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STUDY OF PHYSIOLOGICAL TOLERANCE TO CENTRIFUGATION

15 JUNE 1971

FINAL REPORT

FACILITY FORM 602

N71-29216 (ACCESSION NUMBER)

(THRU)

20 (PAGES)

G3 (CODE)

CR-115068 (NASA CR OR TMX OR AD NUMBER)

04 (CATEGORY)

Contract NAS 9-11314

JUL 1971 RECEIVED NASA STI FACILITY INPUT BRANCH

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Manned Spacecraft Center
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CR-115068

STUDY OF PHYSIOLOGICAL TOLERANCE TO CENTRIFUGATION

FINAL REPORT

15 JUNE 1971

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Contract NAS 9-11314

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1. INTRODUCTION

Current plans for the probable reentry trajectory of the Space Shuttle entail exposing the passengers and crew to a deceleration load unlike those experienced in the Mercury, Gemini, or Apollo missions. The effects of the required deceleration, the attitude of the craft, and the seated postures of the occupants will be to produce $+G_z$ forces (headwards or eyeballs down) of more than 300 seconds duration.

One of the earliest effects of $+G_z$ acceleration exposure, of slow onset, is a loss of peripheral vision. This loss of peripheral vision may occur very close to the acceleration levels at which complete blackout and unconsciousness occur. It is evident that the occurrence of any of these symptoms in the flight crew during reentry could have particularly disastrous results. The need to ensure that the accelerations experienced will not cause significant performance decrements must also take into account the interindividual tolerance differences found to exist. The difficulty of ensuring that an individual may undergo the expected stresses without significant performance decrement is compounded by the fact that he may have been exposed to extended periods of weightlessness prior to reentry. It is known that $+G_z$ acceleration effects may be countered, to a limited extent, by cardiovascular compensation; it is not known, however, what changes occur to an individual's thresholds for blackout or performance decrement in these circumstances. Information is required on the extent to which normal acceleration tolerance thresholds are reduced by the amounts of cardiovascular decompensation which may be induced by periods of weightlessness of days or weeks.

In order to assess the practical possibility of functional impairment, due to the proposed shuttle reentry acceleration profile, a bed rest centrifugation study has been conducted. The study provided for centrifugation of the subjects. Before and after the rest period, the subjects were put on the centrifuge and subjected to a simulation of the anticipated reentry acceleration profile. This centrifuge testing was performed twice on each subject for control purposes and again at the end of 24-hour and 7-day periods of bed rest.

The program involved the care (monitoring, feeding, and entertaining) of the subjects during the bed rest period, their transportation to the various facilities where tests were performed, the coordination of the groups concerned in the study, the scheduling of data collection, and the analysis of data made available by the study.

2. OBJECTIVES

Preliminary designs for the space shuttle suggest that passengers and crew returning to earth will be subjected to $+G_z$ acceleration loading during reentry. Preliminary trajectory calculations indicate a nominal reentry load of 2.5 $+G_z$ for 370 seconds. Off-nominal reentries, however, could produce loads of up to 4.5 $+G_z$ for 150 seconds(1). Miller, et al (2) has reported the median voluntary $+G_z$ tolerance time at 4.5 $+G_z$ to be eight minutes, for experienced subjects in good physical condition without G-suit protection. Gaver(3) noted that most subjects experience peripheral vision loss at 3.0 - 3.5 $+G_z$ and approach unconsciousness at 4.5 - 5.0 $+G_z$. While a large number of investigators have examined tolerance to $+G_z$ accelerations, few have dealt with long-term exposures (more than 60 seconds) and none have dealt with the effects of extended weightlessness (zero-G exposure) on long-term $+G_z$ tolerance. The difficulties of simulating weightlessness on earth are well known. It has, however, been argued that the physiological effects of absolute bed rest may approximate those of weightlessness. Miller and Leverett(4) have performed a bed rest study followed by relatively short term $+G_z$ loading. They found an insignificant decrement in $+G_z$ tolerance following four weeks of bed rest. Heart rate, however, was noted to be significantly higher at equivalent G-levels. In contrast, White, et al (5) showed a 12-38% drop in tolerance to high gradient acceleration following ten days of modified bed rest.

