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THE EFFECTS OF BED REST ON CREW PERFORMANCE DURING SIMULATED SHUTTLE REENTRY

Volume I: Study Overview and Physiological Results

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16. Abstract

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Study results indicate: (1) Heart rate increased during the simulated reentry when no G protection was given, and remained at or below pre-bed rest values when G-suits were used. (2) Pilots preferred the use of G-suits to muscular contraction for control of vision tunneling and grayout during reentry. (3) Prolonged bed rest did not alter blood pressure or respiration rate during reentry, but the peak reentry acceleration level did. (4) Pilot performance was not affected by prolonged bed rest or simulated reentry.

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TABLE OF CONTENTS

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SUMMARY

A centrifuge study was carried out to measure physiological stress and control task performance during simulated Space Shuttle Orbiter reentry. Jet pilots were tested with and without anti-G-suit protection. The pilots were exposed to simulated Space Shuttle reentry acceleration profiles before and after ten days of complete bed rest, which produced physiological deconditioning similar to that resulting from prolonged exposure to orbital zero G. Pilot performance in selected control tasks was determined during simulated reentry and before and after each "flight." Physiological stress during reentry was determined by monitoring heart rate, blood pressure, and respiration rate.

Study results indicate: (1) Heart rate increased during the simulated reentry when no G protection was given, and remained at or below pre-bed rest values when G-suits were used. (2) Pilots preferred the use of G-suits to muscular contraction for control of vision tunneling and grayout during reentry. (3) Prolonged bed rest did not alter blood pressure or respiration rate during reentry, but the peak reentry acceleration level did. (4) Pilot performance was not affected by prolonged bed rest or simulated reentry.

INTRODUCTION

Objectives

Space Shuttle Orbiter reentries may pose new physiological or performance problems for astronauts, primarily because the crew will be seated upright as in conventional aircraft. For this seat orientation, the Orbiter reentry acceleration will result in inertial forces directed from head to foot ($+G_Z$) rather than the chest-to-back forces ($+G_X$) typical of previous manned spacecraft reentries. Since pilot acceleration tolerance and performance is most sensitive to $+G_Z$ (eyeballs down) acceleration, the effects of deconditioning due to extended exposure to weightlessness assume primary importance.

To date, a number of experiments have been conducted to determine the effects of simulated orbital deconditioning (produced by extended periods of bed rest) on man's physiological processes and the extent to which these effects alter his tolerance to $+G_z$ accelerations. There is a marked degradation in time-tolerance to $+G_z$ accelerations, for both experienced (ref. 1) and inexperienced (ref. 2) centrifuge subjects.

For the operation of the Space Shuttle, it is expected that the physiological tolerance of the crew, while important, will not be paramount in the selection of operational design criteria. On the other hand, the Shuttle crew may be required to fly the total reentry profile (reentry, cross-range maneuvers, touchdown, etc.), and therefore their capacity for highly proficient performance will be essential.

Previous studies have shown that with normal ambulatory subjects, increased levels of G_z acceleration result in changes in various measures of performance (tables 1(a), (b), (c)); bed rest deconditioning may further enhance these effects (refs. 3, 4, and 5). In the previous bed rest/shuttle reentry studies, pilot performance was not measured, nor were highly trained pilots used as subjects.

Potential remedial techniques for countering possible adverse effects of the deconditioning and G_z stress are also of interest. One prime candidate is the anti-G suit. Anti-G suits are commonly used in high-performance aircraft for acceleration protection and have been shown to improve G_z tolerance of bed rested subjects (refs. 6 and 7). None of the previous studies has examined the influence of anti-G suits on either the physiological tolerance or performance of deconditioned subjects undergoing simulated shuttle flight.

This experiment was designed to determine whether simulated orbital deconditioning produces any serious degradation in performance and whether the use of anti-G suits alters this effect.

Specifically, the following questions were asked:

1. Are the combinations of acceleration levels and time, originally selected for tolerable habitability, compatible with the needs for possible emergency manual control?

2. What is the effect of bed rest deconditioning on the control task abilities?

3. What are the effects of anti-G_z protection suits?

Approach and Scope

Current studies of the high cross-range Space Shuttle Orbiter configuration indicate reentry accelerations from 1 G to a peak of 3 G. To achieve maximum cross range, the acceleration levels are low (1 to 2 G) because the kinetic energy of the vehicle is dissipated over a longer period of time. A precision turning maneuver will be executed (in which pilot holds vehicle at a precise bank and pitch angle), requiring a high degree of pilot proficiency if manual control of the vehicle becomes necessary. In low cross-range operations, the acceleration levels are higher (2 to 3 G) because the vehicle follows more closely a ballistic trajectory and the kinetic energy is lost more rapidly. Again, manual control would require holding a precise pitch attitude of the vehicle. In all modes of operation, the pilot role will be to monitor critical subsystems and, if necessary, to manually fly the vehicle in the "airplane" mode to touchdown.

For this study, two acceleration profiles (2 G and 3 G) were chosen to simulate Shuttle operations. The 2-G test profile was intended to bracket Shuttle accelerations in the high cross-range mode and the 3-G test profile for low cross-range Shuttle operations. Following both the 2- and 3-G acceleration exposures (reentry), a 1-G postacceleration test period was provided to simulate Shuttle operations in the landing mode.

Since the primary objective of this study was to measure the effects of bed rest and acceleration on pilot performance, eight high-performance jet pilots were selected as subjects. Each pilot was exposed twice to one of the two acceleration profiles both before and after extended bed rest. During the acceleration exposure, physiological and control performance parameters were measured. The control task involved precision two-axis tracking. The pilot had to precisely follow small, but unpredictable, roll commands while simultaneously maintaining a constant pitch attitude. This task simulated manual control of a vehicle with satisfactory roll-damping (not requiring pilot lead-equalization), and with a slightly unstable (divergent) pitch response associated with an aft-c.g., high angle-of-attack condition (ref. 8). This task satisfied the criterion of high "face validity" for the operational scenario; it was sufficiently demanding to reveal the pilot's limits and was easy to learn as an extrapolation of common piloting practice.

EXPERIMENTAL PLAN

Experimental Design

The experiment was structured in a 2 X 2 X 2 nested design, which yielded eight treatments formed by combinations of the three independent experimental variables: (1) bed rest condition (pre- and post-bed rest); (2) maximum G level (2 and 3 G); and (3) G-suit protection (G-suit used and no G-suit used).

Operational constraints required that the subjects be divided into two four-member groups (I and II) which were then tested on alternate days. Although there was no *a priori* basis for grouping individuals, potential differences in the daily environments of the groups I and II as well as order effects of G-suit usage and diurnal effects inherent in AM/PM runs, etc., were considered sufficient reasons to assemble the subjects into blocks for statistical purposes. Thus, the design was further arranged into a randomized block structure based on subject grouping and time of day. This design automatically takes advantage of inherent differences in blocks (replicates) and thereby increases the sensitivity of the test (ref. 9). The four separate blocks were: group I—AM, group I—PM, group II—AM, and group II—PM. The experimental variables and subject run numbers are given in table 2.

In the analysis of the performance data, the +2 G_z profile group and the +3 G_z profile group were treated separately to show intersubject variations. A more detailed discussion of the performance data analysis is provided in Volume II of this report (ref. 10).

Subjects

Eight male volunteers (A through H) were used as test subjects in the experiments. All were currently carrier-qualified Navy Reserve A-7 pilots. These individuals were chosen for their similarities to the population at risk (i.e., future Space Shuttle crew). None of the subjects had any previous centrifuge experience, although all were well acquainted with G exposure in military aircraft.

Prior to selection as test subjects, all individuals passed rigorous medical examinations; their physical characteristics and flight experience are presented in table 3.

Simulated Flight Profile

The reentry flight profile of the Space Shuttle Orbiter will differ markedly from that of the now familiar reentry of the Apollo missions. The Apollo spacecraft has a high-drag ballistic reentry shape, which reduces the reentry velocity through the use of aerodynamic drag on the blunt vehicle. Reentry from Earth orbit results in deceleration loads near 3.4 G, whereas reentry from translunar orbit results in loads near 6.7 G (ref. 11). In each case the astronauts ride passively on couches in a semisupine position and the resulting inertial loads are $+G_X$.

The Space Shuttle Orbiter is designed not as a ballistic vehicle like the Apollo spacecraft but as an aerodynamic vehicle. The Shuttle's aerodynamic operation will begin at the atmospheric entry interface. During reentry, the Orbiter will be guided in four phases to touchdown. For the first phase of the entry profile, a constant angle of attack will be required while bank angle is modulated to maintain a specific heating rate. During the second phase, range errors will be nulled by angle-of-attack modulation, while thermal constraints will be met by bank-angle modulation. During the third phase, bank-angle variations will be used to null range errors and the angle of attack will be reduced to achieve the proper flight profile. Then, when sufficient dynamic pressure builds up, three-axis aerodynamic control will be achieved by the elevons for pitch and roll control and by a centerline vertical surface for yaw control (ref. 12). If manual reentry is required, all controls will be the responsibility of the pilot.

