily forces of the biceps and triceps brachii. Some question might be raised over the validity of doing this with the leg where a number of muscles participate in the action measured; however, cursory examination of the records shows the peak force to be representative of all forces throughout the range of motion. A plot of such maximum forces for a preflight and postflight study from the SL-3 mission is shown in figure 2.4.3-4.

A large number of calibration and control records were made to characterize performance of the machine⁴ and further demonstrate the validity of the test itself. The following statements contain the results derived from these tests. Linearity of machine response was usually within a few percent over the calibrated range and any deviation was further reduced by using the calibration figure nearest the measurement of interest. Speed control was constant within a few percent. No asymmetry in accuracy of measurement during rotation *vs.* counter rotation, *e.g.*, flexion *vs.* extension, could be detected. Machine response speed was much higher than any measurement of interest.

While machine errors were probably plus or minus two to three percent, there were many potentially large errors from the nature of the measurement. Since this method is absolutely dependent upon voluntary effort, the first and primary question concerns the integrity of this effort. In the Skylab crews, integrity of effort is probably as high as can be obtained. In cases where fear of exacerbating an old injury or some similar cause prevents such maximum effort, the disability is usually reported and always obvious from the total record. Such runs are eliminated or run on the opposite side of the body, if possible.

⁴All instrumentation and recorder were added and the manufacturer cannot be responsible for changes in performance resulting from these modifications.

till allowing the
tion in a few
asured after a
nal, fixed,
tive maximum

number obtained
lysis impossible.

as represent-
theoretical basis
rily forces of
raised over the
uscles participate
the records show
ghout the range
ht and postflight

made to charac-
ate the validity
he results derived
ually within a
was further
surement of inter-
ymmetry in accou-
g., flexion vs.
as much higher the

three percent,
e of the measure-
voluntary effort,
f this effort.
high as can be
njury or some
ity is usually
n runs are
possible.

manufacturer cannot
om these modifica-

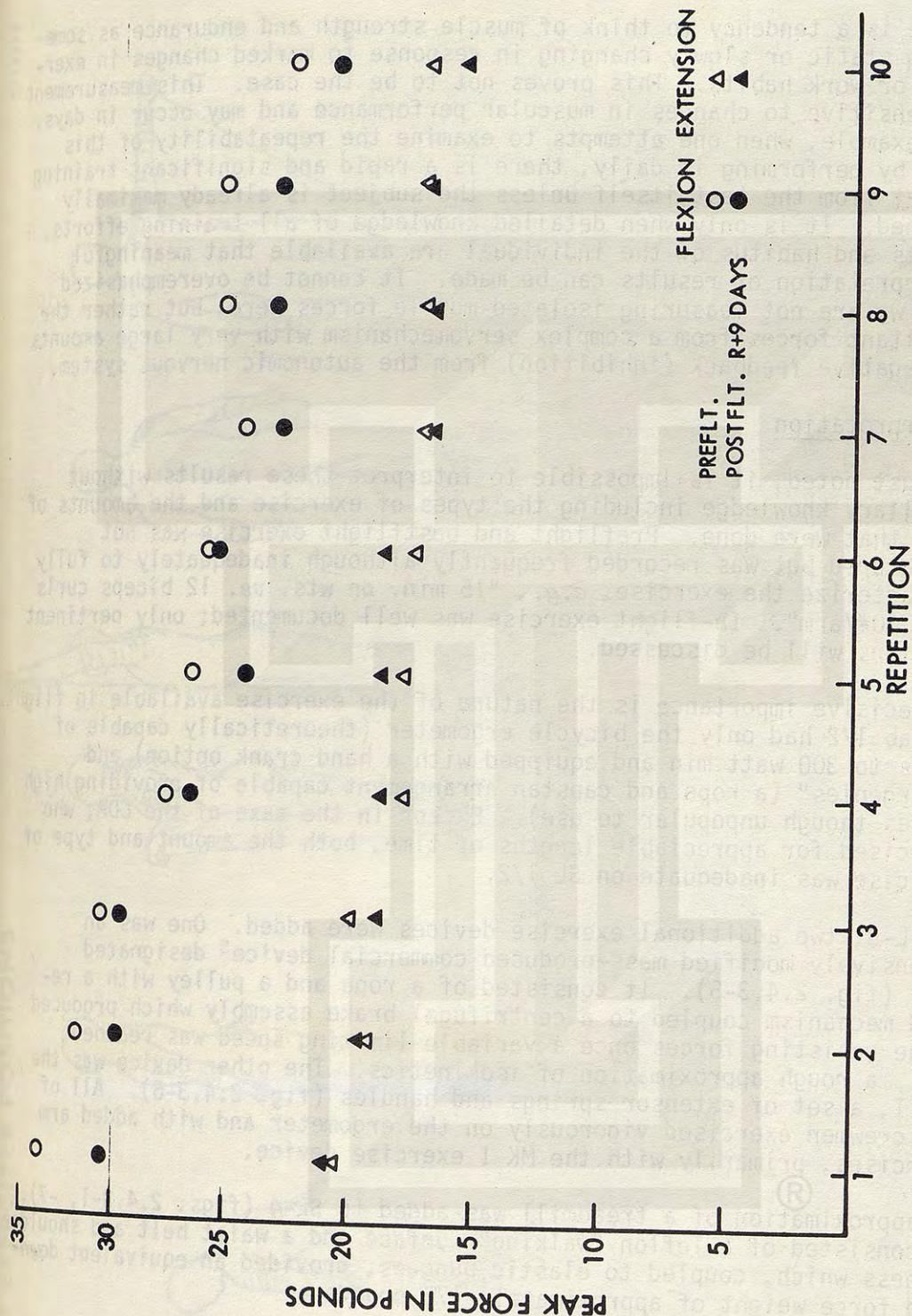


Figure 2.4.3-4. - Preflight and Postflight Arm Forces From SL-3 CDR.
Note Complete Preservation of Extensor Peak Forces.

9/13/73

There is a tendency to think of muscle strength and endurance as something static or slowly changing in response to marked changes in exercise or work habits. This proves not to be the case. This measurement is sensitive to changes in muscular performance and may occur in days. For example, when one attempts to examine the repeatability of this test by performing it daily, there is a rapid and significant training effect from the test itself unless the subject is already maximally trained. It is only when detailed knowledge of all training efforts, habits and habitus of the individual are available that meaningful interpretation of results can be made. It cannot be overemphasized that we are not measuring isolated muscle forces here, but rather the resultant forces from a complex servomechanism with very large amounts of negative feedback (inhibition) from the autonomic nervous system.

Interpretation

As just noted, it is impossible to interpret these results without ancillary knowledge including the types of exercise and the amounts of each that were done. Preflight and postflight exercise was not structured but was recorded frequently although inadequately to fully characterize the exercise, *e.g.*, "15 min. on wts. *vs.* 12 biceps curls with 30#/arm". In-flight exercise was well documented; only pertinent portions will be discussed.

Of decisive importance is the nature of the exercise available in flight. Skylab 1/2 had only the bicycle ergometer (theoretically capable of loads to 300 watt min and equipped with a hand crank option) and "Exergenes" (a rope and capstan arrangement capable of providing high forces though unpopular to use). Except in the case of the CDR, who exercised for appreciable lengths of time, both the amount and type of exercise was inadequate on SL 1/2.

On SL-3, two additional exercise devices were added. One was an extensively modified mass-produced commercial device⁵ designated MK I (fig. 2.4.3-5). It consisted of a rope and a pulley with a rewind mechanism coupled to a centrifugal brake assembly which produced large resisting forces once a variable limiting speed was reached, *i.e.*, a rough approximation of isokinetics. The other device was the MK II, a set of extensor springs and handles (fig. 2.4.3-6). All of the crewmen exercised vigorously on the ergometer and with added arm exercises, primarily with the MK I exercise device.

An approximation of a treadmill was added to SL-4 (figs. 2.4.3-1, -7). It consisted of a Teflon "walking" surface and a waist belt and shoulder harness which, coupled to elastic bungees, provided an equivalent downward force weight of approximately 175 pounds.

⁵Mini-Gym, Inc., Ind., MO.

endurance as some
ed changes in exer-
e. This measurement
may occur in days.
stability of this
significant training
already maximally
training efforts,
that meaningful
e overemphasized
re, but rather the
very large amounts
c nervous system.

results without
and the amounts of
ise was not
equately to fully
12 biceps curls
ed; only pertinent

available in flight
ally capable of
option) and
of providing high
of the CDR, who
amount and type of

One was an
designated
lley with a re-
y which produced
was reached,
r device was the
4.3-6). All of
with added arm

s. 2.4.3-1, -7).
belt and shoulder
equivalent down-

9/13/73

MKI EXERCISER POSITIONS

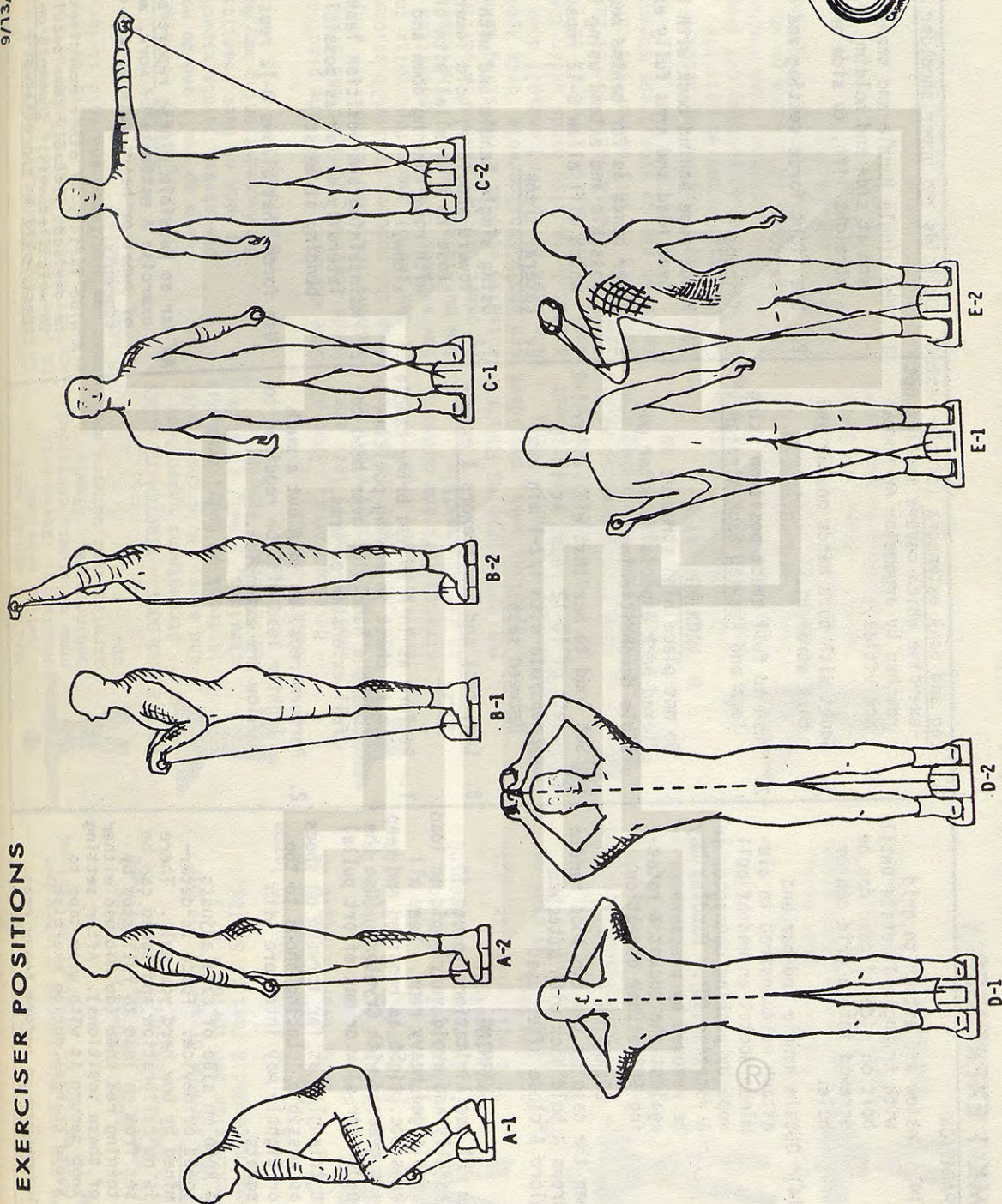


Figure 2.4.3-5. - MKI Exerciser Positions.

MK I EXERCISER

PREPARATION

(W714) Unstow and attach to grid with triangle & rotate until bolt on side of case can be screwed into a grid center hole.

(W714) Obtain handle and bar and attach unit desired to aluminum socket on end of pull rope by pushing connector in & rotating 90°. Handles may be removed by pressure against the socket & rotating 90° either direction.

OPERATION

Open the case by the two loop handle screws & hold back with attached velcro & close after use.

WARNING

The MKI has limitations so use it carefully and avoid very rapid no load or prolonged heavy reps. Keep all screws etc. tight as required and keep gears greased with Crytox. (Use the Exergym for slow or max effort pulls)

Put triangles as far forward on shoes as possible. Lacing shoes to top or tightly may interfere with squats.

Red knob on side of case adjusts speed of device. Force is determined by how hard you pull. There is no calibration and speed can be set from no load to full stop by turning red knob (do not use either knob for position). After setting avoid changes during exercise. Always warm up before heavy work.

A. Leg and back extensors (single best exercise which covers muscles not reached by ergometer or normal activities):		C. Deltoids and upper shoulder muscles
1. Squat with both hands on bar and back straight.		1. Use single handle and stand with arm at side and holding arm straight lift, to side or front.
2. Push to full erect position using legs and keeping back straight.		2. Use light force setting and 8-12 reps.
WARNING Do not place high stresses on flexed back especially after possible deconditioning.		D. Triceps -
3. Set load to max that will allow 1-2 sets of 10-12 reps. at 10-15 reps/min with 1/2-1 min rest between sets.		1. Place rope behind back with bar over head and arms fully extended.
		2. Lower hands as far behind neck as possible and extend using force which will allow 8-12 reps.
B. Leg, back and arm flexors & extensors:		E. Lateral trunk -
1. Perform as in A except bring handle up to chest in rowing position & continue handle up over head to full extension of arms.		1. Using single handle and with thumb toward shoulder, hold lower arm close to & parallel with side with rope running down and over elbow.
2. Perform reps. as in A but a much lighter load will be required to allow arm extension.		2. Maintaining arm position lean laterally as far as possible bending at waist.
		Use force that allows 8-12 reps.

As far as possible please report all exercise & estimate of work, amount of sweat or heart rate or any other comments.

A wide variety of other exercises can be devised, probably involving the use of the MKI in combination with other equipment.

Red knob on side of case adjusts speed of device. Force is determined by how hard you pull. There is no calibration and speed can be set from no load to full stop by turning red knob (do not use either of these positions). After setting of these positions, the red knob should be changed with grey tape to avoid being worn up before being used.

MK II EXERCISER

These are not considered primary but are crew option or in event of failure of MK I.

CAUTION: These springs can cause severe damage should they be allowed to slip (MAX EXTENSION 7 FEET)

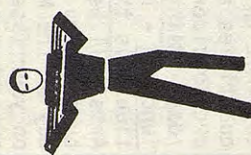
MK II has a force of approx. 5# per foot extension per spring i.e. 5 springs extended 2 feet is 50 lbs.

- A. Place either foot in large handle far enough in to 'lock' over triangle on shoe -

Use one or both hands to hold 2nd handle at waist level -
Alternately raise and fully extend leg keeping back straight -
This will exercise legs and low back

- B. CHEST PULL - NO FAST OR JERKY MOVEMENTS
- Stretch slowly and re-turn to original position without any jerky motion. Start with two or three springs doing 8 repetitions, adding one every third workout to 15 repetitions. Add a spring and repeat.

- C. OVERHEAD PULLDOWN
- Broadens upper back.
Stand erect, feet about 12 inches apart. Hold chest pull overhead
- Stretch arms outward and down.



D. PRESSOUT BEHIND BACK

- Builds arms and shoulders. Stand with arms at sides, chest pull behind back. Slowly stretch arms outward and up.



E. HOLDOUT - STRETCH TO SIDES

- Strengthens upper back and arms. Hold chest pull in front of body, arms out straight, slowly stretch to full arms length.



F. ARCHERS MOTION

- Develops arms. Arms at shoulder level, left arm facing outward, right arm bent at elbow. Hold right arm stiff and slowly stretch left arm outward as far as possible.



G. PULLOUT - BENDING FORWARD

- Develops arms, shoulders and upper back. Stand with arms at sides, chest pull in front. Bend forward from the waist at the same time stretching arms outward slowly.



H. SIDE ARM RAISE

- Broadens shoulders. Stand erect, arms at sides chest pull in back. Slowly and deliberately raise the right arm, stretching to shoulder height. Repeat 10 times and reverse to other arm.



As far as possible please report all exercise & estimate of work, amount of sweat or heart rate or any other comments.

A wide variety of other exercises can be used with this exerciser. Consult the manual for details.

ISOMETRICS:

Much of the human body can be exercised to some extent by exerting forces against another body segment or against fixed objects. The idea is to exert near maximum force and hold it for 6 secs or more.

WARNING

As in any other exercise 'warm up' well and do not overstress joints especially in neck or back, particularly if deconditioning may have occurred.

Some examples of this are placing two hands together in front and slowly pushing the other aside. If properly done the muscles used will be obvious. At the end of the effort relax for a few seconds to allow circulation in the muscle and repeat. The neck may be exercised by pushing or pulling or rotating against a resisting hand. One can apply considerable force against the back by pulling oneself down into a seat by hooking hands under the seat edge. Legs may be stressed in the same fashion. Considerable forces can be developed in this manner and care must be taken not to overstress structure.

Other useful activities peculiar to weightlessness may be possible. For example repeated pushing off from a squatting position, tumbling and landing slowly to a squat on the feet should be beneficial to a number of reflexes and muscles.

MK II EXERCISER

Figure 2.4.3-6 - MKII Exerciser as Used on SL-4.

TREADMILL EXERCISER

GENERAL CONDITIONING COMMENTS

Cardio-vascular systems can be protected by adequate food and water, rest and prolonged moderate to heavy exercise. The bicycle ergometer will probably be the primary tool for this unless the treadmill techniques can be developed to allow prolonged use (20-30 mins) (Leg fatigue is expected to limit this). Minimal daily work quantities based on the ergometer are considered to be 45 watt-mins. /lb. /day - Maintenance of low back & leg function - both strength and coordination - is the major problem remaining. Arms will be relatively well protected by ordinary activities and a few reps/day on the MKI. Remember you will fall on your face from your legs not your arms when you return to one G so spend available time on the legs.

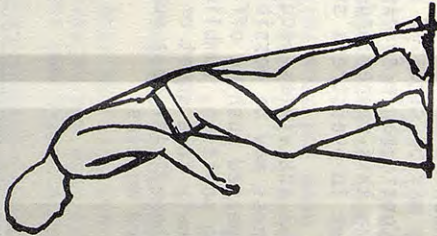
The treadmill was tested as well as possible but will be used by you for the first time and you must work out many details that we could not. The 'treadmill' does not allow normal walking or running but is the closest we could come for the weight. Do not hesitate to make changes (please tell us). One of the major questions will be it's metabolic requirements so as soon as a stable profile can be established please do an MA run during a treadmill exercise.

Finally, monitor your condition: mass, resting H.R. and H.R. at max LBAP, exercise H.R. and urine vol. and take appropriate measures, immediately.

STOW: W742
USE: HAND HELD

TREADMILL EXERCISER

1. Obtain ergometer restraint assy, force cords, treadmill assy and 4 portable tether brackets.
2. Adjust tether brackets for maximum length (large nut counterclockwise)
3. Attach treadmill assy to grid (suggest behind ergometer) using tether brackets (if tether brackets will not lock select another bracket).
4. Attach rear force cord assy to D-ring on back of ergometer restraint.
5. Don ergometer restraint, attach two front force cords to large D-ring in front of restraint.
6. Squat on treadmill and attach two rear force cords to apex holes in grid near rear of treadmill then attach two front force cords to adjacent apex holes in grid near front of treadmill.
7. Stand erect, make adjustments for fit. The shoulder & other straps should be adjusted for relative weight distribution* and comfort.
8. When fit adjustments have been made "walk" by stepping forward with one foot while sliding back on the other. Walk on toes as desired, keeping in acute angle with the treadmill.
9. Stabilization by hands will be required. The hands should be held in front of the body, slightly away from the treadmill.



TREADMILL

MK III (EXER GYM) (for heavy pulls)
Secure one of three units to a floor cross member -
Set approx. load desired as shown on side of unit. Exact load may be continuously controlled by providing slight force on free end of rope as it enters unit. Pull slowly and steadily.
All of the exercises shown for the MK I may be performed here but more slowly and requiring more skill in rope control.

*Forces may be measured with scale in M487 Kit. Try to place $\sim 1/2$ of body weight on shoulders

Note: The more we know of your activities the more we can improve future operations. Please fill in and return this card.

control.

*Forces may be measured with scale in M487 kit. Try to place ~1/2 of body weight on shoulders

Note: The more we know of your activities the more accurately we can operate - this is a goal.

8. When fit adjustments have been made "walk" by stepping forward with one foot while sliding back on the other. Walk on toes as desired, keeping an acute angle with the treadmill.

9. Stabilization by hands will be required but some hands are not required. Some are required.

Finally, monitor your condition: mass, resting H.R. and H.R. at max LBNP, exercise H.R. and urine vol. and take appropriate measures, immediately.

STOM: W742
USE: HAND HELD

The crew on SL-4 used the bicycle ergometer and arm exercisers at about the same level as the SL-3 crew but added the treadmill each day to the fatigue limit, typically 10 or 11 minutes.

Plots of average strength measurement are displayed in figures 2.4.3-8, -9, and -10. A mean of the peak forces for 10 repetitions of flexor and extensor efforts of arm and leg was calculated and used as the measure of muscle strength. Although a muscle fatigue decrement was derived, it is not shown. On SL-4 postflight muscle fatigue decrement was derived; it is not shown. On SL-4 postflight muscle fatigue decrement was, in fact, decreased over the observed preflight muscle fatigue decrements.

As measured for SL-4, the increased number of measurements demonstrated the lability of strength, so much so that it was difficult to choose a preflight baseline. Rather arbitrarily, the first measurement, at F-35 days, was taken as a baseline for these plots before the crew became involved in a preflight control regimen. This "control" period is most unstable in many ways. Twenty-one days preflight was used as the baseline for calculating in-flight changes since this was the reference point used for SL 1/2 and -3.

The SL-4 CDR was not an exercise addict but went on a regimen of running, weights, and MK I exercise which brought him to a good condition of fitness at a level well above his normal. Preflight there was a slight decrease in maximum strength of all segments tested, with a sharp drop for leg strength on F-10 days (fig. 2.4.3-8). In-flight the CDR used a typical daily protocol on the MK I exerciser (fig. 2.4.3-5) of the following positional repetitions: A-40, B-20, D-20, E-20; and on the MK II (fig. 2.4.3-6): C-20, D-20, E-10, F-20 with isometric leg adduction and abduction. He spent 10 minutes walking and one minute running and did several hundred toe rises on the treadmill. His total amount of in-flight exercise was less than the other two crewmen. Figure 2.4.3-8 shows: At R+1 day he had an 11.7 and 4.8 percent decrement in leg extensor and flexor forces. His arms had a much larger loss of forces, 21 percent flexor and 22.4 percent extensor. Post-flight there was the usual rapid increase in leg extensor forces such that by R+5 days he was essentially at preflight baseline and remained so at R+30 days. Leg flexor forces were reduced only 4.8 percent post-flight, but continued to decrease and were 11 percent down on R+31 days.

Neither preflight not postflight exercise was recorded in enough detail to be used quantitatively in any of these analyses. By R+5 days the CDR had only walked in routine duties without arm exercise, and by R+18 days he had run a total of 5 miles. In spite of this small amount of leg exercise, leg extensors had returned to baseline under stresses of gravity while arm forces showed little improvement.

CDR SL-4

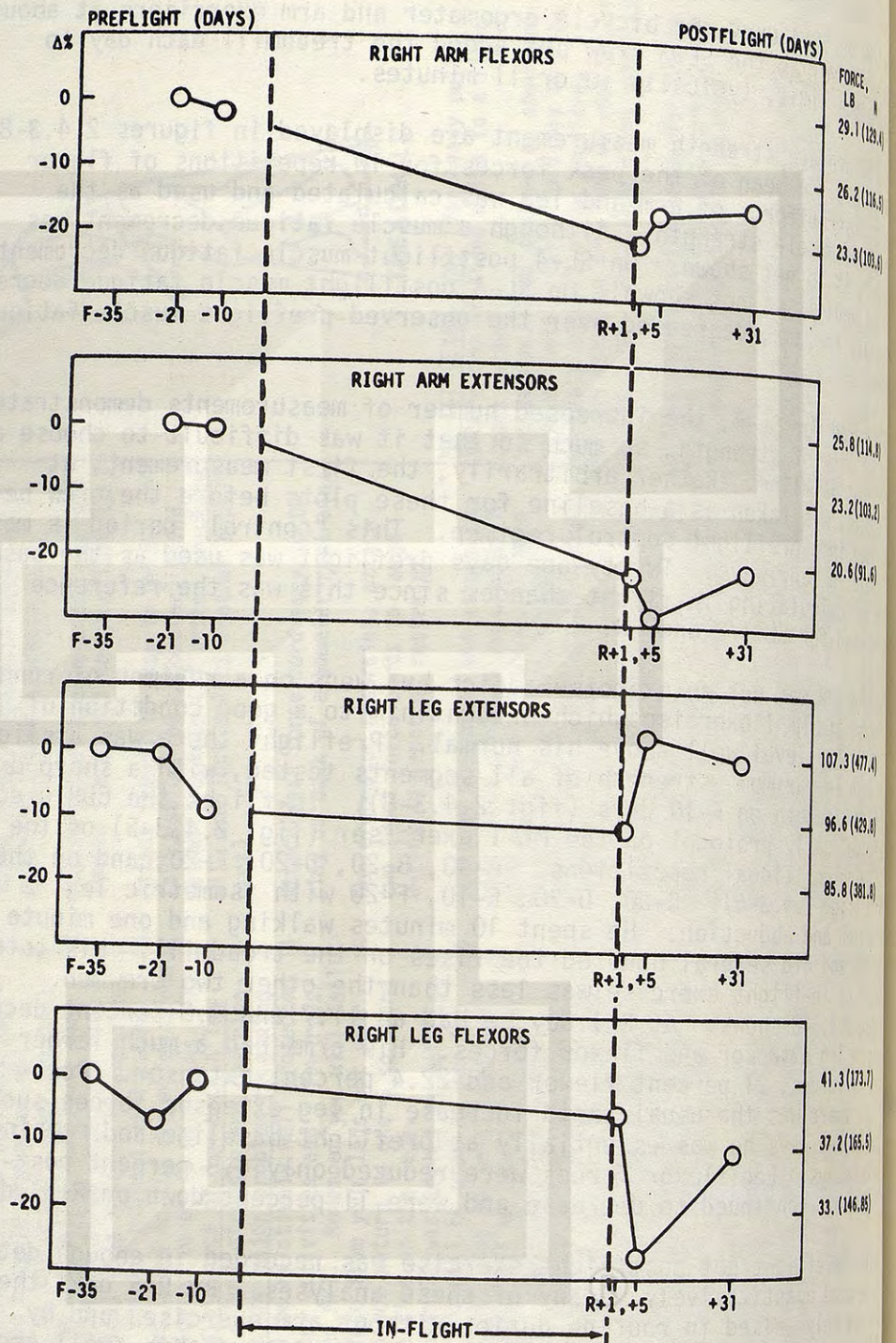
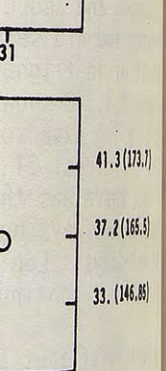
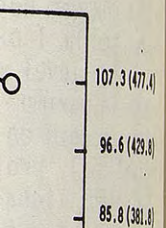
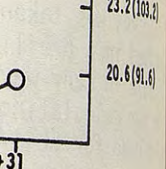
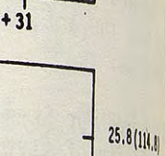
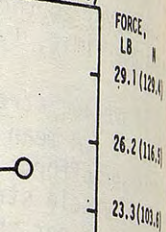


Figure 2.4.3-8. - Average Strength Measurement, SL-4 CDR.

LIGHT (DAYS)



SL-4 CDR.

SPT SL-4

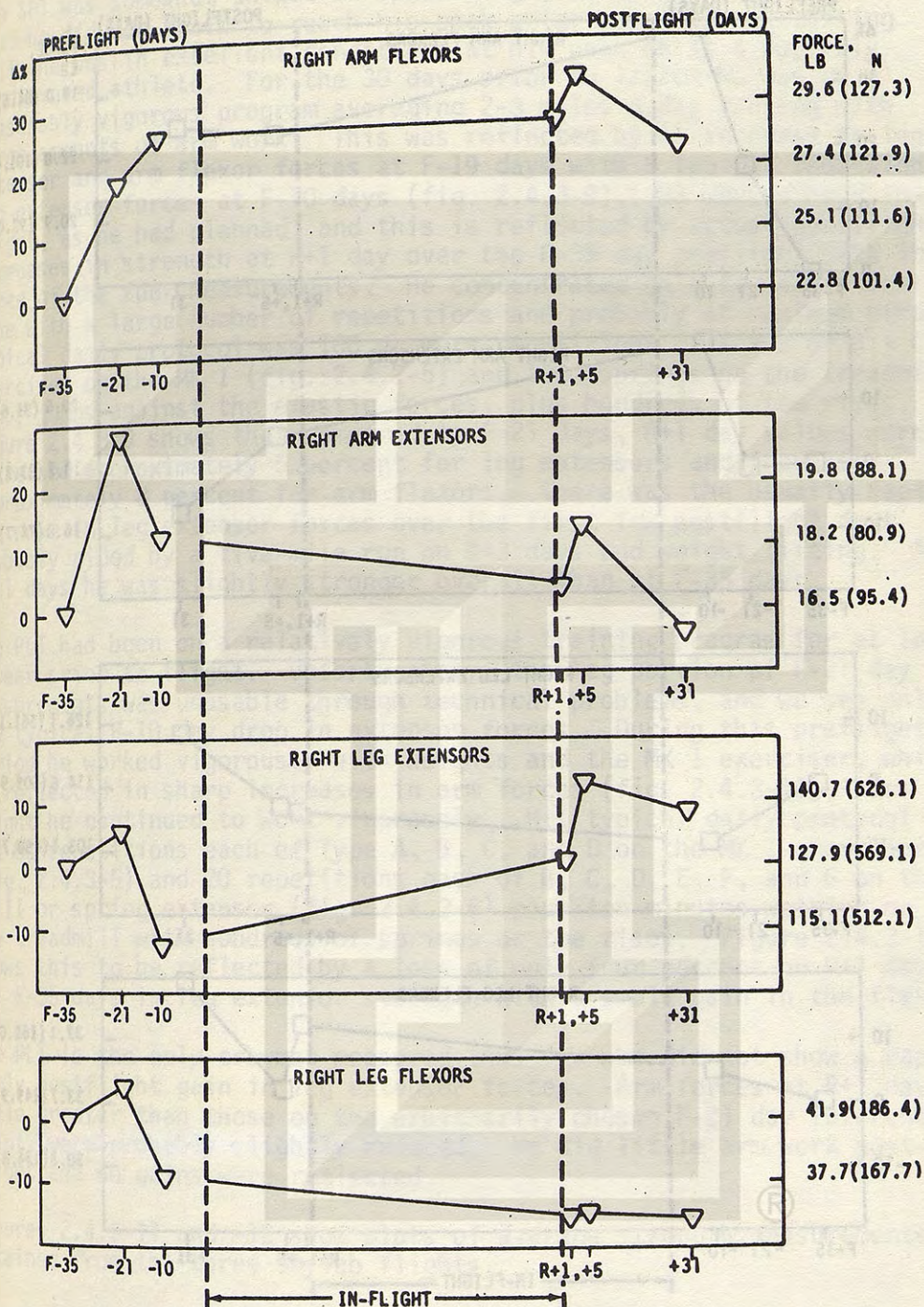


Figure 2.4.3-9. - Average Strength Measurement, SL-4 SPT.

PLT SL-4

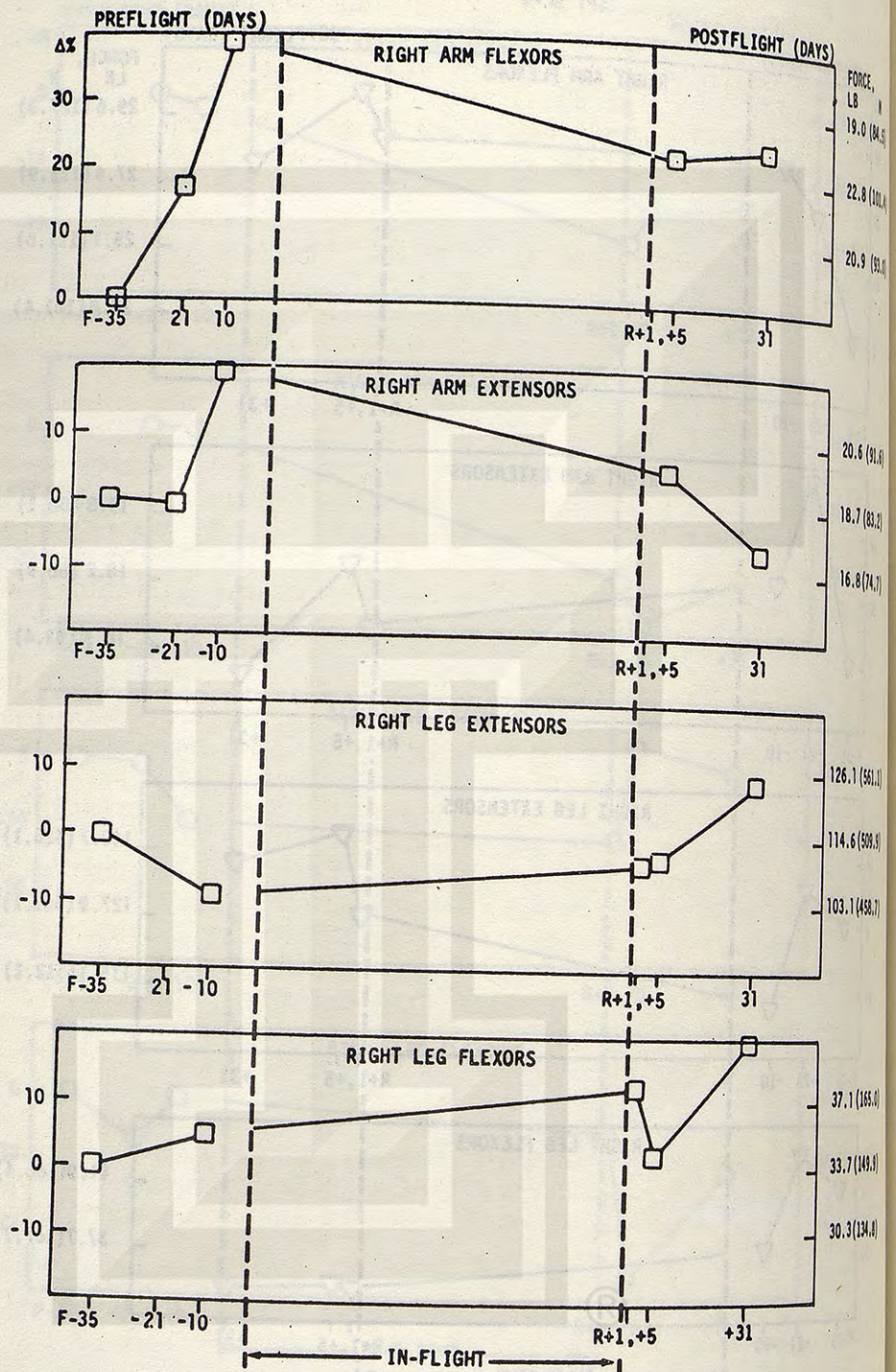
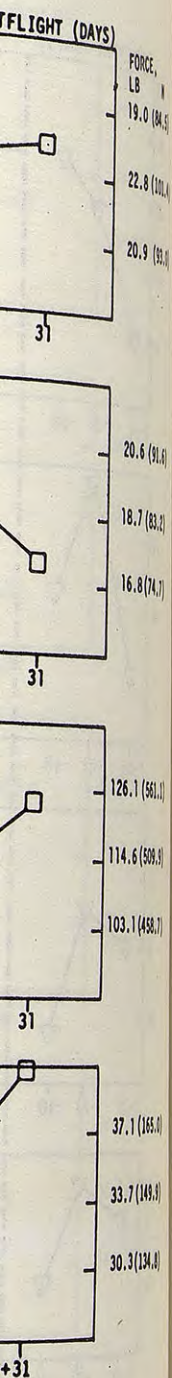


Figure 2.4.3-10. - Average Strength Measurement, SL-4 PLT.



The SPT was somewhat unique in space flight conditioning efforts in that he did not train to reach his peak prior to preflight testing. While he was in excellent condition, at his peak he is a superbly conditioned athlete. For the 30 days prior to launch he was on a reasonably vigorous program averaging 2-3 miles a day running with large amounts of arm work. This was reflected by an increase in leg extensor and arm flexor forces at F-19 days with a typical reduction in leg extensor forces at F-10 days (fig. 2.4.3-9). He worked hard in-flight, as he had planned, and this is reflected by actual postflight increases in strength at R+1 day over the F-35 day preflight data in three of the four measurements. He concentrated on a few exercises done with a large number of repetitions and probably at maximum effort. Typical daily protocol was 100 or more repetitions of A + B or B + C exercises on the MK I (fig. 2.4.2-5) and 1000 springs on the treadmill, i.e., jumps against the elastic forces, plus hundreds of toe rises. Figure 2.4.3-9 shows that compared to F-21 days, R+1 day values were decreased approximately 5 percent for leg extensors and increased approximately 8 percent for arm flexors. There was the usually rapid increase in leg extensor forces over the first few postflight days probably aided by a five-mile run on R+3 days and weight lifting. At R+31 days he was slightly stronger overall than at F-35 days.

The PLT had been on a relatively vigorous training program for at least a year prior to flight. Unfortunately, the leg portion of F-21 day measurements was unusable through technical problems, and we see only the typical F-10 day drop in extensor forces. During this preflight period he worked vigorously with weights and the MK I exerciser, which is reflected in sharp increases in arm forces (fig. 2.4.3-10). In-flight he continued to work vigorously. His typical daily protocol was 50 repetitions each of Type A, B, C, and D on the MK I exerciser (fig. 2.4.3-5) and 20 repetitions each of B, C, D, E, F, and G on the MK II or spring extensor (fig. 2.4.3-6) plus ten minutes walking on the treadmill with hundreds of springs or toe rises. Figure 2.4.3-10 shows this to be reflected by a loss of only four percent on R+1 day vs. F-35 days in leg extensor strength with a small gain in the flexors.

The PLT is the only crewman measured thus far who did not show a rapid, early postflight gain in leg extensor forces. Arm forces at R+1 day, while greater than those on the arbitrarily chosen F-21 day reference point, were probably slightly reduced. He did little arm work post-flight and no gains were reflected.

Figures 2.4.3-11 and -12 show plots of average strength measurements obtained from the three Skylab flights.

Figure 2.4.3-13 is a plot of average losses of each with a listing of exercise devices used.

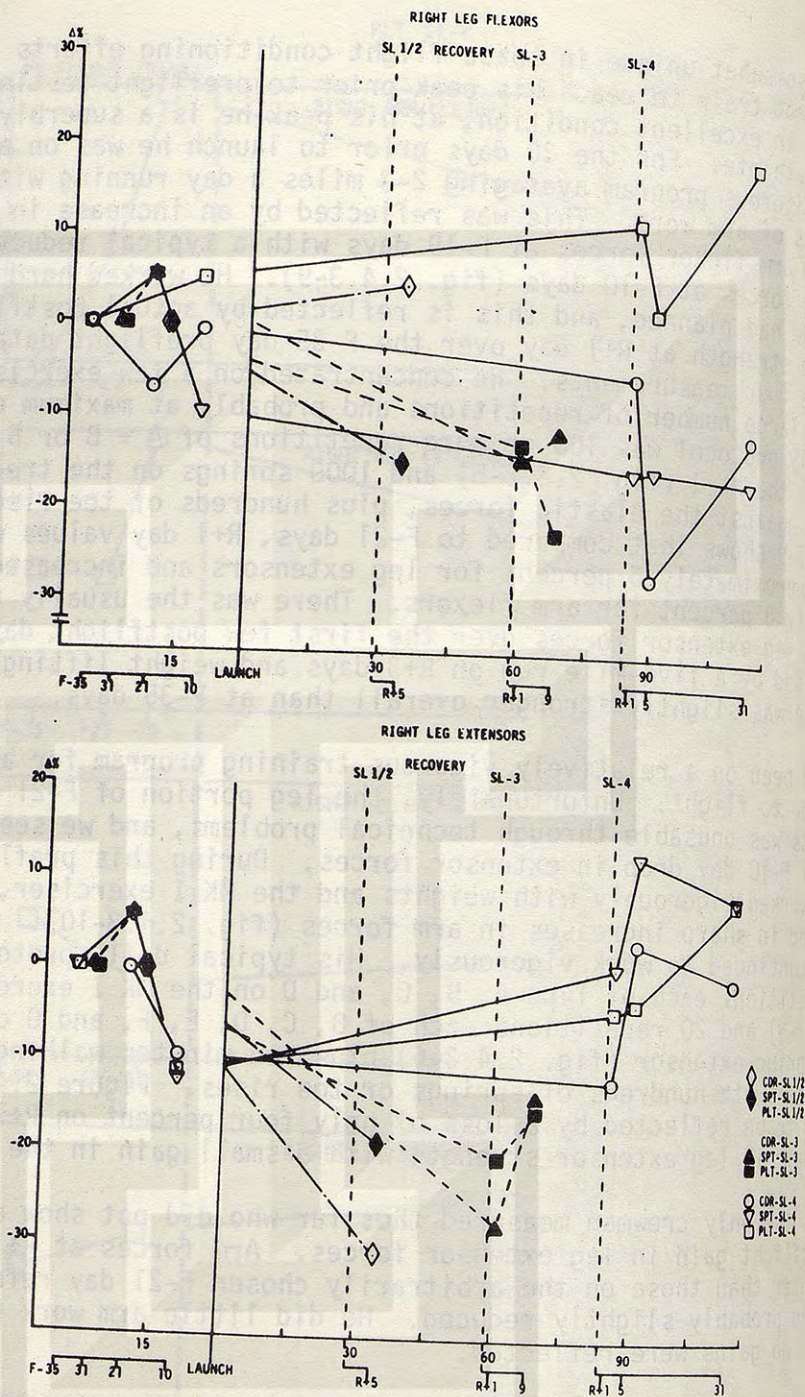


Figure 2.4.3-11. - Preflight vs. Postflight Percent Change In Right Leg Extensor and Flexor Forces.

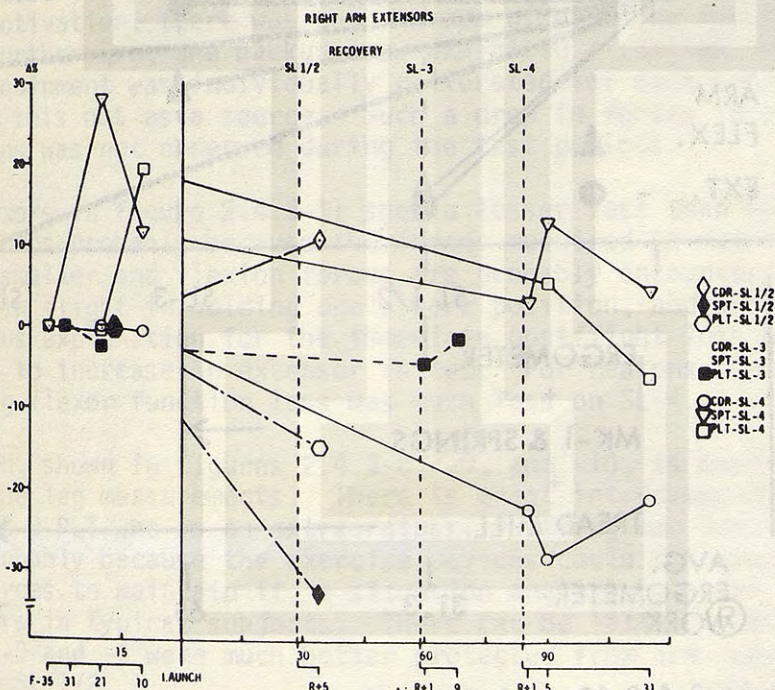
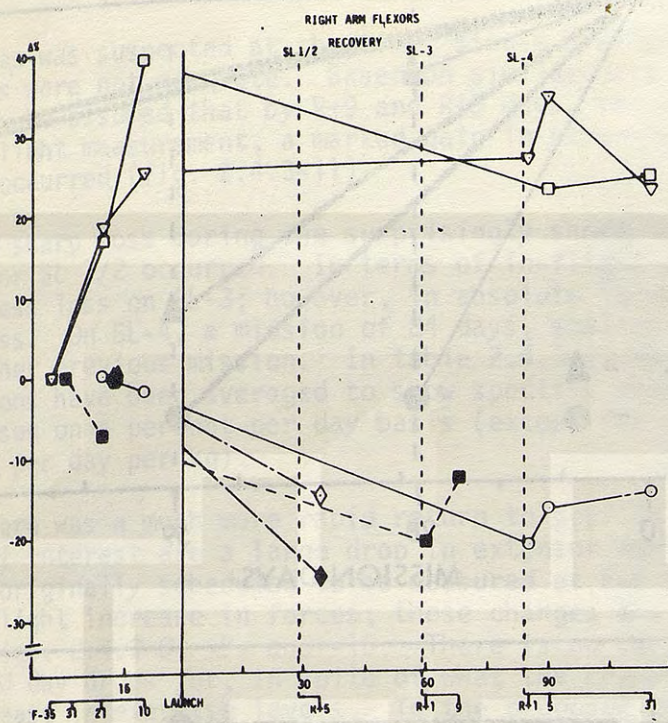


Figure 2.4.3-12. - Preflight *vs.* Postflight Percent Change In Right Arm Extensor and Flexor Forces.