Since shuttle passengers and crew may be exposed to a weightless environment for days or weeks prior to reentry, the effect of such exposures on $+G_z$ tolerance becomes a rather important question.

3. PROCEDURE

In order to study the relationship between zero-G exposure and $+G_z$ tolerance some of the physiological effects of zero-G exposures were simulated by absolute bed rest, and the reentry accelerations by radial acceleration on the Manned Spacecraft Center Flight Acceleration Facility centrifuge. Nine men, from the centrifuge pool at the USAF School of Aerospace Medicine, Brooks Air Force Base, Texas, volunteered for the study. All were healthy, experienced centrifuge test subjects between the ages of 19 and 36.

Bed rest took place in the MSC Lunar Receiving Laboratory, in the dormitory section of the crew reception area. Bed rest was absolute: elbows were kept on the mattress and one flat pillow was placed under the head. Subjects were allowed to roll over or lie on their sides at will, but could not sit up or exercise. Bedpans and urinals were used to handle excretory matter. Eating was accomplished while lying on the side. Meats often had to be pre-cut to bite size portions. No special diet was prepared; three normally balanced meals per day were planned and served. Nurses and orderlies monitored the subjects, assisted them with their feeding, and provided back rubs on request. At the end of their bed rest, subjects were dressed in shirts and shorts, rolled onto the carrying board, loaded into a station wagon, and transported to the flight acceleration facility.

The schedule of events for subjects is shown in Figure 1. Briefly, subjects had two control centirfuge runs separated by three days. Following a five-day ambulatory period, a twenty-four hour bed rest was initiated. Following bed rest, subjects were placed on the centrifuge and exposed to a series of $+G_z$ profiles. A second five-day ambulatory period then began, which ended with the start of seven days of bed rest. Subjects were exposed to the acceleration loads again at the end of bed rest. They were then observed for 24 hours prior to release.

Centrifuge runs were conducted in the same manner on each of the four test series: the subject was placed on a carrier board on a wheeled stretcher, instrumented and transported by elevator to the control room level of the flight acceleration facility. The wind hat was removed from the centrifuge gondola, and the subject and board partially inserted. The restraint harnesses on the board were released, and the subject slid into position on the Apollo couch. While the subject was harnessed into the seat, the wind hat was reinstalled and subject instrumentation connected. After a 10-15 minute checkout period, the acceleration profiles were started.

Each subject was exposed to loads of 2.5, 3.0, 3.5, 4.0 and 4.5 $+G_z$ for 370 seconds or until an earlier loss of peripheral vision. Onset and offset rates were 0.03 G/sec. Each acceleration profile contained a relatively sharp acceleration spike of 2.5 $+G_z$ max (onset and offset rates - 0.15 G/sec) which started at 0.25 $+G_z$ on the deceleration ramp. Tables I, II, and III present initial data which indicate acceleration tolerance decrement after both 24-hour and 7-day rest periods.

Observations and measurements made during acceleration include two channels of EKG (axillary and sternal leads), EEG, EOG, blood pressure, and plethysmograph (half volume). Peripheral vision, central vision, voice, and facial appearance were also subjected to assessment.

Electrocardiograms were taken into both sternal and axillary leads. In addition, an impedance pneumogram was derived from the axillary leads. The electrodes, the harness and the signal conditioners were identical to Apollo flight hardware. Output from the signal conditioners was displayed on an oscilloscope at the medical monitor's console, and recorded on an Offner dynograph and a Sangamo analog tape recorder.

Electroencephalograms and electrooculograms were taken with an electrode cap developed by Dr. Frost. Processed signals were recorded on an Offner recorder and a Sangamo tape recorder.

Blood pressure was measured by a brachial occluding cuff and microphone developed by the USAF School of Aerospace Medicine. Cuff inflation was initiated from the medical control room by a push button, and bleed off rate was pre-set. The pressure ramp and resultant Korotkov sounds were recorded on an Offner recorder, while the ramp alone was recorded on a Sangamo tape recorder.