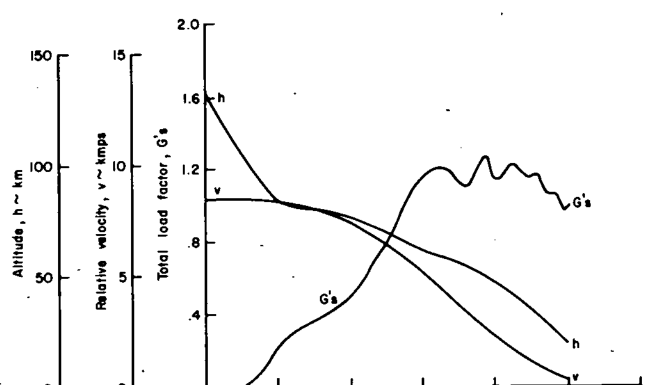

Figure 1.– Lightweight Orbiter preliminary reference trajectory (ref. 12).

Because the Shuttle Orbiter is operated essentially as an aircraft, the crew will be seated upright. Consequently, the Orbiter decelerations will result in loads directed axially along the spine from head to foot ($+G_Z$).

Even this cursory examination of the Orbiter flight makes it clear that manual operation of the vehicle will be very demanding of the crew and that flight simulation must include both reentry and touchdown phases.

Figure 1 shows a hypothetical reentry profile with deceleration loads and velocity and altitude curves for a high cross-range reentry of the Orbiter current. The flight profiles used in this study were idealized representations of this type of flight. Two simulated flight profiles were used. Each consisted of an orbital or zero G_Z portion, an entry or peak G portion, and a landing or 1 G_Z portion (fig. 2). The $+2\ G_Z$ test profile was intended to bracket high cross-range Shuttle operations, while the $+3\ G_Z$ test profile was intended to bracket low cross-range operations.

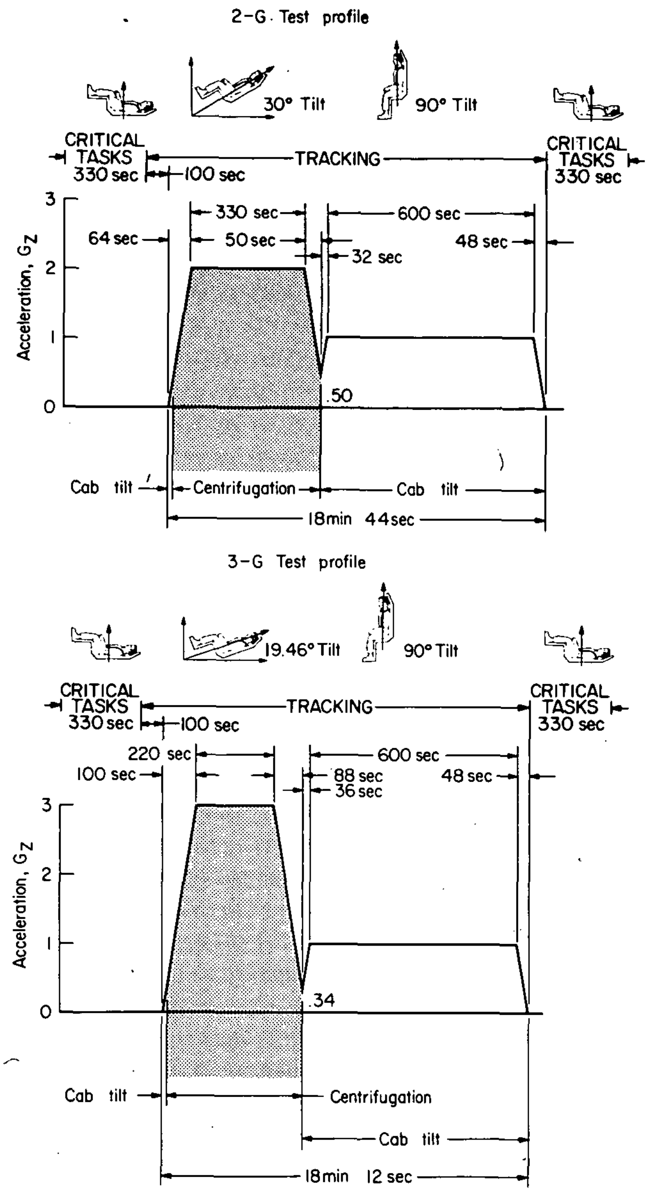

Figure 2.– Simulated flight profiles.

G-Suit Operation

The use of G-suits as a method for countering possible adverse effects of cardiovascular deconditioning required the selection of appropriate suit pressure levels and operation sequences. The following factors were considered in this selection:

1. The "normal" gravitational condition ($+G_Z$) of the astronauts (subjects) during orbital flight (bed rest) is zero G; any increase in G_Z above this can cause blood pooling in the lower extremities.

2. To be most effective as a remedial tool for deconditioning, the G-suit should be activated before blood pooling occurs.

3. G-suit usage should continue as long as the $+G_Z$ level is above normal (zero G_Z) condition.

4. The G-suit pressure level should approximate the average theoretical counter pressure required for a sitting subject, that is, 86.4-cm (34-in.) foot-to-heart height.

5. If possible, G-suit pressure levels should be similar to those used in current operating systems and/or other studies to allow a comparison of physiological data.

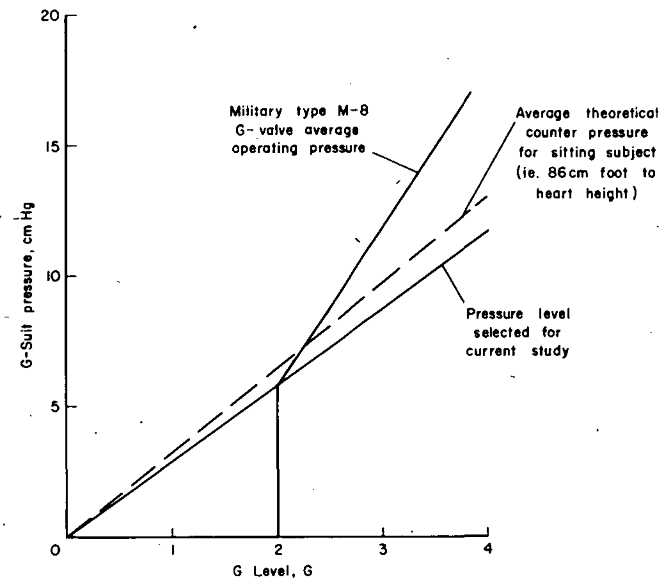

Figure 3.— G-suit pressure levels.

Figure 3 shows the G-suit pressure levels selected. These levels coincide with the military M-8 G-value operating pressure at 2 G.

The G-suit pressurization was started with the onset of acceleration and continued until the subject was returned to zero G (semisupine condition). The pressure level used in each test was that appropriate for the peak G level (i.e., 5.8 cm Hg for the 2-G plateau, 8.7 cm Hg for the 3-G plateau, and 2.9 cm Hg during the 1-G land phase).

EQUIPMENT AND FACILITIES

Human Research Facility

The subjects were housed throughout the study in the Human Research Facility at Ames Research Center. The facility includes four semiprivate (two-bed) ward rooms, food preparation and personal hygiene facilities, and medical and nursing staff areas.

Shuttle Flight Simulator

The flight simulator used in this study was the Flight and Guidance Centrifuge, located at Ames Research Center, approximately 200 m from the Human Research Facility where the subjects were housed. The centrifuge has a completely enclosed 3.2-m (10.5-ft) cab mounted on the end of a 15.2-m (50-ft) arm. Each subject was seated in the centrifuge cab in a semisupine position in a modified F-111B Seat (fig. 4). The seat and cab layout are shown in figure 5. The seat allows the eye position of all subjects to be held constant relative to the centrifuge cab and performance task display. The seat pan and foot rests adjust to accommodate differences in subject trunk height and leg length. Because of the seated semisupine position, the subject's feet are elevated above his trunk in the zero G_z position.

The G_z accelerometer is mounted parallel to, but 55.9 cm (22 in.) below, the seat back; thus, in thé pre- and post-test conditions a slight G_z load is recorded. The G_x and G_y accelerometers are mounted at the same site but oriented in each of their respective axes. The control stick (sidearm controller) used in the performance measurement is mounted on the right arm rest of the seat.