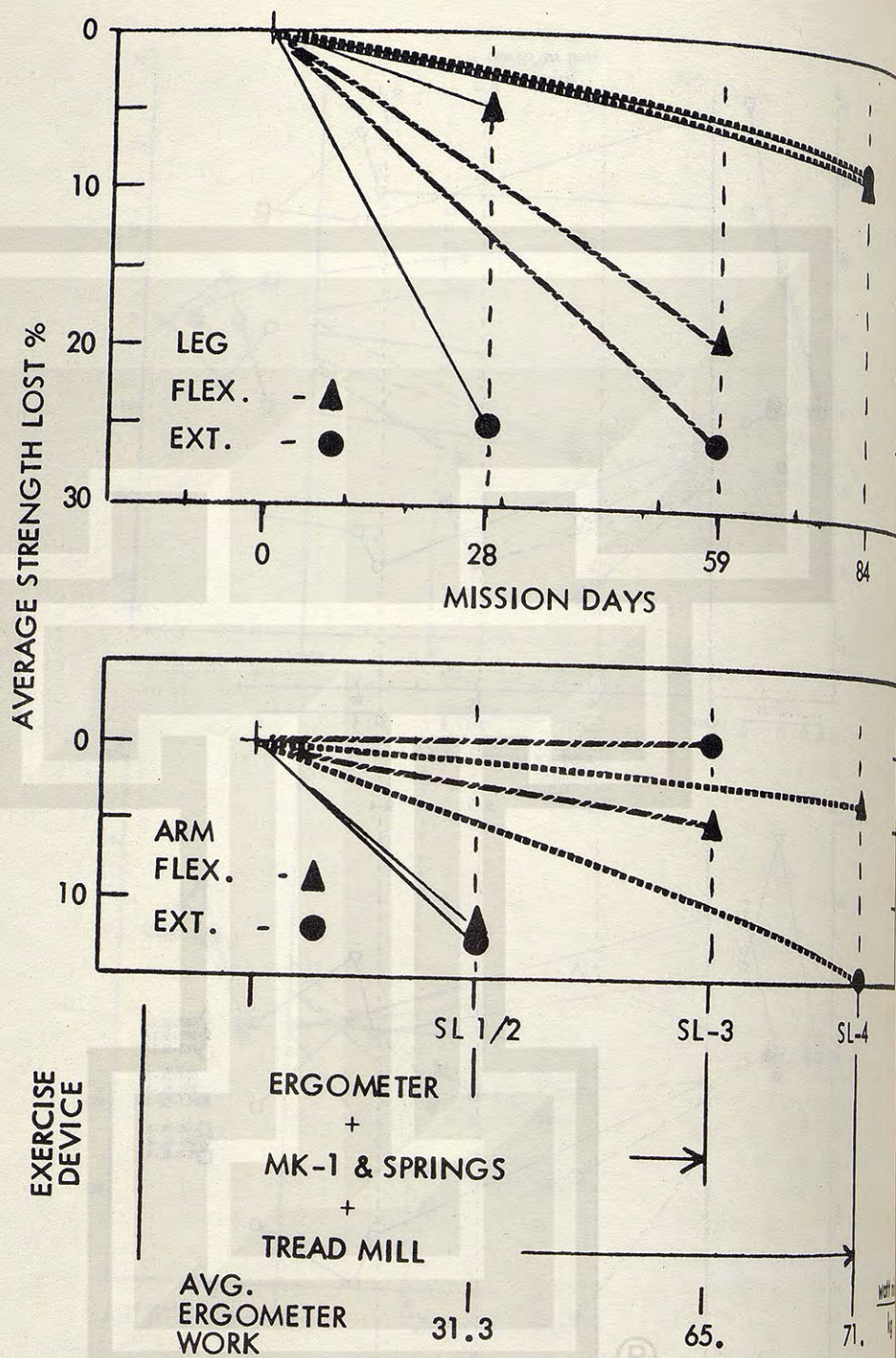
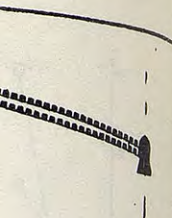
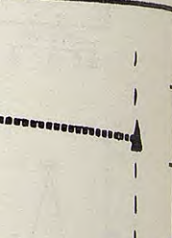


Figure 2.4.3-13. - Average Strength vs. Mission and Duration of Mission.



On SL 1/2, as was suspected at the time, single preflight and postflight measurements were not adequate. Based on similar data from SL-3 and SL-4, it may be assumed that by R+9 and R+5 days, respectively, the first postflight measurement, a marked gain in strength of leg extensors would have occurred (fig. 2.4.3-11).

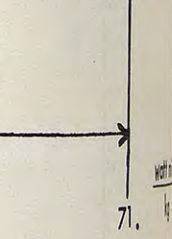
Actually, a sharp loss during the surprisingly short in-flight period (29 days) for SL 1/2 occurred. In terms of in-flight duration (59 days) there was less loss on SL-3; however, in absolute terms there was still a marked loss. On SL-4, a mission of 84 days, smaller losses occurred than on either previous mission. In table 2.4.3-I, data from these three missions have been averaged to show specific exercise relationships for comparison on a percent per day basis (except for ergometer exercise in watt min per day per kg).



On SL-4, there was a much more rapid return to preflight levels. Other phenomena of interest are a large drop in extensor forces measured at F-10 days (originally scheduled to be measured at F-5 days) and the rapid postflight increase in forces; these changes are displayed in more detail in figs. 2.4.3-8, -9, and -10. There is no obvious explanation for the F-10 day drops for, in spite of what the crewmen thought, there was no decrease in exercise levels. To the proposed question of decreased motivation, there was not a trace of evidence for such a cause and furthermore, the backup crew exhibited a similar drop. The recording equipment was individually calibrated for each subject's run thus ruling this out as a source. Such a drop in forces in other muscle groups was not observed during the test periods.



The leg flexors in figure 2.4.3-11 show a lesser loss than seen in the extensor groups probably because the forces required to maintain these groups are smaller and flexion forces are probably encountered more frequently in flight in holding one's work position, and such. There is no obvious explanation for the immediate postflight loss of flexion in contrast to increase in extensor forces. For reasons that are not obvious, leg flexor function loss was much less on SL-4.



Arm function, shown in figures 2.4.3-8, -9, and -10, is much more variable than the leg measurements. There is great intracrewmen variability, e.g., the SL-3 PLT who is an extraordinarily strong man lost arm flexor strength probably because the exercise devices could not provide the required forces to maintain it, a situation analogous to the case of leg extensors in typical subjects. There can be little doubt that the crews on SL-3 and -4 were much better protected from arm losses than the crew on SL 1/2.

While the foregoing is direct quantitative data, two other sources cannot be overlooked. The first is the crew's observations and reports.

TABLE 2.4.3-1. DATA AVERAGES OF CERTAIN EXERCISE RELATED QUANTITIES

Skylab Crew	Change in Leg Ext. Forces F-15* to R+1 %/Day	Change in Mid Calf Area F-15* to R+5 %/Day	Change in Arm Flexor Forces F-15* to R+1 %/Day	Change in Body Weight F-1 to R+0 %/Day	Avg. Ergometer Exercise Doned watt min per Day per Kg BW ^e
1/2 ^a	-0.89	-0.37	-0.45	-0.13	31.3
3 ^b	-0.44	-0.10	-0.005	-0.08	65.0
4 ^c	-0.09	-0.03	-0.17	-0.02	71.0

Key:

Exercise Devices flown:

^aBicycle ergometer

^bBicycle ergometer and MK I and MK II exercisers

^cBicycle ergometer, MK I and MK II exercisers, and the treadmill

^dData from experiment M171, sec. 3.15

^eBW = Body weight

*In some cases data were extrapolated to provide a common time period.

Although no ques fairly feet an spinal dition but slo complai tivity but be apparen vigorous ran fiv member but lit

The oth measure sively. from MO (sec. 3 extenso plicate majority are mix

Also tal exercis based o theless

Both le large i appreci in arm devices fat or than we of legs in stre changed leg are afforde

⁶Measur

Although two of the three SL 1/2 crewmen recovered rapidly, there is no question but that, on return, they were weak and complained of fairly severe myalgias and arthralgias, and told of hypersensitivity of feet and soles in-flight as well. Even on R+5 days there was marked spinal flexion. The SL-3 crewmen seemed to be in about the same condition as the SL 1/2 crew, although possibly a little stronger initially, but slower to return to preflight activity levels. They expressed complaints of arthralgias and myalgias also but they had no hypersensitivity problems in-flight. In contrast, by R+1 day, one could not but be impressed by the SL-4 crew's ability to walk and stand without apparent difficulty. They made few complaints until they resumed vigorous activity such as running several miles. For example, the SPT ran five miles on R+3 days, something I doubt any previous Skylab crew-member would have attempted. Following such efforts there were myalgias but little in the way of joint complaints.

The other source of ancillary data is the various anthropometric measurements. There has not been time to analyze these data comprehensively. But, the calculated cross-section area of mid calf derived from M092 measurements is shown in table 2.4.3-I and figure 3.5-14 (sec. 3.5), together with the amounts and type of exercise and leg extensor strength decrements. These calf area measurements are complicated by the metabolic losses suffered by all crews since the great majority of authorities in the field recognize that metabolic losses are mixed, *i.e.*, both fat and muscle are lost (7).

Also tabulated in table 2.4.3-I are daily average amounts of ergometry exercise and daily average weight loss. Although these "averages" are based on samples much too small for statistical validity, they nevertheless correlate well with observations.

Both leg and arm strength, and mid calf cross-section area⁶ losses were large in SL 1/2. On SL-3 there was a sharp drop in arm losses with appreciable losses in leg strength and cross-section. The improvement in arm performance can be reasonably attributed to the added arm exercise devices used while the decreased rate of leg atrophy could be decreased fat or muscle loss, but these losses are, in SL-3, proportionally less than weight losses observed. Increased exercise time and some loading of legs by the arm exercises performed undoubtedly made the difference in strength and probably also in atrophy. On SL-4 arm losses are little changed from SL-3, but both the atrophy and the strength losses of the leg are sharply reduced; the reasonable explanation is the protection afforded by the treadmill.

⁶Measured at R+5 days to allow for complete body fluid redistributions.

The muscle studies on Skylab corroborated what had been fairly well established by previous Earth based studies: namely,

- Disuse atrophy may occur rapidly and results not only in loss of strength and endurance but also loss of muscle tissue.
- Muscles require stresses near or at their maximum tension level to be able to maintain their level of strength and muscle mass, *i.e.*, many repetitions at a fraction of the maximum forces will not maintain muscle strength and mass.
- Relatively few repetitions near the muscle's maximum strength are required to maintain its condition.
- No one aspect of body conditioning can be emphasized without cost to the body's overall function, *i.e.*, cardiovascular conditioning must be accompanied by general muscular conditioning and conversely, if ability to function under one-g is to be retained after return from zero-g.
- Joint and skeletal functions are intimately related to muscle tone and condition.
- Above all the muscle system is an intimate and integrated part of the human body and affects and is affected by not only extrinsic factors such as exercise, food, and rest, but by more subtle intrinsic factors such as the nervous, cardiovascular, and other systems of the body, and especially by the conscious mind, *e.g.*, the crew's comments on feelings of well-being post exercise and the feeling of a need for exercise.

To plan a logical course for the future, the main effort should be directed toward further investigations. Some of the priority areas of concern are:

- To determine losses of muscle mass and muscle function under conditions of weightless and the relationship of this skeletal muscle loss to cardiovascular condition and to diet. Only two crewmen (SL 1/2) were virtually unprotected from muscular deconditioning and only the SL-4 CDR suffered no weight loss. This implies a need for controlled study with preflight, post-flight and possibly in-flight measurements.

- To improve measurement techniques of muscle and associated systems. Muscle itself is not measured in any currently available test, but rather the force from the muscle whose potential maximum force is greatly reduced by a complex neural feedback. New techniques are under study which may allow a nearer approach to a "pure" muscle measurement. At the same time, the associated nervous system should be investigated by EMG⁷ stimulation and transmission time studies and more attention given to coordinated muscular performance. Simple semiquantitative ciné pictures of crewmen's gait preflight and postflight would have been of great value.
- To understand interrelationships of the muscle system to other conditioning and deconditioning factors affecting other systems, *i.e.*, the cardiovascular system. For example, it appears that the condition of leg muscles is associated with orthostatic hypotension. Studies of vascular compliance of the leg should be related to muscle condition also.
- To develop more efficient forms of exercise. These are dependent on exercise devices; hence, this is a hardware problem. But, unlike most previous efforts, the hardware development must be directed by the physiological requirements. It must truly be a "total body" device that stimulates or stresses the following functions.
 - a. Produce aerobic energy costs which may be continued for appreciable periods of time to insure cardiovascular conditioning.
 - b. Provide realistic loads for as many of the muscle groups of the body as possible, but especially leg and trunk muscles. Use of this device should also retain typical coordinated movements such as walking or jogging to maintain such coordination.
 - c. It may also be desirable to provide lower body negative pressure or some other method of forcing appreciable quantities of blood into the lower extremities separately or in combination with the two functions mentioned in steps a. and b. (see Leg Hemodynamics, sec. 2.17).

In addition, this exercise device should meet the following operational requirements: be as light and small as possible, especially for stowage; be independent of spacecraft systems, *i.e.*, a passive device if possible; be quantitative; and be safe.

⁷EMG studies had been planned as a part of strength measurements for SL-3 and SL-4, but were prevented.

The requirements of appreciable aerobic load and high-stress trunk and leg forces indicate some form of walking or running which, in turn, implies a treadmill. It is quite possible that the functions of body negative pressure and large forces to simulate weight can be combined. It may be possible to develop a passive treadmill which provides power for a negative pressure pump both to be combined with a lower body negative pressure chamber which could also provide the necessary loading for the trunk and leg conditioning. Arm exercise could be an added feature, but might be a separate device. The device could be portable, collapsible (probably $<2 \text{ ft}^3$ stowed) and have a weight of approximately 20 pounds to give it "carry on" usability.

Although these studies were constrained by the small number of samples, especially on SL 1/2, by variations in flight protocols and diets which resulted in significant weight losses, and although exercise protocols and devices were crude and protection incomplete, a number of conclusions seem evident. These can be summarized simply by the statement: if man is provided a certain minimal amount and type of diet and exercise both of which can be realized in practical space flight, his musculoskeletal system appears to be capable of sustaining space flights of any length practicable at this time.

References

1. *Skylab 1/2 Preliminary Biomedical Report*, JSC 08439. Sept. 1973, sec. 2.4.
2. Rushmer, Robert. 1961 *Cardiovascular Dynamics*, 2nd ed., p. 172. W. B. Saunders & Co., Phila. & London.
3. Ochsner, A., Jr., et. al. 1951. Normal Blood Pressure in the superficial venous system of man at rest in the supine position. *Circulation*, 3:674-680.
4. Gauer, O. H. and J. P. Henry. 1963. Circulatory basis of fluid volume control. *Physiological Rev.* 43:423.
5. Clarke, H. H. 1966. *Muscular Strength and Endurance in Man*. Prentice Hall.
6. *Physical Fitness Research Digest*, Series 4 No. 1, Jan. 1974. President's Council on Physical Fitness and Sports.
7. J. E. Vanderveen and T. H. Allen. 1972. Energy Requirements of Man in Weightless Environment. *Life Sciences and Space Research*, COSPAR, vol. X. Akademie-Verlag, Berlin.

2.5 EVA Metabolic Rate Assessment (SL-4)

James M. Waligora and David J. Horrigan

During SL-4, four extravehicular activities were conducted having a total duration of 22 hours and 15 minutes. Metabolic rates were calculated for each of the extravehicular activities using the correlation of heart rate and Astronaut Life Support Assembly (ALSA) parameters to metabolic rates. The metabolic rates and durations are presented in table 2.5-I. The metabolic rates were at or below the predicted levels based on previous EVA's. During the EVA's the crewmen shared coolant flow from a single suit umbilical cooling loop as in the prior Skylab EVA's. This configuration provided adequate cooling during the EVA's. With two hours remaining in the fourth EVA, the SPT developed a water leak in his pressure control unit (PCU) connector. The leak greatly reduced the effectiveness of the LCG and during the last 60 minutes he was effectively cooled by gas cooling only. The use of gas cooling for that limited period and at the metabolic rates experienced was not a problem and did not limit the EVA.

Table 2.5-II lists the metabolic rates for each crewman for specific activities during EVA 1 performed on MD 7. As shown, the peak workload for the PLT was 1445 Btu/h during his egress to foot restraints. The SPT had a peak of 1369 while translating to the Center work station and installing the S228 experiment. The average rates for the total duration of 6 hours and 34 minutes are shown in table 2.5-I. The primary objectives of this EVA were to install film and to repair the S193 Earth Resources tracking antenna. These objectives were essentially completed - the S193 being enabled to operate on its roll axis only, whereas it had been inoperative.

The second EVA was performed on MD 40 with a duration of 6 hours and 54 minutes. Resupplying film and comet experiments were the major objectives and they were accomplished. The PLT had a peak workload of 969 Btu/h while he was working on S020, the X-ray/ultraviolet solar photograph and T025, the coronagraph. The peak workload for the CDR was 1061 Btu/h during the egress. Table 2.5-III has the listing of metabolic rates by activity.

On MD 44, EVA 3 was accomplished in 3 hours and 28 minutes. The peak workload for the SPT was 1291 Btu/h during the egress. The CDR's peak was 822 Btu/h during the retrieval of the AM meteoroid sample. Major objectives were comet observations and experiment deployment and retrieval. The specific tasks which were successfully accomplished are shown in table 2.5-IV along with the corresponding metabolic rates. The average metabolic rates again indicated low to moderate work levels and are listed in table 2.5-I.

On MD 80, EVA 4 had a duration of 5 hours and 19 minutes. The objectives were film retrieval and photography and, again, they were successfully carried out, as shown in table 2.5-V. The peak workload for the SPT was 1098 Btu/h during offloading and setting up of T025. The CDR had the peak workload of 1215 Btu/h during D024 retrieval and stowage. Again, the average work rates were moderate, being 883 Btu/h for the CDR and 730 Btu/h for the SPT. As mentioned before, the SPT completed the last hour of the EVA on gas cooling only. This action was prompted by a water leak in the SPT's pressure control unit; and did not impair his performance or successful completion of the EVA.

TABLE 2.5-I. AVERAGE METABOLIC RATES DURING SL-4 EVA'S

EVA	DURATION		METABOLIC RATES (Btu/h)		
	h	min	CDR	SPT	PLT
1	6	34	---	982	920
2	6	54	621	---	815
3	3	28	578	877	---
4	5	19	883	730	---

TABLE 2.5-II. SL-4 EVA 1

G.m.t.	Elapsed Time (minutes)	Activity Completed	Metabolic Rate Btu/h	
			PLT (EV1)	SPT (EV2)
326:17:43	0	Depressurization		
326:17:47	4	PLT egress to foot restraints	1445	1087
326:18:08	21	Unstowing gear and setting up in FAS area	1427	1202
326:18:18	10	Taking T025 exposures and working on broken shutter speed knob	1067	679
326:18:28	10	Unstowing more equipment	1187	956
326:18:33	5	Translating to center work station and installing S228 experiment	725	1369
326:18:43	10	S056 and H α -1 film installed	1055	1123
326:19:03	20	S082 A and B film installed	755	1207
326:19:18	15	Working on H α -2 door	577	797
326:19:33	15	S149 deployed	789	1029
326:19:38	5	Transfer to FAS	761	1069
326:20:12	34	Twin sail sample & D024	771	1154
326:20:38	26	Deployed S230	898	1057
326:20:49	11	Stowing trees & unloading gear for S193	1009	1127
326:20:52	3	Transfer to S193 area	1185	677
326:21:06	14	Setting up portable foot restraint and deploying tools	1124	1040
326:21:54	48	Cleaning out S193 roll pot	646	473
326:23:13	79	Install S193 jumper box and checking out	758	892
327:00:00	47	Pin the S193 pitch gimbal and install disable plug	1031	729
327:00:18	18	Clean up S193 area, translate to FAS, enter AM and close hatch	948	1250

TABLE 2.5-III. SL-4 EVA 2

G.m.t.	Elapsed Time (minutes)	Activity Completed	Metabolic Rate Btu/h	
			PLT (EV1)	CON (EV2)
359:16:54	0	Depressurization		
359:17:00	6	EV1 egress to foot restraints	948	1061
359:17:38	38	Unstowing equipment and setting up S020 and T025	946	971
359:18:06	28	EV2 traversing to VC to replace film EV1 working on S020 & T025 & supplying EV2	969	729
359:18:37	31	EV1 doing T025, EV2 waiting in VC	778	606
359:19:33	56	Replace S052, S054, S056 and H α -1 film	644	788
359:20:26	53	Sun end film replacement	682	785
359:21:50	84	Working on S201	581	699
359:23:26	96	Installing new S054 camera	655	954
359:23:38	12	Finishing S020	772	958
359:23:48	10	Stowage and close hatch	600	928

TABLE 2.5-IV. SL-4 EVA 3

G.m.t.	Elapsed Time (minutes)	Activity Completed	Metabolic Rate Btu/h	
			SPT (EV1)	CDR (EV2)
948	363:17:29	Depressurization		
946	363:17:33	EV1 egress, EV2 managing umbilical	1291	402
969	363:17:43	Orientation and retrieval of SEVA sail sample	1135	597
	363:17:47	Retrieval of AM meteoroid sample	706	822
778	363:18:06	Unstow S020 and T025	1083	529
644	363:18:20	Setting up T025 and starting S020	995	350
682	363:18:58	T025 operations	759	350
581	363:19:43	Comet photos, rest, and S201 preparation (night pass)	752	466
655	363:20:36	S201 operations	825	365
772	363:20:48	Temperature measurements on S201 and comet ob- servations	606	512
600	363:20:57	Stow S201 and close hatch	611	547

TABLE 2.5-V. SL-4 EVA 4

G.m.t.	Elapsed Time (minutes)	Activity Completed	Metabolic Rate Btu/h	
			SPT (EV1)	CDR (EV2)
034:15:19	0	Depressurization		
034:15:21	3	EV1 egress to foot restraints	661	539
034:15:35	14	Offloading & setting up T025	1098	1080
034:15:48	13	S020 offloaded, set up and aligned	1063	684
034:16:19	31	Start T025 exposures	727	701
034:16:25	6	Work on clothesline & take Nikon photos	621	526
034:16:35	10	Retrieve S054, S056, S052, and H α -1 photos	577	992
034:16:50	15	More T025 exposures	753	884
034:17:04	14	Aligning clothesline & sun end film replacement	605	566
034:17:25	21	DAC photos of spacecraft	595	753
034:17:50	25	More T025	618	750
034:18:00	10	Finish T025 and stow T025 and DAC in AM	625	860
034:18:13	13	Getting sample of airlock material cover	458	965
034:18:36		SPT has water leak		
034:18:55	42	Returning US Tree to FAS, Stowing S020 and taking Nikon photos	957	1023
034:19:36		Crew comments temperature OK		
034:19:38	43	Retrieve S149	699	854
034:19:52	14	Retrieve S230, S228, and sail sample	545	789
034:20:08	16	D024 retrieved & stowed	549	1216
034:20:16	8	Nikon photos from VC & deployment of boom	534	1099
034:20:38	22	Stowage of gear & hatch closing	879	942

2.6 Drug Sensitivity Testing

J. R. Hordinsky, M.D.

The 62 drugs in the IMSS were tested according to the following rationale:

- Oral drugs To be tested if no prior history of exposure; some very potent drugs used largely in emergency situations were also omitted from testing.
- Injectable drugs To be tested in oral form if no prior history of exposure; again some emergency drugs were omitted from testing.
- Topical drugs All topicals were tested.

Actual Testing

a. Oral phase:

Each drug was individually packaged and provided to the crewmen with a schedule of testing dates. The individual drugs were to be taken in the morning with the exception of the hypnotics and the laxative. Log sheets for recording pertinent reactions were to be utilized by the crew. Particular attention was directed to side effects of scopolamine/dextroamphetamine sulfate (Scop/Dex), Demerol®, Valium®, Thorazine®, and Marezine®. Flying and alcohol intake were restricted with intake of certain of the drugs.

Oral drug testing was conducted in May and June 1973. The following drugs were actually tested for the individual crewmen:

CDR	SPT	PLT
Ampicillin	Ampicillin	Ampicillin
Chloral Hydrate	Chloral Hydrate	Chloral Hydrate
Erythromycin	Sulfisoxazole	Sulfisoxazole
Sulfisoxazole	Cephalexin	Cephalexin
Cephalexin	Tetracycline	Erythromycin
Secobarbital	Secobarbital	Secobarbital
Tetracycline	Penicillin	ASA® Codeine
Penicillin	Pseudoephedrine	Meperidine
Pseudoephedrine	Actifed®	Dextroamphetamine
Flurazepam	Flurazepam	Flurazepam
Actifed®	ASA® Codeine	Cyclizine
ASA® Codeine	Meperidine	Scop/Dex
Meperidine	Dextroamphetamine	Chlorpromazine
Dextroamphetamine	Cyclizine	Diazepam
Cyclizine	Scop/Dex	Peri-Colace®
Scop/Dex	Chlorpromazine	Donnatal®
Chlorpromazine	Diazepam	Robitussin-DM®
Diazepam	Peri-Colace®	
Donnatal®	Lomotil®	
Peri-Colace®	Donnatal®	
Lomotil®	Phenazopyridine	
Phenazopyridine	Darvon Compound 65®	
Mylanta®	Mylanta®	
Robitussin-DM®	Robitussin-DM®	

®=Registered

Subsequent testing was done over a period of three days with various combinations of scopolamine/dextroamphetamine sulfate and with promethazine-ephedrine (Pro-Eph). This will be described in a separate section. The oral testing did not reveal any unique intolerances. It should be noted that since the SL-3 and SL-4 backup crew were the same, no additional testing of the backup crew was done, but the PLT was known to have a demonstrated intolerance to scopolamine.

b. Topical phase:

All 20 topical drugs were applied to the back as patch tests and they remained in place for 48 hours (figure 2.6-1). None of the crewmembers demonstrated any unique skin sensitivity. The tested topical drugs were:

Alpha Keri [®] Lotion	Fluocinolone acetoneide	Idoxuridine
pHisoHex [®]	Neosporin [®] Ointment	Blistex [®]
KY [®] Jelly	Mycolog [®] Cream	Prednisolone
J&J [®] First Aid Cream	Mafenide Cream	Oxymetazoline
Chloramphenicol	Tolnaftate Solution	Hyoscine
Pilocarpine	Polymyxin B	Proparacaine hydrochloride
		Ponaris [®]
		Methylcellulose

[®] Registered

Application of skin tests was on 7 July and reading on 9 July 1961.

Hypnotics

As a byproduct of the drug sensitivity testing, a preference for the three hypnotics was made by each individual crewman. These preferences were largely maintained in flight.

Antimotion Sickness Drug Testing

Due to the concern about early in-flight motion sickness, special attention was paid to evaluating sequential doses of specific antimotion sickness medication. The two primary drug combinations evaluated were:

Scopolamine/Dextroamphetamine sulfate (0.4 mg/5 mg) and

Promethazine-Ephedrine (25 mg/50 mg).

three days with
amphetamine sulfate
This will be des-
ing did not reveal
that since the
additional testing
known to have a

k as patch tests
ure 2.6-1). None
kin sensitivity.

Idoxuridine
Blistex®
Prednisolone
Oxymetazoline
Hyoscine
Proparacaine hydro-
chloride
Ponaris®
Methylcellulose

reading on 9 July 1971

reference for the
These preferences

ness, special at-
specific antimotion
ons evaluated were:

(mg) and

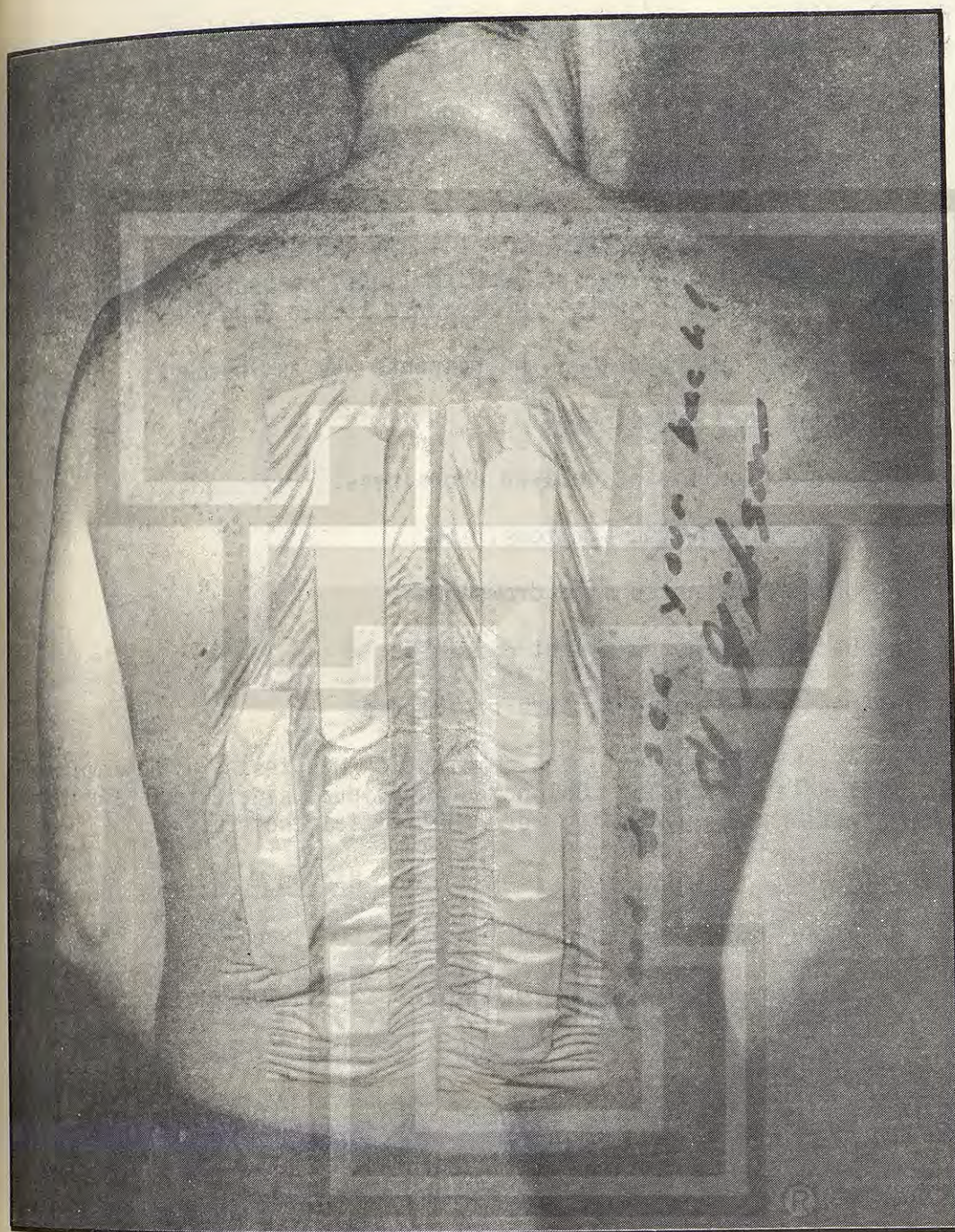


Figure 2.6-1. - Topical Drugs Tested by the Patch Test Method.

Firstly, individual samples of the above were administered. With Scop/Dex, the response was as follows:

CDR noted slight euphoria and drowsiness

SPT noted occasional dizziness

PLT noted general edginess.

The backup CDR and SPT had no problems, but the backup PLT developed scotomata and visual changes in response to the drug combination.

With Promethazine-Ephedrine, the response was as follows:

CDR noted more drowsiness.

SPT noted significant delayed drowsiness.

PLT noted no adverse symptoms.

The backup CDR noted mild drowsiness.

The backup SPT noted slight dizziness.

The backup PLT noted no adverse effects.

Secondly, the efficacy of each combination was tested using exposure the M131 Rotation Chair. Balancing individual side effects and effects of protection, the following were the initial choices:

<u>Prime Crew</u>	<u>Backup Crew</u>
CDR, Scop/Dex	CDR, Scop/Dex
SPT, Scop/Dex in the a.m. Pro-Eph in the p.m.	SPT, Scop/Dex
PLT, Pro-Eph	PLT, Pro-Eph

The drugs of choice were then taken sequentially. Various symptoms were noted, the major one of which was insomnia for the CDR of the Prime Crew when taking Scop/Dex sequentially.

Table 2.6-I shows the final Skylab-4 Antimotion Sickness Medication Plan. The "X" through the Scop/Dex of the SPT on MD 1 indicates that dose of Scop/Dex was omitted on that particular day.

administered. With

backup PLT developed
drug combination.

follows:

tested using exposure
side effects and effi
ices:

Crew

op/Dex

op/Dex

o-Eph

Various symptoms
or the CDR of the

Sickness Medication
MD 1 indicates that
ay.

TABLE 2.6-1. SKYLAB-4 ANTIMOTION SICKNESS MEDICATION PLAN

MISSION EVENT	APPROX. TIME (hours)	CDR	SPT	PLT
Launch Day (MD 1)				
After Insertion	0900		Scop/Dex	Pro-Eph
After NC-1	1100	Scop/Dex	Scop/Dex*	
	1300			
After Docking	1600	Pro-Eph	Pro-Eph	Pro-Eph
	2030			Pro-Eph**
MD 2 & MD 3				
On Arising	0600	Scop/Dex	Scop/Dex	Pro-Eph
	1000	Scop/Dex	Scop/Dex	
	1400	Pro-Eph	Pro-Eph	Pro-Eph
MD 4				
On Arising	0600	Scop/Dex	Scop/Dex	Pro-Eph
	1400			Pro-Eph**
(Medication up through the 0600 dose on MD4 was mandatory)				
MD 85				
About 2 hours prior to splash (entry)		Scop/Dex	Scop/Dex	Scop/Dex

* Dose omitted-Real time decision

** Dose added-Real time decision

Since antmotion sickness medication was mandatory for the upcoming flight, the CDR chose to take Scop/Dex in the morning and Pro-Eph in the afternoon as per the SPT's plan, thus reducing the chance of insomnia.

The CDR requested to take his first medication only after a critical burn had been completed.

A vestibular evaluation conference on 25 October with Dr. Joe Kerwin, Dr. Owen Garriott and numerous other consultants evaluated the need for preventive action in the upcoming flight. It was the consensus of the conference which led to the aforementioned medication plan.

2.7 Biosensor Sensitivity Testing

J. R. Hordinsky, M.D.

As none of the SL-4 crewmen had demonstrated any particular sensitivity to the OBS (ECG) or to the VCG electrodes, paste, or overtape, no special testing of these was conducted.

After the M133 experiment was added to SL-4, the SPT applied a sample of the EEG electrode paste to his forehead. The site was examined after 24 hours; no untoward reaction was noted.

2.8 Biostereometric Analysis of Body Form

*Michael Whittle, M.D., Robin Herron, Ph.D.
and Jaime Cuzzi, B.Sc.*

Stereometric analysis of body form was performed on the final Skylab crew using four-camera stereophotogrammetry. Sets of imagery were obtained four times preflight on days F-35, F-21, F-10, F-6 and four times postflight on days R+0, R+1, R+4 and R+68. Reduction of optical imagery to coordinate data is complete for all measurements except the last.

Comparison between the immediate preflight measurement, on day F-6, and immediate postflight, on day R+0, reveals a pattern seen on both previous Skylab flights--a loss of volume in the legs, but no consistent changes in the remainder of the body.

Table 2.8-I compares the weight and total body volume of the crewmen.

TABLE 2.8-I. WEIGHT AND VOLUME OF SL-4 CREWMEN AT F-6 AND R+0 DAYS

TIME DAYS	CDR		SPT		PLT	
	WEIGHT kg	VOLUME Liters	WEIGHT kg	VOLUME Liters	WEIGHT kg	VOLUME Liters
F-6	68.72	68.48	70.99	71.60	67.13	67.26
R+0	67.93	68.68	68.95	67.82	66.68	66.57
Difference	-0.79	+0.20	-2.04	-3.78	-0.45	-0.69

Within the estimated accuracy of the volume determination (about 1%) these figures do not suggest the PLT showed any marked changes in the ratio of fat to denser tissues; the SPT probably lost some body fat, and the CDR may have increased his body volume, without a concomitant increase in weight, by replacing part of his muscle bulk with fat.

Table 2.8-II compares the volume changes in the legs with those in the remainder of the body. All three crewmen show a greater proportional change in the legs than in the body above this level, the CDR and PLT showing modest increases in volume above the legs, the SPT demonstrating volume loss throughout the body, but proportionally greater in the legs.

The interpretation of the stereometric analysis will be enhanced by consideration of the other preflight and postflight results, which have been analyzed by computer, but not yet subjected to physiological

interpretation. The data given here suggest that both CDR and PLT lost some muscle bulk, particularly in the legs, and may have added little to their body fat. The SPT probably lost both fat and muscle in the course of the mission. The loss of muscle bulk in the legs was probably of similar magnitude to that seen on both the previous missions (SL 1/2 and SL-3).

TABLE 2.8-II. VOLUME CHANGES IN THE LEGS AND THE REMAINDER OF THE BODY IN THE SL-4 CREW (liters)

TIME DAYS	CDR		SPT		PLT	
	HEAD, ARMS, TRUNK	LEGS	HEAD, ARMS, TRUNK	LEGS	HEAD, ARMS, TRUNK	LEGS
F-6	54.50	13.98	56.25	15.35	51.34	15.92
R+0	55.32	13.36	53.99	13.83	51.61	14.96
Differences	+0.82	-0.62	-2.26	-1.52	+0.28	-0.96
% Change	+1.5	-4.4	-4.0	-9.9	+0.5	-6.1

at both CDR and PLT
, and may have added
t both fat and muscle
le bulk in the legs
oth the previous

AND THE REMAINDER
EW

	PLT	
HEAD,		
ARMS,		
TRUNK	LEGS	
1.34	15.92	
1.61	14.96	

0.28	-0.96
0.5	-6.1

2.8.1 Skin Fold Thickness

Michael Whittle, M.D.

Using "Lange" skin fold calipers and standardized technique, the thickness of folds of skin at six points on the body surface were measured by the same observer. Measurements were made four times preflight at F-21, F-10, F-6, and F-1 day, and three times postflight at R+0, R+1, and R+4 days. The three points on each side of the body measured are shown in figure 2.8.1-1. These points were:

- Triceps, normal to the posterior axis of the arm, midway between the olecranon and acromion.
- Subscapular, normal to a line running laterally and down at 45° from the horizontal, from the lowest point of the scapula, two inches from that point.
- Abdominal, normal to a line running laterally from the umbilicus, and immediately superior to the anterior superior iliac spine.

Preflight and postflight mean results are given in table 2.8.1-I. All three crewmen showed a reduction in mean triceps skin fold thickness. Only one measurement, the 0.73 mm triceps skin fold loss on the PLT, is statistically significant. Pooling the results for the three men, making the appropriate adjustments for differences in their initial skin fold thickness, shows that the crew as a whole lost about 10% of the skin fold thickness over the triceps, a figure which is statistically significant at the 5% level. No such trend is apparent in the subscapular or abdominal skin fold measurements.

The lack of statistical significance in much of this data is a reflection on the inherent variability of skinfold thickness measurements. It may be stated with confidence, however, that no marked general increase or decrease in subcutaneous fat occurred in any of the crewmen. The significant losses in the triceps skinfold measurement are more likely to represent a regional fat loss than a generalized loss, which failed to appear in the other measurements. It is interesting to speculate that such regional loss may be connected with the increased use of the arms in zero gravity.

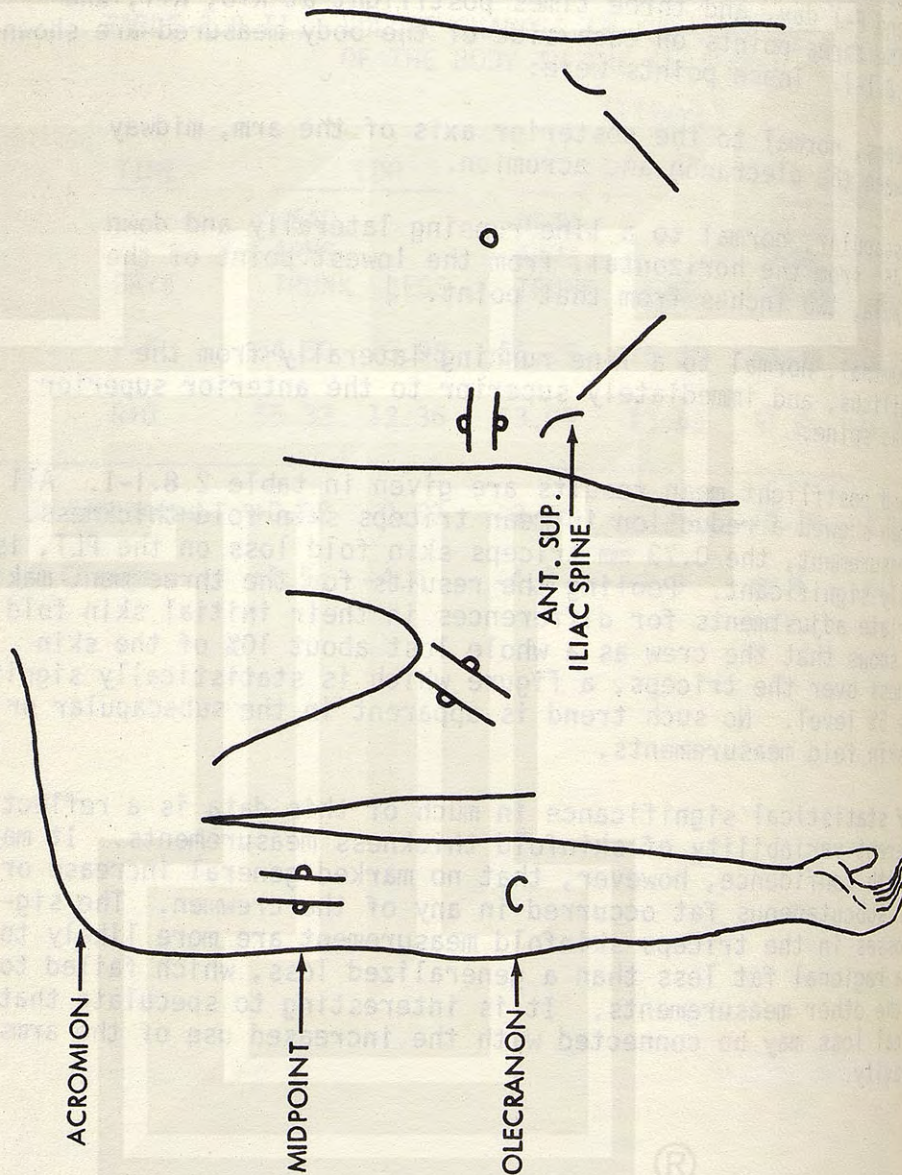


TABLE 2.8.1-I. PREFLIGHT AND POSTFLIGHT SKIN FOLD MEASUREMENTS
(MEAN FOR BOTH SIDES OF BODY)

	COMMANDER			SCIENTIST PILOT			PILOT		
	TRICEPS	SUBSCAP	ABDO	TRICEPS	SUBSCAP	ABDO	TRICEPS	SUBSCAP	ABDO
Preflight	6.13	12.44	9.06	10.44	9.81	7.94	4.06	8.06	5.75
Postflight	5.67	13.42	10.17	10.00	10.00	6.92	3.33	8.08	5.00
Difference	-0.46	+ 0.98	+ 1.11	- 0.44	+ 0.19	-1.02	-0.73	+0.02	-0.75
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	SIG.	N.S.	N.S.

SIG. = Significant at 5% level

N.S. = Not significant

2.9 Skylab-4 Visual Function Report

Lester R. Loper, O.D.

The Skylab-4 astronauts were given a complete ophthalmic preflight examination which included refraction of the eye and binocular measurements in addition to the items reported on here. Statistical analysis of the data presented is not possible due to the instrumentation employed and the number of subjects involved and, thus, this report should be considered in the nature of clinical observations. The SL-4 astronauts noted that their conjunctival vessels became engorged during the first few days of the flight and the CDR and PLT reported that near vision deteriorated during the flight. The preflight examination showed the CDR to have ample accommodative reserves (R. 5.25 diopters and L. 5.75 diopters); the PLT had been fitted with reading spectacles.

The entire crew showed a slight decrease in visual acuity on R+1 day and returned to normal by R+5 days, the only across-the-board trend noted.