Plethysmograms were taken by capacitance calf bands and processing electronics developed at the USAF Academy. Output signals were displayed on a meter in the medical control room, and were conducted both on an Offner recorder and a Sangamo tape recorder.

Peripheral vision was monitored by the use of two green lights and one red light. The subject was instructed to fixate on the central red light and to turn out (by means of a hand-held push button) the green lights when they appeared. Lights were operated by an operator in the medical control room. Signals indicating when the lights were on were recorded on a

Sangamo recorder. This data is also being inspected for information on reaction times during the various acceleration profiles (Table IV indicates preliminary results).

Central vision was monitored by presenting a number just below the red fixation light and having the subject attempt to identify and call out the number displayed. In addition, a number of letters of different sizes were mounted near the test display, and subjects were asked to comment on their legibility during acceleration.

Two television cameras, one with an overall view of the subjects, and one trained on the subject's face, were used to observe his condition. Voice recordings of all communications were made on the Sangamo tape.

In addition to the basic centrifuge bed rest protocol a number of other measurements were made on the subjects to give a better indication of the physiological effects of the experimental procedure. Instrumentation, procedures, and results of these tests will be reported as appendices to this report. The tests include lower body negative pressure response, exercise physiology, pulmonary functions, blood chemistry, and hematology.

4. RESULTS - Summary of Current Status

Preliminary results indicate that bed rest did achieve various degrees of physiological deconditioning and that following 24-hour and 7-day rest periods, $+G_z$ acceleration tolerance was found to be reduced in most subjects.

An informal presentation of reduced data, made available to the contractor, is included as an appendix to this report.

5. SUMMARY

A centrifuge bed rest study designed to determine the physiological effects of acceleration, following simulated weightlessness, was performed at the NASA Manned Spacecraft Center. Technology Incorporated was involved in design, maintenance of the subjects, instrumentation scheduling, data coordination, and data reduction for the study. Preliminary results of the study show a general decrease in tolerance to $+\ddot{G}_z$ acceleration loads following seven days of bed rest.

6. REFERENCES

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(2) Miller, H., Riley, M. B., Bondurant, S., and Hiatt, E. P., The Duration of Tolerance to Positive Acceleration, J. Aviat.Med., 30, 360-366, 1959. In Gaver and Zuidema (Ed) Gravitational Stress in Aerospace Medicine, Little, Brown and Co., London, 1961

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(5) White, P. D., Nyberg, J. W., Finney, L. M., and White, W. J., Influence of Periodic Centrifugation on Cardiovascular Functions of Man During Bed Rest. NASA CR 65-422, National Aeronautics and Space Administration, Washington, D. C. 1966.

APPENDIX

TABLE I

$+G_z$ Level	Control 1	Control 2	Bedrest (24 hour)	Bedrest (7 day)
2.5	6/6	9/9	9/9	7/9
3.0	5/6	8/9	7/9	5/9
3.5	5/7	4/9	4/9	2/9
4.0	3/6	3/9	2/9	1/9
4.5	1/7	2/9	1/9	0/9

Upper digit indicates number of subjects successfully completing indicated run; lower digit indicates number of subjects eligible for that run.

TABLE II

G Level	Time
2.5	370
3.0	220
4.0	150

Projected nominal and off-nominal reentry $+G_Z$ level versus time histories.

TABLE III

CONDITION

$+G_z$ Level	Control 1	Control 2	Bedrest (24 Hour)	Bedrest (7 Day)
2.5	6/6	9/9	9/9	7/9
3.0	6/6	9/9	7/9	6/9
4.0	4/6	4/6	3/9	1/9

The number of subjects whose tolerance times exceed the times in Table II for each G-level, again shown as a fraction of the number of subjects tested.