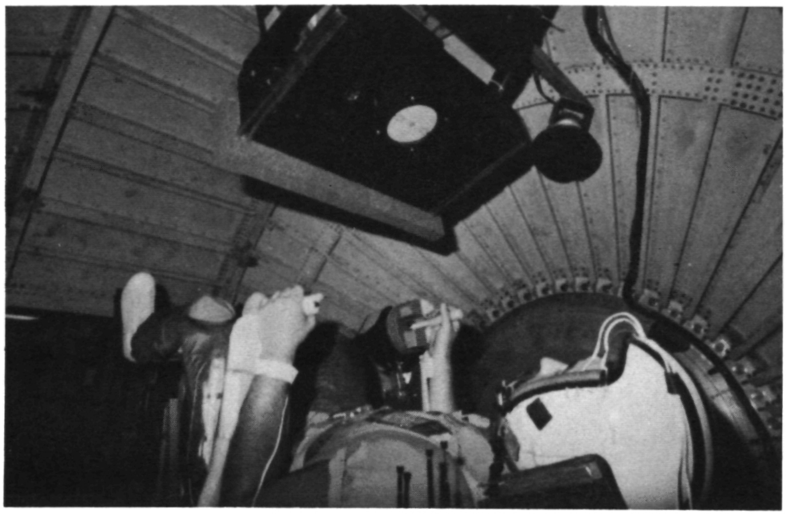

Figure 4.– Simulator seat and subject.

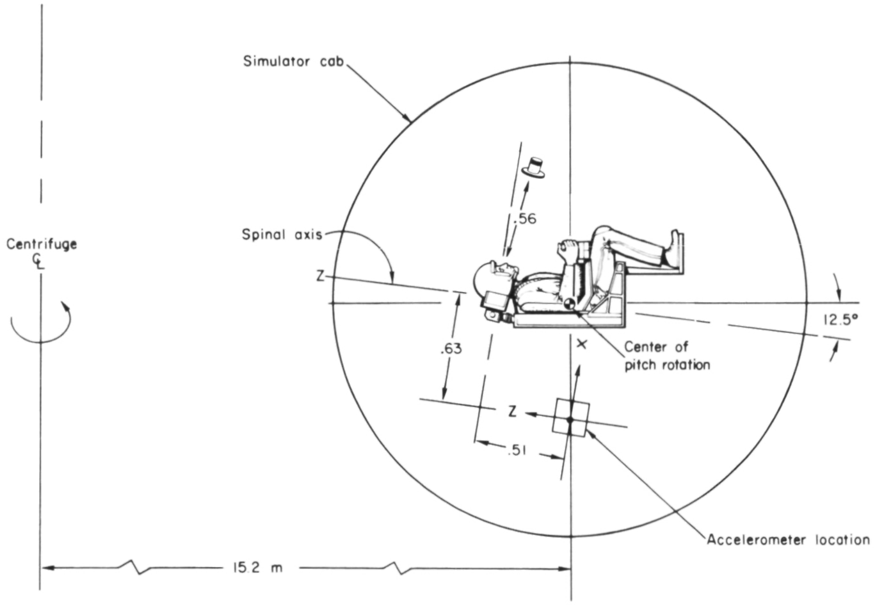

Figure 5.– Simulator cab layout.

Control Task

During the simulated flight, the subject's piloting ability was tested with a dual (two-axis) control task. The primary task was to maintain a specified roll attitude on a moving symbol CRT-generated flight director using side forces on the control stick. The roll guidance commands were a random appearing sum of five nonsimple harmonic sinusoids. The simulated controlled element was a first order (rate-control) system:

$$Y = \frac{K}{s}$$

The secondary task was to maintain zero pitch angle using fore-aft forces on the control stick. The simulated control element was again first order but this time unstable with a time constant of 0.5 sec:

$$Y = \frac{K}{s-2}$$

No input (forcing function) in the pitch axis was necessary because the subject's own visual-motor noise was sufficient to excite the unstable element.

These tasks represented a semirealistic Shuttle operation and provided the means by which the subject's performance and describing function could be determined. Just prior to and after the G exposure, and while the subject was supine, a set of critical instability trials was run. There were three trials each for the roll axis, pitch axis, and both axes combined. In these critical instability trials, the controlled element was an unstable first-order system,

$$Y = \frac{K\lambda}{s-\lambda}$$

whose instability λ was gradually increased to λ_c when control was lost. This task depended primarily on the subject's effective time delay while tracking and was used to compare baseline performance limits before and after the simulated flight.

A more detailed discussion of these performance and behavioral measures is available in Volume II of this report (ref. 10).

Instrumentation

Figure 6 is a schematic of the medical monitoring and data collection facilities used in these tests. Sternal ECG leads were used in the measurement of heart rate. Indirect recordings of blood pressure were obtained with an automatic pressure cuff and microphone system mounted over the brachial artery on the left arm. Respiration rate was monitored by measurement of temperature fluctuations of a small thermistor inserted in the nasal opening. In addition, the subject was continuously monitored by closed-circuit television.

G-Suit

The G-suits used were standard Air Force issue CSU-3/P. The suits were individually fitted, and each subject used the same suit for all runs.

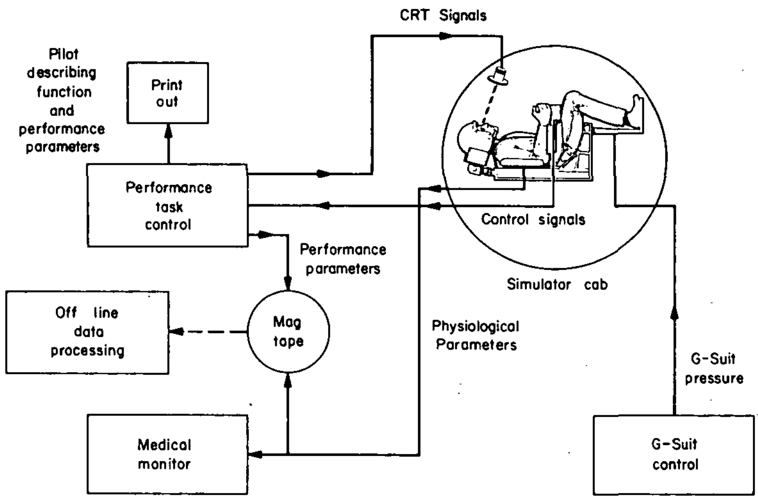

Figure 6.– Medical monitoring and data collection schematic.

EXPERIMENT PROCEDURES

Experiment Schedule

The experiment schedule consisted of a familiarization and training period; a control period during which the pre-bed rest control flights were made; the bed-rest period at the end of which the test flights were conducted; and, finally, an ambulatory recovery period.

To eliminate any within-subject diurnal variations, each subject was always tested at the same time each day. However, because of the long preparation time (especially during the bed rest centrifuge tests) and the length of the tests themselves (approximate 30 min), only two subject runs in the morning and two in the afternoon were conducted each day. The eight subjects were divided into two groups of four subjects each, and the test flights of the groups were on alternate days. The complete test schedule is shown in figure 7.

During the two weeks preceding the formal test, each subject made several visits to Ames to practice operating the performance-measuring tracking task. Then, during the first four days of the formal experiment period, these practice sessions were intensified to ensure that the subject was well trained in this task and no learning effects would later influence the data collected during the formal tests. On the fourth day, the subject underwent a practice centrifugation identical in all aspects to the later formal tests. He also observed runs of other subjects.

The pre-bed rest control tests were conducted on the sixth and eighth days. The use of G-suits during these tests depended on the subject's group – if the subject was in group I, he did not use a G-suit on the first control test (sixth day) but did on the second control test (eighth day); the reverse was true for the subjects in group II. The bed rest period started when the subject retired on his eighth day at Ames and continued for ten days. On the eighth and tenth days of the bed rest period, the subject was again exposed to the flight simulations, using a G-suit on the appropriate

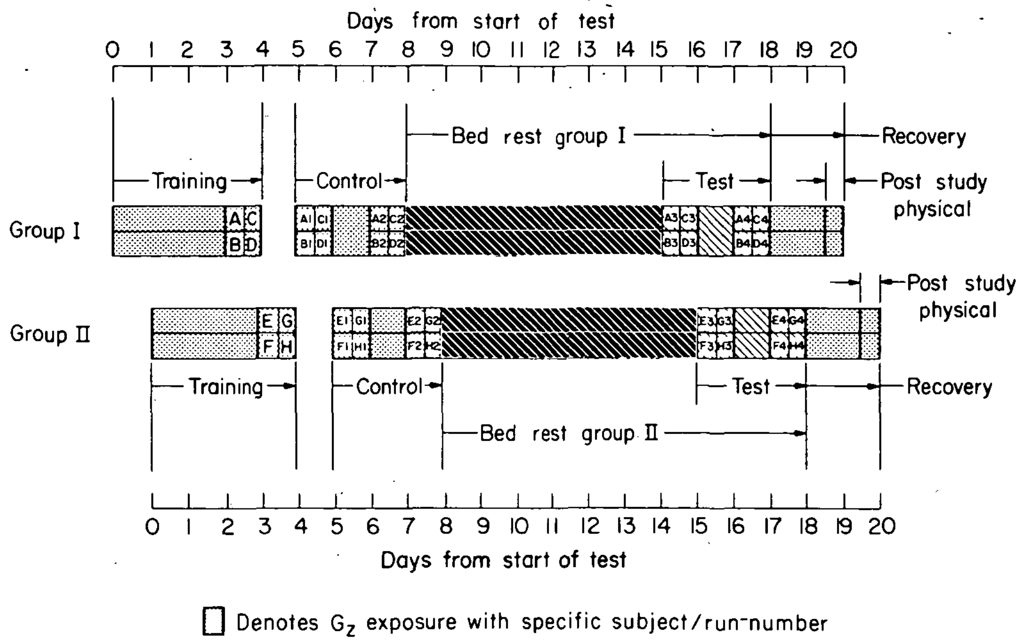

Figure 7.— Test schedule.

day for his group, and then returned to bed. After the test on the tenth day, the subject was returned to the Human Research Facility where, under medical supervision, he was allowed to get up from bed. The formal experiment was completed with a poststudy physical and release of the subject.