The CDR in addition to the decreased acuity showed decreased accommodation on R+1 day which returned to preflight levels at R+5 days, his intraocular pressure was down at R+1 and R+5 days which returned to the preflight level by R+17 days. There were no other significant ocular changes.

The ocular fundus examination of the SPT on R+1 day showed the retinal arteries to be constricted with an arteriovenous ration of 1:2. This returned to normal by R+5 days. There were no other significant ocular changes.

Peripheral field measurements of the PLT at R+1, R+5, and R+17 days showed an erratic superior field contraction. This field contraction proved to be an artifact caused by deep-set eyes. His depth perception was down on R+1 day and returned to normal on R+5 days. There were no other significant ocular changes.

Tables 2.9-I, -II, and -III summarize the Skylab-4 Visual Function Data.

CDR

TABLE 2.9-I. SUMMARY OF SKYLAB-4 VISUAL FUNCTION DATA, COMMANDER

Unit	Preflight		Day		R+1		R+5		R+17	
	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.
Visual Acuity - 20 feet	20/21	20/17	20/27	20/22	20/19	20/18				
Accommodation	5.25	5.75	4.60	4.80	6.00	6.25				
Intraocular Pressure	14.5	17.0	11.3	12.5	12.0	10.5			14.0	15.5
Peripheral Fields										
Superior	47	37	46	36	45	39				
Sup. Temp.	64	49	56	55	62	55				
Temporal	90	88	92	89	91	88				
Inf. Temp.	87	85	91	86	92	88				
Inferior	73	70	73	73	71	68				
Inf. Nasal	51	56	56	60	57	54				
Nasal	56	57	61	57	59	63				
Sup. Nasal	54	52	57	47	56	53				
*Depth Perception	58.2		34.1		19.1					
Color Perception (Nagel Anomaloscope)	42.8		43.9							

*Depth Perception: Subject has exhibited considerable variability previously - average of 34.1 plus last three annual physicals is 34.8 mm.

TABLE 2.9-II. SUMMARY OF SKYLAB-4 VISUAL FUNCTION DATA, SCIENTIST PILOT

SPT

Sup. Nasal

*Depth Perception

mm

Separation

Color Perception
(Nagel Anamaloscope)*Depth Perception:
Preflight plus last three annual physicals

Subject has exhibited considerable variability previously - average of 54.0 mm.

TABLE 2.9-II. SUMMARY OF SKYLAB-4 VISUAL FUNCTION DATA,
SCIENTIST PILOT

SPT

	Unit	Preflight		Day R+1		R+5	
		R.	L.	R.	L.	R.	L.
Visual Acuity - 20 feet	Snellen Fraction	20/22	20/17	20/22	20/20	20/17	20/17
Accommodation	Diopters	5.75	5.50	-	-	5.75	6.00
Intraocular Pressure	mm Hg	17.0	16.5	19.0	18.0	17.5	15.0
Peripheral Fields	Degrees						
Superior		52	47	49	49	53	45
Sup. Temp.		73	64	73	63	76	57
Temporal		95	93	96	86	97	96
Inf. Temp.		94	86	93	89	92	89
Inferior		70	60	70	64	72	61
Inf. Nasal		46	54	53	48	49	56
Nasal		53	59	59	65	59	67
Sup. Nasal		60	56	54	54	57	57
Depth Perception	mm Separation	20.4		*		7.8	
Color Perception (Nagel Anamaloscope)		40.8		41.5			

*R+1 depth perception data not available due to instrument malfunction.

Ophthalmoscopy: R+1 day O.D. and O.S., retinal arteries attenuated A-V ratio 1:2. R+5 day negative.

TABLE 2.9-III. SUMMARY OF SKYLAB -4 VISUAL FUNCTION DATA, PILOT

PLT

Unit	Preflight		Day		R+17	
	R.	L.	R.	L.	R.	L.
Visual Acuity - 20 Feet	20/14	20/15	20/20	20/20	20/12	20/12
Accommodation	2.00	1.75	-	-	1.75	1.75
Intraocular Pressure	21.5	19.0	20.0	20.5	20.0	18.0
Peripheral Fields						
Superior	40	41	46	42	34*	29*
Sup. Temp.	60	55	63	53	49*	47*
Temporal	93	88	94	93	98	83
Inf. Temp.	89	88	95	88	95	86
Inferior	70	77	70	72	76	73
Inf. Nasal	57	64	60	63	54	61
Nasal	57	68	61	66	57	67
Sup. Nasal	45	50	54	40*	48	36*
Depth Perception	mm					
Separation	6.7		22.0		8.2	
Color Perception (Nagel Anomaloscope)	43.3		41.6			

*Superior field constricted due to deep-set eyes.

In cont
vestibu
no stru
interre
to habi
the M13
motion
fact wa
engage
vestibu

During
engage
toleran
line mo
line te
Also, a
30 rpm
antimot
complet
thus in

A second
batics
may hav
activit
The aer
stress
the fly
ing fly
FCHSP w

By acco
experie
aerobate
Sketch
g-stres

CDR

2.10 Preflight Vestibular Habituation

J. L. Homick, Ph.D. and J. R. Hordinsky, M.D.

In contrast to the first two Skylab missions no formal preflight vestibular habituation protocol was developed for the SL-4 crew. That no structured procedures were recommended stemmed from at least two interrelated factors. First, there was no clear evidence that attempts to habituate the first two crews to stressful vestibular stimulation in the M131 rotating chair had any value in protecting these men against motion sickness when they entered weightlessness. Coupled with this fact was a strong desire expressed by the astronauts themselves to engage in other activities which might increase their tolerance to vestibular stress upon entering zero-g.

During the course of preparing for their mission the crewmen did however, engage in several activities which had the net effect of increasing their tolerance to normally stressful vestibular stimuli. Included was baseline motion sensitivity testing in the M131 rotating chair. These baseline tests numbered 4, 6, and 4 for the CDR, SPT, and PLT, respectively. Also, approximately 10 days before launch, each crewman had one run at 30 rpm in the M131 rotating chair to test the effectiveness of his antinotion sickness drug of choice in preventing symptoms. All crewmen completed the required 150 head movements with no symptoms reported, thus indicating the efficacy of the drug.

A second type of activity, performed by the prime SPT only, was aquatics (post antinotion sickness drug ingestion) in a water tank which may have contributed minimally to his increased tolerance. A third activity performed by each of the SL-4 crewmen was aerobatic flying. The aerobatics provided rapid roll rates and high-g exposures thus stressing both the semicircular canals and otolith organs. In addition, the flying was stimulating to the crew just from the point of maintaining flying proficiency and providing diversion, especially once the FCHSP was in full effect.

By accompanying the crewman on several occasions, the Crew Surgeons experienced the exact stresses that the crew was experiencing in the aerobatics. The routine aerobatics for the crewmen began as noted below. Sketches of some of the procedures are included with the maximum g-stresses associated also noted.

CDR: Start of routine aerobatics, 19 September.

Frequency of one hour/week then about two hours/week in mid October.

Sup. Nasal

Depth Perception

Color Perception
(Nagel Anomaloscope)

*Superior field constricted due to deep-set eyes.

mm

Separation

62
38*

66
44

67
36*

57
48 8.2

50
40*

54 22.0 41.6

45 6.7 43.3

50

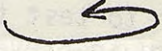
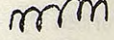
SPT: Start of routine aerobatics, 1 October

Frequency 1-1/4 hours/week then 2-1/2 to 3-1/2 hours/week in mid October.

PLT: Start of routine aerobatics, 10 September

Frequency of one hour/week, up to two hours/week in mid October.

Some of the typical procedures shown below are illustrated in more detail in figure 2.10-1.

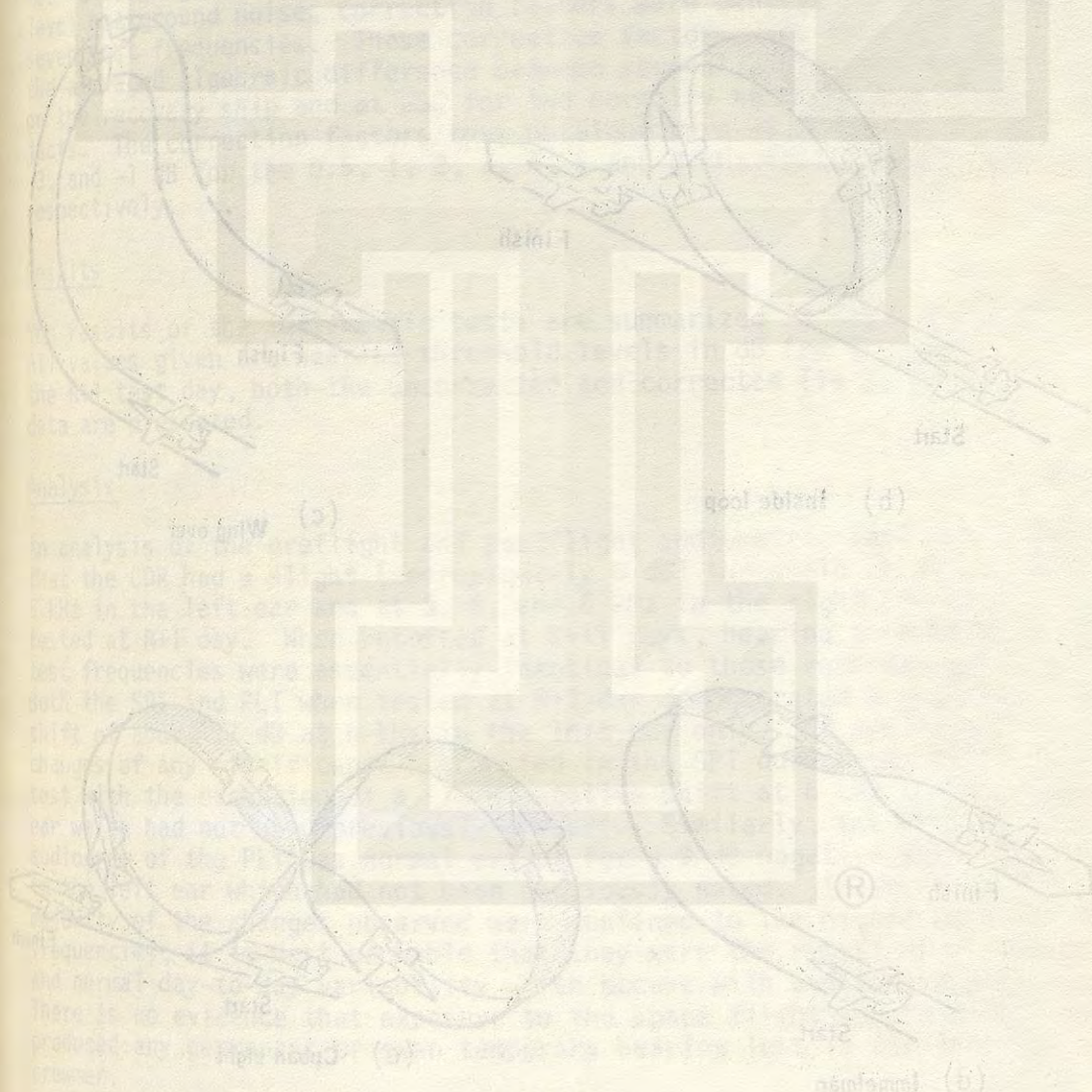
	Side View	Top View	G-Forces
Loops (b)			4-5
Cuban 8's (e)			4-5
Immelmanns (d)			4-5
Wing Overs (c)			3
Wing Over Rolls			3
Clover Leafs			4.5
Aileron Rolls (L&R) (a)			
(Head in various positions)			
Barrel Rolls			3
Lazy 8's			2.5
Random Turns			Variable
Loose Trai↑			Variable

Of the various preflight activities the areobatic flying experience was apparently the most significant in increasing each crewman's tolerance to vestibular stress. All of the crewmen, especially the CDR and SPT, had a much higher threshold of susceptibility to motion sickness at the end of the M131 preflight baseline data collection period than they had

had at the beginning of the baseline period. This upward shift in threshold was not observed in previous Skylab crews who had not engaged in extensive preflight aerobics.

The fact that very early in the mission the CDR experienced mild symptoms and the PLT severe symptoms suggests that the increased vestibular tolerance acquired preflight did not transfer to the weightless environment. Furthermore, any valid conclusions about effectiveness of preflight vestibular training procedures were completely confounded by the fact that all crewmen were on a mandatory schedule of antinotion sickness drug use during the first three days of flight.

to 3-1/2 hours/week
er
ours/week in
lustrated in more
op View
g-Forces
4-5
4-5
4-5
3
3
4.5
3
2.5
Variable
Variable



ing experience was
ewman's tolerance
y the CDR and SPT,
on sickness at the
period than they had

Acrobatic maneuvers

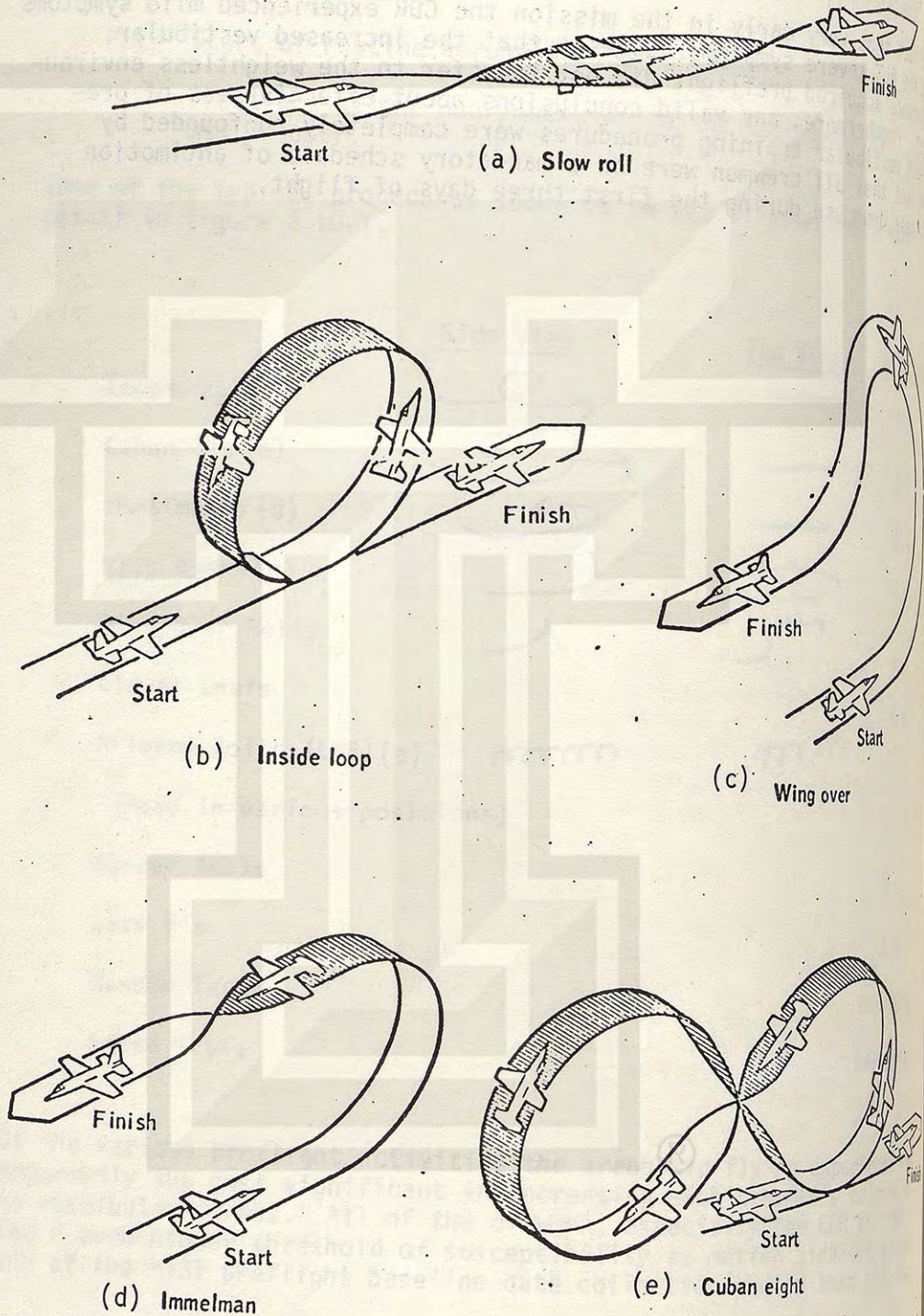


Figure 2.10-1. - Acrobatic Maneuvers Performed by the Crew in a T-38 Trainer.

2.11 Audiometry Tests

J. L. Homick, Ph.D. and M. F. Reschke, Ph.D.

Protocol

Standard clinical audiometric tests were performed on each of the crewmen at F-35, R+1, and R+11 days. The F-35 and R+11 day tests were conducted at JSC; the R+1 day test was conducted onboard the primary recovery ship. All testing was done with the crewmen seated in a standard audiometric test booth. Octave-band sound level measurements made inside of the audio booth on the recovery ship indicated the presence of masking noise slightly in excess of those values recommended for standard audiometric testing. In order to compensate for masking caused by the low level background noise, correction factors were derived for each of the seven test frequencies. These correction factors were obtained by taking the averaged algebraic difference between several audiograms conducted on the recovery ship and at JSC for two normally hearing control subjects. The correction factors thus obtained were -8, -4, -3, -2, -1, -3, and -1 dB for the 0.5, 1, 2, 3, 4, 6 and 8 kHz test frequencies, respectively.

Results

The results of the audiometric tests are summarized in table 2.11-I. All values given are hearing threshold levels in dB (re ISO 1964). For the R+1 test day, both the uncorrected and corrected (in parenthesis) data are presented.

Analysis

An analysis of the preflight and postflight audiometric data indicates that the CDR had a slight (approximately 6 dB) threshold shift at 2 and 6 kHz in the left ear and at 3, 4, and 6 kHz in the right ear when tested at R+1 day. When retested at R+11 days, hearing thresholds at all test frequencies were essentially identical to those recorded preflight. Both the SPT and PLT when tested at R+1 day demonstrated a negative shift of about 12 dB at 6 kHz in the left ear only. No additional changes of any significance were noted in the SPT during the R+11 day test with the exception of a 17 dB negative shift at 6 kHz in the right ear which had not been previously present. Similarly, the R+11 day audiogram of the PLT was normal except for a 9 dB negative shift at 8 kHz in the left ear which had not been previously noted. Inasmuch as the majority of the changes observed were confined to the higher test frequencies, it is most probable that they were the result of tinnitus and normal day-to-day variability which occurs with auditory acuity. There is no evidence that exposure to the space flight environment produced any permanent or even temporary hearing loss in any of the crewmen.

TABLE 2.11-I. PREFLIGHT AND POSTFLIGHT HEARING THRESHOLD LEVELS IN dB AT EACH OF SEVEN TEST FREQUENCIES FOR THE CDR, SPT, AND PLT OF SKYLAB 4

VALUES IN PARENTHESES HAVE BEEN CORRECTED FOR MASKING.

Frequency in Kilohertz

Time in Days	LEFT							RIGHT						
	0.5	1	2	3	4	6	8	0.5	1	2	3	4	6	8
CDR														
F-35	8	7	12	10	5	21	8	3	9	7	10	6	22	8
R+1	15(12)	14(10)	20(17)	12(10)	12(11)	31(28)	14(13)	15(7)	15(11)	20(17)	20(18)	20(19)	31(28)	11(10)
R+11	11	5	14	10	9	22	10	4	11	13	7	5	22	5
SPT														
F-35	6	3	3	0	0	10	0	-2	-4	-7	-7	-8	-3	0
R+1	8(0)	5(1)	-	6(4)	4(3)	25(22)	6(5)	6(-2)	-5(-9)	-2(-5)	-3(-5)	-10(-3)	0(-3)	-3(-4)
R+11	6	0	-4	-10	-5	3	5	5	0	3	0	-5	20	3
PLT														
F-35	13	5	-10	16	21	4	7	0	-5	-5	40	43	27	5
R+1	12(4)	3(-1)	0(-3)	25(23)	20(19)	18(15)	10(9)	8(0)	0(-4)	-5(-8)	37(35)	45(44)	22(19)	10(9)
R+11	7	-2	-8	20	12	-	18	0	-4	-7	30	42	17	10

5	10(9)	17	42	30	-7	-4	0	8(0)	0	7	10(9)	18	4	18(15)	12	20	25(23)	20(19)	21	16	25	12(4)	7	5	3(-1)	0(-3)	-8	-2	13	12	7	17	43	45(44)	22(19)	27	5
---	-------	----	----	----	----	----	---	------	---	---	-------	----	---	--------	----	----	--------	--------	----	----	----	-------	---	---	-------	-------	----	----	----	----	---	----	----	--------	--------	----	---

2.12 Skylab 4 Muscular Electromechanical Activity

A. Nicogossian, M.D.; J. T. Baker, B.S.; G. W. Hoffler, M.D.;
J. R. Hordinsky, M.D.; E. Burchard, M.D.; W. Thornton, M.D.
and R. L. Johnson, M.D.

Introduction

A generalized hyperreflexia was reported in the SL 1/2 crewmen during the R+0 day clinical evaluations (1). This finding supports earlier reports of postflight increase in reflex amplitude by Soviet investigators (2). In order to assess possible neuromuscular alterations following long duration space flights it was decided to conduct measurements of Achilles tendon reflex and its associated muscle potentials, together with surface electromyography of the right gastrocnemius muscle. The present investigation is an attempt to quantitate

- the time course of the postflight Achilles reflex duration, and,
- the muscle potential associated with the gastrocnemius muscle during selective mobilization.

Methods and Materials

Each one of the SL-4 crewmembers participated in three preflight and six postflight tests. On SL-3 crewmen, only one preflight test (F-5 day) and four postflight tests were obtained. The postflight tests were done immediately on recovery day and thereafter on a regular basis at the end of M092 experiments. The schedules for SL-3 and -4 tests were on the following days:

	Preflight	Postflight
SL-3	F-5	R+0, R+4, R+16, R+29
SL-4	F-21, F-10, F-6	R+0, R+1, R+5, R+11, R+17, R+31

The duration of the Achilles reflex and associated muscle potential were obtained in the following manner.

The crewmember positioned his right knee on the torso support section of the LBNP apparatus and was asked to achieve a maximum relaxation of the right leg muscles. A displacement transducer (Hewlett-Packard APT-16, Palo Alto, Calif.) was firmly attached to the plantar anterior bearing surface. Three sites were prepared on the midsection of the gastrocnemius muscle and regular VCG electrodes were placed to record the muscle electrical activity. The signals from both the displacement transducer and the surface electrodes were amplified and recorded

simultaneously on a strip chart (Brush MK 480, Cleveland, Ohio) and magnetic tape (Ampex 1260, Redwood City, Calif.). To obtain a reproducible and well inscribed tendon reflex the Achilles tendon was stimulated every two seconds for a total of thirty seconds with a percussion hammer; for the surface myography portion of the test, the displacement transducer was removed and the astronaut's (standing relaxed) right gastrocnemius muscle electrical activity was recorded for a period of 20 seconds. The potentials of the gastrocnemius muscle were then obtained during a 30-second toe stand, first supporting the total body weight and then repeated while holding a 40 pound weight in the right hand. Postflight data were compared to the preflight baseline values (Student's t-test SL-3 and 95% fiducial limits SL-4).

For each experiment an average number of 12 complexes were analyzed. The Achilles reflex duration was measured from the initial stroke to the tendon until all oscillations had ceased. This approach allowed for variations which might occur during either the contraction or relaxation phases. The electromechanical muscle potential interval delay for each reflex was measured from the time of the beginning of the upstroke to the point of greatest amplitude of the muscle potential spike (figure 2.12-1).

Results

The results of SL-3 crewmen Achilles tendon reflex durations are presented in figure 2.12-2. Table 2.12-I summarizes the data obtained from SL-4 astronauts.

Both the SPT and PLT exhibited a significant shortening of the reflex duration ($p < 0.01$) on R+0 day. The CDR failed to show any significant changes in the immediate postflight or on R+1 test day. On R+5 days, the CDR and SPT showed a markedly prolonged reflex duration, while the PLT did not exhibit the same trend until R+11 days. By R+31 test day all reflexes returned to their preflight values.

As can be seen from figure 2.12-3 both SL-3 and SL-4 crewmen exhibited similar trends in their reflex duration. The muscle electrical component of the reflex proved to be extremely difficult to obtain on the PLT. On R+1 and R+17 days the muscle electrical activity data on the CDR were not recorded. This might have been due to a faulty electrode. A full set of data was obtained on the SPT. The course of this data, despite the spotty values obtained on the CDR, paralleled the reflex duration time.

Discussion

The results, as presented here, closely follow those reported for SL 1/2 and SL-3 (1, 5) as well as by Russian investigators (2).

A — REFLEX DURATION — C

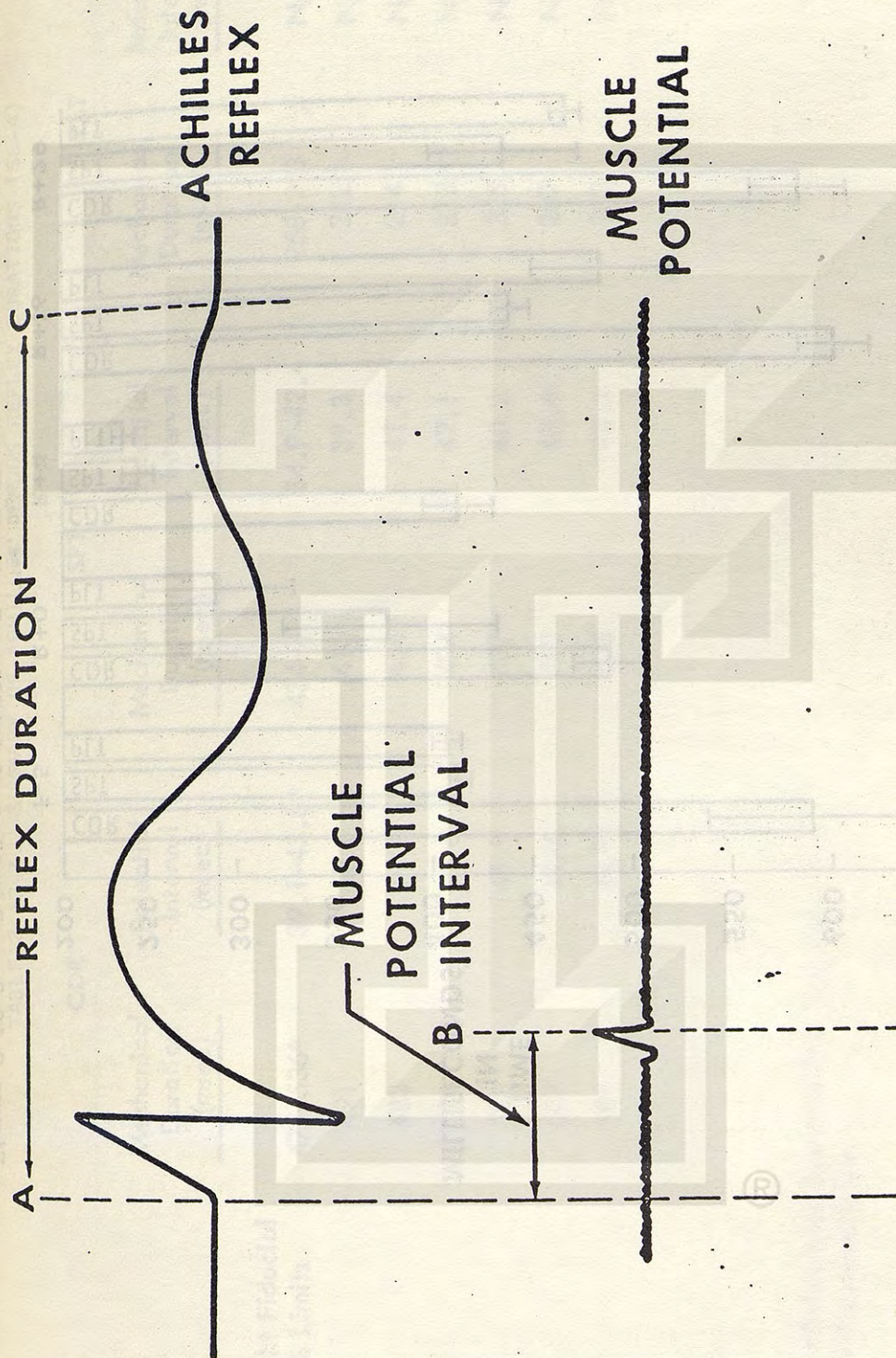


Figure 2.12-1. - Electromechanical Muscle Potential Interval.

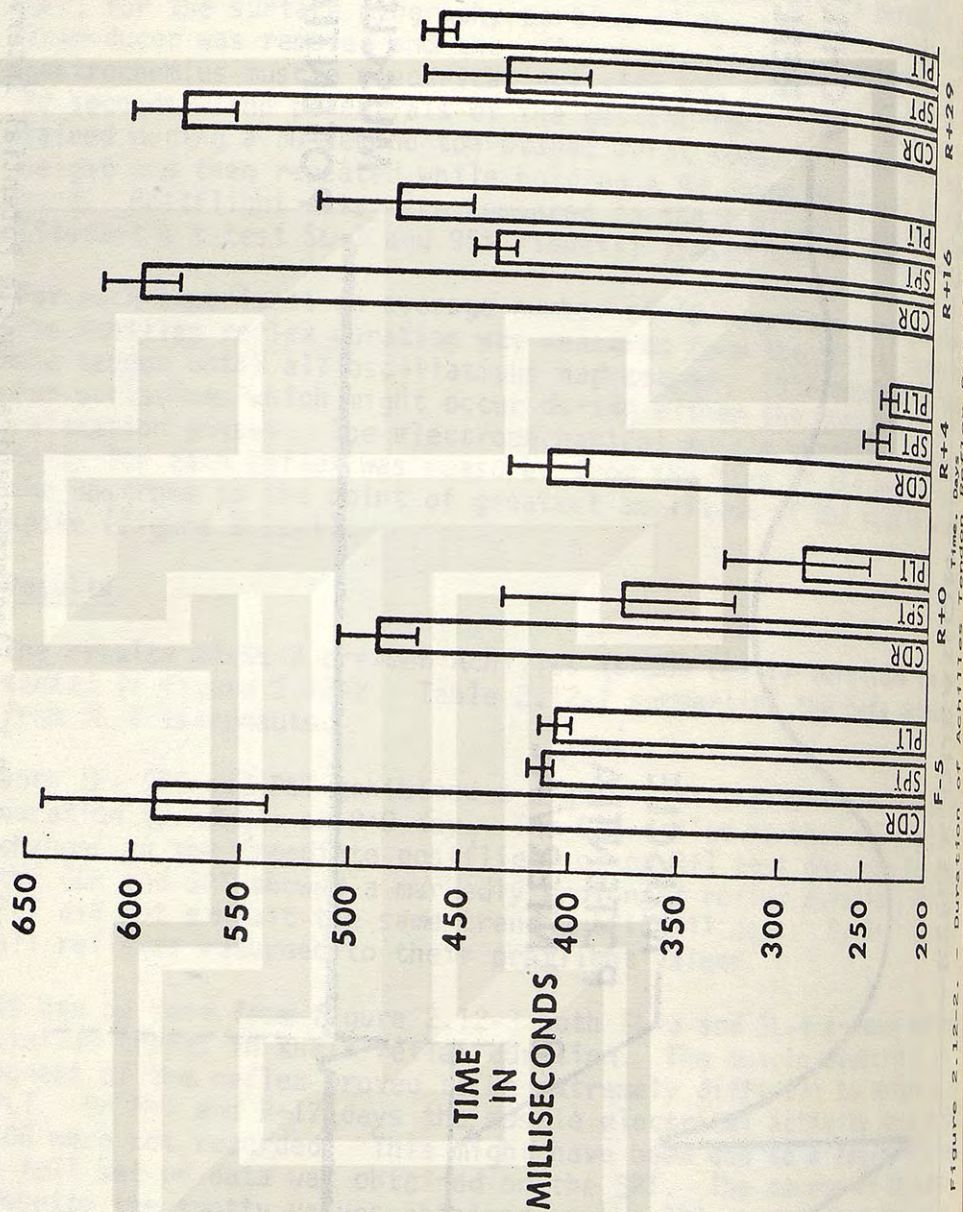


FIGURE 2.12-2. Duration of Achilles Tendon Reflex Durations (SL-4)

TABLE 2.12-1. SUMMARY OF ACHILLES TENDON REFLEX DURATIONS (SL-4)

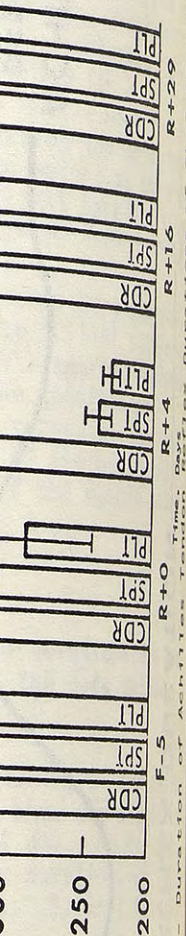


FIGURE 2.12-2. - DURATION OF ACHILLES TENDON REFLEX DURATION (SL-4)

TABLE 2.12-1. SUMMARY OF ACHILLES TENDON REFLEX DURATIONS (SL-4)

	CDR			SPT			PLT		
	Mechanical Duration (msec)	Potential Interval (msec)	Mechanical Duration (msec)	Mechanical Duration (msec)	Potential Interval (msec)	Mechanical Duration (msec)	Mechanical Duration (msec)	Potential Interval (msec)	Potential Interval (msec)
Preflight Fiducial	477-536*	39.1-43.8*	434-471		34.9-42.4	258-283		N/A**	
95% Limits									
Day R+0	491	40.6	416		39.3	242		N/A	
R+1	483	N/A	464		41.4	214		N/A	
R+5	556	45.6	494		47.1	213		N/A	
R+11	538	45.9	437		40.2	325		N/A	
R+17	537	N/A	482		45.6	287		N/A	
R+31	501	N/A	475		40.6	282		N/A	

*Calculated from the F-5 Day Values.

**Not available.

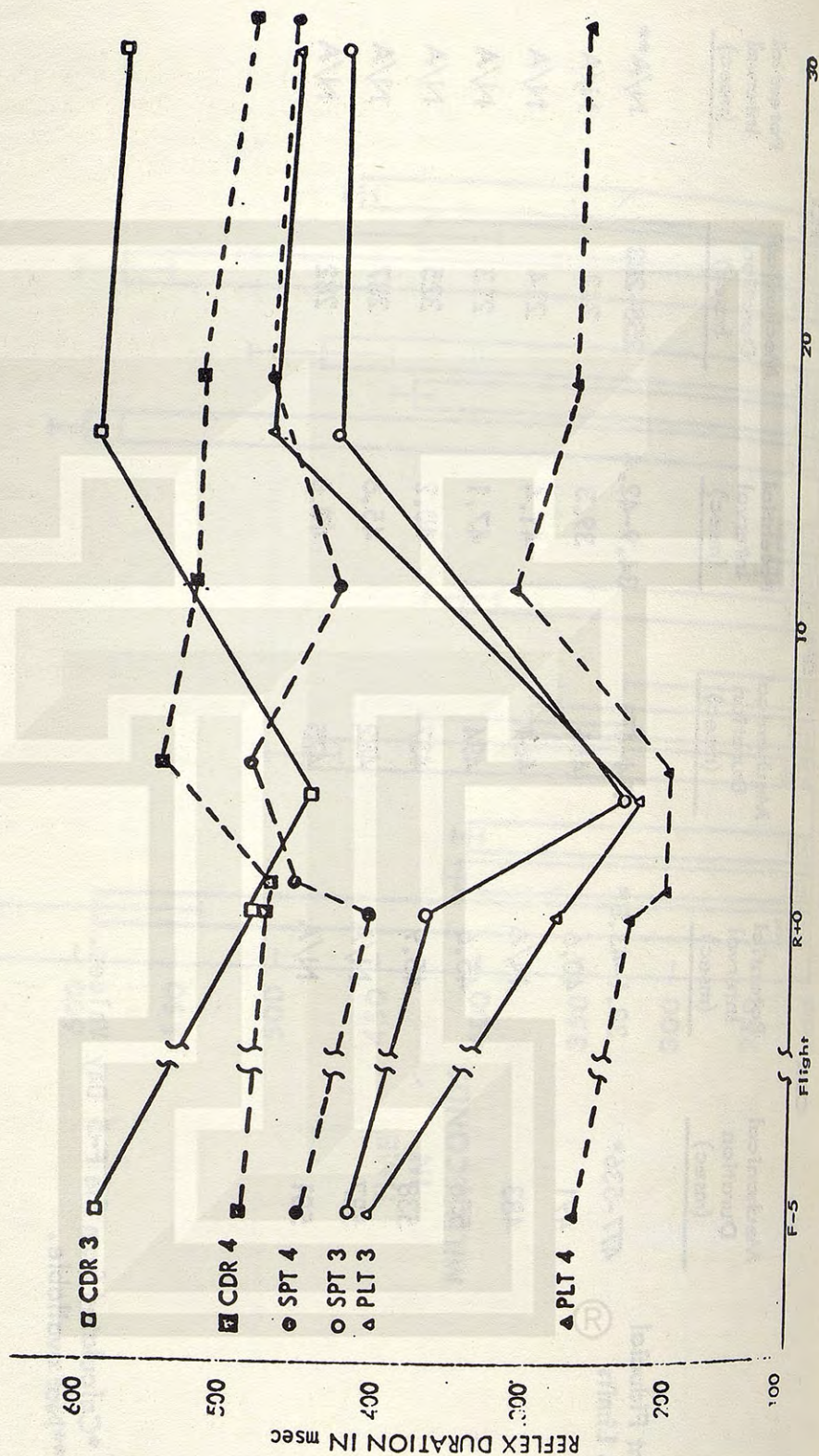


FIGURE 2-12-3. - Skyles 3 and 4. Common Achilles Tendon Reflex Duration.

These 1
tationa
in move
flexes
lacking

It is p
factors
Postfli
elevate
for som
calcium
ionized
the obs
possibl
differen
of inad
the sup
strain
the neu
duratio
an over
Finally
the ref
duratio
muscula
support
on the

Referen

1. Ros
Pre
2. Che
Pri
Kos
3. No
Thy
4. Bow
Ref
5. Bak
Cor
Aer

These findings include a peculiar gait upon return to the Earth's gravitational environment, muscle soreness and weakness, over-compensation in movements while in a vertical position and alterations in the reflexes. While a satisfactory explanation for these findings is still lacking, several causal factors can be implicated.

It is possible that an interaction between biochemical and/or hormonal factors and reflex durations is present during the postflight period. Postflight thyroxine and epinephrine values have been reported to be elevated to some degree (sec. 3.2) and could account, at least in part, for some of the alterations in the reflex duration. Though a transient calciuria has been observed postflight, due to a lack of data on ionized serum calcium, no correlation could be made at this time with the observed changes in the reflex durations. At this point, the best possible explanation is that postflight there is an imbalance between different postural muscle groups. The antigravity muscles after weeks of inactivity are suddenly exposed to one-g environment and must resume the support of the whole body in an erect position. The attendant strain and stretch in these muscles result in an over stimulation of the neuromuscular system resulting in the initial decrease in the reflex duration. As the muscles regain strength and mass (6, 7) there occurs an over compensation reflected by the increased reflex duration. Finally, when an adequately balanced neuromuscular state is reached the reflex duration returns to normal. Interestingly, the reflex duration does return approximately to preflight values at the time muscular soreness disappears. In general the available data seem to support the proposed hypothesis concerning the effect of weightlessness on the antigravity muscles.

References

1. Ross, C. E. and J. R. Hordinsky. 1973. Crew Health; *Skylab 1/2 Preliminary Biomedical Report*, JSC-08439.
2. Cherepakhin, M. A. and V. I. Peruushin. 1970. Medical Support and Principal Results of Examination of the "Soyuz-9" Spaceship Crew; *Kosmicheskaya Biologiya i Meditsina*, Russian. 4:34-41.
3. Nordyke, R. A. 1970. Long Term Follow Up of Patients Treated for Thyrotoxicosis Using Achilles Reflex Times; *Hormone*. 1:36-45.
4. Bowley, A. R., et al. 1971. A New Simple Detector for Achilles Reflex Measurement; *Medical and Biological Engineering*. 9:351-357.
5. Baker, J. T., et al. Measurement of a single Tendon Reflex in Conjunction with a Myogram: The Second Manned Skylab Mission; Aerospace Medicine Annual Meeting, Washington, D.C., May 1974.

6. Thornton, W., et al. 1973. Anthropometric and Functional Changes Skylab-3 Preliminary Biomedical Report, JSC-08668.
7. Johnson, R. L., et al. 1973. M092 Lower Body Negative Pressure Skylab-3 Preliminary Biomedical Report, JSC-08668.

2.13 Microbiology

2.13.1 Crew Microbiology

Gerald R. Taylor, Ph.D., and Bernard J. Mieszkuc, M.S.

Introduction

The objectives of the crew microbiological studies for the last manned Skylab mission were to detect the presence of pathogenic microorganisms on the crewmembers and to obtain data which would contribute to our understanding of the response of the crew's microbial flora to the space flight environment.

Complete bacteriological and mycological analyses were performed on each specimen. Complete virological analyses were conducted on specimens collected 10 days before flight, the morning of launch, and immediately after recovery. Because of their inherent slow growth rate, yeasts and filamentous fungi will not be included in this report, but will be reported later.

Sample Collection

The microbial load of astronauts has been variously monitored during each mission since the first manned Apollo Flight in October 1968. The exact microbiology protocols have varied somewhat from mission to mission with the third set of Skylab crewmembers receiving the most extensive microbiological analysis.

Twelve areas, outlined in table 2.13.1-I, were sampled from each astronaut during each of the eight collection periods. Two calcium alginate swabs, wetted in phosphate buffer, were used to sample the nostrils and each external body surface area. One of each pair of swabs was placed in trypticase soy broth (TSB), which served as the sample transport medium preceding aerobic identification and quantitation. The other swab of the pair was placed in veal infusion broth (VIB) for sample transport preceding anaerobic identification and quantitation.

A single, dry alginate swab was used to sample the throat. Phosphate buffer was used to rinse the oropharyngeal cavity. Additionally, a midstream urine sample was collected from the first void of the day and a fecal specimen was collected at the convenience of the subject.

All the samples except throat swab were used for bacteriological analysis. The specimens used for virological analysis were throat swab, gargle, urine, and feces.

TABLE 2.13.1-I - CREW SAMPLE COLLECTION SITES

<u>Sample Site</u>	<u>Area Sampled</u>
Neck	13 cm ² below hairline at base of neck
Ears	Right and left external auditory canals with two revolutions of each swab in each canal
Axillae	6.5 cm ² below hair area on each side
Hands	6.5 cm ² on the right and the left palms
Navel	The internal area of the umbilicus, and a surrounding 13 cm ² area with at least two revolutions made with each swab
Groin	5 cm strip from rear to front on right and left inguinal area between legs
Toes	Area between the two smallest toes of each foot
Nares	Both nostrils
Throat Swab	Surfaces of tonsils and posterior pharyngeal vault swabbed with each of two dry calcium alginate swabs
Gargle	60 ml phosphate buffer used as gargle and rinsed through the oral cavity three times
Urine	60 ml midstream sample
Feces	Two samples of 100 mg each taken from center of the fecal specimen

These specimens were collected over a period in excess of six months; the first sample being collected 87 days before flight (F-87) and the last sample being collected 17 days after return (R+17) of the astronauts as shown in table 2.13.1-II. No additional contingency clinical specimens were obtained from the astronauts for medical microbiology evaluation before, during, or after the flight of SL-4.

TABLE 2.13.1-II - CREW MICROBIOLOGY SAMPLE COLLECTION DATES

<u>Collection Period Designation</u>	<u>Days Before Launch</u>	<u>Days After Recovery</u>	<u>Calendar Date</u>	<u>Place Where Sample Was Collected</u>
Preflight (F-)	87		8-21-73	JSC
	35		10-12-73	JSC
	21		10-26-73	JSC
	10		11-6-73	JSC
	0		11-16-73	KSC
Recovery (R+)		0	2-8-74	PRS
		11	2-19-74	JSC
		17	2-25-74	JSC

During this period the crew was subjected to four different types of environments. First, the premission environment in which each crewmember experienced his own "normal" environment up to the last 21 days before launch. Second, the preflight health stabilization environment where each crewmember spent the last 21 days prior to launch in living quarters with a carefully controlled environment and was allowed contact with only a limited number of specified persons (primary contacts). Third, the mission environment where the astronauts were confined to the Apollo transport vehicle, the Skylab workshop, and the EVA clothing throughout the 84-day mission. Fourth, the postmission environment in which the astronauts were carefully reintroduced into the biosphere, closely monitored, and maintained on a diet of Skylab flight food for 17 days after recovery.

Analyses of the stability or variability of the major components of the astronauts' autoflora throughout this six-month period are as follows.

Recovery of Viruses and Mycoplasma

No viruses were recovered from any of the specimens analyzed. These results are similar to those obtained on previous missions. The isolation of viruses from healthy individuals is an extremely rare occurrence. *Mycoplasma orale* I was routinely isolated from the throat of the CDR. There was no evidence of cross-infection. *M. orale* I is the most frequently isolated mycoplasma from human throats. Currently, these microorganisms are of no medical significance.