TABLE IV

	24 Hr. 2.5	7 Day 2.5	24 Hr. 3.0	7 Day 3.0	24 Hr. 3.5	7 Day 3.5	24 Hr. 4.0	7 Day 4.0	24 Hr. 4.5	7 Day 4.5
(Subject #1)										
Mean	613.66	578.79	640.52	592.45	746.17	575.79	615.30	520.46	736.72	879.01
S.D.	252.12	290.64	304.94	278.58	271.07	253.27	351.67	211.14	358.35	533.40
N	244.00	196.00	206.00	156.00	227.00	219.00	235.00	230.00	232.00	83.00
(Subject #2)										
Mean	574.16	(No data)	747.55	541.5						
S.D.	233.96		285.73	99.7						
N	292.00		117.00	2						
(Subject #3)										
Mean	544.69	620.41	721.12	(No data)						
S.D.	290.06	315.08	399.25	(No data)						
N	263.00	189.00	249.00	(No data)						
(Subject #4)										
Mean	447.61	432.68	500.28	531.37	(No data)	452.00				
S.D.	183.28	220.38	243.26	247.16	(No data)	193.91				
N	261.00	226.00	303.00	164.00	(No data)	54.00				
(Subject #5)										
Mean	535.32	597.36								
S.D.	296.96	224.06								
N	283.00	97.00								
Subject #6)										
Mean	468.91	529.91	464.66	642.28	617.12	556.58	376.88	633.00		
S.D.	206.67	236.35	206.02	369.07	478.57	562.53	187.88	477.91		
N	200.00	227.00	259.00	214.00	148.00	83.00	41.00	19.00		
(Subject #7)										
Mean	381.14	428.02	390.44	834.41	803.82	959.03	1173.15	388.07		
S.D.	175.47	330.99	169.75	901.23	887.12	650.40	1014.19	818.50		
N	284.00	162.00	281.00	143.00	220.00	98.00	69.00	57.00		

Page -2- TABLE IV (continued).....

	24 Hr. 2.5	7 Day 2.5	24 Hr. 3.0	7 Day 3.0	24 Hr. 3.5	7 Day 3.5	24 Hr. 4.0	7 Day 4.0	24 Hr. 4.5	7 Day 4.5
(Subject #8)										
Mean	523.09	494.00	593.45	497.43	527.20	554.21	600.39	548.71	619.50	
S.D.	277.42	272.30	279.35	286.81	261.41	386.46	359.51	358.09	412.18	
N	301.00	204.00	290.00	223.00	321.00	191.00	278.00	7.00	48.00	
(Subject #9)										
Mean	412.07	475.63	451.53	481.62	415.59	788.38	855.98		1002.22	
S.D.	127.28	122.02	209.67	194.73	154.89	529.40	720.98		579.35	
N	270.00	243.00	275.00	215.00	271.00	84.00	50.00		9.00	

Table IV above summarizes the light bar response data for 24 hour and 7 day bedrest. Each cell shows mean response time, standard deviation and number of responses for a given subject at a given $+G_z$ level and condition.

Figure 1.

SUBJECTS:	31 Mon.			1 Tues.			2 Wed.			3 Thurs.			4 Fri.			5 Sat.			6 Sun.			7 Mon.			8 Tues.			9 Wed.			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1	X			C			E			Y															B			Z			
2		X		C				E			Y															B			Z		
3			X	C					E			Y															B			Z	
4	C			X						E			Y															B			
5	C				X						E			Y															B		
6	C					X						E			Y															B	
7	C						X						E												Y						B
8	C							X						E												Y					
9	C								X						E												Y				

X = First Control Run
- a. Pulmonary Function
- b. Centrifugation
- c. LBNP

Y = Second Control Run
- a. Centrifugation
- b. 30 ml Hematology
- c. LBNP
- d. Pulmonary Function

Z = First Bed Rest Run
- a. Centrifugation
- b. 30 ml Hematology
- c. LBNP

B = Start of
- a. Check
  B.P.
- b. 30 ml
- c. Start

E = Ergometry

C = Full (46

FOLDOUT FRAME

	10			11			12			13			14			15			16		
	Thurs.			Fri.			Sat.			Sun.			Mon.			Tues.			Wed.		
3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
													(B)								
														(B)							
Z															(B)						
	Z															(B)					
		Z															(B)				
B			Z															(B)			
	B			Z															(B)		
		B			Z															(B)	
			B			Z															(B)