With this experiment schedule, each subject was tested at the same time each day and his tests were always two days apart.

Bed Rest Procedures

The purpose of the bed rest was to bring about a physiological deconditioning similar to that experienced by astronauts exposed to zero gravity. In order to achieve this, it was necessary to have the subjects remain in a completely supine position with movement of the head, torso, and legs restricted to the horizontal plane only. The subjects were directed to lie on their backs or stomachs and not to sit up or raise their legs. Each individual was given a standard-sized pillow for use under his head or knees, but otherwise no elevation or support was allowed. Eating, excretion, and other personal hygiene functions were performed with the subjects only raising their upper torso to the point of resting on their elbows.

In previous bed rest studies, the nature of the subjects' diet was controlled. This procedure was not followed in the current study for two reasons: (1) The diet of the actual Shuttle crews will surely be pleasant, palatable, and essentially unrestricted; and (2) the study subjects were confined to a very limited area in which meals became a major center of interest and played a very important role in maintaining high morale. Good morale, in turn, was essential if the subjects were to give their maximum effort in the control task. A daily accounting of each subject's caloric intake showed an overall average for the study of 2900 cal/day. The subjects carried out no exercise during the period of bed rest.

Flight Simulation

The test procedure started with a series of critical task performance measurements with the subject lying in the semisupine position. On completion of the critical task measurements, the two-axis tracking task was started. The acceleration profile was initiated 430 sec after the start of the test sequence. On completion of the acceleration profile, the subject was again tested with a series of critical task performance measurements before termination of the formal test. Thus, in addition to the 1124-sec simulated 2-G flight and the 1092-sec 3-G flight, 330-sec of testing before and at least 296 sec after the flight provided baseline measurements.

During the bed rest period, the subjects were transferred in a supine position on a gurney from the Human Research Facility to the flight simulator. At the simulator ready room they were lifted from the stretcher and placed in the centrifuge seat without disturbing their horizontal position. On completion of the tests, the subjects were lifted from the simulator seat and returned supine to their beds in the Human Research Facility.

The subjects were instructed to use whatever means they desired (e.g., grunt breathing, muscular contraction, etc.) to counter the effects of the acceleration during the test. All subjects had a light meal at least three hours prior to centrifugation.

Data Collection

During the entire test period, body weight, basal heart rate, blood pressure, respiration rate, and temperature were monitored daily. During the flight tests, continuous recordings were made of EKG; respiration profile; X, Y, Z accelerations; and G-suit pressures. Blood pressure measurements were made during each test segment – that is, preflight, max G, 1 G, and postflight. In addition, heart rate, respiration rate, X, Y, Z accelerations, and G-suit pressure were digitized at 2-sec intervals for later off-line data processing.

Performance measurement parameters were also recorded and are presented in Volume II (ref. 10).

PHYSIOLOGICAL RESULTS

Summary of Data

Figure 8 shows average daily (morning) weight and basal measurements of blood pressure, heart rate, respiration rate, oral temperature, and body weight.

Figures 9 and 10 show the mean (±SD) levels of acceleration attained during the 2-G tests and 3-G tests, respectively. Note that during the test specified as 2 G_z the actual mean z-axis acceleration achieved was 1.87 G_z and that during the test specified as 3 G_z the actual mean z-axis acceleration achieved was 2.91 G_z. Figures 11 and 12 show the mean (±SD) levels of G-suit pressurization during the 2-G and 3-G suited tests.

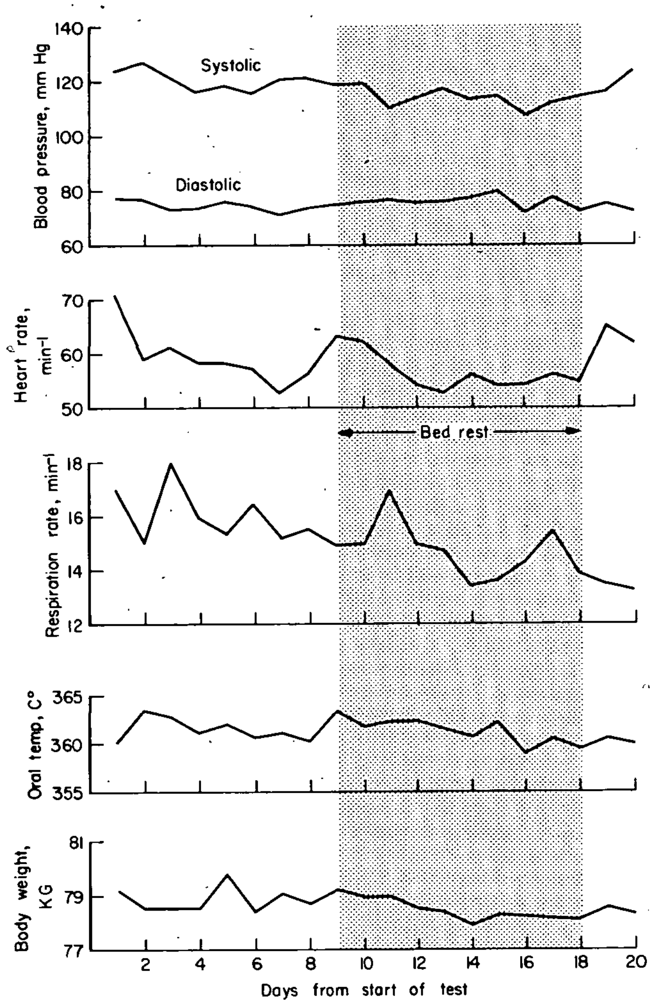

Figure 8.– Daily averages of physiological measurements.

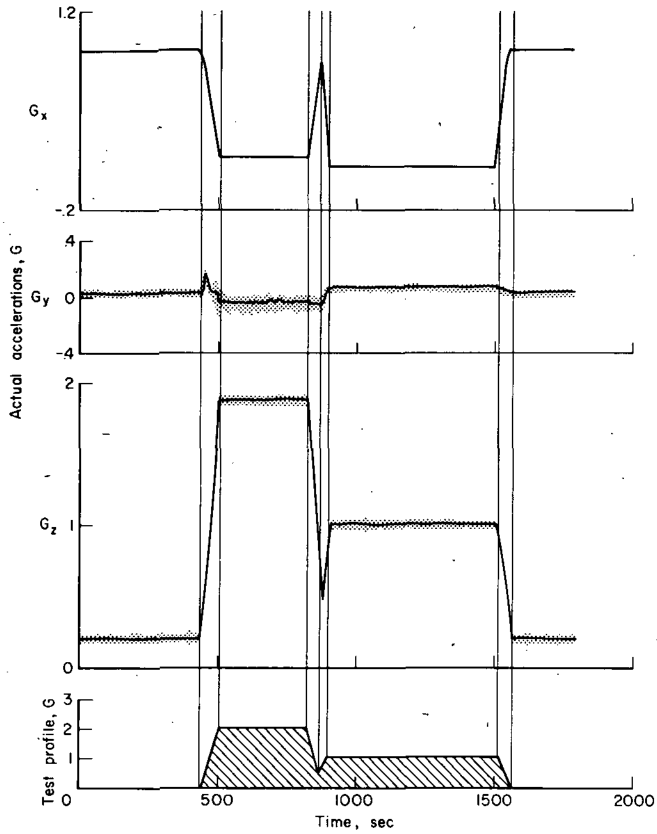

Figure 9.– 2 G_Z acceleration profile, mean (±SD).