Medical Bacteriology Evaluation

The species of bacteria which were recovered from pre- and postflight crew specimens and which may be considered to be potentially of medical importance are presented in table 2.13.1-III. These data illustrate that from 9 to 12 different isolates, representing 4 to 7 different species of bacteria, were reported for each of the five preflight sample periods. Although the number of species recovered immediately after flight (R+0) was within the preflight range, these species were recovered from a significantly larger number of sites (preflight mean was one-half of the R+0 value) indicating a spread of these microorganisms over the body. These results indicate that the postflight increase in medically important bacteria reported for shorter duration missions, also applies to this, the longest manned flight to date.

The most notable buildup was observed for *Klebsiella pneumoniae* which was never recovered more than twice from any preflight sample set but was recovered seven times from the R+0 sample set. *Serratia marcescens* was recovered from all three crewmembers at R+0 but was never recovered

TABLE 2.13.1-III
RECOVERY OF BACTERIA OF POTENTIAL MEDICAL SIGNIFICANCE
FROM CREWMEMBERS OF SKYLAB 4

Species	Number of Isolates	Astro-naut	Sample Period (Days)						
			F-87	F-35	F-21	F-10	F-0	N40	N41
<i>Haemophilus parainfluenzae</i>	26	CDR SPT PLT	Gargle Gargle Gargle	Gargle Gargle Gargle	Gargle/ Nasal Gargle Gargle	Gargle/ Nasal Gargle Gargle	Gargle Gargle Gargle	Gargle Gargle Gargle	Gargle Gargle Gargle
<i>Klebsiella pneumoniae</i>	16	CDR SPT PLT	---	---	---	---	---	Axilla/ Groin Axilla/ Hand Navel/ Groin	---
<i>Enterobacter aerogenes</i>	11	CDR SPT PLT	---	---	---	---	---	---	---
<i>Escherichia coli</i>	11	CDR SPT PLT	---	---	---	---	---	---	---
<i>Haemophilus parahaemolyticus</i>	9	CDR SPT PLT	---	---	---	---	---	---	---
<i>Serratia marcescens</i>	6	CDR SPT PLT	---	---	---	---	---	Axilla/ Urine/ Toes Axilla/ Groin	---
<i>Proteus mirabilis</i>	5	CDR SPT PLT	---	---	---	---	---	Axilla Navel/ Groin	---
<i>Moraxella</i> sp.	4	CDR SPT PLT	---	---	Toes Toes/ Urine*	Gargle	---	---	---
<i>Haemophilus haemolyticus</i>	3	CDR SPT PLT	---	---	---	Gargle	---	Gargle Gargle	---
<i>Mima polymorpha</i>	2	CDR SPT PLT	---	---	Axilla	---	---	---	---
<i>Herella</i> sp.	1	CDR SPT PLT	---	Hand	---	---	---	---	---
<i>Proteus</i> sp.	1	CDR SPT PLT	---	---	---	---	---	Toes	---
<i>Enterobacter agglomerans</i>	1	CDR SPT PLT	---	---	---	---	---	Axilla	---
<i>Pseudomonas</i> sp.	1	CDR SPT PLT	---	---	---	---	---	Axilla	---
<i>Pseudomonas stutzeri</i>	1	CDR SPT PLT	---	---	---	---	---	---	---
<i>Serratia</i> sp.	1	CDR SPT PLT	---	---	---	---	---	---	---
<i>B-Streptococcus</i> sp. Not Group A	1	CDR SPT PLT	---	---	---	---	---	---	---
<i>Pectobacterium</i> sp.	1	CDR SPT PLT	---	---	---	---	---	---	---
Total species isolated			6	6	4	7	5	7	9
Total isolates reported			11	9	12	12	10	22	13

* 120/ml
+ 330/ml

preflight. This is especially notable because this species was also shown to inhabit the workshop, apparently being introduced with this particular Skylab mission. Such a species may be used as a marker to study the cross-contamination of crew and equipment items in the Skylab environment. *Serratia* were recovered from the remaining postflight nostril samples of the PLT indicating that, for this individual at least, the contamination was not ephemeral.

It is important to observe the complete absence of one medically important bacterial species, *Staphylococcus aureus*. A buildup of this species in the workshop was demonstrated through the second manned mission, with an associated high incidence among the second crew. Because *S. aureus* was never isolated from preflight sampling of the third crew, there was some concern about the result of occupying a workshop which may still have been heavily contaminated with this microorganism. This level of contamination apparently had decreased significantly between the second and third missions as it was not recovered from any of the subsequent workshop or crew samples. The causes for the disappearance of this species are currently under investigation.

Recovery of Aerobic Bacteria from Astronaut Specimens

All specimens obtained (except throat swab samples) were analyzed for the total number and specific types of aerobic bacteria present at each of the sample collection periods outlined in table 2.13.1-II. By comparing the data for each astronaut over all eight of the sample periods, it can be shown that there was no statistical difference ($p \leq 0.05$) between crewmembers for total quantitation (number of viable aerobic bacterial cells), number of genera, or number of species recovered. Therefore, it was valid to treat the specimens from each sample period as containing a replicate of three. The final values used in the following analyses are means of the three replicate astronaut samples.

The values presented in table 2.13.1-IV were calculated according to the above method. These data are presented in an effort to demonstrate the response of the total aerobic bacteria load to the 84-day space flight. For each of the sample sites the preflight mean (of 5 sample periods) is presented along with the range of values obtained for this site. To these values are compared the mean of values obtained from the three crewmember samples taken immediately after the flight (R+0). These comparisons are accomplished in two ways.

Those R+0 values which are found by the T-test to be significantly ($p \leq 0.05$) different than the preflight values are indicated. It will be noted that the total quantitation of aerobic bacteria recovered from the

TABLE 2.13.1-IV - RECOVERY OF AEROBIC BACTERIA FROM SKYLAB 4 ASTRONAUTS*
A Comparison of Preflight Baseline With R+0 Recovery

Sample Site	Total Quantitation (in Log 10)				Number of Genera Isolated				Number of Species Isolated			
	Preflight		R+0	Sig. # @ 0.05	R+0 Not in Preflight Range	Preflight		R+0	Sig. @ 0.05	R+0 Not in Preflight Range	Preflight	
	Mean	Range				Mean	Range				Mean	Range
NECK	3.2	2.9-3.5	3.5	No		3.3	2.7-4.0	2.0	No	↓	4.5	3.0-5.7
EARS	4.3	3.7-4.8	3.8	No		2.6	2.0-3.7	2.7	No		2.9	2.0-3.7
AXILLA	2.2	1.7-2.7	2.9	No	↑	2.3	1.7-3.0	2.3	No		2.6	1.7-4.0
HANDS	2.3	2.0-2.5	2.9	No	↑	2.9	1.3-4.7	2.3	No		3.6	1.7-5.0
NAVEL	3.3	2.3-4.2	3.4	No		3.5	2.3-5.0	2.0	No	↓	5.4	4.0-8.7
GROIN	5.1	4.8-5.9	6.2	Yes	↑	3.1	2.3-4.0	4.3	No	↑	5.8	4.7-7.3
TOES	5.4	4.9-5.9	6.1	No	↑	2.8	2.0-3.7	3.0	No		4.3	3.7-5.3
ALL SKIN SITES	5.9	5.6-6.5	6.5	Yes		7.1	6.9-9.0	7.0	No		18.2	16.0-22.7
GARGLE	6.8	6.5-7.5	6.3	No	↓	5.6	5.3-6.3	6.0	No		8.9	7.3-10.0
NARES	4.9	4.2-5.2	5.0	No		3.5	3.0-3.7	4.3	No	↑	4.8	3.7-5.3
FECES	8.1	7.7-8.8	8.8	No		3.1	2.7-3.3	3.7	No	↑	4.6	3.3-5.3

* Each value represents a mean of 3 crewmembers for a particular sample period.
† Mean of values obtained from 20 preflight samples.

skin is
in quan
was in
R+0 va

This re
all mic
epiderm
crewmen
Klebsie
crewmen
aerobic
The sig
mention
epiderm
crewmen
individu
buildup
of S. e

The oth
were ou
be show
are mar
the R+0
the tot
often h
postfli

It is n
species
can gen
aerobic
is ofte
the pre
recovery
preflig

Recovery

As with
of the
for the
collect
more va
of the
(p≤0.05)
ingly t

skin is significantly higher than the preflight mean, due to an increase in quantitation from groin samples. The only other significant change was in the number of species recovered from the umbilicus, where the R+0 value was depressed.

This reduction in the number of species was the result of a loss of all microorganisms except the Gram-positive cocci (*Staphylococcus epidermidis*, *Micrococcus* sp., and *Streptococcus faecalis*) from two crewmembers, whereas only Gram-negative rods (*Escherichia coli* and *Klebsiella pneumoniae*) were recoverable from the umbilicus of the third crewmember. There was no significant ($p \leq 0.05$) change in the number of aerobic genera or species recovered from any of the other sample sites. The significant ($p \leq 0.05$) increase in quantitation from groin samples, mentioned above, was due to a high quantitation of *Staphylococcus epidermidis* in the immediate postflight (R+0) groin samples of two crewmembers. Staphylococci were not recovered from the groin of these individuals before the flight. This occurrence is analogous to the buildup of *Staphylococcus aureus* during the SL-3 mission and the buildup of *S. epidermidis* during both the SL 1/2 and SL-3 missions.

The other method of analysis was to note those postflight values that were out of the established preflight range, whether or not they could be shown to be significantly different by the T-test. These cases are marked by an arrow on table 2.13.1-IV which indicates whether the R+0 value is low or high. Using this method it may be noted that the total quantitation of aerobic bacteria recovered from the skin was often higher postflight than at any time preflight, whereas the postflight gargle value was lower than the preflight range.

It is more difficult to recognize trends in the incidence of genera and species, largely because of the small numbers involved. However, it can generally be observed that the number of genera and species of aerobic bacteria recovered from the skin immediately after the flight is often lower than the preflight range, and more frequently lower than the preflight mean. By contrast, the number of genera and species recovered from the R+0 nasal and fecal samples was higher than the preflight range.

Recovery of Anaerobic Bacteria from Astronaut Specimens

As with the aerobic analysis, all specimens recovered, with the exception of the throat swabs, were qualitatively and quantitatively analyzed for the presence of anaerobic bacteria at each of the eight sample collection periods. Typically, the anaerobic microbial population is more variable with time than is the aerobic population, largely because of the lower numbers involved. Because of this variability, significant ($p \leq 0.05$) differences between the crewmembers could not be shown. Accordingly the specimens from each sample period were treated as a replicate

NARES FECES	4.9 8.1	4.2-5.2	5.0	No	No	3.1	2.7-3.3	3.7	No	8.9	7.3-10.0	9.3	No
						3.5	3.0-3.7	4.3	No				

Each value represents a mean of 3 crewmembers for a particular sample period. Values in parentheses indicate values for preflight periods.

of three. As with the aerobic analyses the final values used for a particular sample period are the means of three replicate astronaut samples.

A summary of the recovery of anaerobic bacteria from crewmembers before and after the flight is presented in table 2.13.1-V. Analysis of the data reveals nine occurrences in which there is a significant ($p \leq 0.05$) difference between the immediate postflight value and the preflight mean (indicated by a "Yes" in table 2.13.1-V). In each of these cases the immediate postflight value is depressed when compared to the preflight mean. In addition, 13 other values were shown to be lower immediately after the flight (indicated by the arrows in table 2.13.1-V) but, because of the low numbers and normal variability, these values cannot be shown to be significantly ($p \leq 0.05$) different than the preflight mean. Even though not always significant, it is important to note that the recovery of anaerobic bacteria from five of the ten areas (50%) sampled immediately after the flight and reported in table 2.13.1-V was zero, whereas this value was obtained only once in the 50 sample sets (2%) obtained throughout the preflight monitoring period. Analysis of the data presented in table 2.13.1-V indicates that this postflight reduction applies to the total quantitation of anaerobic bacteria recovered from several sites as well as the number of genera and species identified from most sample sets.

Summary

Microbiological specimens were collected from the three SL-4 crewmembers over a period of six months, and examined for the presence of fungi, yeasts, viruses, aerobic bacteria, and anaerobic bacteria. No viruses were recovered, and collection of data relating to yeasts and fungi has not yet been completed. Therefore, the observations presented in this communication relate only to recovery of bacteria from astronaut specimens.

Analyses of recovered microorganisms of medical importance indicate that the number of different kinds recovered from the three crewmembers immediately after flight was within the preflight range although the number of recoveries from different sites had doubled. This demonstrates a significant intra- and intercrewmember spread of these potentially harmful bacteria with no increase in number of different types. This phenomenon has been observed following several other space flights.

Analysis of the occurrence of aerobic bacteria shows that the total number of viable cells recovered from the skin immediately after flight is often elevated although the number of different kinds is frequently depressed when compared to the five preflight sample sets. Although the occurrence of anaerobic bacteria was more variable, it can be clearly

TABLE 2.13.1-1-V - RECOVERY OF ANAEROBIC BACTERIA FROM SKYLAB 4 ASTRONAUTS*
A Comparison of Preflight Baseline With R+0 Recovery

Sample Site	Total Quantitation (in Log 10)					Number of Genera Isolated					Number of Species Isolated				
	Preflight		R+0	Sig.† @ 0.05	R+0s Not in Preflight Range	Preflight		Sig. @ 0.05	R+0 Not in Preflight Range	Preflight		Sig. @ 0.05	R+0 Not in Preflight Range		
	Mean†	Range				Mean	Range			Mean	Range				
NECK	2.6	2.0-3.2	3.8	No	+	0.9	0.7-1.0	1.0	No		0.9	0.7-1.0	1.3	No	+
EARS	1.7	0.8-3.0	0	No	+	0.7	0.3-1.0	0	No	+	0.7	0.3-1.0	0	No	+
AXILLA	1.8	1.3-3.1	0	Yes	+	0.7	0.7-1.0	0	Yes	+	0.7	0.7-1.0	0	No	+
HANDS	1.6	0-2.5	0.3	No		0.7	0-1.0	0.3	No		0.7	0-1.0	0.3	No	
NAVEL	2.4	1.6-3.3	0	Yes	+	1.5	0.3-2.7	0	Yes	+	1.6	0.3-2.7	0	Yes	+
GROIN	1.4	0.7-2.7	0	No	+	0.5	0.3-1.0	0	No	+	0.7	0.3-1.3	0	No	+
TOES	1.6	1.1-2.0	0	No	+	0.4	0.3-0.7	0	No	+	0.4	0.3-0.7	0	No	+
ALL SKIN SITES	4.3	4.1-4.5	3.8	No	+	2.7	2.0-3.3	1.0	Yes	+	3.5	3.3-4.0	1.7	No	+
GARGLE	6.1	5.2-6.6	5.4	Yes		5.5	5.0-6.7	3.7	Yes	+	6.1	6.9-7.3	6.0	No	
NARES	2.7	1.3-4.8	2.0	No		1.1	0.7-1.7	0.7	No		1.1	0.7-1.7	1.0	No	
FECES	10.0	9.8-10.4	10.7	No	+	4.5	4.0-4.7	3.7	No	+	9.5	8.7-10.7	6.7	Yes	+

* Each value represents a mean of 3 crewmembers for a particular sample period

† Mean of values obtained for all 5 preflight periods

F-test for preflight values vs. R+0 values demonstrates a significant difference at the 5% level

\$ + = R+0 is higher than preflight range; + = R+0 is lower than preflight range

shown that the total quantitation, the number of genera, and the number of species recovered from a particular sample site postflight was usually lower than the value obtained from any of the five preflight samples of that same site. In general, all of the above-mentioned changes returned to within the preflight range by the 17th day after recovery, when the last samples were taken.

2.13.2 Oral Microbiology, Oral Immunology, and Oral Clinical Assessments
of Skylab-4 Crewmembers

*Lee R. Brown, Ph.D., William J. Frome, D.D.S. and
Merrill G. Wheatcroft, D.D.S.*

Summary

The purpose of this study was to monitor SL-4 crewmembers for mission-related:

- Shifts in oral microbial populations
- Changes in secretion of specific salivary partitions
- Alteration in clinical indices of oral health and preexisting dental disease

Microbiologic assessments were made at scheduled intervals beginning 57 days before and ending 17 days after the mission from three intra-oral sites - gingival sulcus fluid, stimulated whole saliva, and dental plaque. The saliva samples also were used for total protein, IgA, lysozyme, and flow rate determinations. Clinical evaluations were performed at F-57, F-4 and at R+4 days for increments of dental plaque and calculus formation, gingival inflammatory response, and alterations in teeth, alveolar bone, and oral mucosa. The most distinctive changes noted were:

- Increased counts of specific anaerobic and streptococcal components of the saliva and dental plaque microflora
- Elevations in levels of secretory IgA concurrent with diminutions of salivary lysozyme
- Increased increments of dental calculus and gingival inflammation

The changes detected in SL-4 were very similar to those observed in SMEAT and the two previous Skylab missions. Most of the microbial changes were diet-related rather than flight-related. This was evidenced by statistical comparisons of cumulative counts from the 18 crewmembers of all three Skylab missions before and after the incorporation of space diets during preflight samplings. Secretory IgA elevations, which occurred in two of the prime crewmembers of SL-4, corresponded to those observed with two out of the three of the SMEAT crew, and with the six prime crewmembers of SL 1/2 and SL-3. As in the case of the prime crew of the two previous Skylab missions, secretory IgA levels started increasing just before flight and were still elevated at recovery check points. Such changes were presumably due to subclinical infections.

Increased increments of dental calculus and gingival inflammation in SL-4 were similar to those detected in SMEAT and SL 1/2. Such changes were not apparent in SL-3 which suggest that changes in indices of oral health in space flights correspond closely to those under conventional circumstances; *i.e.*, individuals free of oral health problems are less susceptible to detrimental changes under a specific challenge than subjects with preexisting dental problems. Assuming no future clinical detection of mission-related intraoral complications, the most significant finding from these investigations was the relative nonexistence of hazardous intraoral changes.

Procedures

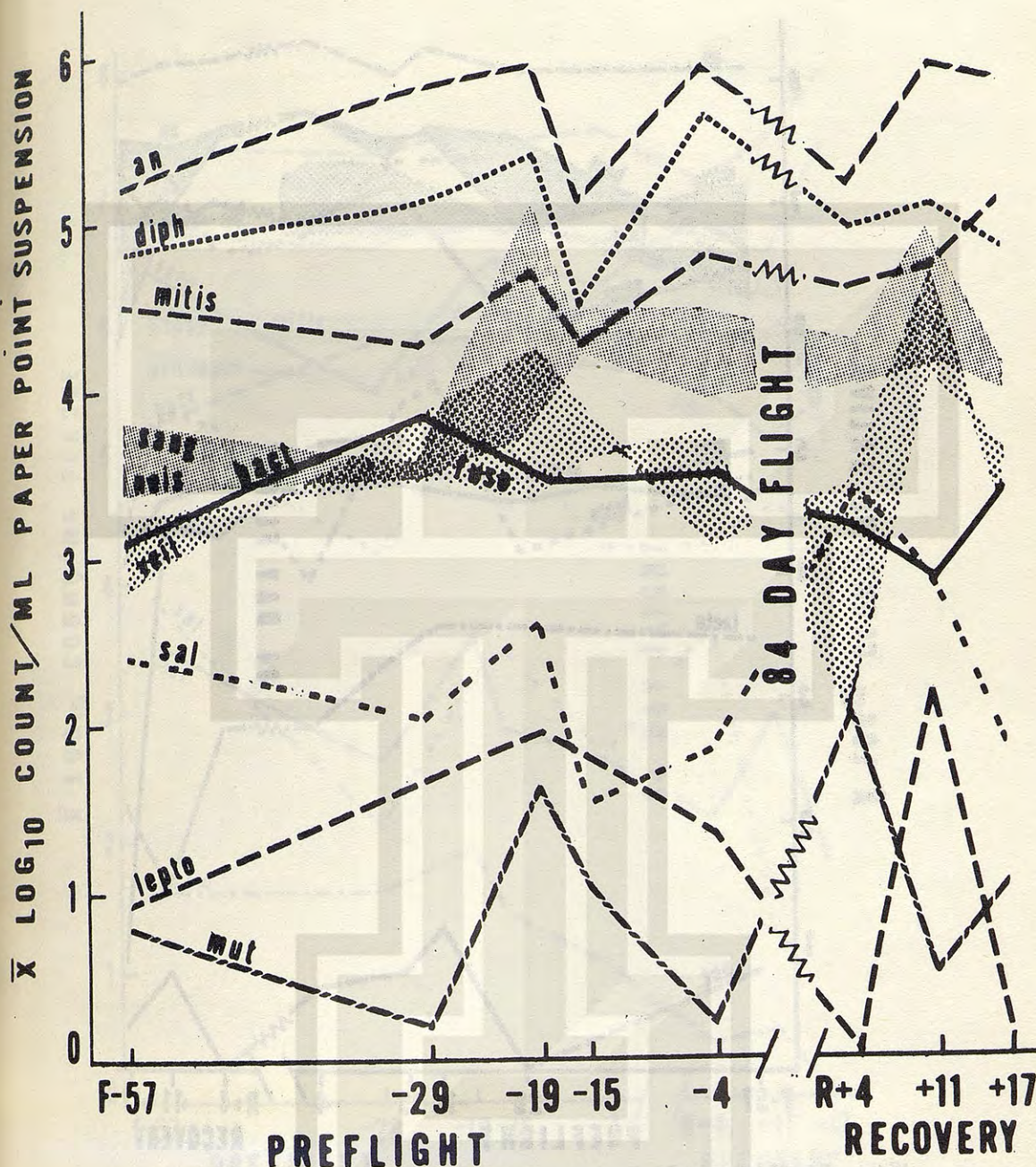
Oral evaluations of the prime crewmembers were made at F-57, F-29, F-4, R+4, R+11 and R+17 days. Evaluation of the backup crewmembers was made one day preceding or following those of the prime crew during the preflight sampling period. Details of oral hygiene practices, laboratory and clinical assessments, and statistical analyses have been described previously¹.

Results

Mean $\log_{10}$ counts of the microorganisms enumerated from each intraoral site sampled are shown in figures 2.13.2-1, -2 and -3. Preflight values are mean values of the combined prime and backup crewmembers; recovery values are means of the prime crewmembers. The most distinctive changes involved increases of certain anaerobic and streptococcal components of the stimulated saliva and dental plaque microflora (figures 2.13.2-1 and -3). These changes usually became apparent after the incorporation of the space diet at F-18 days. Statistical values of a two-way analysis of variance are summarized in table 2.13.2-I for those microbial increases found to be statistically significant. The cumulative before and after diet counts from 18 prime and backup crewmembers of all three Skylab missions were also statistically compared (paired T-tests - table 2.13.2-II for diet relatedness. Data points from flight recovery samples were excluded to avoid any possible flight-related influences. Most of the oral microbial changes noted during each mission appeared to be associated with diet change as evidenced by the statistically significant, post-diet increases (table 2.13.2-II and fig. 2.13.2-4).

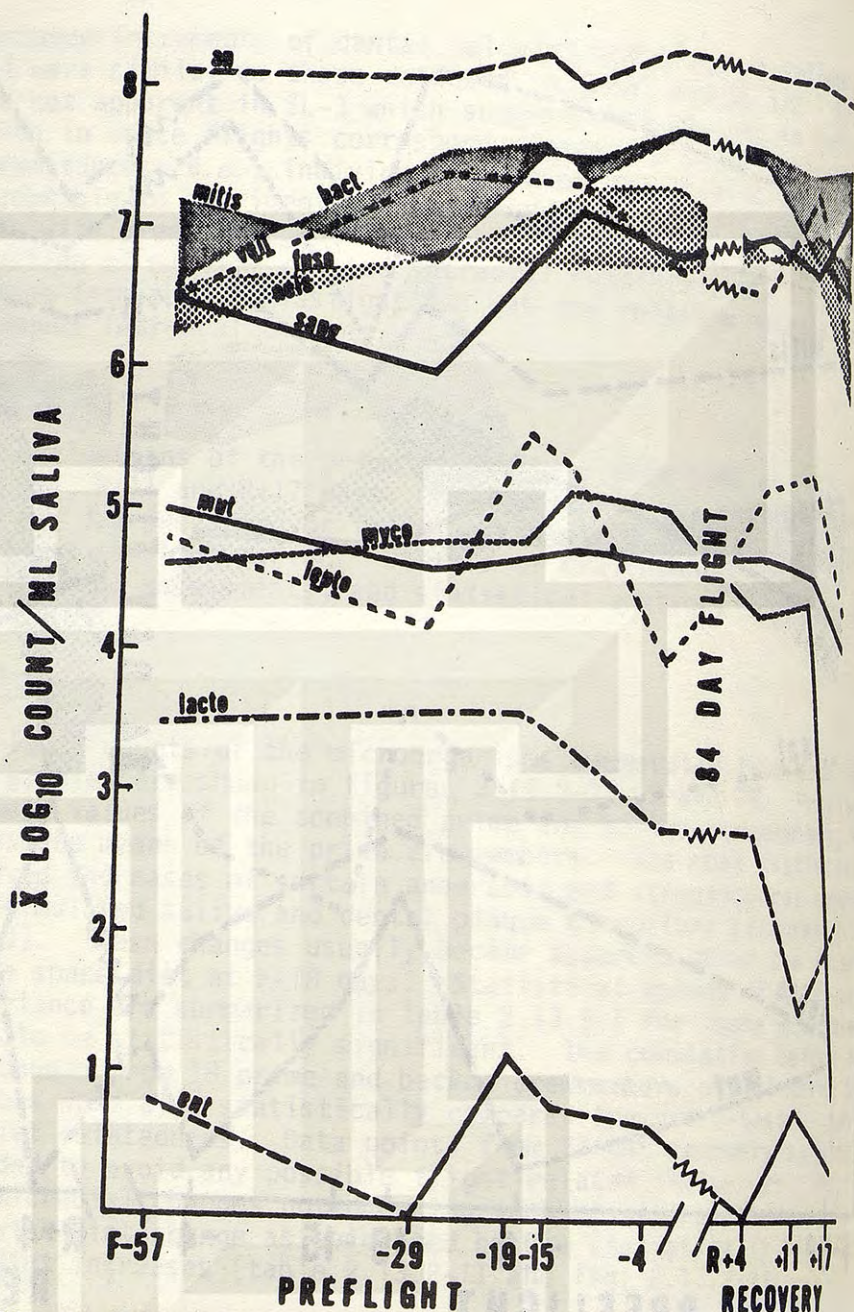
Saliva flow rates and the secretory components of saliva assayed are presented for the SL-4 prime crewmembers in figure 2.13.2-5. Saliva

¹Frome, W. J., L. R. Brown and M. G. Wheatcroft. Sept. 1973. Oral Microbiology, Oral Immunology, and Oral Clinical Evaluations of Skylab 1/2 Crew. JSC-08439, *Skylab 1/2 Preliminary Biomedical Report*, pp. 130-149.



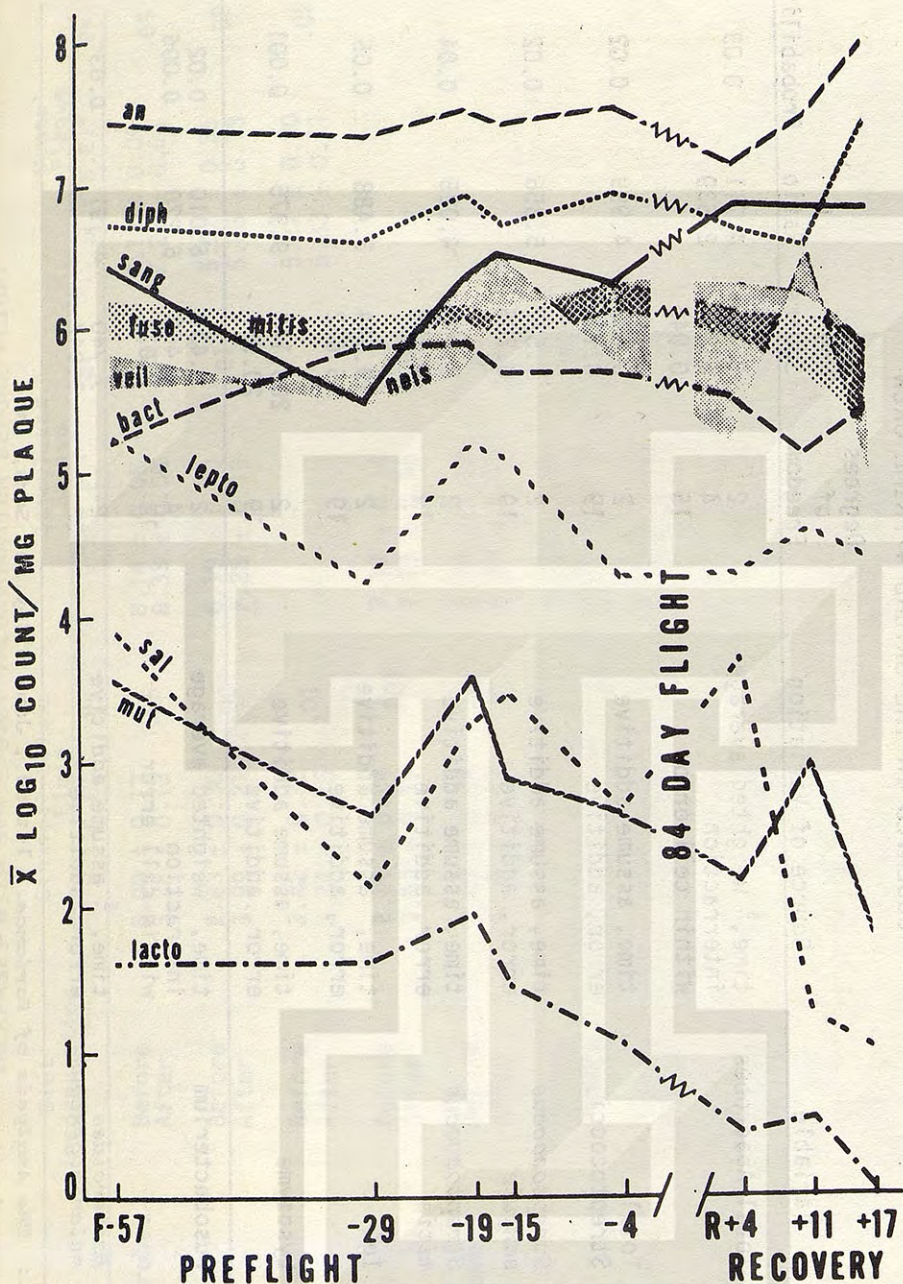
KEY: Preflight values are means of both the prime and backup crewmembers. Recovery values are means of the prime crew. AN - Total Anaerobes, DIPH - Diphtheroids, MITIS - *Streptococcus mitis*, NEIS - *Neisseria*, SANG - *S. sanguis*, SAL - *S. salivarius*, BACT - *Bacteroides*, VEIL - *Veillonella*, FUSO - *Fusobacteria*, MUT - *S. mutans*, LEPTO - *Leptotrichia*.

Figure 2.13.2-1. - Microbial Counts from Gingival Fluid Before and After the Skylab-4 Mission.



KEY: Preflight values are means of both the prime and backup crewmembers. Recovery values are means of the prime crew. AN - Total Anaerobes, MITIS - *Streptococcus mitis*, SAL - *S. salivarius*, BACT - *Bacteroides*, VEIL - *Veillonella*, NEIS - *Neisseria*, SANG - *S. sanguis*, FUSO - *Fusobacteria*, MUT - *S. mutans*, LEPTO - *Leptotrichia*, MYCO - *Mycoplasma*, LACTO - *Lactobacilli*, ENT - *Enterics*.

Figure 2.13.2-2. - Microbial Counts from Stimulated Saliva Before and After the Skylab-4 Mission.



KEY: Preflight values are means of both the prime and backup crewmembers. Recovery values are means of the prime crew.
 AN - Total Anaerobes, DIPH - Diphtheroids, MITIS - *Streptococcus mitis*, NEIS - *Neisseria*, SANG - *S. sanguis*, BACT - *Bacteroides*, VEIL - *Veillonella*, FUSO - *Fusobacteria*, SAL - *S. salivarius*, LEPTO - *Leptotrichia*, MUT - *S. mutans*, LACTO - *Lactobacilli*.

Figure 2.13.2-3. - Microbial Counts from Dental Plaque Before and After the Skylab-4 Mission.

TABLE 2.13.2-I. TWO-WAY UNBALANCED ANALYSIS OF VARIANCE* OF THE SIGNIFICANT CHANGES[†] OF MICROBIAL COUNTS AND IMMUNOLOGIC SECRETIONS OBSERVED IN THE SKYLAB 4 PRIME CREW

Intraoral Site	Variable	Source of Variation	Degrees of Freedom	Mean Square	F Ratio	Probability
Stimulated Saliva	Total Anaerobes	time, [§] weighted average interaction within cell error	2	0.213	4.711	0.03
			4	0.115	2.539	
			15	0.045		
	Total Streptococci	time, assume additive error, additive	2	0.682	4.999	0.02
			19	0.136		
	<i>Streptococcus sanguis</i>	time, assume additive error, additive	2	1.527	5.356	0.02
			19	0.285		
	<i>Streptococcus mitis</i>	time, assume additive error, additive	2	0.519	4.025	0.04
			19	0.129		
	IgA	time, [§] assume additive error, additive	2	19.644	3.488	0.05
Dental Plaque			19	5.632		
	Lysozyme	time, assume additive error, additive	2	205.148	9.975	0.001
			19	20.567		
	Fusobacterium	time, [§] weighted average interaction within cell error	2	0.439	6.010	0.02
			4	0.458	6.270	0.006
			12	0.073		
	<i>Bacteroides melaninogenicus</i>	time, [§] assume additive error, additive	2	7.740	4.191	0.03
			18	1.847		

*Scheffe', H.: *The Analysis of Variance*. 1st ed. John Wiley and Sons, Inc.
[†]All changes were increases except salivary lysozyme.
[§]Assumes no interaction between variables.

TABLE 2.13.2-II. MEANS* STANDARD ERRORS OF LOG₁₀ COUNTS SHOWING SIGNIFICANT INCREASES WITH SPACE DIET INCORPORATION BEFORE FLIGHT

Plaque	Bacteroides melaninogenicus	interaction within cell error	time, s error, additive	4 12 18	0.458 0.073 1.740	0.010 6.270 4.191	0.02 0.006 0.03
--------	--------------------------------	----------------------------------	----------------------------	---------------	-------------------------	-------------------------	-----------------------

*Scheffe', H.: *The Analysis of Variance*, 1st ed., John Wiley and Sons, Inc.
 †Changes were increases except salivary lysozyme
 ‡Means of cumulative counts from the 18 crewmembers of all three missions.

TABLE 2.13.2-II. MEANS* STANDARD ERRORS OF LOG₁₀ COUNTS SHOWING SIGNIFICANT INCREASES WITH SPACE DIET INCORPORATION BEFORE FLIGHT

Microbial Categories	Diet Incorporation	Gingival Sulcus Fluid		Stimulated Saliva		Dental Plaque	
		$\bar{X} \pm S.E.$	P<	$\bar{X} \pm S.E.$	P<	$\bar{X} \pm S.E.$	P<
Total Anaerobes	Before After	5.00 $\pm$ 0.17 5.22 $\pm$ 0.13	.05	8.14 $\pm$ 0.08 8.33 $\pm$ 0.08	.05	7.12 $\pm$ 0.06 7.27 $\pm$ 0.04	.05
Neisseria	Before After	2.83 $\pm$ 0.30 3.99 $\pm$ 0.21	.001	6.19 $\pm$ 0.40 7.28 $\pm$ 0.13	.01	5.02 $\pm$ 0.36 5.83 $\pm$ 0.13	.02
Veillonella	Before After	2.42 $\pm$ 0.32 3.74 $\pm$ 0.16	.01			5.22 $\pm$ 0.20 5.83 $\pm$ 0.11	.02
Bacteroides	Before After	2.61 $\pm$ 0.24 3.83 $\pm$ 0.17	.001	7.17 $\pm$ 0.14 7.73 $\pm$ 0.08	.001		
Streptococcus sanguis	Before After	3.69 $\pm$ 0.24 4.29 $\pm$ 0.17	.02	6.23 $\pm$ 0.18 6.94 $\pm$ 0.11	.01		
Mycoplasma	Before After			4.31 $\pm$ 0.28 4.91 $\pm$ 0.22	.001		
Staphylococcus aureus	Before After			0.49 $\pm$ 0.20 1.03 $\pm$ 0.30	.05		
Fusobacteria	Before After	1.94 $\pm$ 0.33 3.15 $\pm$ 0.20	.001				
Diphtheroids	Before After	4.51 $\pm$ 0.19 5.16 $\pm$ 0.15	.01				

*n = 18

†n = 17

‡Means of cumulative counts from the 18 crewmembers of all three missions.

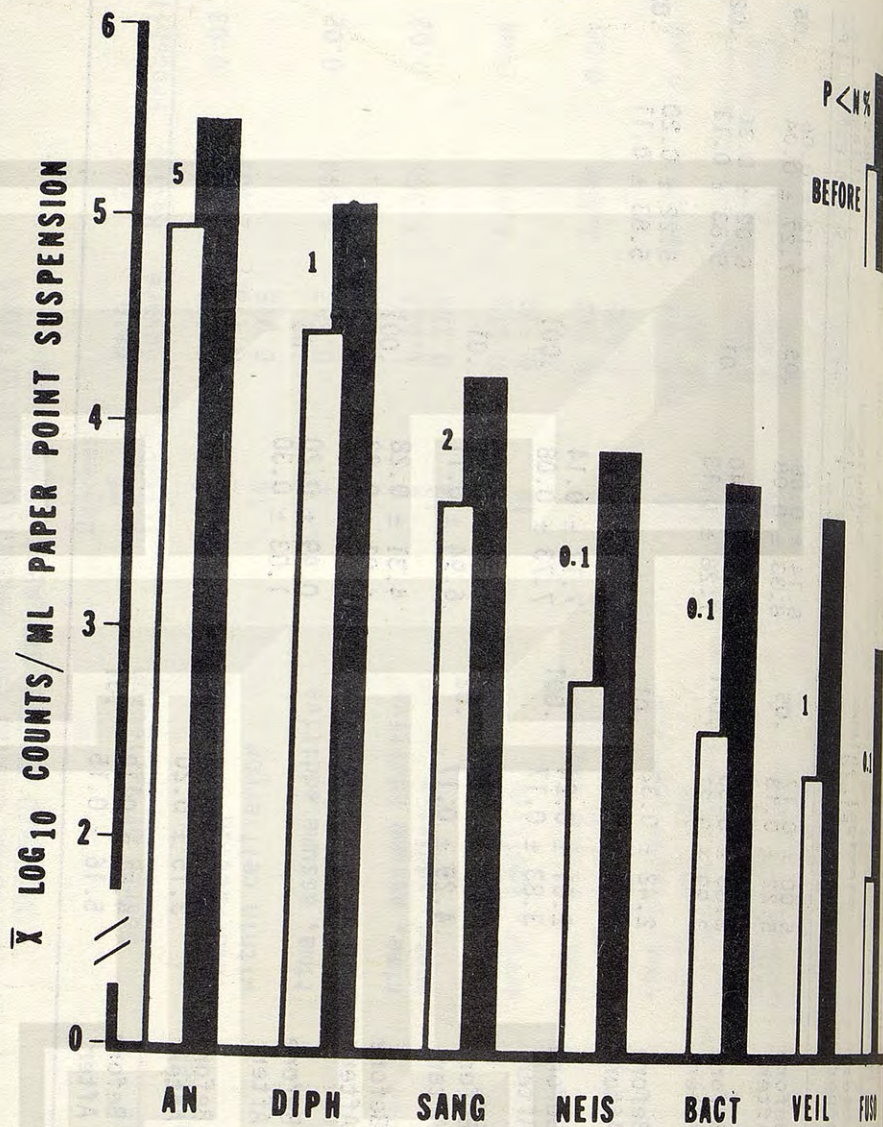
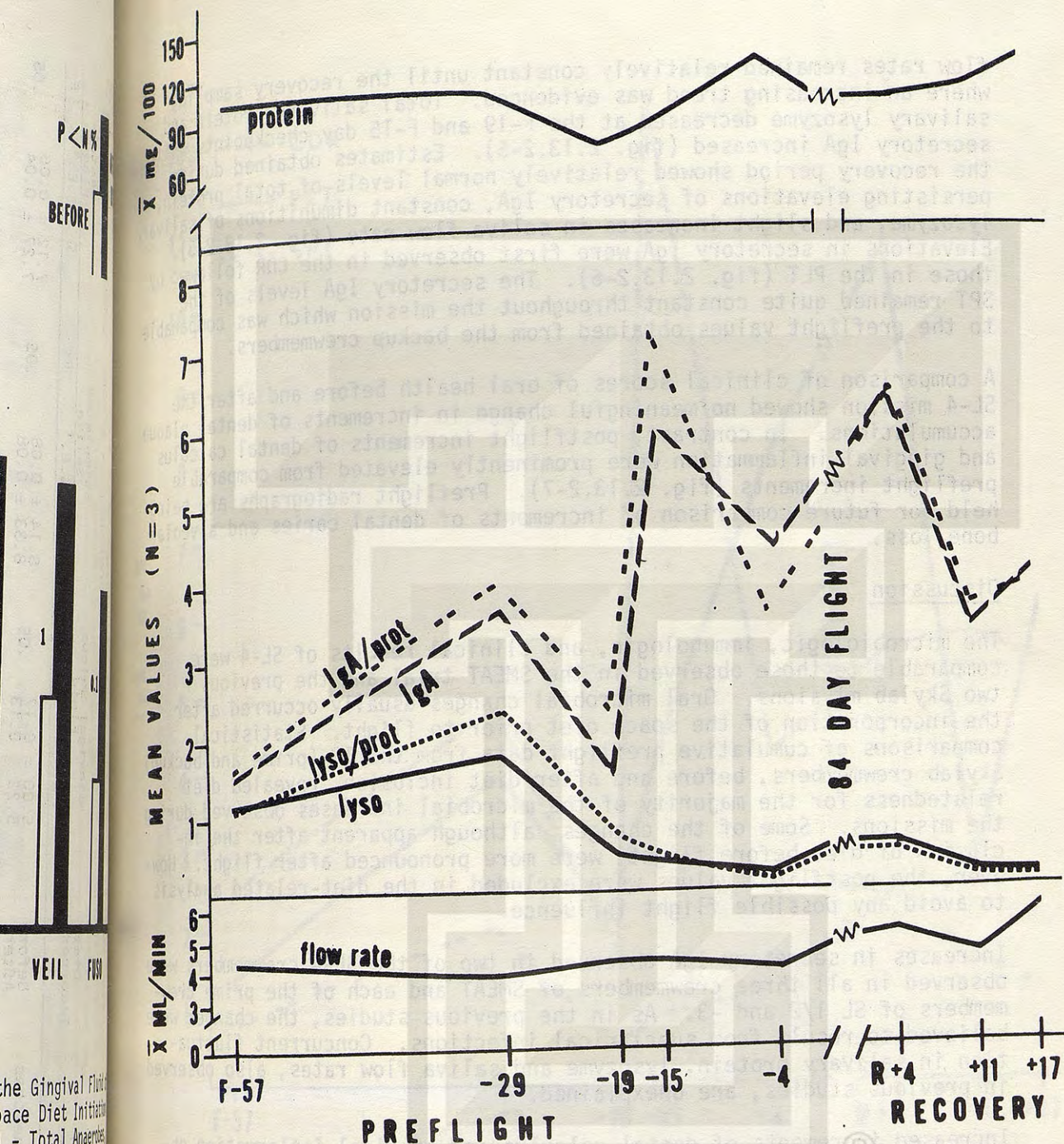


Figure 2.13.2-4. - Cumulative Microbial Counts from the Gingival Fluid of 18 Crewmembers Before and After Space Diet Initiation Prior to Three Skylab Flights. AN - Total Anaerobes, DIPH - Diphtheroids, SANG - *Streptococcus sanguinis*, BACT - Bacteroides, VEIL - Veillonella, FUSO - Fusobacterium



KEY: IgA/PROT - Ratio of secretory IgA to total saliva protein concentration.
 LYSO/PROT - Ratio of salivary lysozyme to total saliva protein concentration.

Figure 2.13.2-5. - Saliva Protein Concentrations, Secretory IgA and Lysozyme Levels, and Saliva Flow Rates of the Prime Crewmembers of the Skylab-4 Mission.

flow rates remained relatively constant until the recovery sampling where an increasing trend was evidenced. Total salivary protein and salivary lysozyme decreased at the F-19 and F-15 day checkpoints and secretory IgA increased (fig. 2.13.2-5). Estimates obtained during the recovery period showed relatively normal levels of total protein, persisting elevations of secretory IgA, constant diminutions of salivary lysozyme, and slight increases in saliva flow rate (fig. 2.13.2-5). Elevations in secretory IgA were first observed in the CDR followed by those in the PLT (fig. 2.13.2-6). The secretory IgA levels of the SPT remained quite constant throughout the mission which was comparable to the preflight values obtained from the backup crewmembers.

A comparison of clinical scores of oral health before and after the SL-4 mission showed no meaningful change in increments of dental plaque accumulations. In contrast, postflight increments of dental calculus and gingival inflammation were prominently elevated from comparable preflight increments (fig. 2.13.2-7). Preflight radiographs are being held for future comparison of increments of dental caries and alveolar bone loss.

Discussion

The microbiologic, immunologic, and clinical results of SL-4 were comparable to those observed in the SMEAT trial and the previous two Skylab missions. Oral microbial changes usually occurred after the incorporation of the space diet prior to flight. Statistical comparisons of cumulative preflight data from the 18 (prime and backup) Skylab crewmembers, before and after diet inclusion, revealed diet relatedness for the majority of the microbial increases observed during the missions. Some of the changes, although apparent after the inclusion of diet before flight, were more pronounced after flight. However, the postflight values were excluded in the diet-related analysis to avoid any possible flight influence.