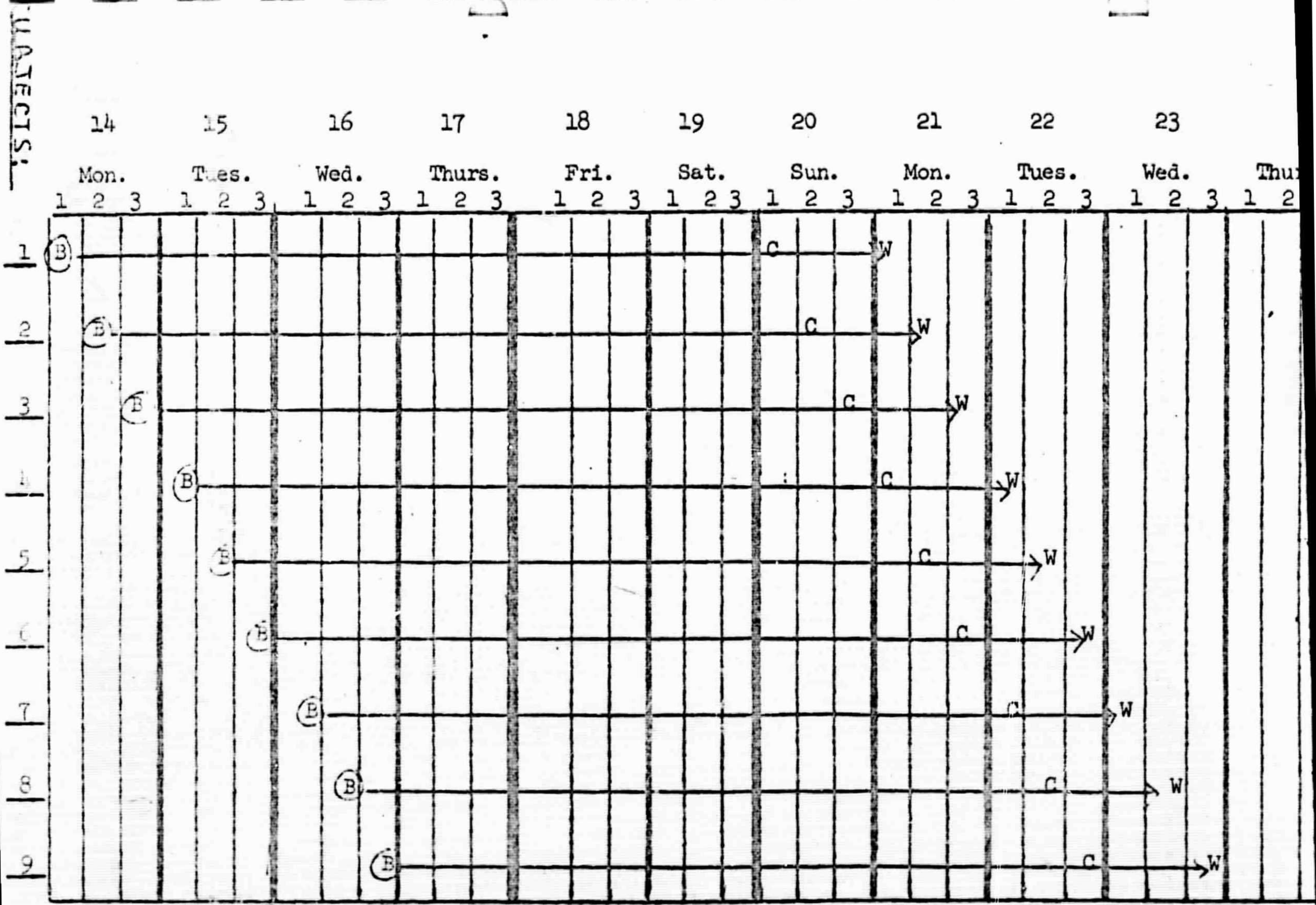
rt of Bed Rest
Check in(weight, height,
B.P. Temp.)
30 ml Hematology
Start Bed Rest

ometry

l (46 ml) Hematology

(B) = Start of Bed Rest (7 Days)
a. Check in(weight, height,
B.P. Temp.)
b. 46 ml Hematology
c. Bed Rest