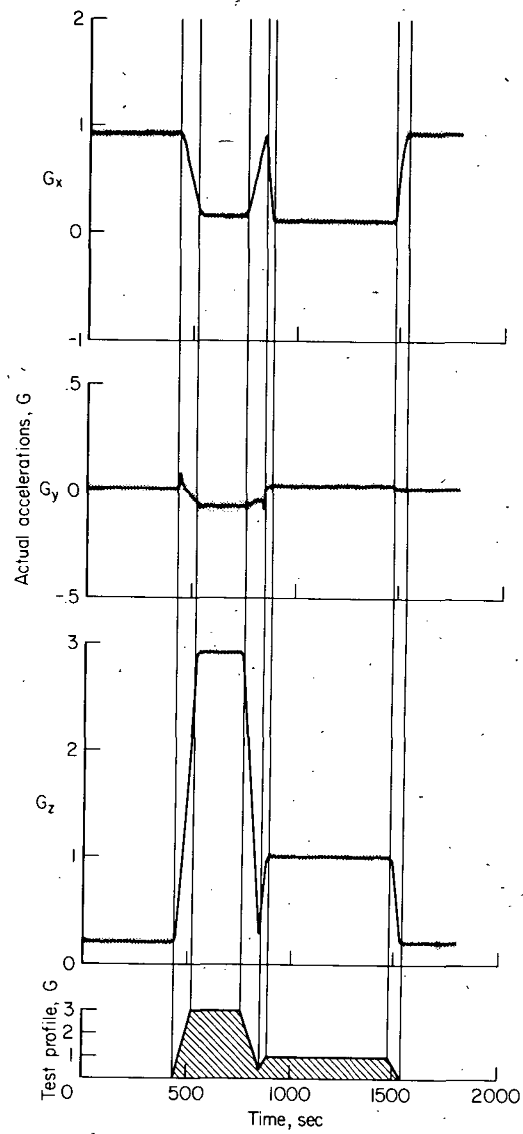

Figure 10.– 3 G_Z acceleration profile, mean (±SD).

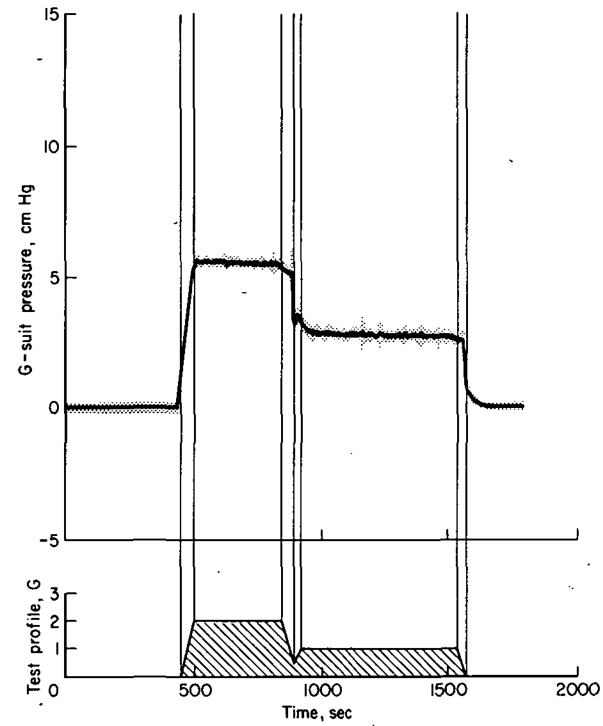

Figure 11.– 2 G_z G-suit pressure profile, mean (±SD).

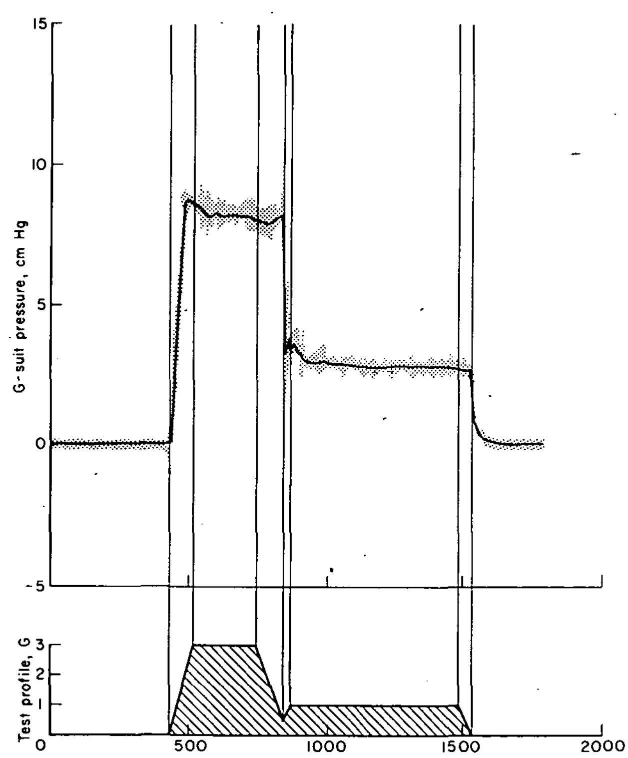

Figure 12.– 3 G_z G-suit pressure profile, mean (±SD).

In the remaining figures and tables as well as the analysis of variance, the data for heart rate, respiration rate, and blood pressures are presented as changes in values from the zero G_Z (preacceleration) levels. Using this (paired comparison) approach, each subject is treated as his own control, and variances among individuals are eliminated.

Figures 13 through 16 show the mean (±SD) levels of the changes in heart rate during the 2- and 3-G tests, pre- and post-bed rest, and with and without G-suits. Tables 4a–c present mean

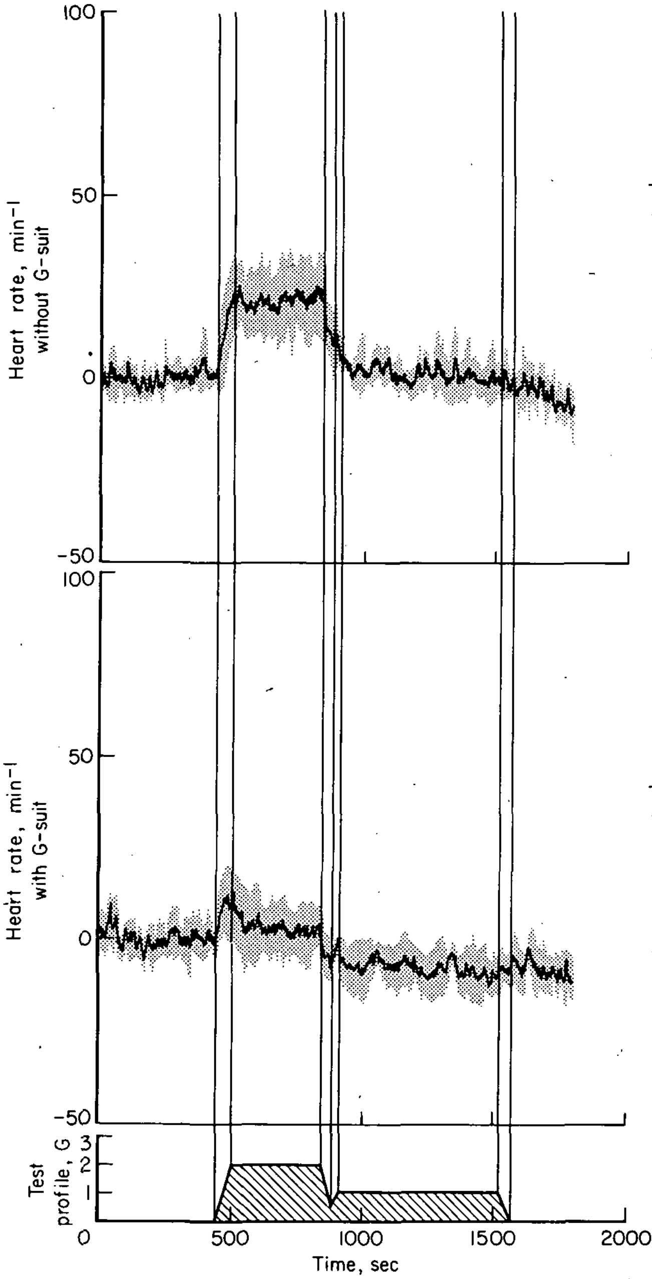

Figure 13.– 2 G_Z change in heart rate pre-bed rest mean (±SD).