Increases in secretory IgA observed in two of the SL-4 crewmembers were observed in all three crewmembers of SMEAT and each of the prime crewmembers of SL 1/2 and -3. As in the previous studies, the changes were believed to result from subclinical infections. Concurrent fluctuation in salivary protein, lysozyme and saliva flow rates, also observed in previous studies, are unexplained.

Increased increments of dental calculus and gingival inflammation observed in this study were similar to those observed in SMEAT and SL 1/2. Such changes were not, however, observed in the SL-3 mission indicating that clinical changes in oral health in space flight correspond to those under more conventional circumstances, i.e., individuals free of oral health problems are less susceptible to detrimental changes under a specific challenge than those with preexisting dental problems.

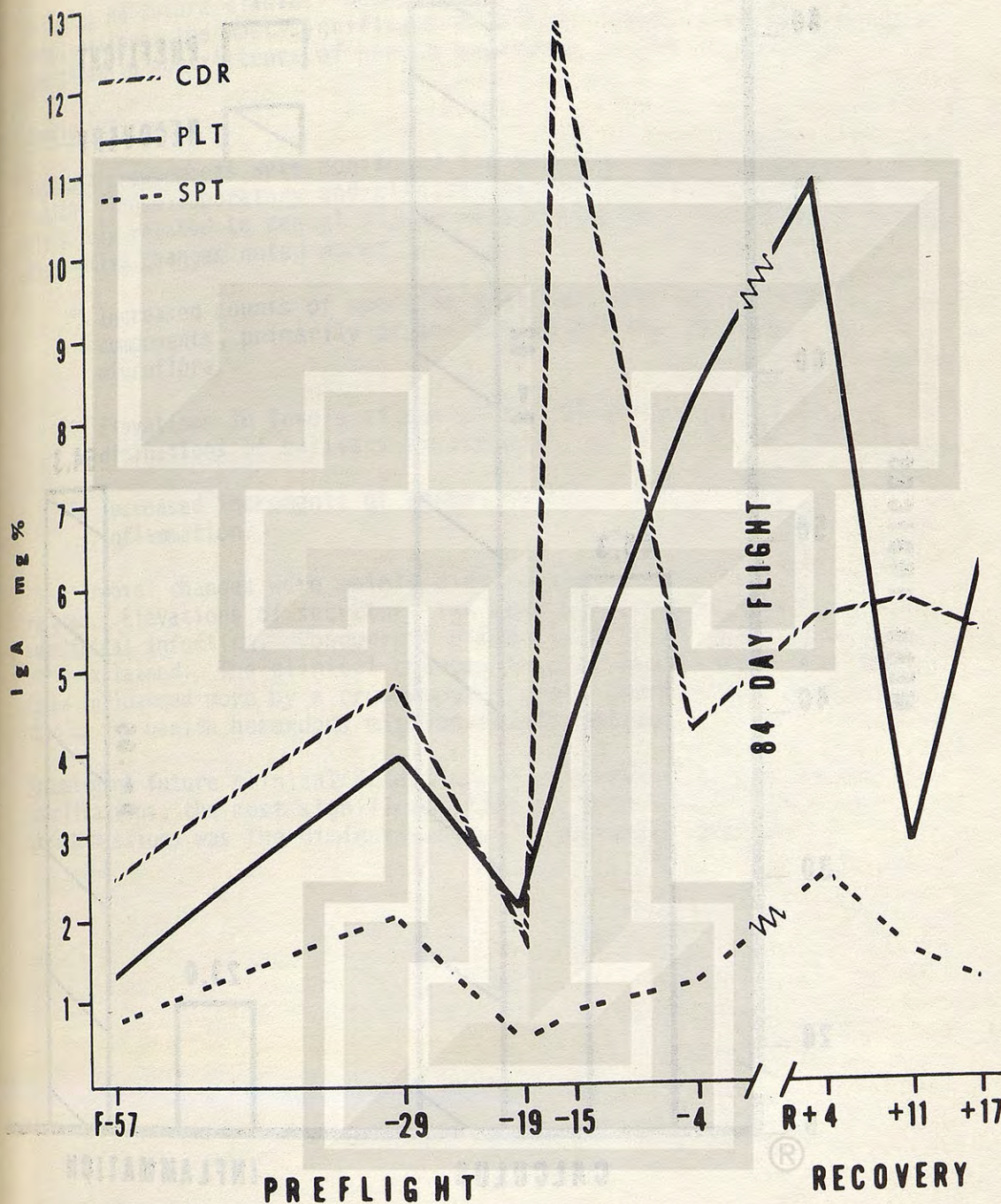


Figure 2.13.2-6. - Secretory IgA Levels of the Individual Crewmembers of Skylab-4. CDR - Commander, PLT - Pilot, SPT - Scientist Pilot.

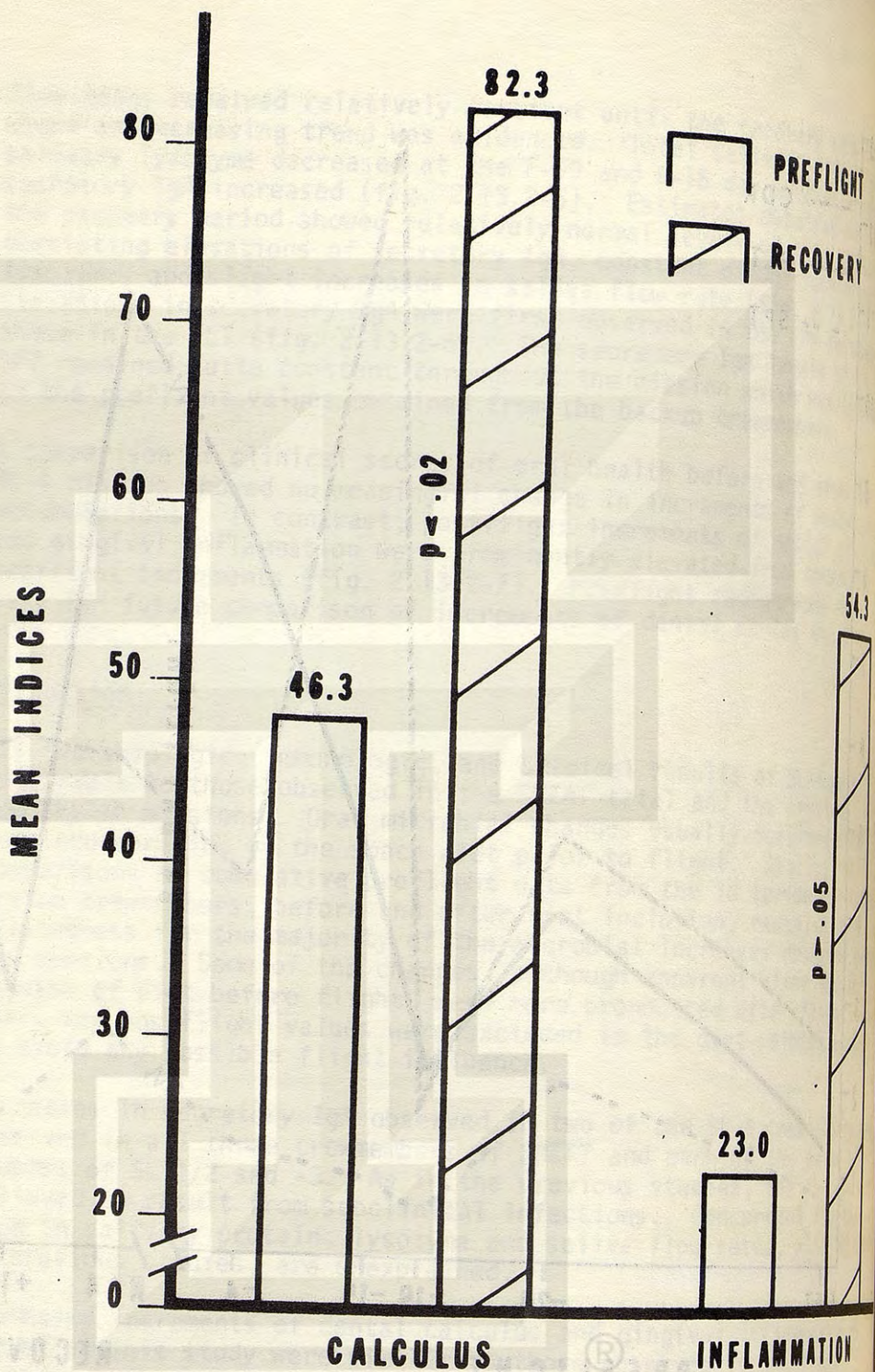


Figure 2.13.2-7. - Mean Clinical Scores of Dental Calculus and Gingival Inflammation of the Prime Crewmembers of Skylab-4.

Assuming no future clinical detection of mission-related intraoral complications, the most significant aspect of these investigations was the relative nonexistence of health hazardous intraoral changes.

Conclusion

Skylab-4 crewmembers were monitored for mission-related effects on oral health. Those laboratory and clinical parameters considered to be ultimately related to dental injury were evaluated. Of these, the most distinctive changes noted were:

- Increased counts of specific anaerobic and streptococcal components, primarily of the saliva and dental plaque microflora.
- Elevations in levels of secretory IgA concurrent with diminutions of salivary lysozyme.
- Increased increments of dental calculus and gingival inflammation.

The microbial changes were mainly diet-related rather than flight-related. Elevations of secretory IgA were believed to result from a subclinical infection. Concurrent diminutions of salivary lysozyme are unexplained. The clinical changes in oral health were considered to be influenced more by a crewmember's preexisting dental problems than by any health hazardous mission-related effect.

Assuming no future clinical detection of mission-related intraoral complications, the most significant finding from this and previous Skylab missions was the diminutiveness of intraoral changes.

2.13.3 In-Flight Medical Microbiology Unit (IMMU)

J. K. Ferguson, Ph.D. and R. M. Brockett, Ph.D.

In-flight microbiological samples were obtained as scheduled for the SL-4 mission. The crew samples and the first set of environmental samples were taken on MD 69. The air samples and the second set of environmental samples were taken on MD 81. Food overcans containing heat sinks were used as an alternate method for sample recovery. Initial sample processing occurred on the recovery vessel immediately after the samples were removed from the Command Module.

Results

Crew and environmental samples

Medically important microorganisms isolated from the MD 69 samples consist of a Beta hemolytic streptococcus (not type A) from the throat sample of the PLT and *Moraxella* sp. found in one of the environmental samples.

On MD 81 *Pseudomonas aeruginosa*, *Klebsiella pneumoniae* and *Serratia marcescens* were isolated from the environmental samples (table 2.13.3-I). All three bacteria were isolated from the sample of the debris screen in the WMC. *Serratia marcescens* had not been isolated previously from the crew or the OWS.

Twenty of the 29 SL-4 environmental samples were found to contain fungi. Many of these samples contain more than one type of fungus (table 2.13.3-II). This represents a significant increase over six samples from SL 1/2 containing fungi and 11 from SL-3. *Aspergillus* sp. and *Penicillium* sp. were each found at a total of 10 sampling sites.

Air samples

A significant increase in the microbial content of the air occurred on this mission. The counts ranged from 7.3 to 12.8 bacteria per cubic foot (table 2.13.3-III). An average of 41.6 percent of these counts were due to the presence of *Serratia marcescens*.

The count of fungi in the air ranged from 2.7 to 6.0 viable particles per cubic foot. No fungi were isolated from the air during SL 1/2 or the SMEAT. A single fungal colony was isolated during SL-3. The microorganisms found appear to be the same types found on the LCG and in the environmental sample.

The total viable count in the SL-4 air ranged from 10.7-17.2. Although the total count is considerably higher than those of the earlier Skylab missions, the range remained within those observed during the SMEAT.

TABLE 2.13.3-I. MICROORGANISMS ISOLATED FROM SKYLAB ENVIRONMENTAL SAMPLES

MICROORGANISM	PREFLIGHT	SKYLAB 1/2		SKYLAB 3		SKYLAB 4
		MM*	EM†	MM	EM	
<i>Bacillus pantothenicus</i>	1	0	0	0	0	0
<i>Bacillus</i> sp.	0	0	0	3	2	0
<i>Corynebacterium</i> sp.	0	0	0	1	0	1
Evans Group A	0	1	0	0	0	0
Evans Group B	0	0	0	0	0	0
Evans Group D	2	0	0	1	0	0
Evans Group E	0	0	0	0	0	0
Evans Group G	0	0	0	0	0	0
<i>Eubacterium pentum</i>	0	0	0	1	0	1
<i>Herellea vaginicola</i>	1	0	0	0	1	0
<i>Klebsiella pneumoniae</i>	0	0	0	0	0	0
<i>Micrococcus</i> sp.	0	1	0	1	0	0
Subgroup 1	0	0	0	3	1	2
Subgroup 2	0	0	1	1	2	1
Subgroup 3	0	0	0	0	4	2
Subgroup 5	0	0	0	1	1	0
Subgroup 7	2	0	0	0	3	2
<i>Mima polymorpha</i>	0	0	0	0	0	1
<i>Moraxella</i> sp.	0	0	0	0	0	0
<i>Peptococcus marbillarum</i>	0	0	1	0	0	0
<i>Peptococcus magnum</i>	0	0	1	0	0	0
<i>Peptococcus saccharolyticus</i>	0	0	0	1	0	0
<i>Propionibacterium acnes</i>	1	3	0	2	7	0
<i>Pseudomonas aeruginosa</i>	0	0	0	1	0	0
<i>Serratia marcescens</i>	0	0	0	0	0	0
<i>Staphylococcus aureus</i>	1	0	2	3	5	0
<i>Staphylococcus epidermidis</i>	0	1	0	1	0	2
Subgroup II	5	1	5	3	4	2
Subgroup III	0	0	0	0	0	0
Subgroup IV	2	1	0	1	1	0
Subgroup V	0	1	1	2	2	1
Subgroup VI	0	0	1	1	1	1
<i>Streptococcus faecalis</i>	0	0	0	0	1	0
<i>Streptococcus mitis</i>	0	0	1	0	2	0
Unidentified (Gram Pos. Cocci)						0
Unidentified (Gram Neg. Rod)						1
TOTAL ISOLATIONS	15	9	13	27	36	18
AVG. CONC. (ORGS./IN ²)	5.2x10 ¹	8.4x10 ¹	3.2x10 ¹	1.1x10 ³	5.7x10 ³	1.7x10 ²

*MM = Midmission

†EM = End-of-Mission

TABLE 2.13.3-III. COUNTS OF VIABLE PARTICLES IN SKYLAB AND SWEAT AIR (MICROORGANISMS/FT³)

	SKYLAB 1/2		SKYLAB 3		SKYLAB 4	
	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
EXP. STATION (10 min)	3.0	0	1.3	0	7.3	3.4
EXP. STATION (5 min)	2.5	0	2.0	0	12.8	4.3
OWS HATCH (10 min)	1.7	0	1.6	.14	8.5	2.7
OWS HATCH (5 min)	5.4	0	2.9	0	10.7	6.0
SWEAT RANGE (10 min)	3.9-25					
SWEAT RANGE (5 min)	3.7-16					

Command m
Preflight
16 locati
In the pr
fungi iso
normal hu
activity.
adequate
during th

The postf
mentous f
isolates
isolates
the long
were most

Preflight
showed 6
samples f
fungi. T
effects o
if the su

Conclusion

Levels of
greater t
contamina
to *Serrat*
microorga

Twelve po
returned
116-418 c
dominant
of the O
LCG since
samples a

The conta
numerous
occur wit
by materi
seen on S
materials
for futur
measures

Command module and suit samples

Preflight and postflight microbiological samples were obtained from 16 locations in the CM and 4 locations from each of the 3 flight suits. In the preflight CM samples there were 33 bacterial and 6 filamentous fungi isolates from the 16 locations. All the bacterial isolates were normal human flora and would be expected in areas of high personnel activity. The relatively low numbers of filamentous fungi indicate an adequate effort in maintaining a controlled environment for the CM during the prelaunch period.

The postflight CM samples showed only 11 bacterial isolates, 3 filamentous fungi and 3 yeasts from the 16 locations and again the bacterial isolates were from normal human flora. The reduction in bacterial isolates would be expected due to "die off" of the microorganisms during the long flight. Those microorganisms present at postflight sampling were most likely shed by the crew during the return flight.

Preflight samples taken from the pressure garment assembly (PGA) suits showed 6 isolates of filamentous fungi for the 12 locations. Postflight samples from the same 12 locations showed 32 isolates of filamentous fungi. This is a significant increase and could prove to have detrimental effects on the suit material during long duration missions; especially if the suits were subjected to abnormal stresses.

Conclusion

Levels of contamination on SL-4 have been observed to be considerably greater than levels found on SL 1/2 and SL-3. The increased levels of contaminations are primarily due to the presence of numerous fungi and to *Serratia marcescens*, a soil microorganism. The source of this microorganism had not been determined.

Twelve postflight samples (contact plates) were obtained from the LCG returned from the OWS. In these samples fungal counts ranged from 116-418 colonies per plate. *Aspergillus* and *Penicillium* were the predominant genera isolated. It is most probable that the heavy contamination of the OWS with fungi resulted from dispersal of microorganisms from the LCG since the predominant fungi found on the LCG and in the environmental samples are of the same type.

The contaminant load observed on SL-4 has the potential of producing numerous problems in the space environment. Medical problems could occur with the crewmen or hardware and clothing problems could occur by material degradation from microbial growth. Contaminant loads as seen on SL-4 can be prevented. Attention should be given to all materials, systems, experiments and personal hygiene procedures developed for future missions in relation to contamination control. Preventive measures can then be developed once potential problems have been identified.

2.14 Potable Water System

R. L. Sauer, G. K. Jorgensen, and R. L. Reisenweber

The Saturn Workshop potable water system provided water for metabolic and hygienic needs. The 10 water tanks were designed to supply water for use in the WR, the WMC for hygienic use and emergency water for fire protection. The specific water tank allocations are shown in table 2.14-I. Iodine was injected as needed into the water tanks in order to maintain the water biologically safe. An onboard iodine color comparator was provided for the crew to use periodically to evaluate I_2 concentration and adjust the tanks as necessary. Iodine depletion within the tanks followed predicted curves (table 2.14-II). In-flight samples were taken and returned to JSC for postflight analysis. The samples were taken to verify the chemical quality of the water. The postflight analysis is a mandatory requirement so that assessment can be made of the impact of potable water chemical constituents on experiment M071, Mineral Balance (sec. 3.1), and M073, Bioassay of Body Fluids (sec. 3.2). The results are shown in table 2.14-III.

Water usage for all phases of the Skylab mission was below preflight estimates. The quantities used per mission and amounts remaining in the tanks following SL-4 are shown in table 2.14-IV.

In summary, the water system performed satisfactorily throughout the mission. No significant problems were experienced.

TABLE 2.14-I. WATER TANK ALLOCATION

<u>TANK NUMBER</u>	<u>SEQUENTIAL USAGE</u>
1	First Wardroom Tank
2	Third Wardroom Tank
3	Fourth Wardroom Tank
4	Fifth Wardroom Tank
5	Sixth Wardroom Tank
6	Urine Flush/Contingency Tank
7	First Waste Management
8	Second Waste Management
9	Contingency (Wardroom or Waste)
10	Second Wardroom Tank

TABLE 2.14-II. IODINE DEPLETION RATES

TANK NUMBER	DEPLETION RATES in ppm per day
1	0.023
2	0.0507
3	0.0526
4	0.02583
5	0.0277
6	0.03214
7	0.0464
8	0.018
9	0.072
10	0.045

TABLE 2.14-III. SKYLAB 4 IN-FLIGHT WATER SAMPLE

	Preflight	In-flight	Spec. Limit
Electrical Conductivity (mho/cm)	23	45	Ref. Only
pH	4.5	4.9	4 ↔ 8
Turbidity (Units*)	4	16	11
Color (Units*)	100	5.0	Ref. Only
Iodine (ppm)	8	0.7	Ref. Only
Ionic Species			
Cd	<0.01	<0.001 [†]	0.01
Ca	<1.0	0.2	5.6
Cr	0.02	<0.005 [†]	0.05
Cu	<0.05	<0.005 [†]	1.0
Fe	0.09	0.15	0.3
Pb	<0.05	<0.005 [†]	0.05
Mn	<0.01	<0.005 [†]	0.05
Hg	<0.005	<0.0001 [†]	0.005
Ni	<0.05	<0.01 [†]	0.05
Zn	<0.05	0.01	5.0
Se	<0.01	0.01	0.01
Al	<0.1	<0.05 [†]	Ref. Only
K	1.7	9.6	Ref. Only
Si	<0.5	0.01	Ref. Only
Na	<0.1	.12	Ref. Only
Ag	<0.02	0.005	0.05

* = Units as defined in JSC Potable Water Specification Spec-1 Rev. D
[†] = Represents lowest level of detectability

TABLE 2.14-IV. WATER USAGE DURING MISSIONS

A. AT THE END OF SL 1/2

560.4 pounds of water used for the Wardroom from Tank 1

257.6 pounds of water used for the Waste Management Compartment from Tank 7

Total water usage represented 92% of preflight estimates.

B. AT THE END OF SL-3

496.3 pounds of water used for the Wardroom from Tank 10

330.4 pounds of water used for the Wardroom from Tank 2

334.5 pounds of water used from Tank 7 for the Waste Management Compartment

Total water usage represented 72.5% of preflight estimates.

C. AT THE END OF SL-4

264.7 pounds of water used for the Wardroom from Tank 2

533.2 pounds of water used for the Wardroom from Tank 3

416.6 pounds of water used for the Wardroom from Tank 5

430.8 pounds of water used from Tank 8 used for Waste Management

Total water usage represented 72% of preflight estimates.

D. REMAINING WATER TANK QUANTITIES

Tank Number	Quantity at Launch	After SL-4
	1b	1b
1	595.2	90
2	595.1	0
3	595.2	51
4	589.6	256
5	589.6	173
6	594.2	594
7	596.0	110
8	592.8	162
9	572.4	517
10	595.6	75

2.15 Skylab 4 Radiological Health

Robert A. English, Ph.D. and J. Vernon Bailey

Crew Radiation Exposure

A. Initial Predictions

Radiation dose predictions for the SL-4 crewmen were provided prior to the mission. The predictions were based on SL-3 dosimetry results, and assumed a continuation of a nominal space radiation environment. The preflight predictions provided a broad range of from 7 to 18 rem for skin dose equivalent due to the large influence of relatively slight changes in EVA schedules. Dose equivalents to lens of the eye and blood forming organs (BFO) were projected at 5-7 rem and 3-4 rem, respectively, for a 60 day mission. These projections are compared in table 2.15-I with the MD 84 in-flight dose estimates and preliminary postflight dosimetry results.

TABLE 2.15-I. SL-4 CREW RADIATION DOSE COMPARISON

<u>Crewman</u>	<u>Tissue</u>	<u>Projection* (rem)</u>	<u>In-flight (rem)</u>	<u>Postflight (rem)</u>
CDR	Skin	7-18	9.9	14.3
	Eye	5-7	7.3	12.2
	BFO	3-4	3.9	6.95
SPT	Skin	7-18	14.6	17.1
	Eye	5-7	7.3	10.3
	BFO	3-4	3.9	5.89
PLT	Skin	7-18	13.8	15.4
	Eye	5-7	7.4	9.52
	BFO	3-4	3.9	5.44

*Projection was for a 60-day mission: adjusted for 84 days, doses would be 10-25 rem skin; 7-10 rem lens; and 4-6 rem BFO.

B. In-flight and Postflight Dosimetry

Operational radiation measurements were made in accordance with the functional objectives of the *Skylab Mission Requirements Document* 1-MRD-001F, in order to provide data for daily analysis of crew dose. Daily reports on crew dose were submitted by the Space Radiation Analysis Section (SRAS) and the Radiological Health Officer (RHO). Results as of the MD 85 report are given in the "In-flight" column of table 2.15-I.

Preliminary postflight analyses of thermoluminescent dosimeter materials from the continuously worn crew passive dosimeters (CPD) provide a further refinement of crew dose determination. The postflight values are included in table 2.15-1 to provide a comparison of the projection, in-flight estimate, and postflight analysis results.

Procedures and Problems

A. Real Time Dosimetry

- ° Personal Radiation Dosimeter (PRD). - Personal Radiation Dosimeters were assigned to the crewmembers to provide onboard readouts of integrated radiation doses. One additional PRD was launched as a spare in CM stowage locker B-1. Use of the spare was not required during this mission.

Each crewmember wore his PRD from launch through the first four days of flight, all EVA's and reentry. During the remainder of the mission, crew PRD's were positioned as follows: CDR - plus Z Scientific Airlock (+Z SAL), SPT - Experiment Compartment Wall, and PLT - Sleep Compartment. All PRD's functioned well throughout the mission. Results of PRD readouts were used in real time support of the mission to validate and refine premission projections of crew dose. Values for crew dose in the "In-flight" column of table 2.15-1 are based primarily upon PRD results.

No problems occurred with the PRD's. Crew readouts and subsequent data recovery via voice dump tapes were excellent. Data receipt was approximately 60% above the level stipulated in the *Skylab Mission Requirements Document* 1-MRD-001F.

- ° Van Allen Belt Dosimeter (VABD). - The VABD met all functional objectives of the *Skylab Mission Requirements Document* 1-MRD-001F throughout the unmanned and manned phases of SL-4.

Noise pulses appeared on the VABD telemetry following transfer of CM guidance and control heater circuits to the AM2 buss. A similar situation occurred during SL 1/2 and SL-3. The phenomenon is discussed in more detail in the JSC-08439 *Skylab 1/2 Preliminary Biomedical Report*. These transient pulses did not compromise the dosimetric accuracy of the instrument - output format from the Mission Data Retrieval System which was simply modified to recall data between the regularly spaced transient pulses.

- fluorescent dosimeter (FD) and passive dosimeters (PD) were used for radiation monitoring. The FDs provide a comparison of the radiation environment to the flight analysis.
- Radiation Survey Meter (RSM). - The RSM was utilized in accordance with the Mission Rules, section 12-1, by the non-EVA crewmember during each EVA. No abnormally high readings were reported during any of the four EVA periods.

A set of calibration readings was taken on MD 5 with the RSM positioned near the Van Allen Belt Dosimeter. The calibration followed routine RSM battery replacement, and indicated very close dose rate agreement between the RSM and VABD.

A radiation survey of the OWS film vault was performed by the PLT on MD 75. The survey was performed during a high dose rate pass through the South Atlantic Anomaly (SAA). Radiation Survey Meter readings were made within drawers A and E of the film vault, and external to the vault. Dose rate data were obtained from the VABD concurrent with the survey. Space Radiation Analysis Support personnel are in the process of assessing the survey as it applies to photographic film dosimetry, and in general, to thick shield attenuation of Van Allen Belt protons.

- Electron-Proton Spectrometer (EPS). - The EPS met all functional objectives of the *Skylab Mission Requirements Document* 1-MRD-001F.

B. Radiation Events

No increases in the nominal radiation environment were measured at any time during the SL-4 mission. No above-ground nuclear testing occurred during the mission, and there were no solar particle events of radiation dose significance to the crew.

C. Astronaut Passive Dosimetry

One passive dosimeter (PD) was worn by each crewman throughout the mission. The CDR wore his dosimeter on the right ankle throughout the mission, while the SPT wore his on the wrist. The PLT wore his dosimeter on the wrist for the first nine days of the mission, then transferred the dosimeter to a pocket in his coverall garment for the remainder of the mission. The coverall, with its dosimeter, was stowed in close proximity to the shoulder of the PLT during sleep. The other two crewmen normally wore their dosimeters while asleep. During EVA's, each of the crewmen wore the passive dosimeters in a garment pocket (chest location) beneath the space suit.

Each PD contains lithium fluoride thermoluminescent dosimeter chips, nuclear emulsions, high atomic weight particle detectors, and neutron activation foils.

- Results of TLD Analysis. - The reported thermoluminescent dosimeter readings, in rad, are:

CDR	8.68
SPT	7.36
PLT	6.80

- Other Analyses. - Nuclear emulsion analysis is in progress at the Naval Aerospace Medical Institute, and high atomic number particle detectors are being analyzed at the University of San Francisco. Tantalum and iridium neutron activation foils are being analyzed at the JSC Low-Level Counting Facility. In addition, the Radiological Health Section is coordinating post-flight analyses of induced radioactivity in urine. These specimens also are under-going analysis at the JSC Low-Level Counting Facility.

D. Combined Dosimetry Results

Final dose equivalent (rem) evaluation must await completion of passive dosimeter analyses. At present, however, a reasonable estimate of the proton dose equivalent at tissue depths comparable to skin, lens of the eye and bone marrow may be made by utilizing TLD results, the observed VABD skin/bone ratio (3/2 for penetrating protons), and quality factors (late effects)¹ computed for skin, particle spectra indicated by EPS data (Q.F. = 1.5 for skin, 1.4 for lens of eye, and 1.2 for blood forming organs). Electron doses, which are received only during EVA, are relatively "invisible" to the TLD chips due to shielding by the dosimeter shell, HZE detector foils and nuclear emulsions. Consequently, the electron dose component (Q.F. = 1.0) is calculated from the known radiation environment. Electron dose equivalents are added to the proton dose equivalents to give the "total rem" values shown in table 2.15-II². Electrons have very low penetration ability, and therefore are negligible contributors to lens and BFO doses.

¹Quality factors (Q.F.'s) for early effects are lower, and are approximately 1.1 for blood forming organs, 1.2 for lens of eye and skin. However, early effect Q.F.'s apply only at dose rates above 50 rad/h, and no rates this high were observed during SL-4.

²Identical postflight totals have been given in table 2.15-I for the purpose of comparison with the premission projection and in-flight measurements.

TABLE 2.15-II. POSTFLIGHT DOSE EQUIVALENT VALUES BASED
UPON PARTIAL PASSIVE DOSIMETER ANALYSIS

Astronaut	Location	Proton (rad)	Proton (rem)	Electron (rem)	Total (rem)
CDR	Skin	8.68	13.0	1.34	14.3
	Lens	8.68	12.2	NA*	12.2
	BFO	5.79	6.95	NA	6.95
SPT	Skin	7.36	11.0	6.07	17.1
	Lens	7.36	10.3	NA	10.3
	BFO	4.91	5.89	NA	5.89
PLT	Skin	6.80	10.2	5.22	15.4
	Lens	6.80	9.52	NA	9.52
	BFO	4.53	5.44	NA	5.44

*NA = Not Applicable

E. Visual Light Flash Phenomena

Light flash observations acquired official experiment status for SL-4. Detailed test objectives for these observations are to be found in Section 20.31 of the *Skylab Mission Requirements Document* 1-MRD-001F. The reader is referred to section 2.15.1 of this *SL-4 Preliminary Biomedical Report* for a full discussion of the experiment and its findings.

Conclusion

Preliminary analyses indicate that the absorbed dose from space radiation exposure to SL-4 crewmen ranged from approximately 14 to 17 rem skin, 9.5 to 12 rem lens of eye, and less than 7 rem at bone marrow depth. These doses are equal to or less than 25 percent of the SL-4 guidelines, and are well below threshold for production of detectable medical effects.

2.15.1 Visual Light Flash Investigation

*L. S. Pinsky, Ph.D.; R. A. Hoffman, D.V.M.; Z. Osborne, Ph.D.;
and J. V. Bailey*

Introduction

It has been quite generally accepted that light flashes observed on the Apollo missions were due to passage of HZE ($Z \geq 6$) particles through the retina, although the exact mechanisms of the particle-retina interaction for each of the different types of flashes observed is still uncertain. If this is the cause, a strong latitude dependence of the light flash rate would exist for an observer in Earth orbit. This effect is a consequence of geomagnetic cutoff and the steep energy spectrum of cosmic ray fluxes. In other words, only primary cosmic ray particles with very high energy can reach orbital altitudes near the equator, while particles with much lower energies can be incident near the magnetic poles.

The primary objective of the study reported here was to investigate the frequency and character of visual light flashes in near Earth orbit as the Skylab trajectory passed from northern to southern latitudes. Because the trajectory periodically passed through the South Atlantic Anomaly, another study objective was the investigation of possible visual flashes during passage through this region.

Procedure

Two observation periods were planned with one crewmember (pilot) participating in each period. These observation sessions were accomplished on orbits selected to provide data on both latitude and SAA effects. Unfortunately, no single orbit possessed ideal geomagnetic latitude and anomaly conditions. Hence the first session was selected to provide the best latitude conditions which then passed through only the edge of the SAA region. The second session passed through the center of the SAA but did not achieve geomagnetic latitudes quite as high as the first. The first session occurred on MD 74 and was 70 minutes in duration, while the second occurred on MD 81 and was 55 minutes long. The second period was shorter because of very critical time limitations during the last few days of the mission.

At the start of each session the PLT got into his sleep restraint, set a timer for the prescribed period (either 70 or 55 minutes), donned a blindfold, and began observing for light flashes. Approximately the first 10 minutes of each session were void of observations while the subject was adapting to the dark. During the first session no particular position in the sleep restraint was specified. The OWS was in a Solar Inertial Mode during both periods and local noon occurred

very close to equator passage in both cases. For the second session, directions were given for head positioning which placed the anterior-posterior axis of the head parallel to the Earth's magnetic field lines in the anomaly.

The occurrence of each event along with its description was voice recorded on the onboard tape recorder and a transcript of the recording for each of the two periods was obtained for analysis.

Results and Comments

During the first period, a total of 24 flashes were reported. Figure 2.15.1-1 contains a plot of the trajectory's ground track for both periods with the event occurrences marked. Also included are lines of constant (vertical) geomagnetic cutoff for reference. Figure 2.15.1-2 contains a synopsis of the time of occurrence of the first period flashes, along with the calculated $Z > 2$ integral cosmic ray flux over the period. The Van Allen belt dosimeter readout is also plotted (note different scale for VABD plot). Figure 2.15.1-3 contains a similar plot for the 139 definite flashes and five distinct threshold or background reports. On three separate occasions during the second period (as indicated by the horizontal bars in figure 2.15.1-3), the CDR was simultaneously using the tape and perhaps inhibited the PLT from giving complete descriptions.

The following conclusions can be drawn from these data:

- Dark adaptation of at least 10 minutes duration is required to begin observing the flashes.
- There is a strong correlation with very high flash rates during passage through the SAA; and from physical arguments and event descriptions, it appears certain that these flashes are due to the trapped radiation.
- There is strong evidence for the predicted latitude effect, although the statistics are not yet overwhelming.
- The PLT's sensitivity was markedly less during the first period, and the difference was consistent over the entire trajectory when compared with the second period results. This difference could possibly be due to any one of a number of physiological factors that can affect dark adaptation sensitivity.
- From the second period event descriptions, the area type or "cloud-like" flashes seem to predominate at cutoffs where only high energy particles are allowed.



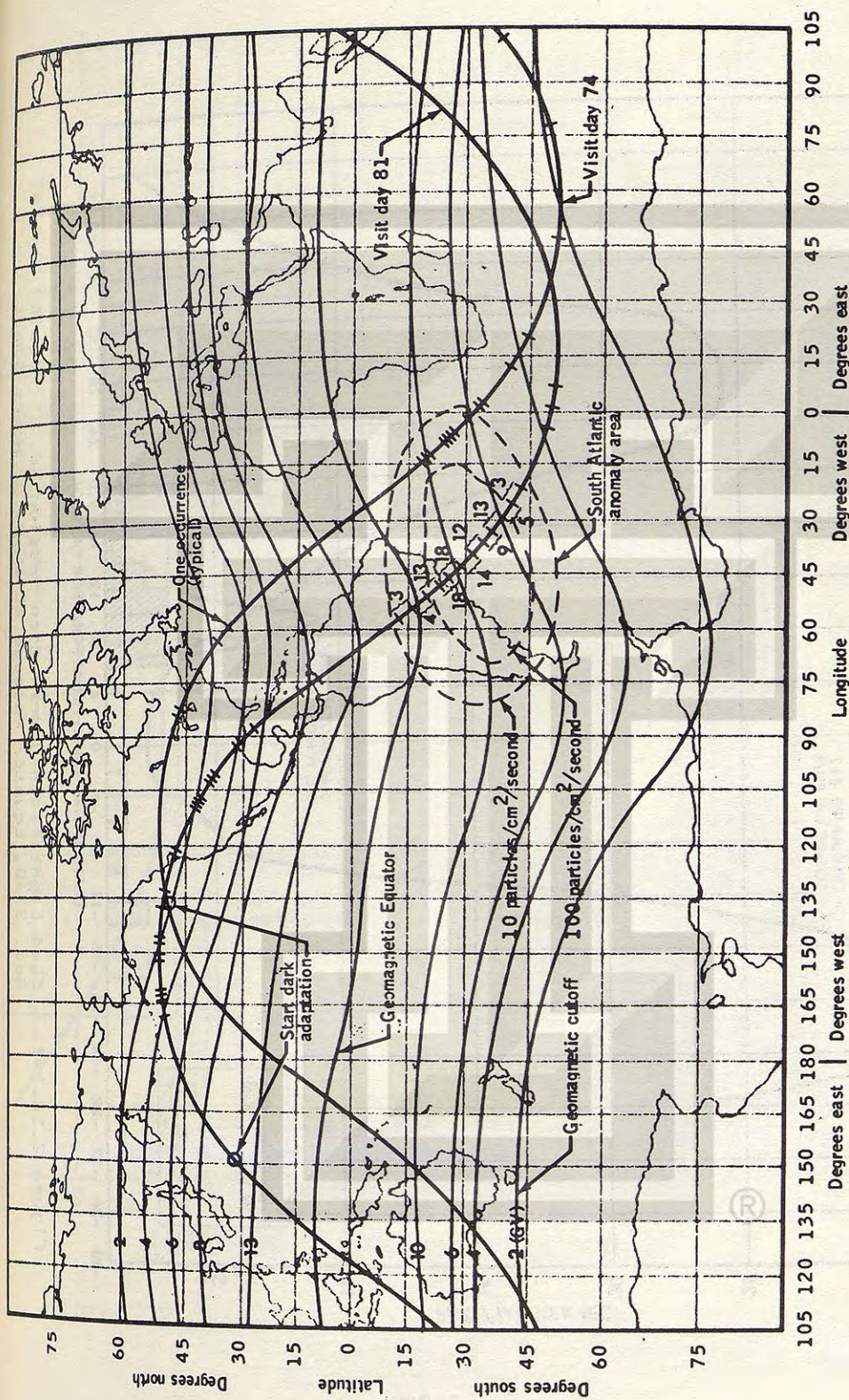


Figure 2.15.1-1. - Event Occurrences Along Ground Tracks For The Two SL-4 Light Flash Sessions, (PLT-Observer).

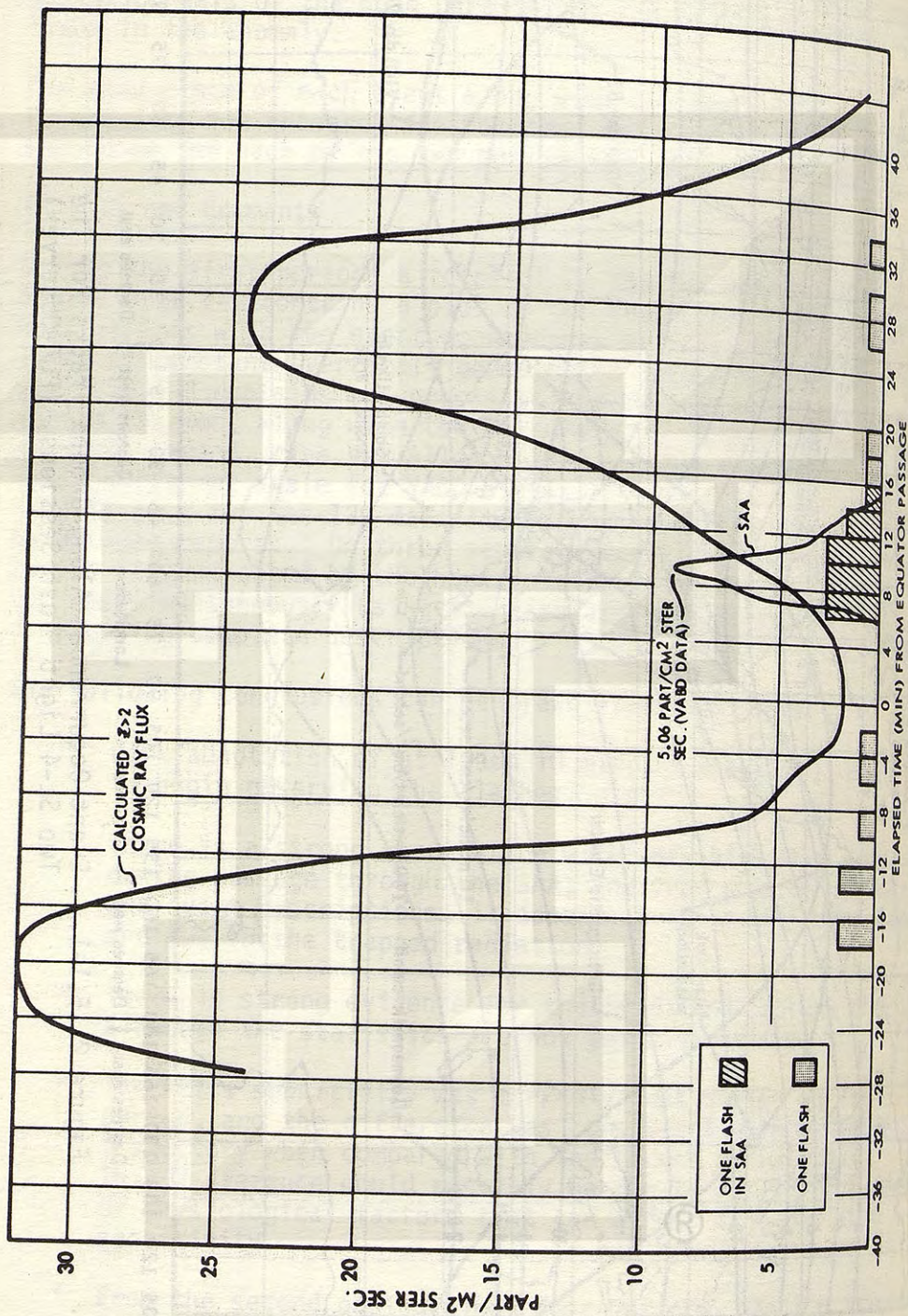


Figure 2.16.1-2. - SL-4 Light Flash Observation Session No. 1 (Mission Day 74)
REV. 37402 EQUATOR PASSAGE AT 16:24:02 Hours G.M.T.

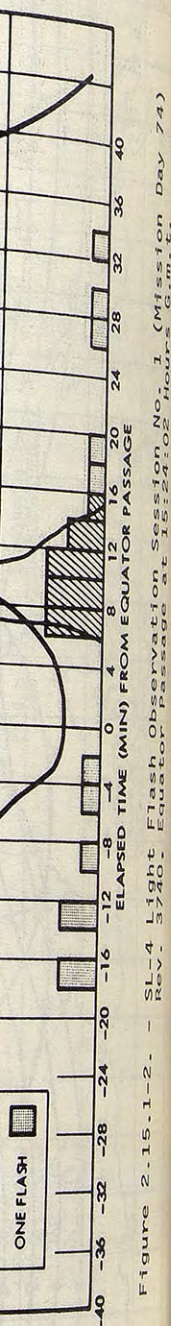


Figure 2.15.1-2. - SL-4 Light Flash Observation Session No. 1 (Mission Day 74) Rev. 3740, Equator Passage at 15:24:02 Hours G.m.t.