FOLDOUT FRAME 2



W = 7 Day Bed Rest Run

a. Centrifugation

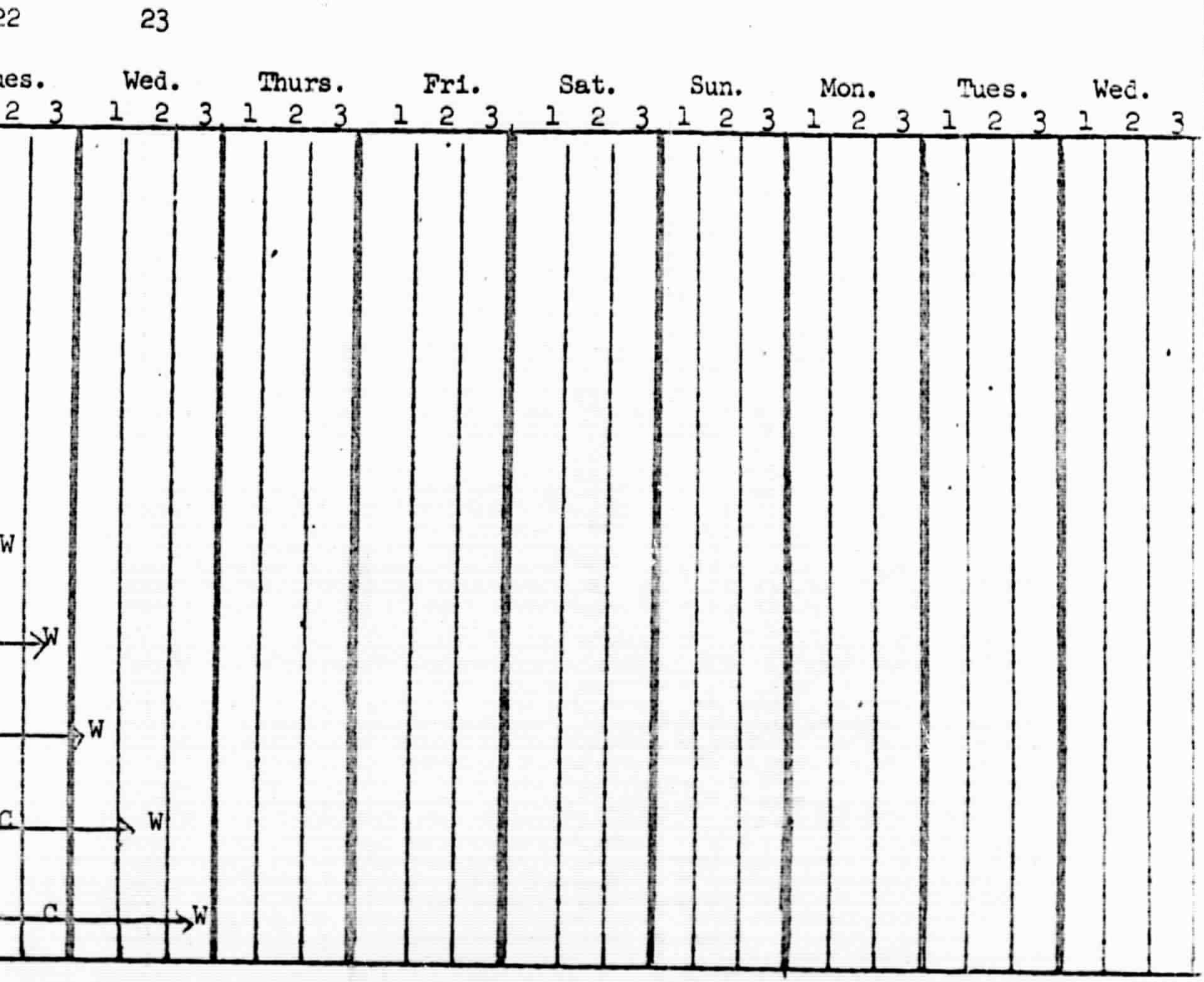
b. Hematology (30 ml)

c. LBNP

d. Pulmonary Function

e. Ergometry

FOLDOUT FRAME



FOLDOUT FRAME 2