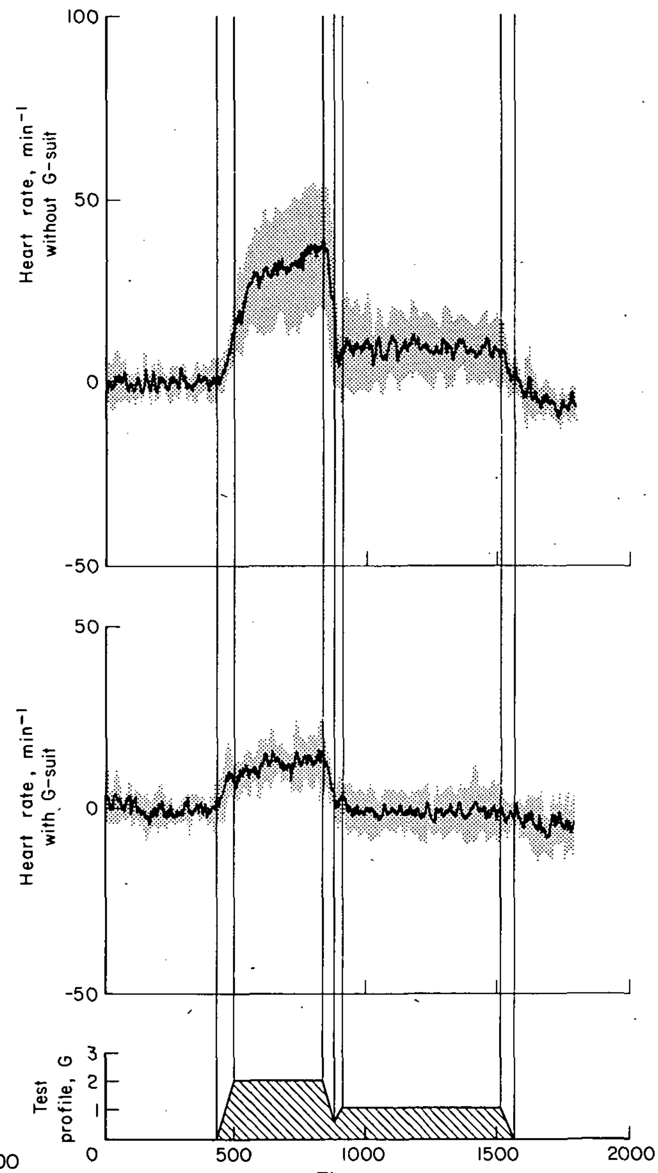

Figure 14.– 2 G_Z change in heart rate post-bed rest mean (±SD).

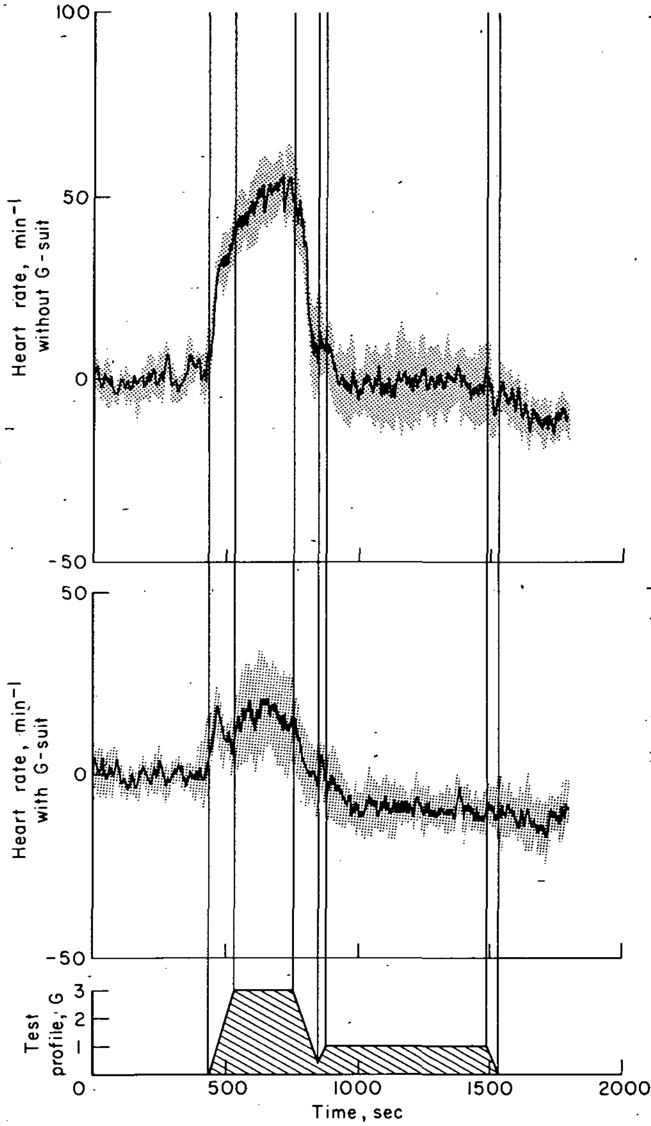

Figure 15.— 3 G_Z change in heart rate pre-bed rest mean (±SD).

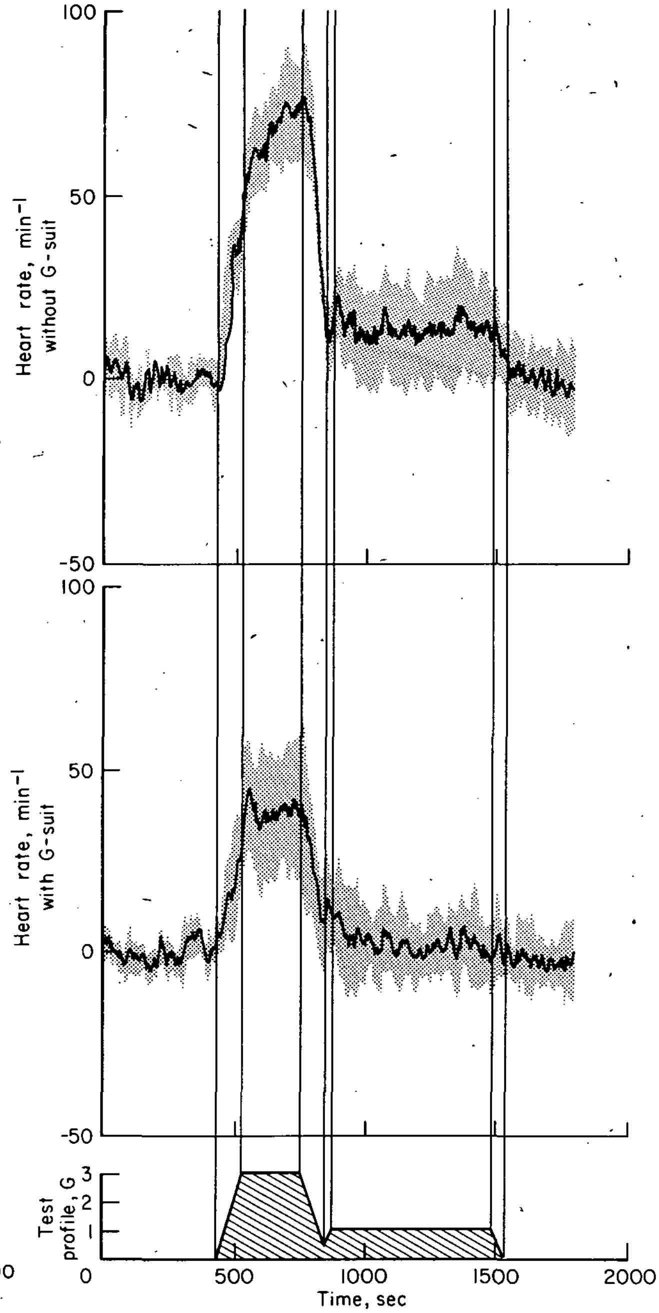

Figure 16.— 3 G_Z change in heart rate post-bed rest mean (±SD).

values of changes in heart rate, blood pressure, and respiration rate measured during specified portions of the flight profile for each experiment treatment. Individual data for heart rate, blood pressure, and respiration rate at selected times during the flight profile are listed in tables 5, 6, and 7.

Bed Rest Effects

A comparison of figures 13 and 14 and figures 15 and 16 shows that bed rest produced a marked increase in the mean heart rates occurring during the simulated flight. The analysis of variance (AOV) results (table 8), as summarized in the tabulation below, also support this conclusion. The levels of blood pressure and respiration rate measured during the simulated flight after bed rest were not significantly different from pre-bed rest levels.

Period of simulation profile	Average change in heart rate: Pre-bed rest	Average change in heart rate: Post-bed rest	Significant difference indicated at P =
Start of peak G	22.0	33.7	0.005
Mid-peak G	23.0	37.8	.001
End peak G	23.3	41.2	.001
Average peak G	22.8	37.4	.001
Start 1 G	−.5	9.0	.005
Mid 1 G	−4.1	4.9	.001
End 1 G	−6.2	5.4	.001
Average 1 G	−4	6.5	.001
Return to zero G	−7	−2	.01

G-Level Effects

Significant increases did occur in mean heart rate during the peak phase of the 3-G runs as compared to levels measured during the 2-G runs. However, these effects did not carry over to the landing portion of the flight: The mean heart rates during this period in the 3-G runs were not found to be statistically different from those in the 2-G runs. A possible exception is the mean heart rate at the start of the 1 G, which appeared to be different only if a very liberal value ($P = 0.1$) was taken for the AOV significance level. This probably indicates that the G-level effects had not quite disappeared and the heart rate returned to an equilibrium level by the start of the landing phase. However, the G-level effects on heart rate clearly did not last long beyond this point, because all subsequent heart rate differences are definitely not significant. These results are shown by a comparison of figures 13 and 15 and figures 14 and 16, and in the tabulation below.