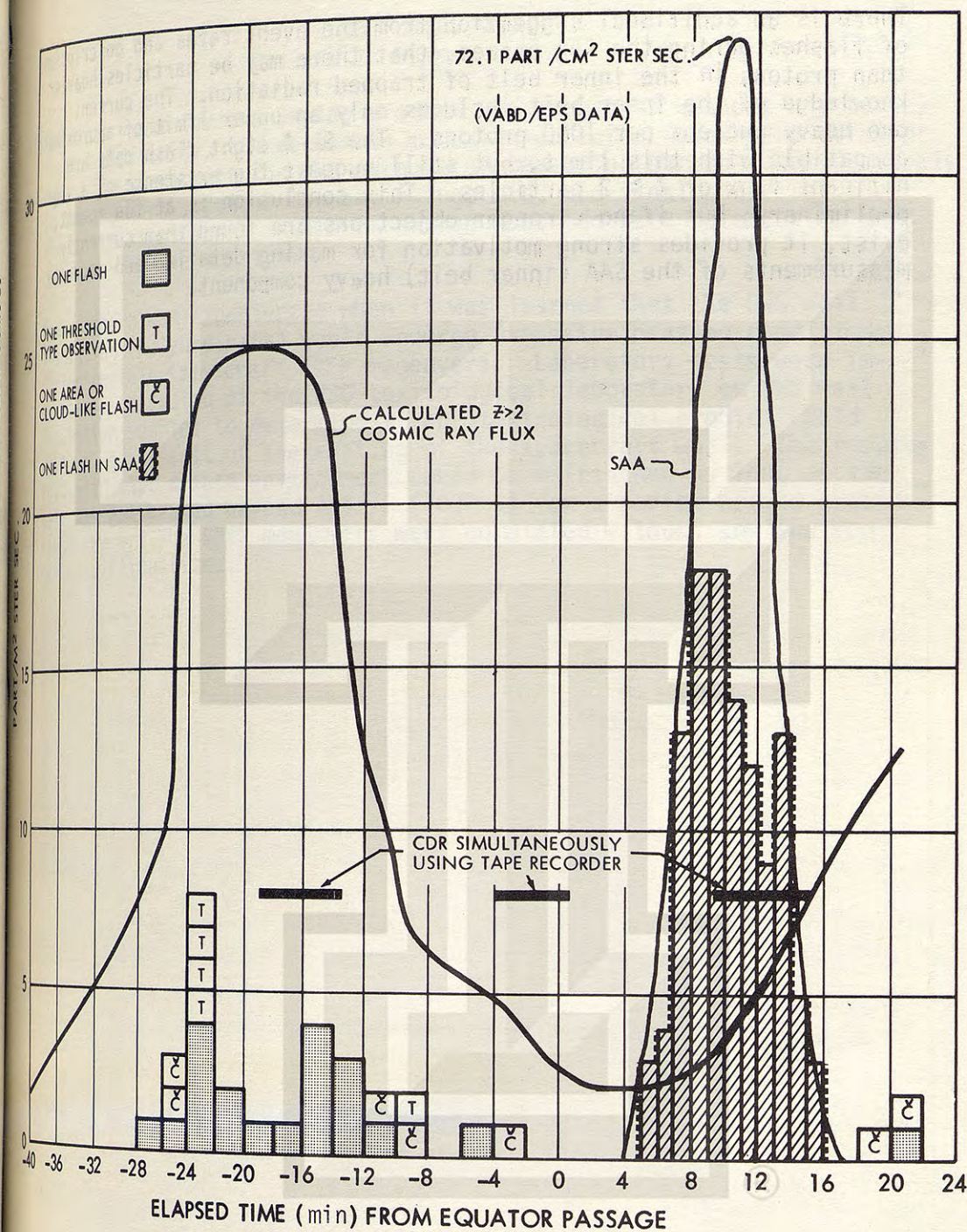


Figure 2.15.1-3. - SL-4 Light Flash Observation Session No. 2 (Mission Day 81) Rev. 3841, Equator Passage at 15:06:04 Hours G.m.t.

There is an additional suggestion from the event rates and descriptions of flashes during the SAA passes, that there may be particles heavier than protons in the inner belt of trapped radiation. The current knowledge of the inner belt includes only an upper limit of approximately one heavy nucleus per 1000 protons. The SL-4 light flash data are compatible with this limit, but still suggest the existence of a significant flux of $Z \geq 2$ particles. This conclusion is at the moment, preliminary; but if no stronger objections are found than currently exist, it provides strong motivation for making detailed and accurate measurements of the SAA (inner belt) heavy component.

2.16 Toxicology

Wayland J. Rippstein, Jr.

The final visit for the Skylab program was completed without any toxicological difficulty. Three carbon monoxide detector tubes were carried aboard the spacecraft for the purpose of measuring carbon monoxide levels in the OWS work space at the beginning, mid, and final phases of the visit. No significant levels of carbon monoxide were detected at any period during the mission.

Some concern was experienced when it was learned that the OWS wall insulation (polyurethane) would undergo excessive heating conditions during certain spacecraft EREP maneuvers. Laboratory tests were immediately conducted at the JSC toxicological laboratory on OWS wall insulation samples to determine if any toxicological problem could develop as a result of the heating of the spacecraft wall. The results indicated that a safe environment could be maintained as long as the wall was not heated beyond 325° F (162° C) for a period not to exceed eight hours. The EREP maneuvers were completed without any environmental difficulties.

2.17 Hemodynamics of the Lower Limbs

W. Thornton, M.D. and G. W. Hoffler, M. D.

Background

Significant among the medical findings following space flight have been reduced orthostatic tolerance and ergometer measured work capacity. Changes in hemodynamics of the legs with increased blood pooling must be considered one of the primary causes of these effects. This plus the marked tissue changes occurring in the legs during flight (1), prompted the addition of several procedures to evaluate changes in arterial blood flow, venous compliance, and muscle pumping. Impromptu studies were implemented during the latter portion of the SL-3 mission. Results were of sufficient value to include more comprehensive studies on SL-4. Results from SL-4 raise a number of issues which will require additional study, but they also provide previously unavailable insight into some fundamental mechanisms. For convenience, the experiment will be described under two headings: (1) arterial flow and venous compliance, and (2) muscle pumping.

Methodology

1. Arterial flow and venous compliance. - If an occlusive cuff placed around a limb segment is inflated somewhat above venous pressure, arterial flow will be little affected, but venous flow will be stopped until venous pressure exceeds cuff pressure. If volume change is also measured, the initial rate of change with time, before appreciable back pressure develops, is arterial inflow. There are many assumptions and sources of potential error in this measurement and those pertinent to this study will be discussed (2, 3).

Vascular compliance, *i.e.*, change in volume/change in pressure, which in this case is assumed to be venous compliance, may be qualitatively estimated from the shape of the volume curves from a tracing following cuff inflation, and a single numerical value may be obtained at cuff pressure, or 30 mm Hg in this case.

Data for these two studies were obtained, as shown in figure 2.17-1, with an arm blood pressure (BP) cuff above the left knee and a capacitance Limb Volume Measuring System (LVMS) band around the maximum girth of the calf. Volume changes actually measured are only those in the segment directly beneath the cuff and are recorded in percent of segment volume. The BP cuff was used to isolate the smallest practical segment to reduce systemic disturbance to a minimum. The least modified response from the vessel was sought as opposed to a measurement such as Lower Body Negative Pressure (LBNP) which induces many compensatory changes.

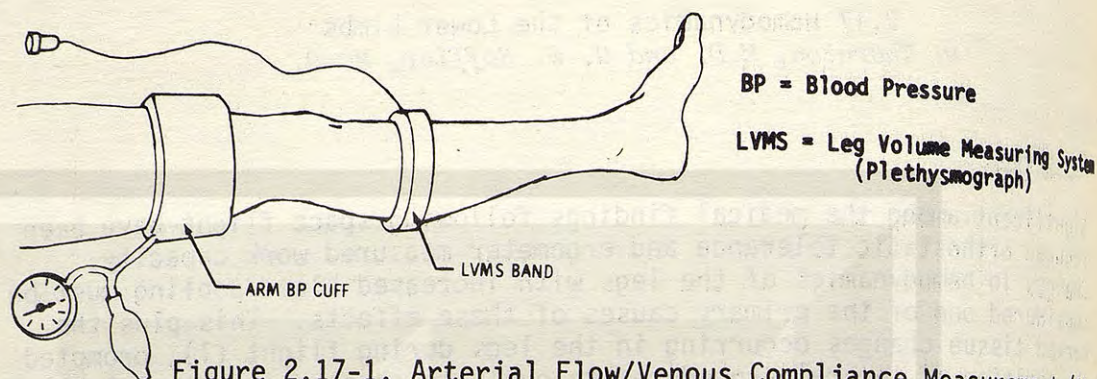


Figure 2.17-1. Arterial Flow/Venous Compliance Measurement (SL-4).

1. Blood flow was recorded three times by rapidly inflating the cuff to and maintaining it at 30 mm Hg for 10 seconds. This sequence was repeated at 50 mm Hg cuff pressure for a total of six determinations for each test session. Curves for such a series at 30 mm Hg are shown in figure 2.17-2. For compliance studies, three minutes later in the mission the cuff was inflated to and held at 30 mm Hg for 2 minutes; the resulting volume curve was recorded and an example is shown in figure 2.17-3.

2. ³ Muscle pumping - The crewman was left in the LBNP apparatus after completion of M092 (sec. 3.5), the LVMS system was rezeroed and recalibrated, and a negative pressure of 30 mm Hg was applied for 3 minutes. At the end of this time the subject made 10 maximum effort isometric contractions of his leg muscles, relaxed for one minute and repeated the maneuver. Changes in a left calf volume segment were recorded from the LVMS, as shown in figure 2.17-4.

Procedure

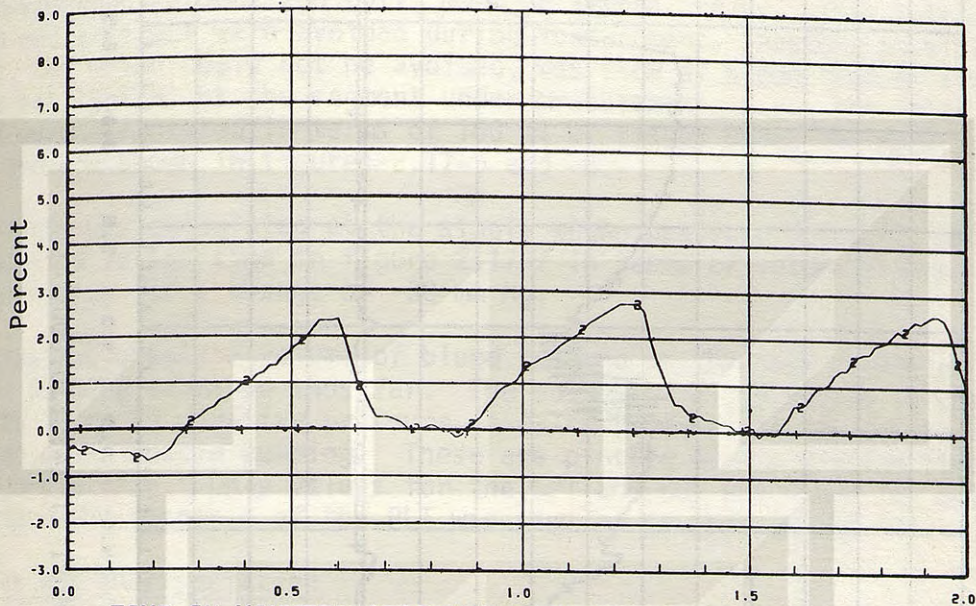
The entire series of procedures was performed three times preflight, seven times in-flight, and three times postflight. The original in-flight schedule was minimal but was reduced even further during periods critical to the experiment. This schedule was not controlled by investigators or crew. Several trials were lost or severely compromised by artifacts which appeared to be electrical. Unfortunately the measurement periods could not be adequately correlated to other factors capable of affecting measurements such as temperature, time relation to meals or exercise and state of hydration. Other than these problems the data were collected without difficulty.

Blood flow was calculated by manually drawing a tangent to the slope and measuring this slope in terms of $\Delta \text{ volume} / \Delta \text{ time}$. Several artifacts

LEG BLOOD FLOW DATA (A)

1. P7036M092

2. P7004M092



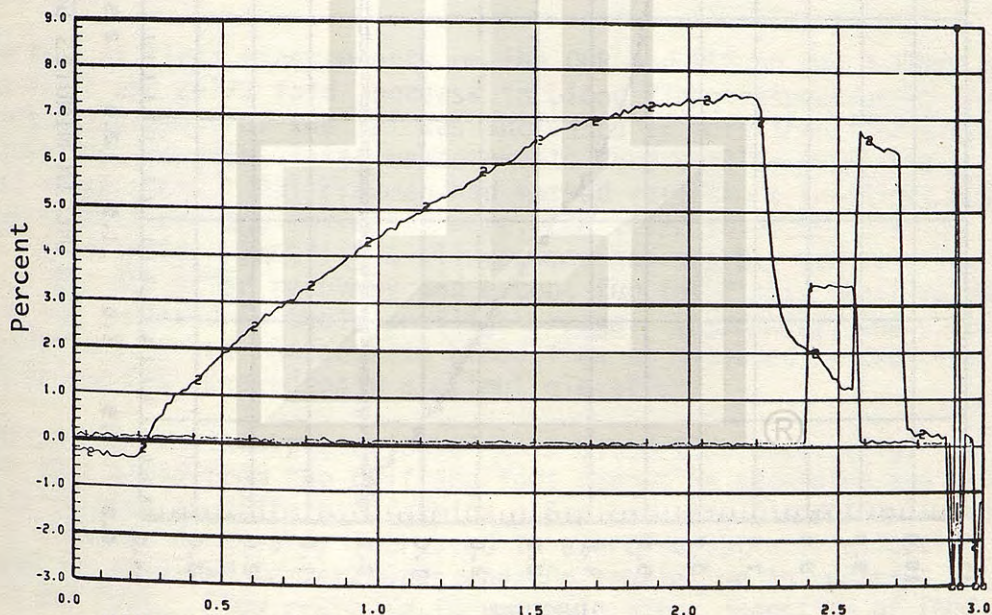
TIME IN MINUTES STARTING FROM MD14 AT 22:42:40:000.

Figure 2.17-2. - Leg Blood Flow Data, SL-4 SPT.

LEG BLOOD FLOW DATA (B)

1. P7036M092

2. P7004M092



TIME IN MINUTES STARTING FROM MD14 AT 22:48:20:000.

Figure 2.17-3. - Compliance Curve (at 30 mm Hg),
SL-4 SPT.

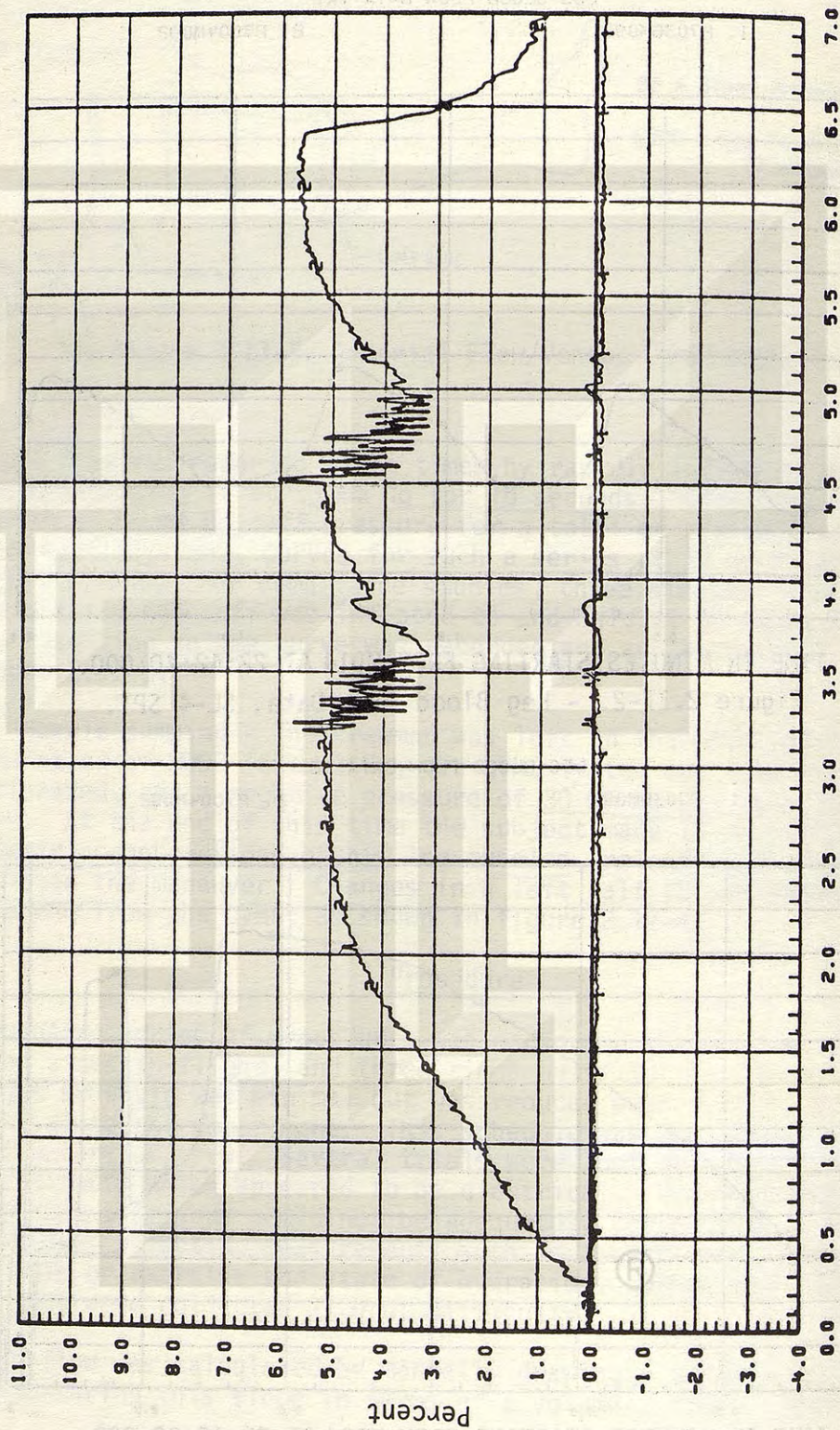


Figure 2.17-4. - SL-4 Muscle Pump Data (Pumping Against 30 mm Hg Negative Pressure).

may be present in this curve. There was an increased rate of volume change during cuff inflation which, in spite of the distance between plethysmograph segment and cuff, must be venous reflux. This initial slope and artifact were avoided during measurement. Another possible error, but which could not be avoided, was flow of blood from or into areas not typical of the segment under measurement, *e.g.*, the foot. Flows were calculated in terms of 100 ml of tissue under the capacitance band and are shown in figures 2.17-5 and -6.

Compliance was calculated at the single known pressure point, 30 mm Hg, and plotted versus time in figure 2.17-7 in terms of volume change/100 ml tissue for a change of -30 mm Hg.

Relative and absolute volume of blood removed is the only aspect of muscle pumping examined thus far. The volume of blood pooled in the legs by 30 mm Hg negative pressure is calculated, as is the amount remaining after muscle pumping. These are plotted *versus* mission time in figure 2.17-8. Only values for the SPT and CDR are shown for graphic clarity. The response of the PLT was similar to that of the SPT.

Results and Interpretation

Blood flow: The blood flow curves in Figs. 2.17-5 and 2.17-6 are reasonably consistent indicating relatively complete venous occlusion with the arm band cuff at both 30 and 50 mm Hg pressure. Preflight values were in the range of 1/2 to 1-1/2 ml/min for 100 ml tissue which is on the low side of the findings from a study of young and old normal, fit, men (4).

By the time of first measurements on the CDR and PLT on day 3 there had been a 1-1/2 and 2-1/2 fold increase in blood flow, respectively. The earliest measurement of the SPT was increased by more than four times over baseline, however, later measurements were smaller than this initial measurement. All crewmen had marked variations in-flight but the approximate average increases were: CDR 1-1/2 fold, SPT 2-fold and PLT 2-1/2 fold. Postflight all crewmen had sharply reduced flow rates by the day after recovery and except for the Pilot, their values were in and remained in their preflight range. In summary, there was a definite and marked increase in blood flow as measured in two crewmen while the CDR showed only a slight elevation.

A major problem in interpretation of this blood flow data, (figs. 2.17-5, -6), is that blood from the calf and foot cannot be separated and these segments respond in different fashion. For example, blood flow in the calf is known to be greatly increased in exercise but only slightly increased by elevated temperatures and CO₂ inhalation in contrast to flow in the foot. Flow response is variable after ingestion of food

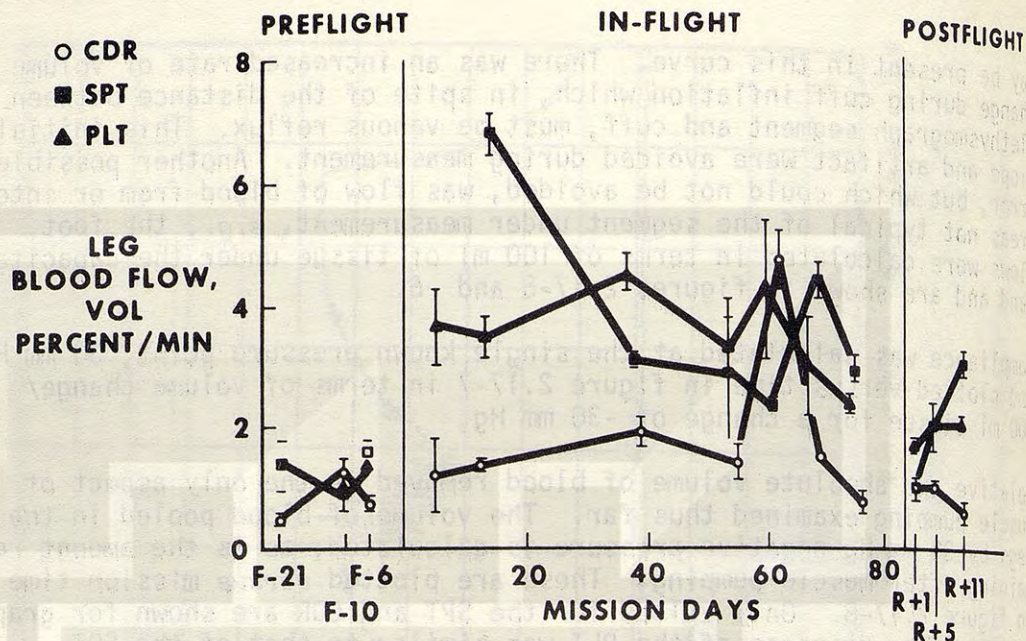


Figure 2.17-5. - Skylab 4 Arterial Blood Flow, Leg Cuff Occlusion Pressure (50 mm Hg).

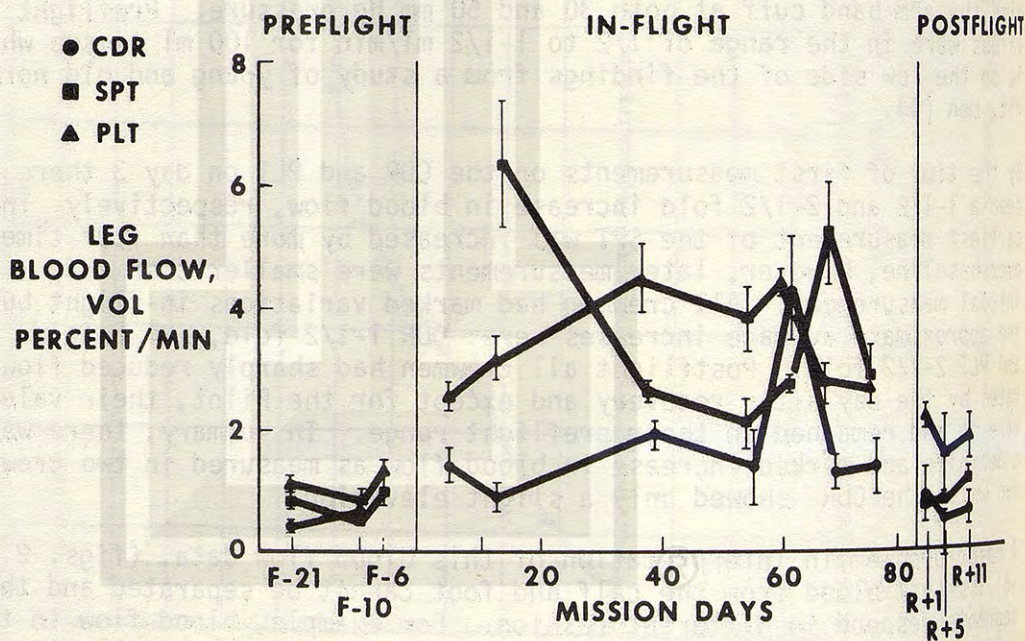


Figure 2.17-6. - Skylab 4 Arterial Blood Flow, Leg Cuff Occlusion Pressure (30 mm Hg).

OSTFLIGHT

POSTFLIGHT

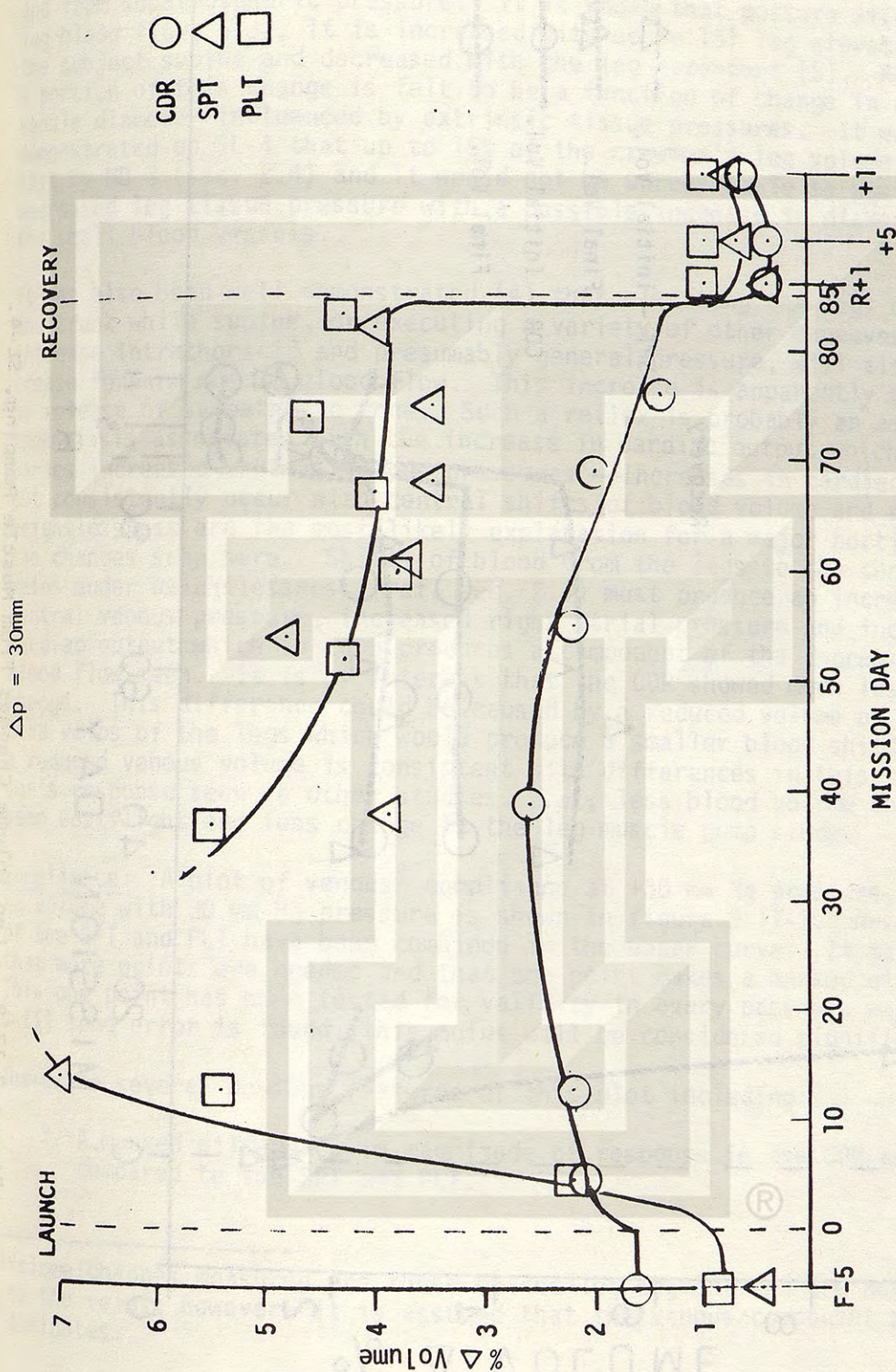


Figure 2.17-7. - Vascular Compliance, Left Leg, SL-4 Crew.

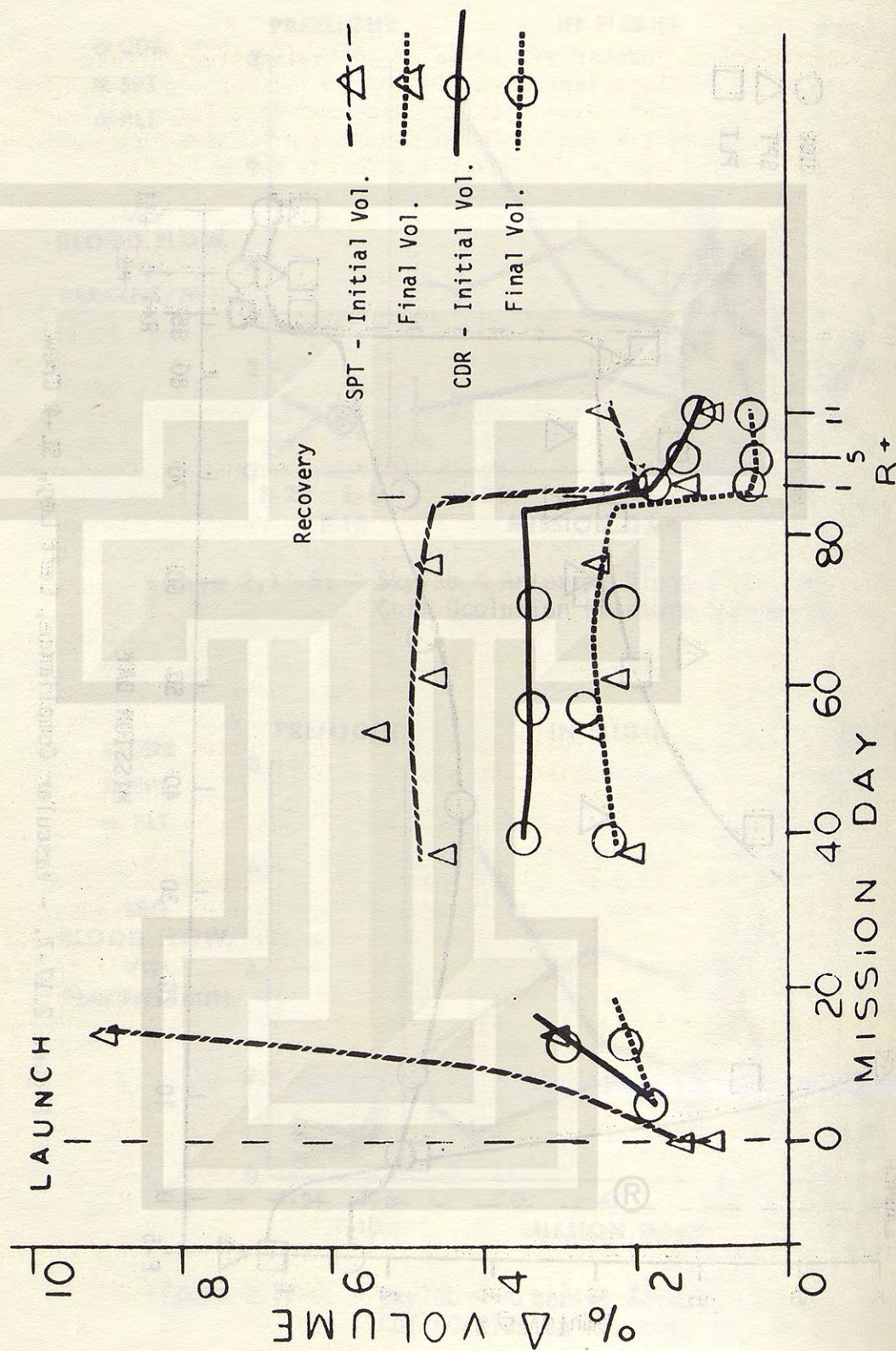


Figure 2.17-8. - Leg Volume Changes From Muscle Pumping, SL-4.

and from subatmospheric pressure. It is known that posture affects leg blood flow, *e.g.*, it is increased with up to 15° leg elevation with the subject supine and decreased with the leg dependent (5). At least a portion of this change is felt to be a function of change in arteriole-venule diameter influenced by extrinsic tissue pressures. It was demonstrated on SL-4 that up to 15% of the crewmen's leg volume had been lost by MD 3 (sec. 2.4) and it would not be unreasonable to postulate decreased leg tissue pressure with a possible increase in diameter of the small blood vessels.

It has also been well demonstrated (4) that elevating the legs or legs and trunk while supine, or executing a variety of other maneuvers which increase intrathoracic and presumably general pressure, will also increase forearm muscle blood flow. This increase is apparently regulated by release of sympathetic tone. Such a reflex is probably an aspect of homeostasis associated with the increase in cardiac output which accompanies increased central venous pressures. Increases in cardiac output consistently occur with central shifts of blood volume and under weightlessness are the most likely explanation for a major portion of the changes seen here. Shifts of blood from the legs to the central veins under weightlessness (ref. sec. 2.4) must produce an increased central venous pressure, increased right atrial pressure and increased cardiac output which in turn produces a component of the increased blood flow seen. It is of interest that the CDR showed much less change. This difference could be caused by a reduced volume of the deep veins of the legs which would produce a smaller blood shift. Such a reduced venous volume is consistent with differences in this crewman's response seen in other studies, *e.g.*, less blood volume change seen postflight and less change in the leg muscle pump study.

Compliance: A plot of venous¹ compliance at +30 mm Hg pressure, *i.e.* %Δ volume with 30 mm Hg pressure is shown in figure 2.17-7. Responses of the SPT and PLT have been combined in the upper curve. It is obvious that more points are needed and that one point makes a marked difference. This one point has been tested for validity in every possible way and until some error is found, this point will be considered significant.

There are several obvious features of this plot including:

- ° A marked difference in magnitude of response in the CDR as compared to the SPT and PLT.

¹Volume changes measured are those of the leg segment and are not limited to the veins; however, it is assumed that the venous component predominates.

- ° A several fold increase in compliance in two crewmen which, however, required some two weeks to reach a maximum.
- ° After this initial increase in compliance there was a decrease, or at least stability, until mission end.
- ° On return to one-g after 24 hours or less there was a return to or even beyond preflight values.

Venous compliance and muscular pumping of venous blood can only be understood in terms of the unique features of leg veins which include a network of superficial veins with heavy muscular walls and many one-way valves, many interconnecting veins or penetrating branches with centrally directed one-way valves, and large thin-walled veins surrounded by muscles which, in turn, are frequently surrounded by fascia. These deep veins are also equipped with centrally directed one-way valves and typically contain 80 to 90% of venous blood in the legs (6).

It was originally postulated that the shifts of fluid and loss of tissue from the legs and particularly from enclosed fascial compartments would produce reductions in effective venous tone, especially those of the deep veins, through reduction in tissue pressures and elasticities external to the veins. This does not seem to be the case for it took some two weeks for compliance to reach a maximum in all crewmen while the fluid changes were probably largely complete in 24 hours (1). A major portion² of this compliance must be associated with the large, deep veins and the "walls" of these are effectively the surrounding somatic muscles. There is some evidence that neuromuscular changes occur in muscle and little question that muscle itself is altered by disuse in weightlessness and it is in the muscle that we believe these relatively slow changes occur. One is then left to explain the almost immediate decrease in compliance after return to one-g. A possibility is that the "slack" left in fascia and elastic tissue by the initial fluid loss after orbital insertion was partially "taken up" during the course of the mission and when the fluid returned under one-g this shifted the compliance curve. Other possibilities are that the stress on leg muscles under one-g produced a marked increase in resting tone, or that the now decreased central blood volume and pressure produced an increased sympathetic tone in these muscles.

Muscle pumping: Muscle pumping is effected by pressure exerted on the veins by surrounding contracting muscles. This pressure can exceed 200 mm Hg in some calf muscles (7). Such pressures propel the blood cephalad through a series of one-way valves. Unfortunately, quantitative

²This appears to be the case with the SPT and PLT. Note muscle pumping results in this respect.

data, especially as regards the effectiveness of removal of blood from connected superficial veins, is not available.

The upper two lines in figure 2.17-8 represent the blood collected in the legs of the CDR and SPT after three minutes of LBNP at 30 mm Hg. The minimum volume remaining during 10 maximal isometric contractions is shown for both subjects by the lower line. Two features of this curve appear significant; (1) there is the relatively slow development of a marked increase in compliance which paralleled that already seen and which was followed by an immediate postflight reduction, and (2) the CDR and SPT show an identical percentage of blood remaining after pumping. It is unfortunate that we do not have some other evidence for the relative distribution in superficial and deep veins. In the absence of such evidence, there is no assurance where the blood remains after pumping, but it seems reasonable to conclude that much of it is in the superficial veins since muscle pumping should more effectively remove the deep portion.³ Another point to be considered is whether this volume represents blood or if an appreciable portion is extravasate produced by increased hydrostatic pressures. If such significant extravasation occurred, one would expect a continuing upward slope on the volume curve and an appreciable volume remaining after rapid cuff deflation. Neither of these features are prominent enough in the records to suggest that appreciable fluid, other than blood, was pooled in the legs.

The curves from these crewmen then, as expected, parallel the compliance curves as regards the blood collected by negative pressure. The unexpected was that both crewmen had the same amount of blood left in the legs after pumping. Although this may be coincidence there is recurring evidence for a significantly smaller venous blood volume in the CDR's legs. Further this decreased volume is assumed to be in the deep veins. A significant portion of the blood is now in the superficial veins which have now markedly increased their compliance, if it is assumed that muscle pumping effectively removes deep venous blood.

Conclusions

A major significance of this study will not be attained until the findings are correlated in detail with those of experiment M092 (sec. 3.5).

³ If this is truly the amount of blood remaining in the superficial veins, then the great change in compliance should be in the deep veins or rather, in their surrounding tissue.

While the responses to LBNP may be considered the final⁴ hence significant response, they are, in effect, the end of a long series of events, a series of events which must be isolated and followed to understand the total response. As demonstrated here, the initial or provocative response is the volume change of capacitance vessels as a function of pressure under static and dynamic conditions and it should be the point of departure for other studies, both in-flight and in bed rest. At the same time these studies, particularly compliance, when combined with the decrease in blood volume and red cell to mass, demonstrated by Dr. Kimzey and others in the M110 series of experiments, provide some basis for interpretation of experiment M092 results. In all of the results seen here the CDR demonstrated much less change in blood flow compliance and muscle pumping than the other two crewmen. The trend charts for experiment M092 (sec. 1.2, figs 1.2-4, -5, -9, -10, -14, and -15) show similar decreased heart rate and blood pressure changes for this crewman at maximum LBNP.

Such a finding is not inconsistent with previous findings of a wide range of responses to orthostatic stresses in the human which in some cases could be attributed to physiological and anatomical differences. It would seem desirable to develop a way to predict individual response and bed rest studies and more severe negative pressure stresses might be initial avenues of approach.

A second impression, strongly shared by the crew was that, after a week of weightlessness, LBNP became increasingly stressful and after a few weeks much less so. Data does not obviously support this and, unfortunately, this critical period was lost to priority problems; but again, what remains indicates that compliance reached a peak in the two to three-week period and then decreased. If one could now add a decreasing red cell mass and blood volume, and a variable state of hydration to these effects, the primary stresses would probably be delineated.

Most fundamental of the problems are identification of causes for the changes seen here. It was originally postulated that a reduction in tissue pressure through loss of fluid and atrophy would directly affect the contiguous vessels. In all three crewmen the major volume loss occurred quickly, within a day or so, and there was a sharp increase in blood flow by the time of the first in-flight measurement and also a sharp drop on recovery. This is in keeping with flow being affected, possibly by venule size or by pressure outside the vessels.

⁴It should not be forgotten that LBNP is a simulation of orthostatic stresses and in itself differs from walking or standing under one-g, especially after the crewmen have a few hours to equilibrate under one-g.

Compliance changes developed more slowly reaching a peak not earlier than two weeks after achieving weightlessness such that the same mechanism as blood flow can hardly be invoked. A slow adaptation of smooth muscle reflexes might fit this picture but further evidence is needed to support pooling of a large quantity of blood in the superficial vessels containing such muscle. Such a hypothesis would also contradict the one proposed in muscle pumping. Reflex changes in the deep vessels and their surrounding structures is, to our knowledge, uninvestigated and unknown. It is to be hoped that bed rest and other simulation studies of the future will take proper cognizance of these fundamental areas.

Finally, it must be recognized that crewmen on SL-4 were on different food and exercise regimens from those of SL 1/2 and SL-3 and that any responses seen will differ not only from those of unprotected individuals exposed to weightlessness, but also from the responses of crewmen on the other missions. Most importantly the changes seen here did level off and possibly improve and promptly reverted to preflight baseline on return to one-g.

REFERENCES

1. Skylab 1/2 Preliminary Biomedical Report, JSC 08439; September 1973. Section 2.4, *Measurement of Crew Somatic and Functional Changes*; Section 3.1, *Mineral Balance*; Section 3.3, *Specimen and Body Mass Measurements*; and Section 3.5, *Lower Body Negative Pressure*.

Skylab-3 Preliminary Biomedical Report, JSC 08668; February 1974. Section 2.4, *Anthropometric and Functional Changes on Skylab*; Section 3.1, *Mineral Balance*; Section 3.3, *Specimen and Body Mass Measurement*; and Section 3.5, *Lower Body Negative Pressure*.
2. Abramson, David I. 1967. *Circulation in the Extremities*. Ch. V. Acad. Press, N.Y. and London.
3. Burch, George E. 1954. *Digital Plethysmography*. Ch. I. Grune and Stratton, N.Y.
4. Sheperd, J. T. 1963. *Physiology of the Circulation in Human Limbs in Health and Disease*. p. 202. W. B. Saunders & Co., New York.
5. Ludbrook, John. 1966. *Venous Function in the Lower Extremities*. Ch. 4. Charles C. Thomas, Springfield, Ill.
6. Ludbrook, John. *op. cit.* pp. 55 and 72.
7. Ludbrook, John. *op. cit.* p. 60.

3.0 MEDICAL EXPERIMENTS

3.0 MEDICAL EXPERIMENTS

3.1 Experiment M071. Mineral Balance

Principal Investigators: G. Donald Whedon, M.D.

Leo Lutwak, Ph.D., M.D.

Principal Coordinating Scientist: M. W. Whittle, M.D.

Introduction

Experiment M071 was an effort to use a relatively precise but arduous technique of study of human metabolic (or chemical) processes - called "Metabolic Balance Study" - to determine major changes in chemical state of the muscular and skeletal systems. This technique is difficult to use correctly even under near-ideal clinical research center conditions, but in Skylab it had to be applied under the peculiar and very limiting conditions of space flight and of the preparation for and recovery from it. The metabolic balance technique requires extraordinarily meticulous attention to detail in dietary intake and collection of excreta hour-by-hour. In Skylab this was possible only because of the dedicated cooperation throughout of dietitians, dietetic staff, specimen collection staff, laboratory staff, NASA management staff at all levels and particularly of the participants - the astronaut crews. The advantage of the balance technique, when properly carried out, is the precision with which changes in body elements in milligram quantities can be measured and the ability with which patterns of almost day-by-day chemical change can be described.

Procedure

The SL-4 crew was fed a diet of known composition (ref. sec. 2.3), augmented as necessary with mineral supplement tablets, for a period of 27 days preflight, 84 days in-flight, and 18 days postflight. Almost complete collection of urine and feces was accomplished during this time.

In order to extend the duration of the mission from 56 to 84 days, the original set of "Skylab" menus was augmented by a series of "high density" menus, which obtained roughly half their calories from high density food bars, and the balance from conventional Skylab foods and Apollo beverages (ref. sec. 2.3). High density menus were consumed on every third day preflight and in-flight. They differed from the "Skylab" menus in that they were higher in calcium, nitrogen, and energy, and lower in water. The other nutrients were in the same range in both menu series. The crew had achieved approximately uniform excretion of the nutrients under study by launch date.

In-flight collection and return of fecal samples were entirely satisfactory. Due to a shortage of urine sample bags, the crew made 36-hour

collections of urine instead of 24-hour collections on 14 occasions between MD 52 and 79. As the input and output data for six days are pooled for M071 data interpretation, the impact on the experiment of this procedure was negligible. On one occasion a urine bag was emptied without being sampled; this single data point was lost.

Data

The only major perturbation to the conduct of the experiment resulted from the motion sickness experienced by the PLT during the first two days of flight. During this period, no attempt was made to control his intake of nutrients, and use of mineral supplements was discontinued for these two days. Full experimental control was reestablished on MD 3. The crew adhered very closely to their nominal menus, augmented by the "calorie adjustment" foods provided for this purpose. Energy intake levels preflight and in-flight are given in table 3.1-1.

TABLE 3.1-1. MEAN DAILY PREFLIGHT AND IN-FLIGHT ENERGY CONSUMPTION

CREWMAN	PREFLIGHT		IN-FLIGHT	
	NOMINAL MENU	ACTUAL CONSUMPTION	NOMINAL MENU	ACTUAL CONSUMPTION
	Kcal	Kcal	Kcal	Kcal
Commander	3118	3103	3175	3202
Scientist Pilot	2912	3152	2924	3093
Pilot	3176	3170	3174	3305

All three crewmen showed mean in-flight energy consumption within 135 kilocalories per day of their preflight level, and weight changes over the duration of the flight were very small: The CDR lost 0.1 lb (0.05 kg), the SPT lost 3.2 lb (1.45 kg), and the PLT lost 3.1 lb (1.41 kg), comparing the weights at launch with the in-flight mass measurement on recovery day. The weights of the crew are depicted in figure 3.1-1.