Period of simulation profile	Average change in heart rate: 2 G_z peak	Average change in heart rate: 3 G_z peak	Significant difference indicated at P =
Start of peak G	15.4	40.3	0.001
Mid-peak G	16.7	44.1	.001
End peak G	19.4	45.1	.001
Average peak G	17.2	43.0	.001
Start 1 G	1.7	6.9	.1
Mid 1 G	.6	.2	Not significant
End 1 G	−.6	−.2	Not significant
Average 1 G	.6	1.9	Not significant
Return to zero G	−3.2	−5.6	Not significant

Both mean systolic and mean diastolic blood pressures measured during the peak-G phase showed significant increases with increasing accelerations (P = 0.01). The mean respiration rate also increased with increasing G level (P = 0.005).

G-Suit Effects

The use of G-suit resulted in a large decrease in the mean heart rate as can be seen in figures 13 through 16. This decrease is statistically significant in all the intervals analyzed as indicated in the tabulation. Note that in both pre- and post-bed rest 3-G tests and in the post-bed rest 2-G tests, when no G-suit was used, the mean heart rate did not reach an equilibrium level by the end of the peak G portion of the test run. However, in the same tests with G suits, the heart rates quickly reached equilibrium levels, and in the 2 G pre-bed rest test, the mean heart rates actually decreased during the G exposure.

Average change in heart rate

Period of simulation profile	No G-suit	G-suit	Significant difference indicated at P =
Start peak G	37.2	18.5	0.001
Mid peak G	42.4	18.5	.001
End peak G	47.1	17.4	.001
Average peak G	42.3	17.9	.001
Start 1 G	8.7	−.2	.005
Mid 1 G	5.6	−4.8	.001
End 1 G	4.9	−5.6	.001
Average 1 G	6.0	−3.6	.001
Return to zero G	−3.7	−5.2	Not significant

In general, the average heart rates were higher before bed rest without G-suits than they were after bed rest with G-suits (table 4a). If heart rate is directly related to cardiac stress, then the G-suits appear to have been successful in reducing increases in cardiac stress at peak G after bed rest to levels lower than the pre-bed rest no G-suit increases.

Subjective Comments

The pilot subjects were asked to relate their subjective feelings about the simulated flight and their ability to operate the two-axis control task both pre- and post-bed rest.

The subjects were unanimous in their opinion that the G_z levels imposed in the simulated flight profile would present no difficulty for experienced pilots, as they put it, "The ride was a piece of cake." All felt that they had no problems either before or after bed rest. However, several mentioned experiencing differing degrees of peripheral vision loss when they relaxed the muscles of their legs during the post-bed rest tests without G-suits. These individuals became aware of this incipient grayout through a loss of perception of the simulator cab lumination lights placed lateral to their heads. In each case, the subjects reported that readjusting muscle tension corrected vision tunneling without affecting either central vision or the tracking task. Nevertheless, these experiences resulted in a consistent agreement among the subject pilots that, while they felt this Shuttle flight would not be physically difficult, they would prefer to use G-suits; moreover, if they were to be passengers or secondary crew, they would insist that the pilot use a G-suit during reentry.

CONCLUSIONS

1. Unless special remedial measures are developed, the Shuttle crew can be expected to experience some physiological deconditioning as a result of exposure to periods as short as 8–10 days of zero-G.

2. This deconditioning was manifested by elevated pulse rates during reentry, and in some individuals by reduced peripheral vision which could be reversed by voluntary contraction of the leg muscles.

3. The use of anti-G-suits adequately reversed these deconditioning effects during reentry G profiles and should be considered for use by the Shuttle crew.

4. To the extent that the control tasks used in this study are representative in difficulty of those required for manual control of the Shuttle, there is no indication that zero-G deconditioning will affect the crew's ability to fly the Shuttle during reentry as long as vision is maintained.[1]

RECOMMENDATION

The use of anti-G-suits by the Shuttle crew is recommended because:

a. It is suspected that without anti-G-suits voluntary muscle contraction will be required to prevent loss of vision in a significant number of crew members. This is clearly undesirable.

b. If weightlessness is slightly more effective in producing deconditioning than bed rest, or if added physiological stresses (heat, dehydration, clinical illness, etc.) should be present during orbital flight, then the probability of partial or complete vision loss during reentry could be enhanced significantly.

c. It is possible that manual control during reentry could present a more stressing task under emergency conditions than was used in this experiment.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, June 6, 1974

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[1] A more complete description of the conclusions regarding the control task can be found in Volume II (ref. 10).

REFERENCES

1. Leverett, Jr., S. D.; Shubrooks, S. J.; and Shumate, W.: Some Effects of Space Shuttle $+G_z$ Reentry Profiles on Human Subjects. Presented at the Annual Sci. Mtg., Aerospace Med. Assoc., Houston, Texas, April 26-29, 1971.

2. Greenleaf, J. E.; van Beaumont, W.; Bernauer, E. M.; Haines, R. F.; Sandler, H.; Staley, R. W.; Young, H. L.; and Yusken, J. W.: Effects of Rehydration on $+G_z$ Tolerance After 14-Days Bed Rest. Aerospace Med., 44(7), pp. 715-722, 1973.

3. Larsen, W. E.; McFadden, N. M.; Sadoff, M.: Effects of Sustained Acceleration, Coriolis Acceleration and Bed Rest on Precision Psychomotor Control Performance. Presented at Annual Sci. Mtg., Aerospace Med. Assoc., May 5-8, 1969.

4. Taylor, H. L.; Henschel, A.; Brozek, J. and Keys, A.: Effects of Bed Rest on Cardiovascular Function and Work Performance. J. Applied Phys., 2(5), pp. 223-239, 1949.

5. Ryback, R. W.; Lewis, O. F.; and Lessard, C. S.: Psychobiologic Effects of Prolonged Bed Rest (Weightless) in Young, Healthy Volunteers (Study II). Aerospace Med., 42(5), pp. 529-535, 1971.

6. Miller, P. B.; Johnson, R. L.; and Lamb, L. E.: Effects of Four Weeks of Absolute Bed Rest on Circulatory Functions in Man. Aerospace Med., 35(12), pp. 1194-1200, 1964.

7. Jacobson, L. B.; Hyatt, K. H.; Sullivan, R. W.; Cantor, S. A.; Sandler, H.; Rositano, S. A.; and Mancini, R.: Evaluation of $+G_z$ Tolerance Following Simulated Weightlessness (Bedrest). NASA TM X-62,311, 1973.

8. Graves, C. A.; and Harpold, J. C.: Apollo Experience Report: Mission Planning for Apollo Entry, NASA TN D-6725, 1972.

9. Cochran, W. G.; and Cox, G. M.: Experimental Design, Second Ed., John Wiley and Sons, Inc., 1964.

10. Jex, H. R.; Peters, R. A.; DiMarco, R. J.; and Allen, R. W.: The Effect of Bedrest on Crew Performance During Simulated Shuttle Reentry. Vol. II: Control Task Performance. NASA CR 2367, 1974.

11. Berry, C. A.: Summary of Medical Experience in Apollo 7 through 11 Manned Spaceflights. Aerospace Med., 41(5), pp. 500-519, 1970.

12. Anonymous. Space Shuttle Program Aerodynamic Design Data Book, Vol. I. Orbiter Vehicle. Rep. SD 72-SH-0060-1 C, Space Division, Rockwell International, April 1973.