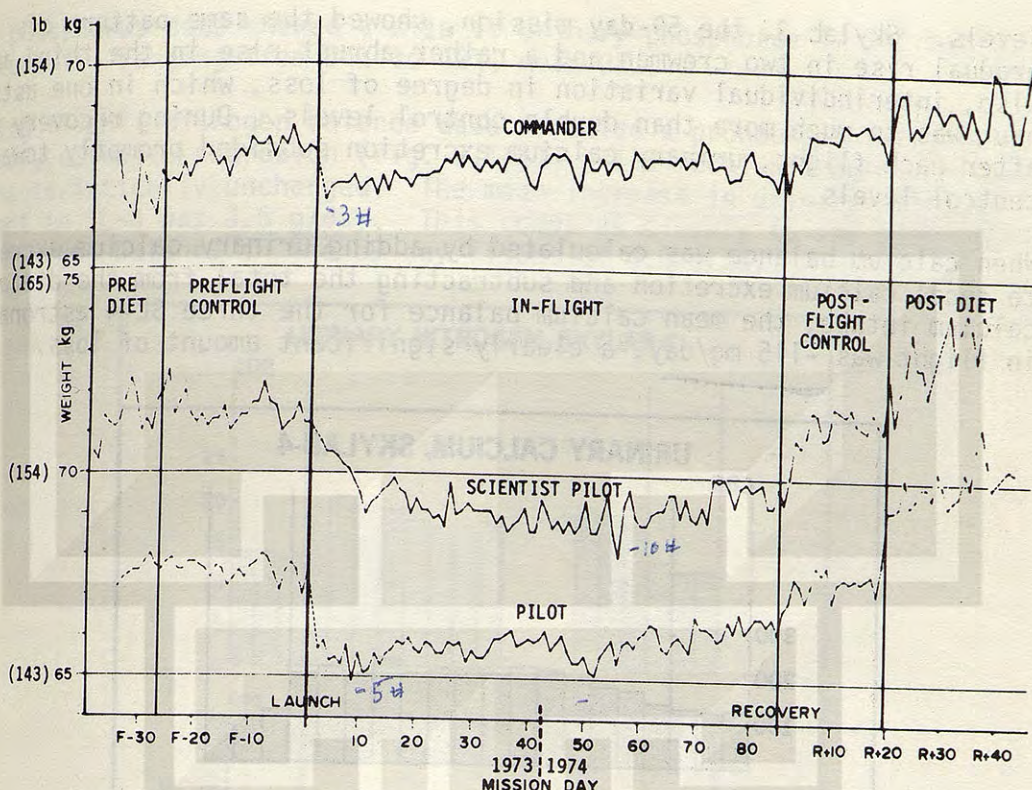


Figure 3.1-1. - Weight Chart For Skylab 4 Crewmen.

Results

Urinary creatinine from the SL-4 astronauts, as well as those of the first two manned missions, showed considerably more fluctuation than is found under good urine collection conditions, but the values were consistent enough to show that average 24-hour urinary creatinine excretion was not changed by space flight.

Urinary calcium in-flight on the SL-4 flight (fig. 3.1-2) increased steadily to a more-or-less plateau peak in virtually the same pattern and degree as in bed rest studies and in earlier Skylab flights. Also, as seen previously, interindividual variation occurred in degree of loss. A particularly important finding was that there was no suggestion of decline toward the end of the 84-day flight in the high level of calcium excretion. The levels of urinary calcium during the last 30 days of flight were 55%, 95% and 94% higher than control preflight levels respectively for the CDR, SPT and PLT. This degree of urinary calcium increases was of the same order as was observed in earlier Skylab flights. In SL 1/2 the peak reached during the latter part of flight was from 80 percent greater to more than double the control, preflight

levels. Skylab 3, the 59-day mission, showed the same pattern of gradual rise in two crewmen and a rather abrupt rise in the third and, also, interindividual variation in degree of loss, which in one astronaut was to much more than double control levels. During recovery and after each flight, urinary calcium excretion subsided promptly toward control levels.

When calcium balance was calculated by adding urinary calcium excretion to fecal calcium excretion and subtracting the total from the dietary calcium intake, the mean calcium balance for the three SL-4 astronauts in flight was -115 mg/day, a clearly significant amount of loss.

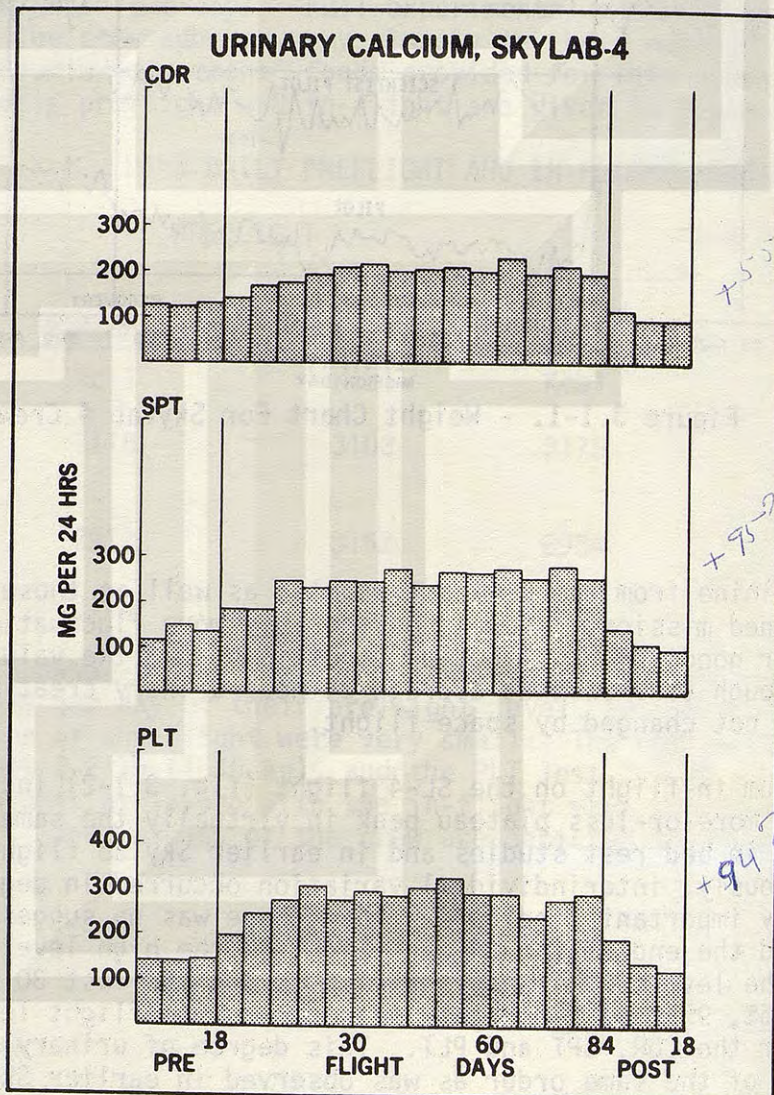


Figure 3.1-2. - Effect of Space Flight on Urinary Calcium Excretion in the Astronauts of the 84-Day Flight (Skylab 4).

The phosphorus data showed a rise in urinary phosphorus in all three astronauts, ranging from 24% to 42%, mean 32%.

During flight, nitrogen balance data revealed a pronounced increase in urinary nitrogen excretion (fig. 3.1-3), while fecal nitrogen remained characteristically unchanged. The mean increase in urinary nitrogen in flight in SL-4 was 3.5 g/day. This compares closely to the mean shift in nitrogen balance in the 59-day flight of 4.0 g/day. -56-3

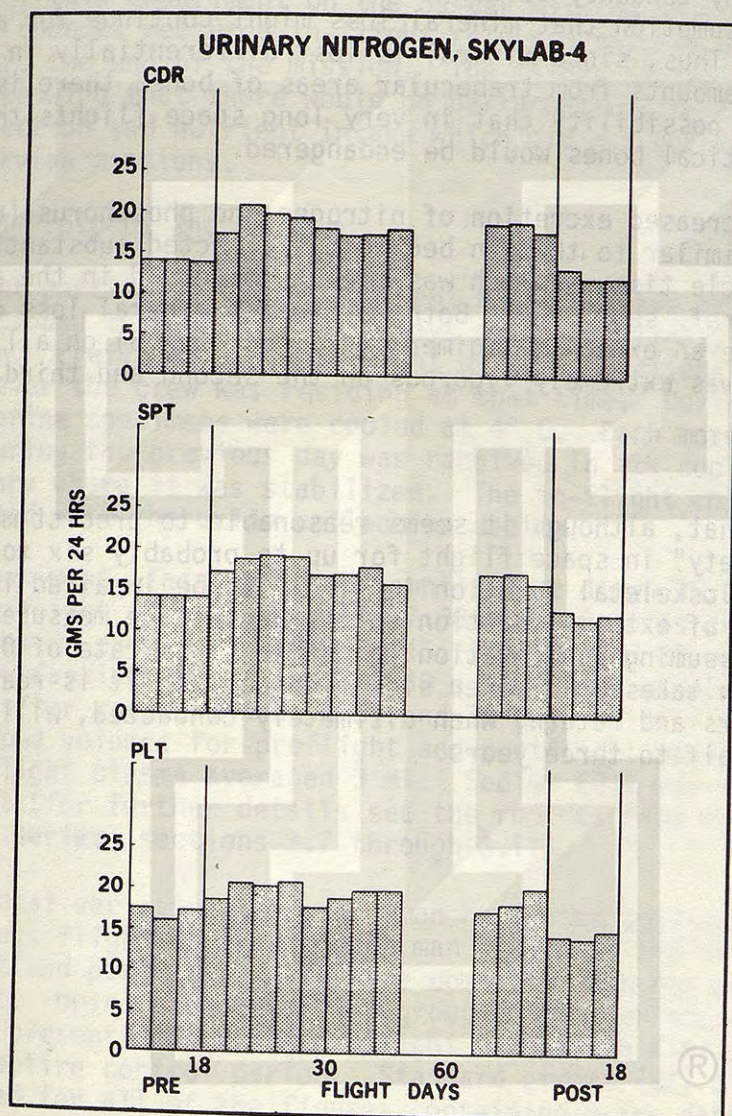


Figure 3.1-3. - Effect of Space Flight on Urinary Nitrogen Excretion in the Astronauts of the 84-day Flight (Skylab 4). The 18-day mid-flight gap in the graph is due to the fact that analyses had not been completed at the time of preparation of the graph.

Discussion

The principal findings of this study for the three Skylab missions were as follows:

- ° Although the total calcium losses appear moderate in relation to the whole skeleton (approximately four grams/month), the similarity to bed rest in pattern and degree and failure to show any tendency to abatement in three months' time forces the assumption that mineral loss might continue for a very long time. Thus, since mineral is lost differentially in greater total amounts from trabecular areas of bone, there is the strong possibility that in very long space flights the strength of critical bones would be endangered.
- ° The increased excretion of nitrogen and phosphorus (ref. sec. 3.2), also similar to that in bed rest, reflected substantial loss of muscle tissue, which was clearly observed in the astronauts' legs (ref. sec. 3.3). Both muscle and mineral loss occurred despite an exercise regimen (ref. sec. 2.4.3) on all flights, which was extremely vigorous on the second and third flights.

Conclusion

We conclude that, although it seems reasonable to predict musculo-skeletal "safety" in space flight for up to probably six to nine months, capable musculoskeletal function is likely to be impaired in crews on space flights of extreme duration unless protective measures can be developed. Assuming continuation, a calcium loss rate of 0.3-0.4 percent per month takes on clearer significance when it is realized that flights to Mars and return, when ultimately conducted, will take from one and one-half to three years.

3.2 Experiment M073. The Biochemistry of Body Fluids

Principal Investigator: Carolyn S. Leach, Ph.D.

Principal Coordinating Scientist: Paul C. Rambaut, Sc.D.

The results of the first two manned Skylab missions confirmed that biochemical changes did occur during the prolonged space flight exposures of 29 and 59 days. It remained after the first two missions to see if an adaptation to the space flight environment did occur as was suggested by results of this experiment on the 59-day mission which indicated that biochemical changes measured in-flight returned to more near normal values toward the end of the mission. The 84-day Skylab mission was undertaken knowing that there would be perturbations in the urine sample collection and nutrient intake which did not occur on the previous two Skylab missions.

Experimental Protocol and Methods

The preflight portion of this experiment began 27 days prior to the flight, continued throughout the 84 days of space flight, and for 18 days after return. Preflight and postflight urine collections were accomplished wherever the crew was residing at that time. During the collection, the urine specimens were cooled at 4° C. Each morning the urine collected during the previous day was received in its cooled state at the laboratory where it was stabilized. The in-flight collections were performed with the urine collection device.

For this experiment, fasting blood samples were drawn 35, 21, 14, 6, and 1 day before flight at approximately 7:00 a.m. Samples drawn during the flight on mission days 3, 5, 21, 38, 45, 59, 73, and 82 were also drawn with the crew fasting and at about 7:30 a.m. Blood samples were drawn immediately after recovery and 1, 3, and 14 days later. For this experiment, the blood volumes for preflight and postflight analyses were 25 ml and the in-flight plasma averaged 3 ml. Sodium EDTA was used as the anticoagulant (for further details see the reports from the experiments for the M110 series, sections 3.7 through 3.11).

Since individual variation among crewmen have been constantly observed during previous flight programs, each man served as his own control; his in-flight and postflight data were compared with his preflight controlled phase. Urine data have been grouped into periods of equal duration for presentation. The preflight value each time is given as a mean of the entire control period. Standard errors (SE) of the mean are also indicated for all of the figures containing urine data.

Frozen samples of urine were received for each day of in-flight collection for each of the three crewmen with only one exception. Of these 230 samples received, 161 were half samples which contained a range of

28 to 77 ml, and 69 were full samples which contained a range from 88 to 152 ml. The urine volume measured by the in-flight urine measuring device is compared to postflight lithium chloride determined urine volumes in table 3.2-I. It can be seen that comparison of these numbers remains to be inaccurate and nonpredictable as was shown after the first two missions. The in-flight collections were in general very good. Due to the extension of the mission to 84 days, a majority of the samples obtained were one-half size rather than the 122 ml volume required by this experiment and M071. The consideration given to the potential loss of urine freezing capability included the addition of 10 grams of boric acid to every other day's urine pool. The freezer temperature was maintained, however, the boric acid which was added to 92 urine samples did prevent the analyses of several compounds on the days it was added to the urine. The other problem occurred in the shortage of urine bags due to an error in spacecraft inventory. This necessitated the reuse of several bags and the collection of 36-hour pools on 14 different times on each of the crewmen resulting in 42 36-hour samples. The data from these days was grouped for 72 hour periods and the mean 24-hour excretion obtained.

Results and Discussion

Fluid and Electrolyte. - Weight losses that occurred on previous missions, some of which have been attributed to water loss, were not as evident in these crewmen. These data are shown in the M071 report (sec. 3.1). The postflight fluctuation with rapid weight regain is evidence of some water imbalance postflight. These data are confirmed by the plasma volume and hematocrit results in the hematology reports. Figure 3.2-1 shows a comparison of the preflight means to the six-day periods in-flight and postflight. It can be seen that the CDR and the PLT had significant decreases in urine volume and water intake the first six-day period in-flight whereas the SPT actually increased urine output with a slight change in water intake in the first period in-flight.

During the remainder of the flight, although it fluctuates some, it appears that the urine volume did not change greatly for the three crewmen; water intake approximated the preflight levels for about half the mission then appeared to decrease in all three crewmen. The mean water intake values for each period are entered above the bar graphs for the urine volume for each of the six day means. The first period postflight showed increased water intake on all three of the crewmen with urine volume remaining about the same. Water intake and urine volume remained high throughout the recovery period. Since the six day mean data includes the first days in-flight which were atypical and the first days on the ground after recovery which were atypical, these results are separated and are shown in figure 3.2-2. The last five days preflight and the first five days postflight samples are graphed on a

TABLE 3.2-I. LiCl vs. PP Volume Correlation SL-4

CDR			SPT			PLT		
MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)
1	1358	-	1	1154	-	1	1318	-
2	942	2000	2	2476	3400	2	764	600
3	930	1200	3	3266	3500	3	1263	2400
4	1003	1200	4	2602	2750	4	1483	1500
5	1428	1400	5	1551	1500	5	1248	1600
6	916	800	6	1037	1200	6	1435	3000
7	1520	1800	7	1543	1700	7	900*	900
8	1616	1800	8	1213	1600	8	2132	2400
9	1081	1200	9	1048	1100	9	2257	2400
10	1428	1500	10	1574	1700	10	1968	2100
11	1715	2100	11	1108	1500	11	1696	3000
12	1371	1200	12	1089	1300	12	1228	1500
13	1786	1800	13	1298	1600	13	2728	2800
14	1850	1300	14	1994	1700	14	1507	1600
15	1530	1900	15	1149	2100	15	2207	1850
16	2414	2200	16	1033	1200	16	2420	2200
17	2414	2500	17	1774	2200	17	3029	3000
18	1288	1100	18	2784	2300	18	2274	2000
19	1493	1400	19	1818	1950	19	2529	2600
20	2711	2200	20	1493	1400	20	2492	2000
21	1239	1200	21	1308	1450	21	1615	1700

*Pressure plate volume - not included in correlation data

TABLE 3.2-I. LiCl vs. PP Volume Correlation SL-4 Cont'd.

CDR			SPT			PLT		
MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)
22	1628	1650	22	1714	1450	22	1589	1800
23	1759	1900	23	1728	2400	23	2006	2100
24	2089	2000	24	1841	1400	24	1250*	1250
25	1140	1300	25	891	1200	25	2132	2200
26	2352	2250	26	1744	1500	26	2155	1850
27	1281	1200	27	1239	1250	27	1247	1500
28	1875	1600	28	1685	1500	28	1948	1900
29	2046	2100	29	1354	1600	29	1714	2300
30	1154	1000	30	1256	1250	30	1425	1800
31	1173	1350	31	1610	1700	31	1990	2000
32	1638	1550	32	1229	1100	32	1652	1500
33	990	900	33	1181	1150	33	1271	1300
34	1596	1850	34	2072	2000	34	1875	1850
35	2072	2000	35	1049	1100	35	2395	2300
36	1308	1200	36	1806	1750	36	2162	2000
37	1520	1600	37	1624	1550	37	2072	2250
38	2000*	2000	38	2250*	2250	38	1800*	1800
39	1750*	1750	39	1121	2000	39	596	1100
40	1019	800	40	1812	1650	40	2338	2200
41	1879	2000	41	888	950	41	2034	1850
42	1081	850	42	2119	1850	42	589	1100
43	1756	1900	43	2099	2050	43	2099	1950
44	1700*	1700	44	1594	1200	44	2191	1850
45	1694	1750	45	1081	1350	45	1302	1500

*Pressure plate volume - not included in correlation data

1950
2099
2191
1302
1500

2050
1200
1350

2099
1594
1081

43
44
45

1900
1700
1750

1756
1700*
1694

43
44
45

*Pressure plate volume - not included in correlation data

TABLE 3.2-I. LiCl vs. PP Volume Correlation SL-4 Cont'd.

GDR				SPT				PLT			
MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)
46	1951	1800	46	1931	2100	46	1942	1750	1942	46	1942
47	1894	2100	47	No Sample	2250	47	2144	2250	2144	47	2144
48	1036	900	48	1137	750	48	2054	1450	2054	48	2054
49	2012	2100	49	2144	2200	49	2622	2500	2622	49	2622
50	2402	2100	50	3050*	3050	50	2076	1900	2076	50	2076
51	1608	1750	51	1036	1750	51	1302	2100	1302	51	1302
52	3776	3600	52	1537	1750	52	3375	2650	3375	52	3375
53 [†]			53 [†]			53 [†]				53 [†]	
54	2134	2400	54	2739	3850	54	2607	2700	2607	54	2607
55	2515	2600	55	1612	1800	55	3537	3350	3537	55	3537
56 [†]			56			56				56	
57	2776	2750	57	1159	1700	57	2375	2500	2375	57	2375
58	1848	1600	58	1990	1750	58	2402	2000	2402	58	2402
59	1738	1800	59	2112	2100	59	1799	2400	1799	59	1799
60	1385	1000	60	1218	2300	60	1814	1300	1814	60	1814
61	2092	2450	61	2848	2850	61	3537	3200	3537	61	3537
62 [†]			62 [†]			62 [†]				62 [†]	
63	1750*	1750	63	1400*	1400	63	1700*	1700	1700*	63	1700*
64	2401	2600	64	1799	1750	64	2544	2600	2544	64	2544
65			65			65				65	
66	1549	1300	66	1638	1300	66	1900	1800	1900	66	1900
67	2702	2650	67	2444	2650	67	3385	4000	3385	67	3385
68			68			68				68	

*Pressure plate volume - not included in correlation data.

[†]Data included in 36 h pools day before and after.

TABLE 3.2-I. LiCl vs. PP Volume Correlation SL-4 Concluded.

CDR			SPT			PLT		
MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)	MISSION DAY	LiCl (ml)	PP (ml)
69	1763	1850	69	1711	1900	69	1801	1900
70	2388	2600	70	1740	1950	70	2974 ⁺	4200
71 ⁺			71 ⁺			71 ⁺		
72	2702	2800	72	1683	1600	72	3020	4200
73	1571	1700	73	928	950	73	1974	1900
74	2388	2100	74	1300	1450	74	1801	1800
75	1283	1150	75	1867	1900	75	1488	1250
76	1257	1200	76	981	850	76	2125	2250
77	2081	2100	77	2067	2000	77	2678	2600
78	1925	1700	78	2852	3000	78	2504	2600
79 ⁺			79 ⁺			79 ⁺		
80	2607	2750	80	1759	2000	80	3615	2250
81	1714	2150	81	1729	1800	81	2455	2000
82	1983	2300	82	2084	2700	82	2150	2100
83	1759	1900	83	1320	1500	83	1806	1850
84	Bladder		84	Bladder		84	Bladder	
$r = 0.91$			$r = 0.83$			$r = 0.77$		
$N = 71$			$N = 71$			$N = 71$		
$\bar{x} \pm SD$	1613 $\pm$ 394	1630 $\pm$ 407	1501 $\pm$ 472	1624 $\pm$ 519		1869 $\pm$ 464	1921 $\pm$ 444	

⁺Data included in 36 h pools day before and after

* $\bar{x}$ of all 36 hour pools - not included in correlation data

$\bar{x} \pm SD$ of LiCl volumes does not include volumes that were assigned.

$\bar{x} \pm SD$ of PP volumes does not include volumes on days that had no true LiCl volume.

*Data included in 36 h pools day before and after
 *X of all 36 hour pools - not included in correlation data
 *X ± SD of LiCl volumes does not include volumes that were assigned.
 *X ± SD of PP volumes does not include volumes on days that had no true LiCl volume.

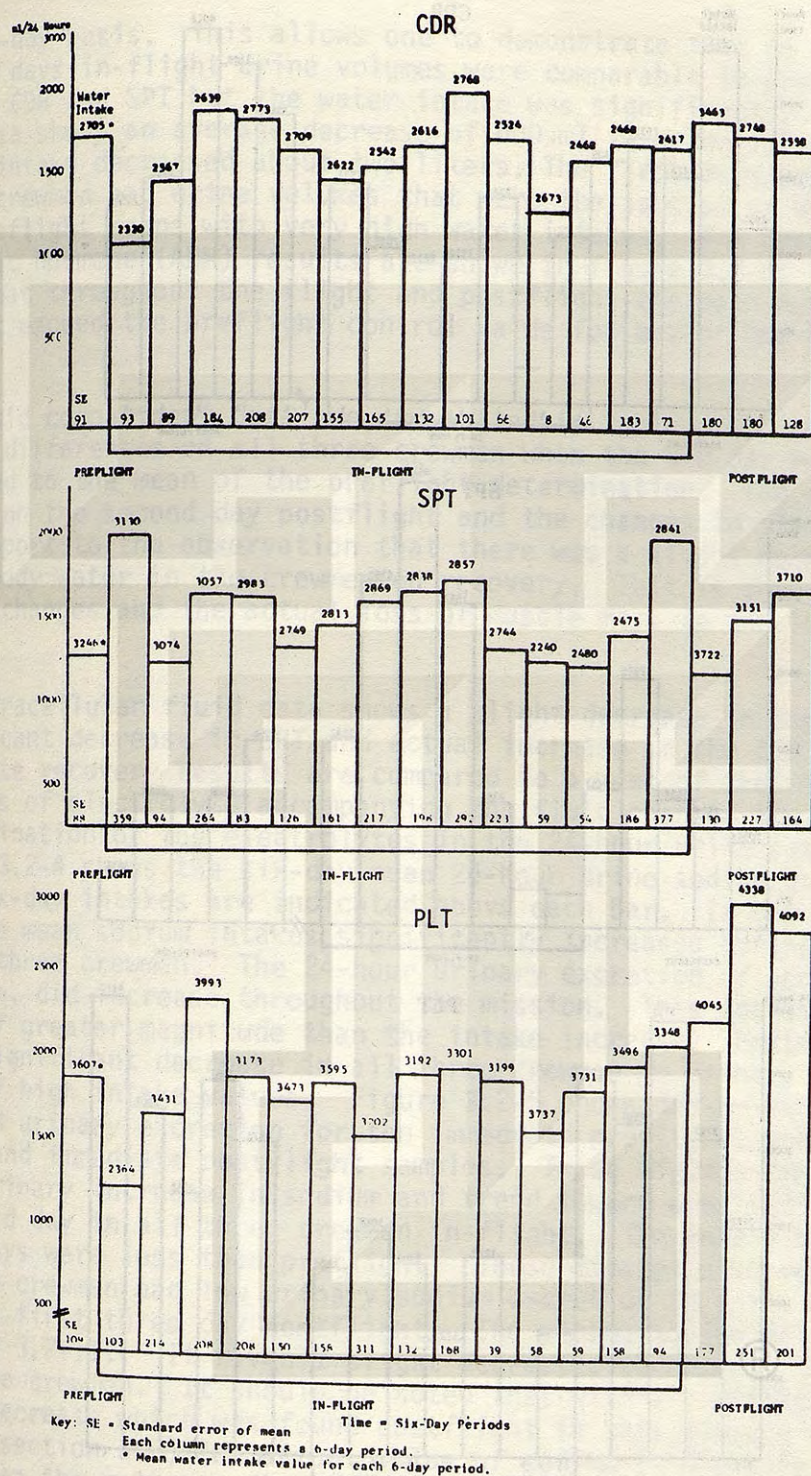


Figure 3.2-1. - Mean Twenty-Four Hour Urine and Water Intake Volume (SL-4).

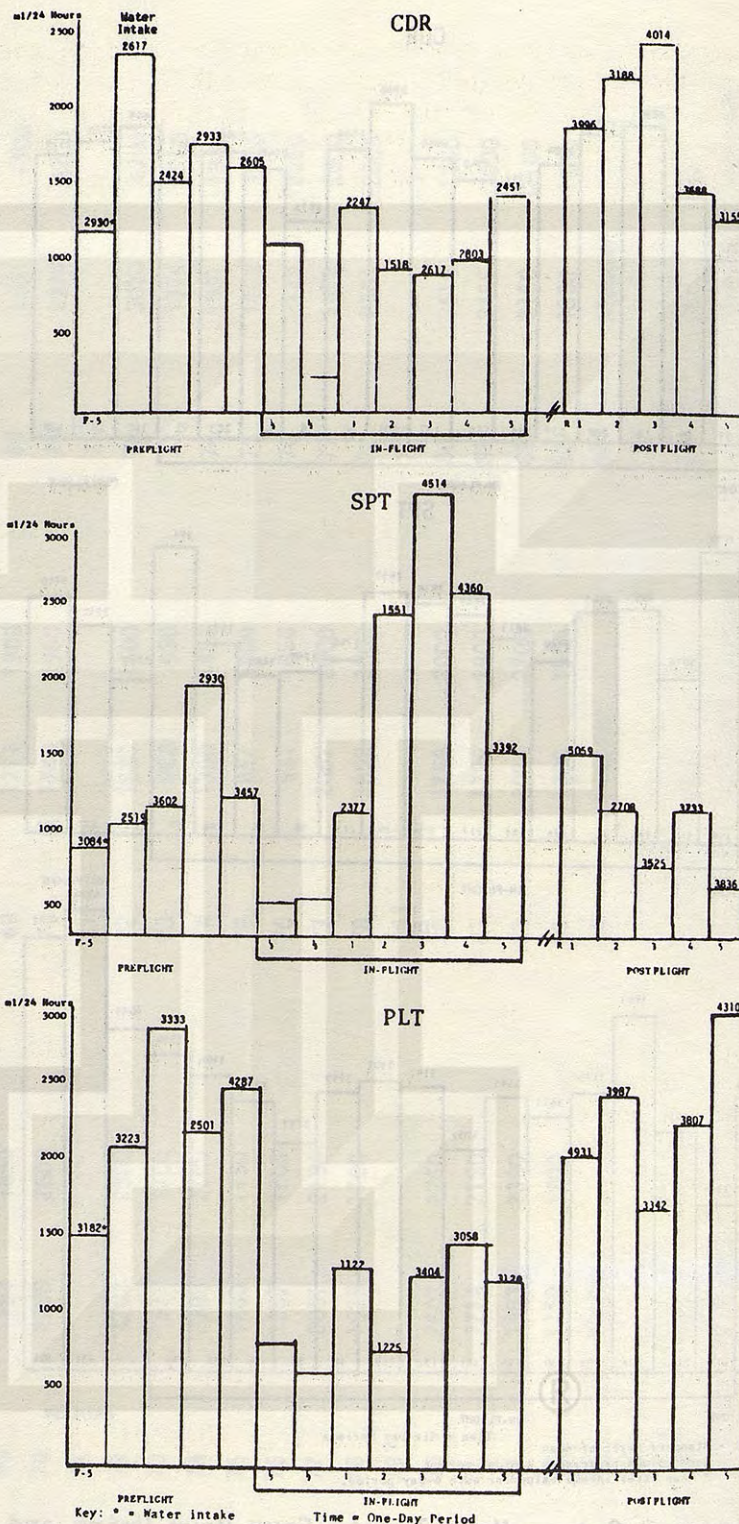


Figure 3.2-2. - Urine Volume and Water Intake (Day by Day).

day-by-
second
on the
PLT dat
water i
three c
the pre
diureti
show th
did not
men.

The flu
slight
compare
regain
add supp
total bo
weight
ities.

The extr
signific
immediat
The loss
an exami
Figure 3
mean six
that the
in all t
variable
to be of
was a si
spite of
take and
flight an
early ur
the thir
these day
that the
take the
in table
all three
volume de
report, s
lower tha

day-by-day basis. This allows one to demonstrate that on the first and second days in-flight urine volumes were comparable to preflight averages on the CDR and SPT but the water intake was significantly lower. The PLT data shows an average decrease of 600 ml in urine volume but the water intake decreased about two liters. The first days postflight all three crewmen had urine volumes that were the same as or higher than the preflight means with very high water intakes. The urinary anti-diuretic hormone (ADH) results are shown in figure 3.2-3. These data show that throughout the flight and postflight the mean ADH excretion did not exceed the preflight control value for any of the three crewmen.

The fluid compartment data are summarized in table 3.2-II. There were slight differences on all three crewmen when the R+0 day results were compared to the mean of the preflight determination. The rapid weight regain on the second day postflight and the changes in plasma volume add support to the observation that there was a slight decrease in total body water in the crewmen on recovery. This is complicated by the weight changes and the actual loss of muscle mass in the lower extremities.

The extracellular fluid data shows a slight decrease in the PLT, a significant decrease in SPT and actual increase in the CDR, when the immediate recovery results are compared to a mean of the preflight day. The loss of electrolyte accompanying the fluid changes are evident by an examination of the electrolytes in the 24-hour urine samples. Figure 3.2-4 shows the six-day mean 24-hour urine sodium excretion, the mean six-day intakes are indicated above each bar. It can be observed that the mean sodium intakes significantly increased during the mission in all three crewmen. The 24-hour urinary excretion of sodium, although variable, did increase throughout the mission. This increase appears to be of greater magnitude than the intake increase. Postflight there was a significant decrease in all three crewmen in urinary excretion in spite of high intake values. Figure 3.2-5 shows day-by-day sodium intake and urinary excretion for the immediate preflight, the early in-flight and immediate postflight samples. These figures demonstrate the early urinary increase in sodium and trend toward preflight values after the third day in all three crewmen in-flight. The intake values for these days were less than preflight. These figures also demonstrate that the crewmen had low urinary sodium excretion in spite of high intake the first three day postflight. The plasma sodium data is given in table 3.2-III. It reveals slight decreases throughout the flight in all three crewmen. It should be noted that with a significant plasma volume decrease which was found postflight in this mission (see M113 report, section 3.9) the actual value of sodium is probably significantly lower than the value preflight.

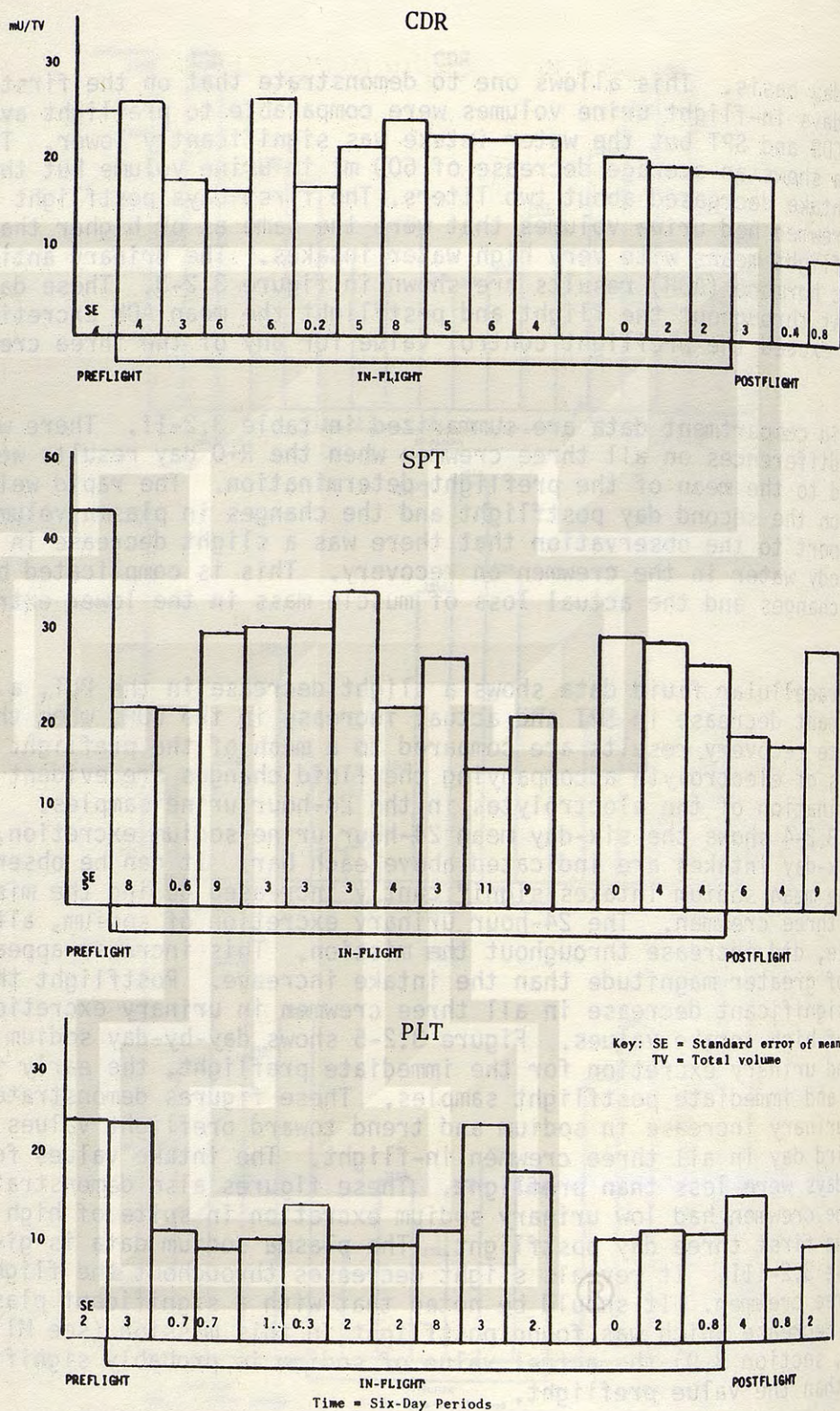


Figure 3.2-3. - Urinary ADH (SL-4).

TABLE 3.2-II. FLUID COMPARTMENT DATA

Total Body Water (liters)			
DAY	CDR	SPT	PLT
F-21	41.8	45.3	45.3
F-1	41.9	45.5	46.0
R+0	41.0	44.9	45.1
% Change	-2.0	-1.1	-1.2
R+14	42.3	45.8	46.5
% Change	+1.1	+0.9	+1.9
ml/kg			
F-21	618	633	667
F-1	615	638	685
R+0	601	641	679
% Change	-2.5	+0.9	+0.4
R+14	615	640	688
% Change	-0.2	+0.7	+1.8
Extracellular Fluids (liters)			
F-21	14.0	16.5	15.6
F-1	13.8	16.4	15.1
R+0	14.9	15.7	15.1
% Change	+7.2	-4.5	-1.6
R+14	14.9	16.7	16.0
% Change	+7.2	+1.8	+3.9
ml/kg			
F-21	207	231	230
F-1	203	230	225
R+0	218	224	227
% Change	+6.3	-2.8	-0.2
R+11	216	234	237
% Change	+2.2	+1.7	+3.9

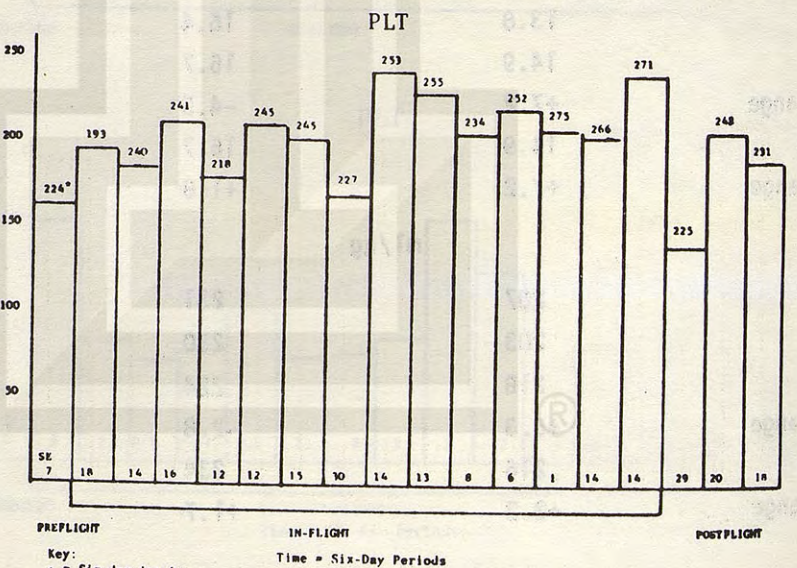
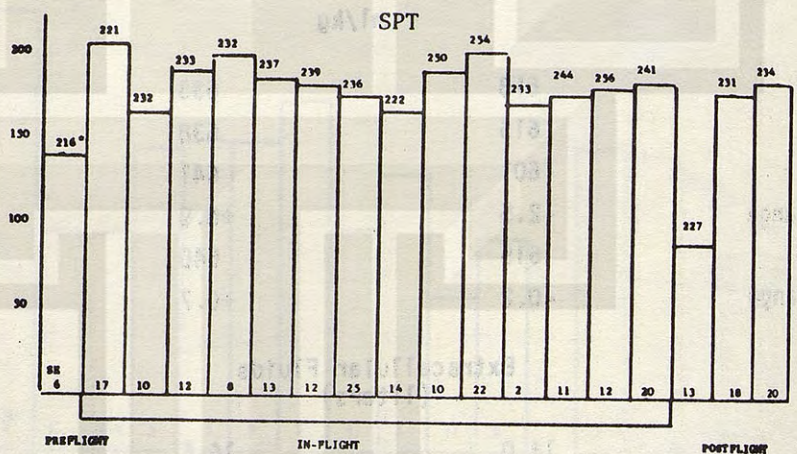
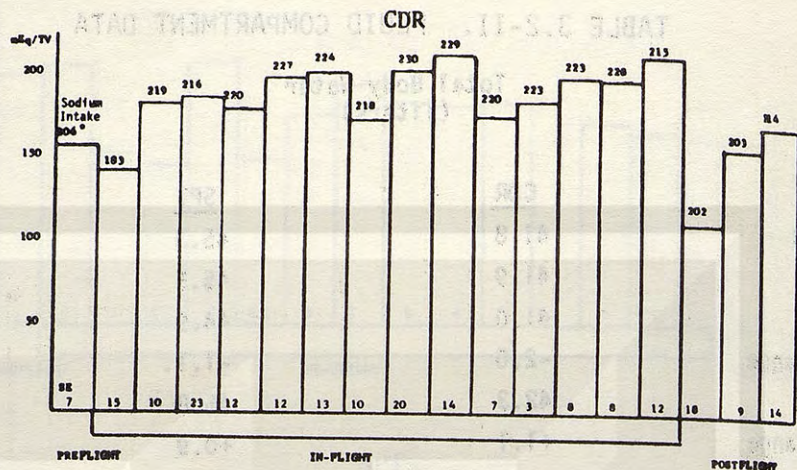


Figure 3.2-4. - Sodium Intake and Urinary Sodium Excretion (SL-4).

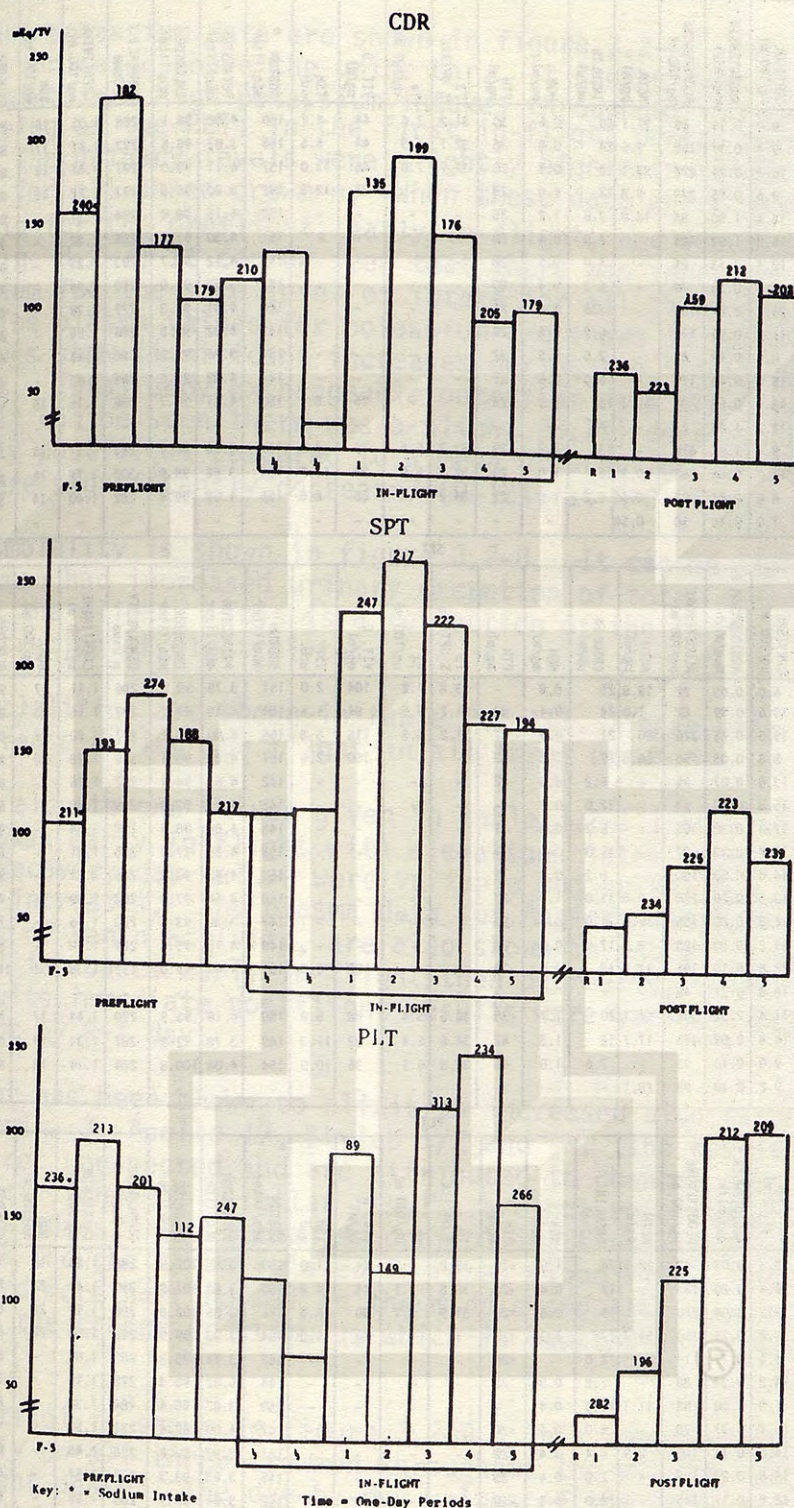


Figure 3.2-5. - Day-by-Day Sodium Intake and Urinary Excretion (SL-4).

TABLE 3.2-III. SERUM PLASMA DATA (SL-4)

CDR

DAY	CORTISOL μg/100 ml	ANGIOTENSIN I ng/ml/h	ALDOSTERONE pg/100 ml	ACTH pg/ml	INSULIN μU/ml	HGH mg/ml	PTH mg/ml	T3 % UPTAKE	T4 μg/100 ml	VIT. D mg/ml	TSH μU	SODIUM mEq/liter	POTASSIUM mEq/liter	CHLORIDE mEq/liter	OSMOLALITY m Osm	CREATININE mg/100 ml	BUN mg/100 ml	GLUCOSE mg/100 ml
F-35	9.0	0.19	59	31.1	29	0.6	30	31.2	7.6	44	4.2	150	4.08	98.1	288	1.31	16	89.1
-21	9.4	0.37	168	7.6	24	0.8	36	32.7	7.3	44	5.5	155	3.87	96.6	293	1.51	17	82.8
-14	16.2	0.24	295	33.1	19	0.8	28	32.7	7.0	46	13.0	157	4.11	99.0	297	1.46	19	85.0
-1	9.6	0.95	275	9.8	12	2.8	23	-	-	32	13.5	147	3.80	96.0	293	1.22	18	84.6
MD 3	14.4	1.50	84	14.0	7.6	1.2	25	-	-	-	-	152	4.16	98.0	294	1.31	-	94.0
5	16.0	1.83	105	-	4.0	0.4	28	-	-	-	-	151	4.30	97.2	285	1.32	-	82.6
21	12.4	0.73	88	-	4.0	0.6	28	-	-	-	-	155	4.12	96.7	293	1.25	-	85.7
38	9.4	0.33	70	-	6.2	0.4	<20	-	-	-	-	142	3.33	93.0	270	1.34	-	79.9
45	20.2	0.27	100	-	7.6	0.8	25	-	-	-	-	148	4.31	94.3	279	1.39	-	81.4
59	11.2	0.90	178	-	6.2	0.8	20	-	-	-	-	142	4.02	96.5	289	1.25	-	82.1
73	8.0	0.43	42	-	2.0	0.6	32	-	-	-	-	154	3.96	92.9	286	1.46	-	84.4
82	16.0	0.40	175	-	5.0	0.6	27	-	-	-	-	148	4.32	95.6	285	1.43	-	78.8
R+0	13.8	0.58	36	10.3	15	3.0	26	-	-	25	8.6	150	4.21	95.7	289	1.16	15	94.3
+0.3h	11.2	1.45	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+1	9.4	1.87	410	-	13	1.3	29	32.7	6.5	26	9.9	149	3.98	96.9	283	1.11	16	75.8
+3	11.0	0.68	250	10.3	16	1.0	25	32.7	6.9	28	13.0	154	3.62	98.9	300	1.17	16	84.2
+14	8.6	0.07	92	0.56	6.2	1.0	28	34.2	7.0	26	8.6	155	4.09	99.4	282	1.40	14	85.1
+14.3h	7.0	0.10	50	0.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-

SPT

DAY	CORTISOL μg/100 ml	ANGIOTENSIN I ng/ml/h	ALDOSTERONE pg/100 ml	ACTH pg/ml	INSULIN μU/ml	HGH mg/ml	PTH mg/ml	T3 % UPTAKE	T4 μg/100 ml	VIT. D mg/ml	TSH μU	SODIUM mEq/liter	POTASSIUM mEq/liter	CHLORIDE mEq/liter	OSMOLALITY m Osm	CREATININE mg/100 ml	BUN mg/100 ml	GLUCOSE mg/100 ml
F-35	6.0	0.03	22	19.8	25	0.8	-	33.8	7.2	104	2.0	151	3.79	99.0	286	1.11	17	91.8
-21	10.6	0.09	82	1.0	24	0.4	48	31.2	6.5	84	1.5	154	4.10	99.2	289	1.16	23	85.0
-14	19.6	0.15	226	320	21	0.6	37	31.2	5.8	116	6.0	156	4.00	100.1	297	1.20	24	90.0
-1	8.8	0.05	56	68.8	17	1.3	37	-	-	100	2.0	157	4.26	98.1	300	1.28	20	81.2
MD 3	13.6	0.07	25	-	6.2	0.6	22	-	-	-	-	142	4.68	94.9	292	1.26	-	84.6
5	15.8	0.40	27	-	12.0	0.4	-	-	-	-	-	145	4.73	93.8	289	1.40	-	83.0
21	17.2	0.30	105	-	6.2	0.8	31	-	-	-	-	148	4.66	98.5	292	1.54	-	85.9
38	16.4	0.23	37	-	11.0	-	-	-	-	-	-	153	4.29	97.9	285	1.31	-	80.1
45	14.0	0.50	130	-	6.2	0.8	32	-	-	-	-	151	4.42	96.3	286	1.21	-	84.6
59	13.6	0.20	225	9.5	11.0	1.2	27	-	-	-	-	150	4.56	97.3	293	1.69	-	78.7
73	16.6	0.20	165	19.5	11.0	0.8	<20	-	-	-	-	147	3.36	93.9	280	1.46	-	76.9
82	17.2	0.30	120	8.5	17.0	0.6	28	-	-	-	-	149	4.16	95.7	289	1.58	-	81.5
R+0	22.6	0.10	105	17.2	18	3.0	25	-	-	108	6.8	151	4.42	99.0	295	1.33	14	118.1
+0.3h	18.6	0.27	48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+1	11.4	2.52	505	14.1	20	1.7	35	34.6	5.4	88	5.9	150	4.19	96.9	290	1.44	17	95.8
+3	16.4	0.09	450	17.7	16	1.3	42	34.6	6.4	82	11.3	149	3.78	97.9	287	1.31	17	88.0
+14	9.0	0.10	98	-	7.6	1.0	46	33.8	6.1	96	10.0	154	4.04	100.8	284	1.29	18	85.9
+14.3h	9.2	0.10	98	28.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

PLT

DAY	CORTISOL μg/100 ml	ANGIOTENSIN I ng/ml/h	ALDOSTERONE pg/100 ml	ACTH pg/ml	INSULIN μU/ml	HGH mg/ml	PTH mg/ml	T3 % UPTAKE	T4 μg/100 ml	VIT. D mg/ml	TSH μU	SODIUM mEq/liter	POTASSIUM mEq/liter	CHLORIDE mEq/liter	OSMOLALITY m Osm	CREATININE mg/100 ml	BUN mg/100 ml	GLUCOSE mg/100 ml
F-35	8.2	0.03	42	22.5	26	1.0	<20	33.8	6.7	44	1.0	153	3.85	102.8	286	1.53	17	90.0
-21	9.4	0.20	135	-	19	0.4	<20	33.8	7.5	44	4.2	150	3.80	101.9	280	1.47	22	89.1
-14	16.2	0.09	710	-	19	0.6	<20	31.9	8.7	50	6.5	146	3.86	102.8	290	1.59	22	87.3
-1	8.2	0.25	150	54.7	17	1.3	<20	-	-	44	5.0	154	3.93	99.9	290	1.78	22	85.0
MD 3	5.4	0.77	10	-	12.0	-	<20	-	-	-	-	152	3.94	95.2	283	1.55	-	85.7
5	14.2	0.37	30	-	2.8	0.8	22	-	-	-	-	145	5.02	95.3	278	1.15	-	87.1
21	6.8	1.00	62	11.1	11.0	0.4	-	-	-	-	-	150	3.87	95.4	284	1.32	-	87.0
38	15.4	0.37	70	-	5.0	0.4	<20	-	-	-	-	147	4.09	92.4	277	1.55	-	80.6
45	14.6	0.17	140	2.9	6.4	0.4	<20	-	-	-	-	141	3.89	92.8	278	1.46	-	83.9
59	14.6	0.23	135	-	2.0	<0.4	25	-	-	-	-	145	3.93	93.3	275	1.61	-	81.2
73	18.8	0.17	145	-	14.0	<0.4	<20	-	-	-	-	152	3.94	96.9	285	1.60	-	81.5
82	15.2	0.27	130	17.6	11.0	0.8	<20	-	-	-	-	150	4.10	96.2	282	1.61	-	82.6
R+0	18.6	0.22	115	14.1	14.0	1.3	<20	-	-	32	5.1	147	4.16	101.7	290	1.56	18	100.1
+0.3h	13.0	0.13	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+1	9.8	0.23	320	11.9	16.0	1.7	<20	32.7	13.3	34	4.4	144	4.10	103.4	289	1.57	15	85.9
+3	14.2	0.10	125	22.1	16.0	3.3	<20	34.6	8.5	29	5.1	149	3.72	102.8	-	1.65	-	88.7
+14.3h	9.8	0.10	185	-	2.7	0.6	<20	32.7	7.8	34	4.4	150	4.00	102.6	283	1.74	16	84.6

*Not corrected for NaEDTA

The urinary potassium data are shown in figure 3.2-6. The intake levels are again indicated above the urine bar. It can be seen that all the crewmen maintained high potassium intakes throughout the flight, the exception being on the PLT; in the first in-flight period potassium was decreased. The urinary levels were slightly higher in-flight than they were preflight for all three crewmen. When these data are considered on a daily basis for the preflight, early in-flight, and immediate postflight levels (fig. 3.2-7) it can be seen that there was increased excretion of potassium for the same level of intake for all three men early in-flight. The plasma values for potassium are shown in table 3.2-III. These values show significant increases during the flight and immediately postflight. Total body exchangeable potassium data are given in table 3.2-IV. It can be seen there was a slight (3.7%) decrease in the CDR immediately postflight compared to a mean of preflight values. The SPT and PLT were significantly decreased (9-12%) at R+0 day.

Urinary osmolality is shown in figure 3.2-8. It can be seen that all three crewmen had increased urinary excretion of total ionic particles throughout the flight. This is a reflection of the increases in urinary excretion of electrolytes.

Plasma osmolalities are shown in table 3.2-III. These data indicate a slight decrease during the flight in all three crewmen.

The plasma aldosterone values given in table 3.2-III show significant decreases early in-flight with elevations later in the mission. Recovery day values were variable but by R+1 day all three men showed increases. The plasma data for Angiotensin I, a direct measurement of renin activity, are also shown in table 3.2-III. These data reveal increases early in flight then decreases. Like the aldosterone results immediate postflight results were variable but increases were evident by R+1 day.

Space flight has been shown to elicit an increased aldosterone in crewmen from Gemini 7, Apollo 17, Skylab 1/2 and -3. The results in this report are not unexpected and are attributed to changes caused by the weightless environment. Similar results are not reported with bedrest or chamber studies. The mechanism controlling these increases is not known but is thought to be related to renal blood flow. The apparent return toward more near normal in the middle and late mission gives evidence to the change in stimulus which is causing the aldosterone production.

Urinary cortisol is shown in figure 3.2-9. This compound was increased significantly on all three crewmen throughout the mission and the immediate postflight phase. The day-by-day values of the urine cortisol (fig. 3.2-10) show significantly elevated values early in the CDR and PLT,

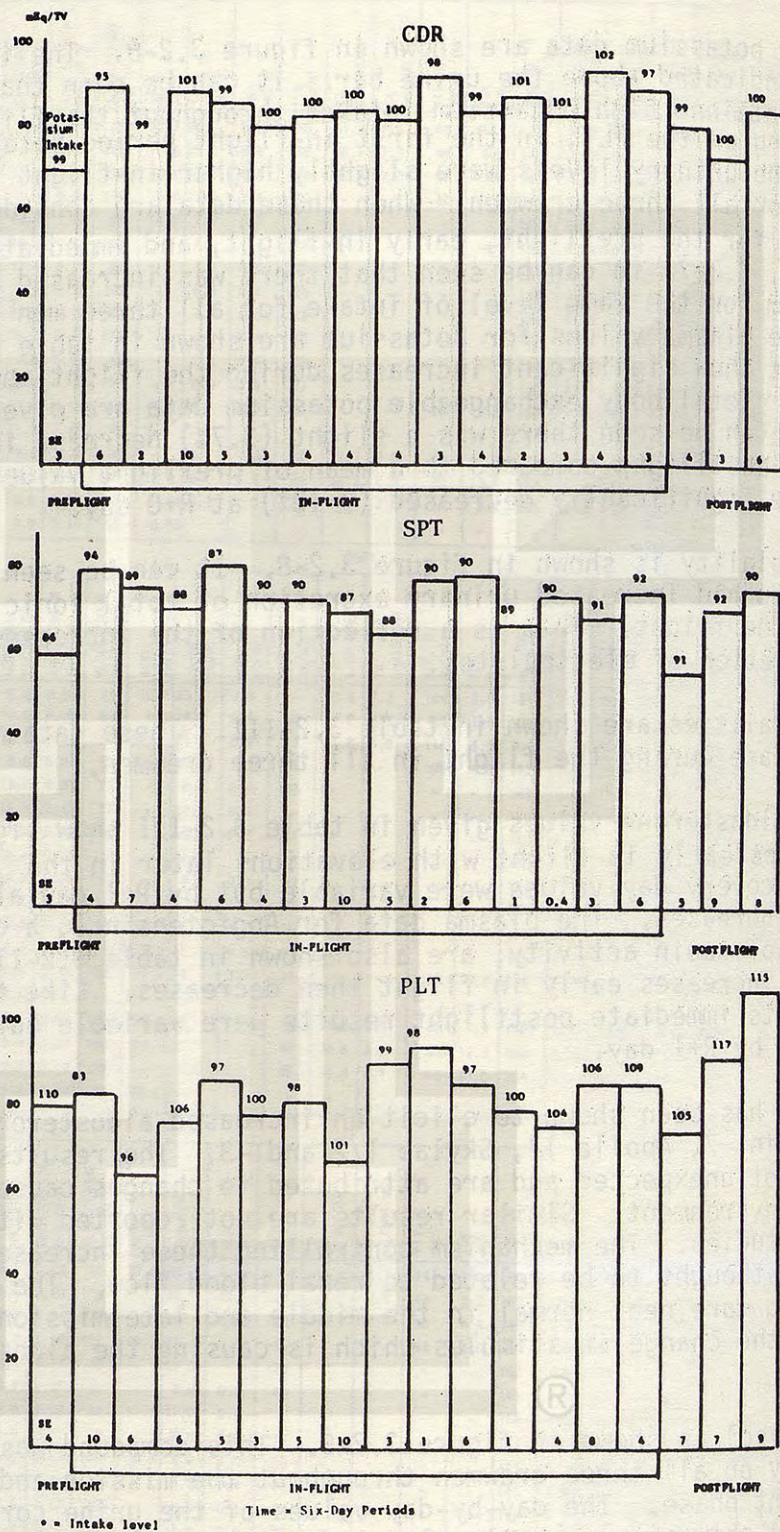


Figure 3.2-6. - Potassium Intake and Urinary Potassium Excretion (SL-4)

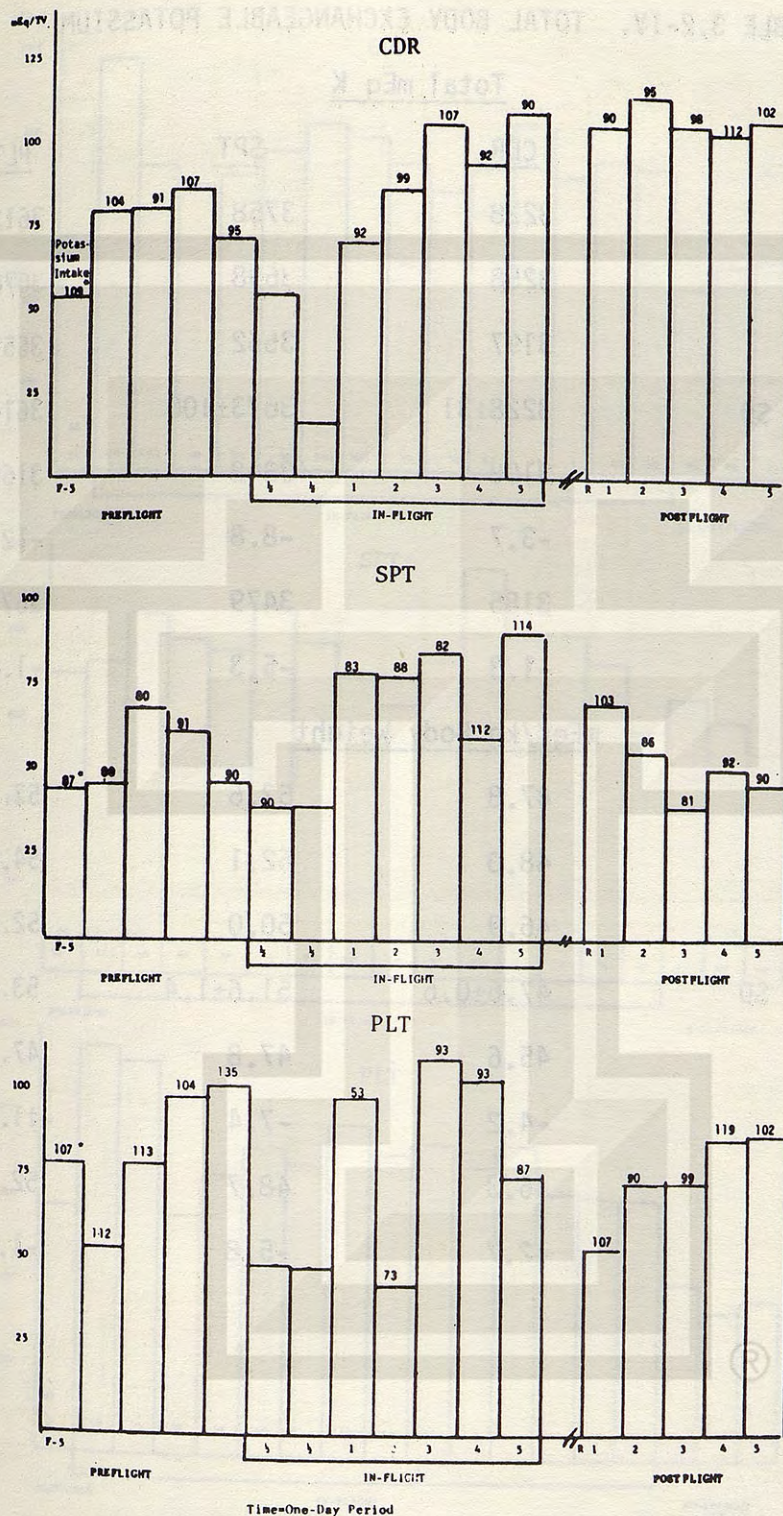


Figure 3.2-7. - Day-by-Day Potassium Intake and Urinary Excretion (SL-4).

TABLE 3.2-IV. TOTAL BODY EXCHANGEABLE POTASSIUM

<u>DAY</u>	<u>Total mEq K</u>		
	<u>CDR</u>	<u>SPT</u>	<u>PLT</u>
F-21	3228	3758	3612
F-14	3258	3698	3678
F-1	3197	3562	3551
Preflight $\bar{x} \pm SD$	3228 $\pm$ 31	3673 $\pm$ 100	3614 $\pm$ 64
R+0	3108	3348	3169
% Change	-3.7	-8.8	-12.3
R+14	3185	3479	3577
% Change	-1.3	-5.3	-1.0
<u>mEqK/kg Body Weight</u>			
F-21	47.8	52.6	53.2
F-14	48.0	52.1	54.6
F-1	46.9	50.0	52.9
Preflight $\bar{x} \pm SD$	47.6 $\pm$ 0.6	51.6 $\pm$ 1.4	53.6 $\pm$ 0.9
R+0	45.6	47.8	47.7
% Change	-4.2	-7.4	-11.0
R+14	46.3	48.7	52.9
% Change	-2.7	-5.8	-1.3

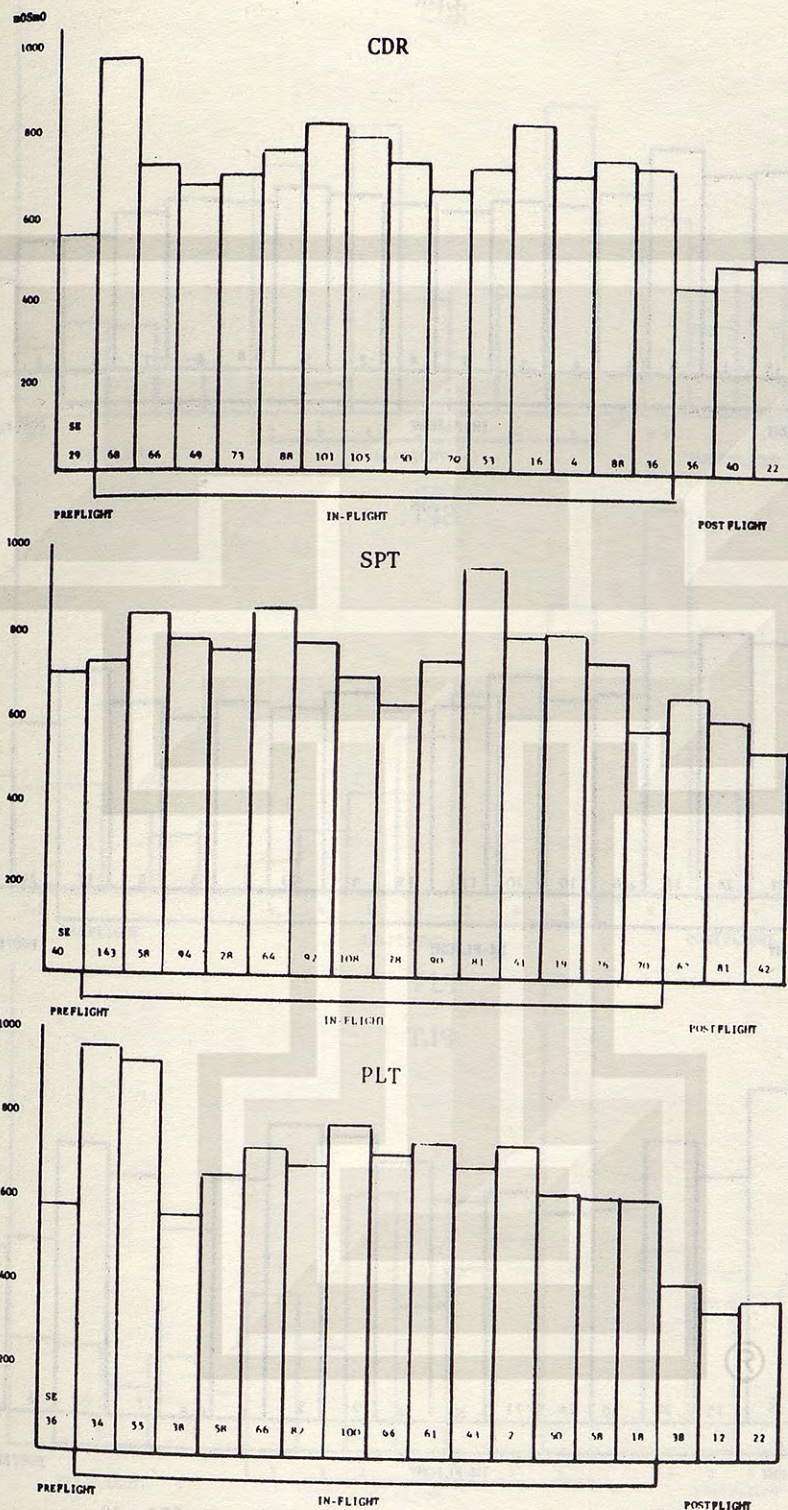


Figure 3.2-8. - Urinary Osmolality (SL-4).

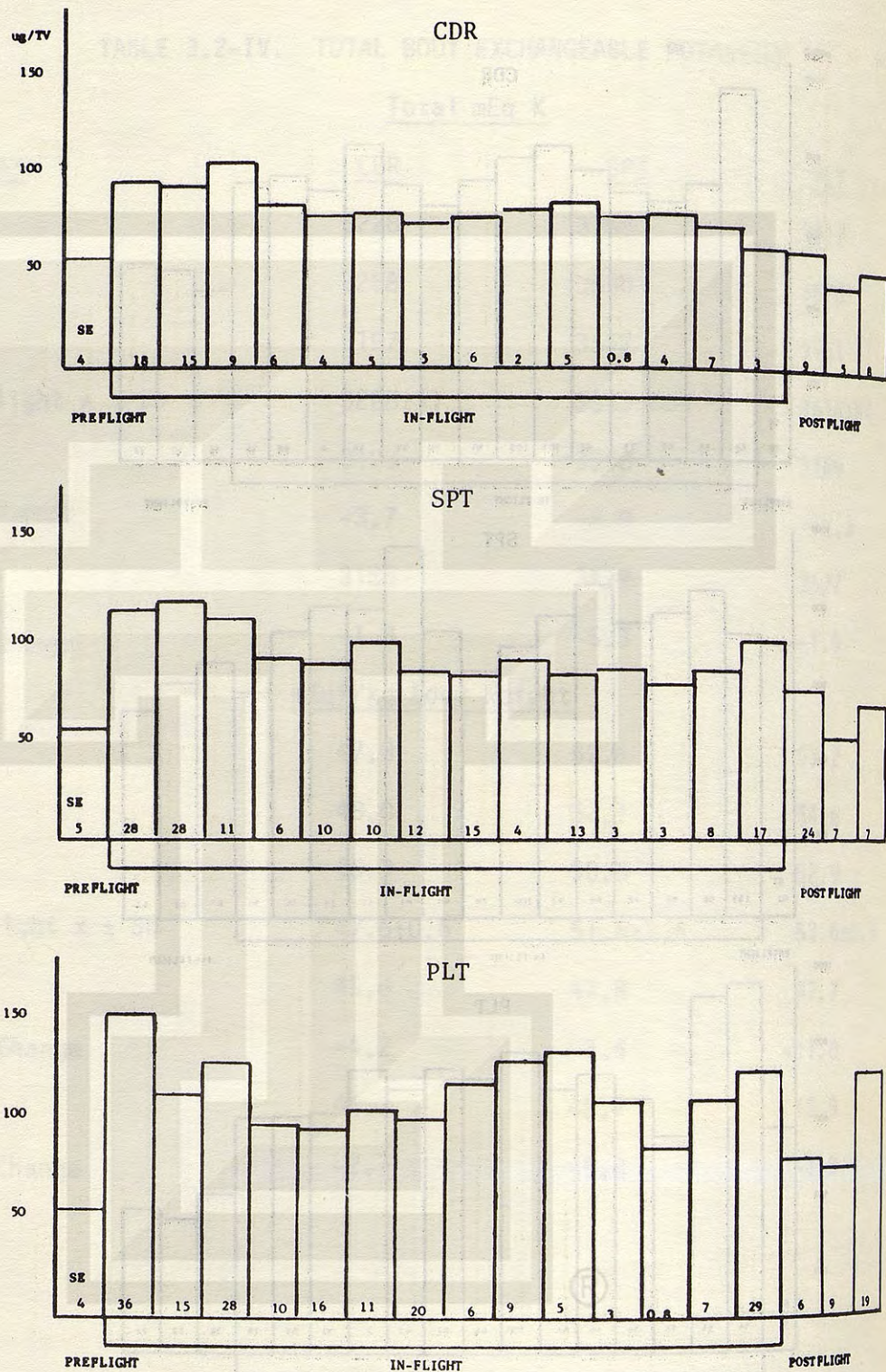


Figure 3.2-9. - Urinary Cortisol (SL-4).

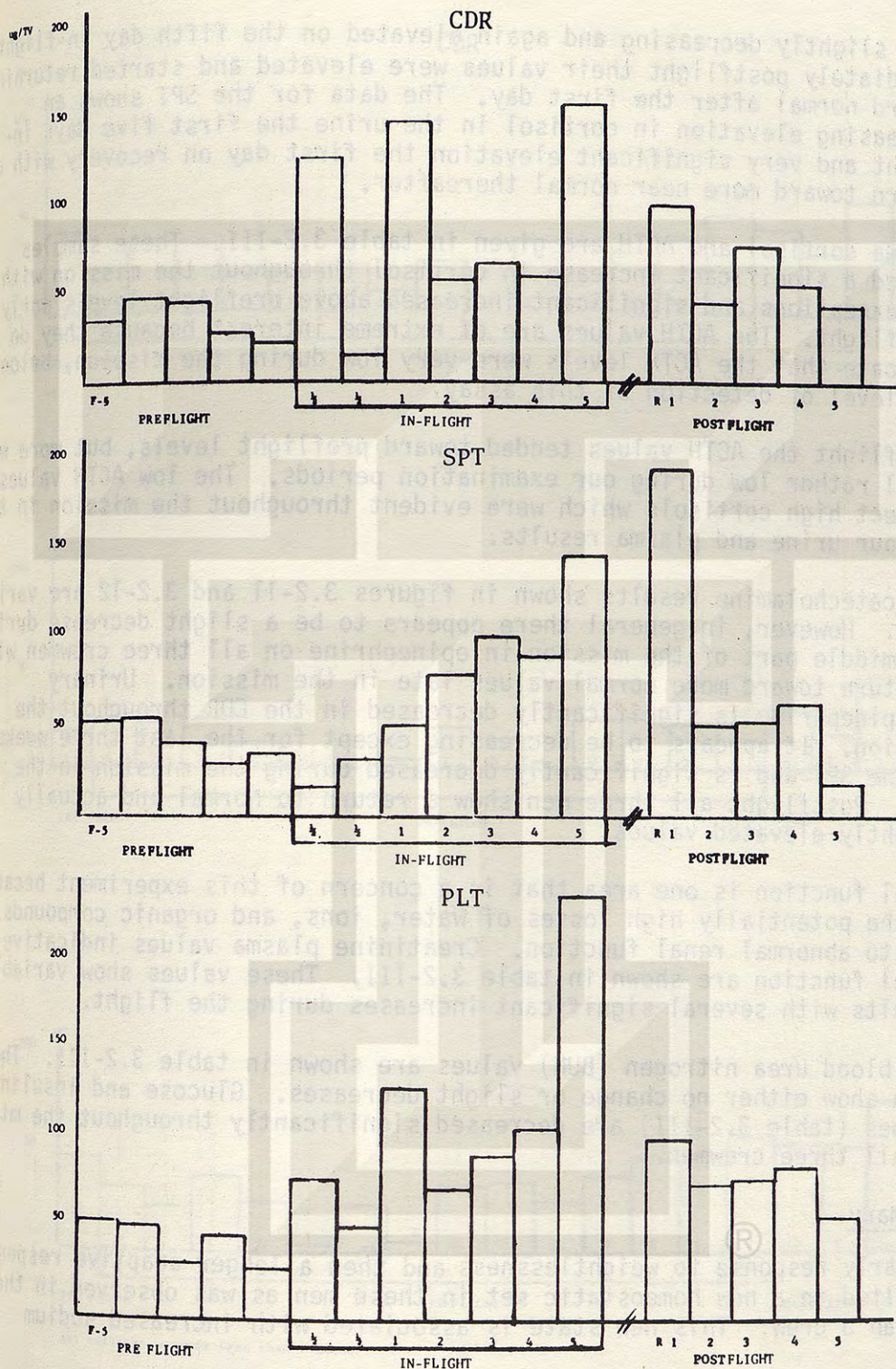


Figure 3.2-10. - Urinary Cortisol, Day-by-Day Data (SL-4).

then slightly decreasing and again elevated on the fifth day in-flight. Immediately postflight their values were elevated and started returning toward normal after the first day. The data for the SPT shows an increasing elevation in cortisol in the urine the first five days in-flight and very significant elevation the first day on recovery with a return toward more near normal thereafter.

Plasma cortisol and ACTH are given in table 3.2-III. These samples showed a significant increase in cortisol throughout the mission with few exceptions and significant increases above preflight levels early postflight. The ACTH values are of extreme interest because they do indicate that the ACTH levels were very low during the mission, below the level of detection of this assay.

Postflight the ACTH values tended toward preflight levels, but more were still rather low during our examination periods. The low ACTH values do reflect high cortisols which were evident throughout the mission in the 24-hour urine and plasma results.

The catecholamine results shown in figures 3.2-11 and 3.2-12 are variable. However, in general there appears to be a slight decrease during the middle part of the mission in epinephrine on all three crewmen with a return toward more normal values late in the mission. Urinary norepinephrine is significantly decreased in the CDR throughout the mission. It appears to be decreasing except for the last three weeks in the SPT and is significantly decreased during the mission in the PLT. Postflight all three men show a return to normal and actually slightly elevated values.

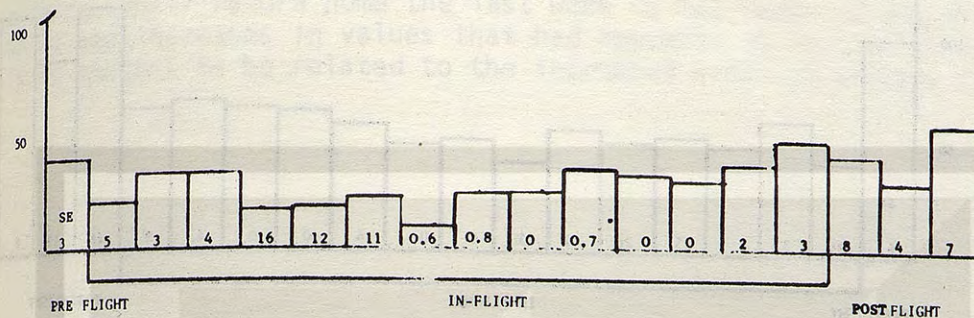
Renal function is one area that is a concern of this experiment because of the potentially high losses of water, ions, and organic compounds due to abnormal renal function. Creatinine plasma values indicative of renal function are shown in table 3.2-III. These values show variable results with several significant increases during the flight.

The blood urea nitrogen (BUN) values are shown in table 3.2-III. These data show either no change or slight decreases. Glucose and insulin values (table 3.2-III) are decreased significantly throughout the mission on all three crewmen.

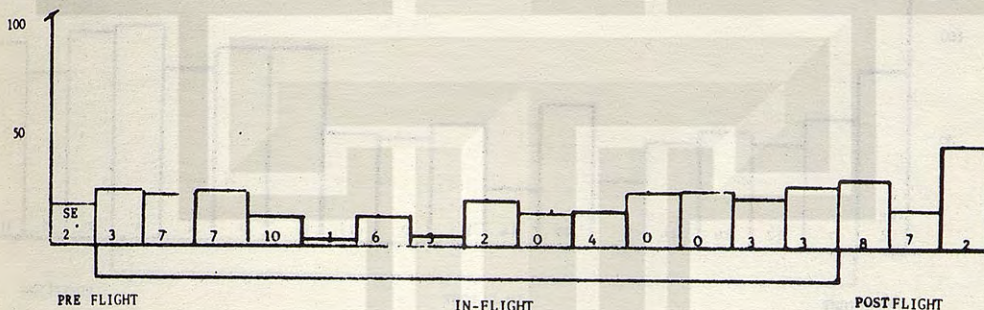
Summary

An early response to weightlessness and then a longer adaptive response resulted in a new homeostatic set in these men as was observed in the Skylab 3 crew. This new state is associated with increased sodium

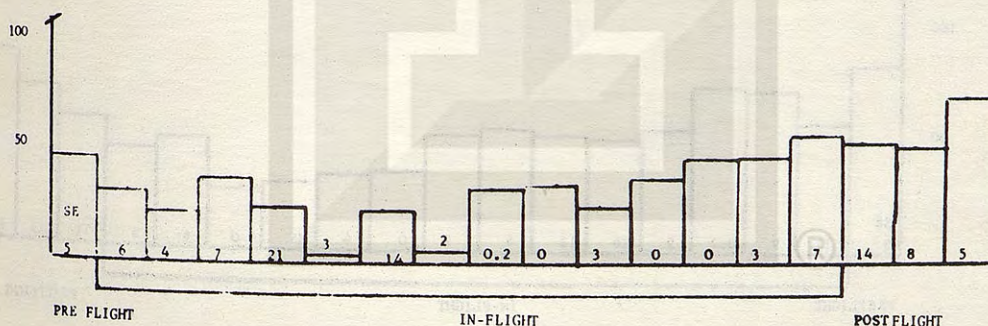
CDR



SPT

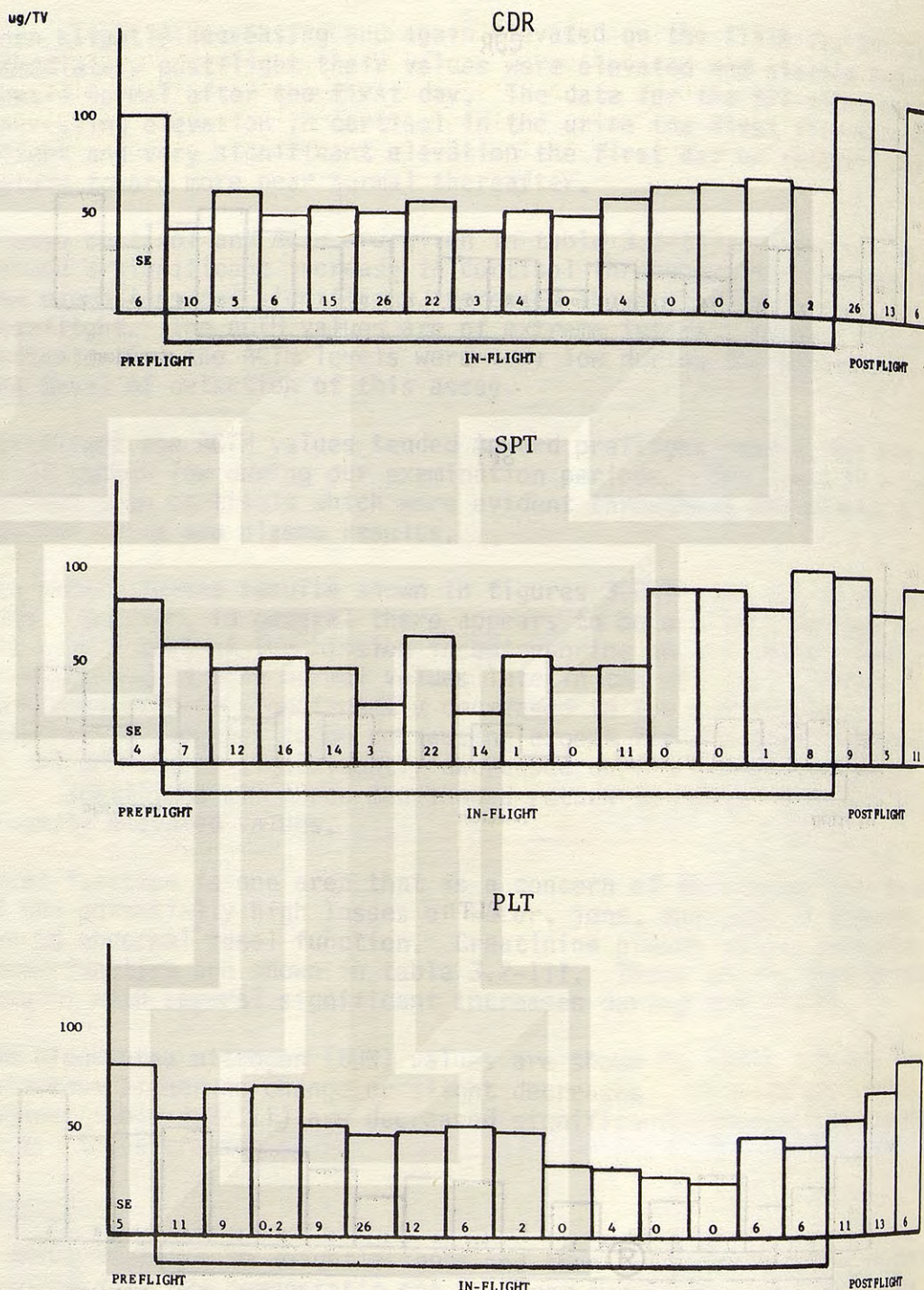


PLT



All in-flight periods less than 6 days.

Figure 3.2-11. - Urinary Epinephrine (SL-4).



All in-flight periods less than 6 days.

Figure 3.2-12. - Urinary Norepinephrine (SL-4).

excretion and other subtle changes in renal endocrine parameters. It appears that this new state did not change until the crewmen were preparing for their return home the last week to two weeks of the mission, then we see increases in values that had appeared to be lower previously. This is thought to be related to the increased workload at this time.



-4).

3.3 Experiment M074/M172. Specimen and Body Mass Measurements

Principal Investigators: W. Thornton, M.D.

J. Ord, M.D.

Three nongravimetric mass measuring devices (MMD's) continued in use on Skylab 4. Although the primary goal had been investigation of the devices, a variety of problems had reduced the operation to primarily one of supporting medical operations. One sample (or specimen) mass measuring device (SMMD), located in the wardroom, was used to measure all food residues, of which there were virtually none on this flight. A second SMMD in the waste management compartment measured all fecal and vomitus samples and a body mass measuring device (BMMD) on the upper deck of the workshop was used to determine daily basal crew weight. After an early Ward Room SMMD electronic package failure had been replaced by the SL-3 crew, operation was routine with exception of attempts to calibrate the BMMD with onboard objects. Inadequate restraint of these objects required taping and other emergency fixes on SL 1/2; additional restraints were added on SL-3 which improved operations although mass stability of the calibration objects was in question by the end of that mission.

Studies on SL 1/2 and -3 indicated that maximum errors were on the order of three to four grams for the SMMD while repeatability for human subjects with the BMMD was ± 0.1 pound (± 45 g) and accuracy was $+0.25$ to $+1.0$ pounds (113 to 454 g) and probably nearer to $+0.25$ pounds.

The following is a first look at results from SL-4. Since the MMD's are fundamentally the same in operation, they will be described together.

Methods

M074: These spring/mass oscillators support a tray and the specimen mass on four elastic flexure pivots which provide a constraint to approximately linear motion and a precise restoring force. The specimen tray is displaced, released, and undergoes essentially undamped natural oscillation whose period is measured to 10^{-5} second by an optical detector and digital timer. The SMMD's are calibrated by adding precise masses to the tray. Calibration values were manually recorded in flight and voice relayed to Earth where they were fitted to curves of the form: $\text{Mass} = A^0 + A^1T^1 + A^2T^2 + \dots + A^nT^n$ (where T = period and A = coefficients) up to the fifth order. The best fit of the curve was then used to generate a conversion table of period to mass values in the region of interest. Any mass measurements made in orbit were voiced down, converted and used as needed; if required on board, mass figures were sent up via teleprinter. An approximate onboard conversion curve was used to translate all fecal mass determinations since the drying time was a mass function. Oscillation periods for fecal mass determinations were recorded and returned at mission end for exact conversions.

M172: The same basic arrangement was used for the BMMD except the crewman to be measured was "folded" into a special seat and restrained with shoulder straps. Calibrations were made with food trays and other onboard objects which were fitted to the seat with adapters. Daily mass of each crewman was obtained each morning after arising, after a "final" void¹, and wearing standardized clothing. Period data was voiced down with the evening report, converted, and returned with the daily medical status report.

Results

SMMD: Operation was nominal with an initial calibration at 11 days into the mission. Twenty-eight days later all calibration masses were reported missing except the 500 g mass. A two-point calibration was done on both SMMD's on mission days 39 and 71.

Approximately one week prior to splashdown the elastic specimen cover on the Waste Management Compartment SMMD pulled loose from its clamp and the Ward Room unit was used to complete the mission.

BMMD: Operation remained nominal on this unit with daily crew masses. In addition, it was used to measure the amount of coolant used to recharge the Skylab refrigerant loop by measuring mass of the storage tank before and after charging from it. Although three calibrations were made on mission days 10, 47 and 74 with improved adapters, the crew still objected to the time, complexity and crudity of the procedure. Conversely, the BMMD appeared to be extremely stable from flight to flight as judged by its zero point. Operation was nominal until several days prior to splashdown when operation of the subject release became intermittent and failed. For the rest of the mission the procedure was completed as a two-man operation with the observer operating the calibration release.

Analysis

Mass conversion was accomplished as described. Examination of SL-4 BMMD calibration results exposed discrepancies that were most likely from changes of calibration mass. A decision was made to trust the stability of the instrument rather than that of the food trays and other makeshift items used as calibration masses; the MD 3 calibration curve from SL-3 was used for all conversions.

Because vomitus and food residue were negligible and fecal data is unremarkable, none of these data will be presented. Crew body mass is plotted vs. time in figures 3.3-1, 3.3-2, and 3.3-3; a three-day sliding average was made to smooth the data.

¹The "final" void closed out the 24-hour urine collection period.

The CD
typical
Skylab
cant
while
stabil
by R+5

Body co
exercis
heat, i
through
and in

Althoug
was sma
sponse
initiat
the rol
the act

Althoug
experie
now app
the fir
SL-4, t
and esp
ent wit
of SL-4
began p

As seen
intakes
respect
obvious
of free
accordi
on each
availabl
surpris
line and

²Caloric

³It coul
there w
include

The CDR's mass record presents a striking contrast to the losses typically seen on previous flights. He was the only crewman in the Skylab program to lose no mass in flight. The PLT showed a significant initial loss followed by stability or even a slight recovery while the SPT showed a much slower initial loss followed by relative stability. Postflight all three crewmen showed a rapid increase and by R+5 days all three had regained their preflight weight.

Body composition changes are directly related to diet and metabolism, exercise, water balance and various kinds of stress such as excessive heat, anorexia, *et cetera*. These relationships are also discussed throughout this document in detailed test objectives of Crew Health and in the experiment sections, M073 and M071.

Although the sample population for the three Skylab manned missions was small, examination of the data indicates similarity of crew response and some answers to questions which were open prior to the initiation of the missions. Outstanding preflight questions included the roles of water loss, caloric intake, heat and other stresses, and the actual physical cost of work in weightlessness.

Although effects from the heat stresses on SL 1/2 and the anorexia experienced by the SL-3 crew and the SL-4 PLT must be considered, it now appears that all the crewmen experienced a rapid loss of mass for the first few days after insertion into orbit. In the CDR and SPT of SL-4, these losses were significantly less. In five of six crewmen, and especially on SL 1/2, there was a continuing loss entirely consistent with a metabolic deficit. This was true for a time with the SPT of SL-4 until caloric intake was increased. This weight loss frequently began preflight and, surprisingly, accelerated in flight.

As seen in figure 3.3-4, plotted normalized weight losses and caloric intakes² from launch weight to the recovery day BMMD reading³ for the respective crewman gives insight into this caloric deficit. It is obvious that, except for the CDR on SL 1/2 who ate appreciable amounts of free caloric items, there are distinct groupings of weight loss according to flights, *i.e.*, there was progressively less weight loss on each flight. Conversely, there was an increasing amount of foods available. Although the sample population is small, six subjects lie surprisingly close to a regression line. Three subjects lie off this line and all three had extremely low body fat.

²Caloric data obtained from the Food Section

³It could be argued that recovery weight would be more practical, but there was marked variation on reentry and recovery losses; also included was at least one gain.