13. Grether, W. F.: Acceleration and Human Performance. Aerospace Med., 42(11), pp. 1157-1166, 1971.

TABLE 1.– SUMMARY OF DATA (ref. 13)

Author	Tests	Acceleration conditions	Major findings
(a) Visual functions as affected by acceleration			
Keighley *et al.* (1951)	Flicker Fusion Frequency	$+G_z$, up to 4.8 G	Up to 3.2 G no change. In range of 3.4 to 4.8 G small but significant reduction
Rogge (1968)	Relation Between Signal Luminance Level (0.2 to 100 ft-L) and Blackout G	$+G_z$, up to level needed to obtain blackout	Blackout G level essentially independent of luminance of central signal light
White (1960)	Absolute Visual Thresholds, Foveal and Peripheral	$+G_z$, up to 4 G with and without anti-G suit	Increase of threshold luminance with increasing G level (See fig. 1)
Braunstein and White (1962)	Brightness Discrimination at 0.03, 0.29, 2.9, and 31.2 ft-L	$+G_z$, up to 5 G $+G_x$, up to 7 G	Some increase in threshold contrast. Greatest effect for $+G_z$ and low luminance
Chambers (1963)	Brightness Discrimination at 0.03 ft-L	$+G_z$, up to 5 G with and without supplementary O_2	Increase in threshold contrast with increasing G. Effect reduced by supplementary O_2 (See fig. 2)
White and Jorve (1956)	Visual Acuity	$+G_z$, up to 5 G $-G_x$, up to 8 G	Decrease in acuity with increase in G. Similar effect for both $+G_z$ and $-G_x$ (See fig. 3)
White (1958)	Visual Acuity, Luminance Range 0.01 to 100 ft-L	$+G_z$, up to 4 G	Decrease in acuity with increase in G. Greatest effect at low luminance levels
Frankenhaeuser (1958)	Visual Acuity	$+G_z$, up to 3 G	Decrement in acuity at 3 G
Warrick and Lund (1946)	Dial Reading	$+G_z$, at 1-1/2 and 3 G	Increased reading errors at 3 G, no decrease in reading speed
White and Riley (1956)	Dial Reading, Luminance Range 0.04 to 42 mL	$+G_z$, up to 4 G	Decreased reading accuracy at 3 and 4 G. Greatest effect at low luminance
White (1962)	Dial Reading, Luminance Range 0.004 to 42 mL	$+G_z$, up to 4 G	Decreased reading accuracy at 4 G, and at 3 G for lowest luminance levels (See fig. 4)
(b) Reaction time as affected by acceleration			
Burmeister (1939)	Simple Visual Reaction Time	$+G_z$, at 3 and 4.5 G $+G_x$, at 4 and 8 G	Increase in reaction time at all increased G levels
Canfield *et al.* (1949)	Simple Visual and Auditory Reaction Time	$+G_z$, at 3 and 5 G	Increase in reaction time at all increased G levels
Canfield *et al.* (1950)	Choice Visual Reaction Time	$+G_z$, at 3 and 5 G	Small increases in reaction time disappeared as subjects became accustomed to increased G
Frankenhaeuser (1958)	Choice Visual Reaction Time	$+G_z$, at 3 G	Increased reaction time at 3 G

TABLE 1.– SUMMARY OF DATA – Concluded

Author	Tests	Acceleration conditions	Major findings
(b) Reaction time as affected by acceleration – Concluded			
Brown and Burke (1958)	Simple Visual Reaction Time, at 0.25 and 4560 m-L Central and Peripheral	$+G_z$, up to 4 G	Increased reaction time with increase in G. Greater effect at low luminance (See fig. 5)
(c) Reaching movements and manipulation tasks as affected by acceleration			
Canfield *et al.* (1953)	Ballistic Reach Movements, 5 in. Target, 19 in. Distance 4 Different Positions	$+G_z$, at 3 and 5 G	Errors and movement time increased with increase in G. Initial movements usually low, but rapid learning to compensate. After return to 1 G initial movements too high
Cohen (1970a and 1970b)	Response Grid at 55 cm and Hidden Behind Mirror in which Target is Visible	$+G_z$, at 1.5 and 2 G	At 2 G subjects initially reached below target, but learned to compensate. After G exposure reached above target. Initial reach below target did not appear at 1.5 G (See fig. 6)
Kaehler and Meehan (1960)	Operation of Toggle Switch, Push Button, Knob, Wheel and Lever	$+G_x$, up to 8 G $-G_x$, up to 4 G	Generally increased response time with increased G
Hill and Webb (1959)	Operation of D-Ring and Face Curtain Ejection Controls	$+G_z$, up to 6 G $+G_x$, up to 6 G $-G_x$, up to 5 G $\pm G_y$, up to 4 G, with various clothing, pressure suit, and seat configurations	Generally time to operate face curtain increased with G, except for $+G_x$. Operation of D-ring little affected by $+G_z$, but was impaired by $+G_x$, $-G_x$, and $\pm G_y$
Bryan *et al.* (1951)	Reaching to and Operating Toggle Switches in Five Locations	$+G_z$, at 2.5 & 4 G	Both reaction time and movement time increased with G. Greatest increase for switch requiring upward movement

TABLE 2.– EXPERIMENTAL DESIGN SHOWING SUBJECT RUN NUMBER

Bed rest condition	Maximum G-level	G-suit protection	Group I Time AM	Group I Time PM	Group II Time AM	Group II Time PM
Pre	2	Yes	A2	C2	E1	G1
		No	A1	C1	E2	G2
	3	Yes	B2	D2	F1	H1
		No	B1	D1	F2	H2
Post	2	Yes	A4	C4	E3	G3
		No	A3	C3	E4	G4
	3	Yes	B4	D4	F3	H3
		No	B3	D3	F4	H4

TABLE 3.– PHYSICAL CHARACTERISTICS AND FLIGHT EXPERIENCE OF THE TEST SUBJECTS

Subject	Age, yr	Height, cm (in.)	Weight, kg (lb)	Flight time, hr	Type of aircraft	Type of current FAA rating
A	29	182 (71-1/2)	71.8 (158)	1500	A-4,A-7	instrument
B	30	173 (68-1/4)	79.3 (174)	1400	A-7,A-4,F-8	commercial, instrument, flight engineer (Turbojet)
C	33	173 (68)	73.0 (161)	2900	A-4,A-7	MEL, commercial, instrument
D	25	190 (75)	83.5 (184)	1050	A-4,A-7	commercial, instrument
E	29	180 (71)	96.8 (213)	1700	A-7	flight instructor, MEL, commercial, instrument
F	28	177 (69-1/2)	76.0 (165)	1500	F-4,A-4,A-7	commercial, instrument
G	29	173 (68)	81.6 (180)	1450	A-4,A-7	flight instructor, MEL, instrument
H	25	171 (67-1/2)	75.9 (167)	850	A-7	commercial, instrument

TABLE 4.– TEST RESULTS DURING SPECIFIED PORTION OF FLIGHT SIMULATION

(a) Changes in average heart rate (min^{-1})

Bed rest condition	Maximum G-level	G-suit protection	Peak G				One G				Post G
			Beginning	Mid	End	Avg.	Beginning	Mid	End	Avg.	
Pre	2	Yes	6.5	2.8	2.3	3.5	−6.5	−7.8	−9.8	−7.8	−3.0
		No	22.0	18.8	23.3	21.8	3.3	1.3	−.3	1.3	−3.5
	3	Yes	16.0	20.3	13.5	16.8	−2.5	−9.3	−11.3	−8.5	−12.0
		No	43.5	50.3	54.0	49.3	3.8	−.8	−3.3	−1.0	−9.3
Post	2	Yes	10.5	13.3	14.5	12.5	.0	−1.5	−1.0	−.8	−3.5
		No	22.5	32.0	37.3	31.0	10.0	10.3	8.8	9.5	−3.0
	3	Yes	41.0	37.5	39.3	39.0	8.3	−.8	−.5	2.8	−2.3
		No	60.8	68.5	73.8	67.0	17.8	11.8	14.3	14.3	1.0

(b) Changes in average respiration rate (min^{-1})

Bed rest condition	Maximum G-level	G-suit protection	Peak G	One G	Post G
Pre	2	Yes	1.75	−.4	0.05
		No	.4	−1.05	−.25
	3	Yes	5.15	2.23	2.25
		No	2.83	−1.3	−.68
Post	2	Yes	−1.1	−1.37[a]	−1.13[a]
		No	−.45	−1.5	.08
	3	Yes	2.6[b]	1.1[b]	1.75[b]
		No	5.45	.93	−.1

(c) Changes in average blood pressure (mm Hg/mm Hg)

Bed rest condition	Maximum G-level	G-suit protection	Peak G	One G	Post G
Pre	2	Yes	30.8/21.8	2.0/5.2	−6.3/−4.3[a]
		No	17.0/23.9	2.0/11.0	1.7/−3.0[a]
	3	Yes	31.3/31.8	7.8/8.5	---
		No	30.9/32.3	0/18[c]	−7/−4[c]
Post	2	Yes	34.5/24.3	−8.5/1.5[b]	−6.6/−.75
		No	24.5/24.54	−3.5/−3.2	−5.7/−3[a]
	3	Yes	44.8/41.8	---	5.25/4.75
		No	43.5/42.3	−5.92/−3.44	−10.3/5.0

[a]Average includes data on only 3 subjects.
[b]Average includes data on only 2 subjects.
[c]Average includes data on single subject only.

TABLE 5.– INDIVIDUAL AVERAGE HEART RATE VALUES DURING SPECIFIED PORTION OF FLIGHT SIMULATION (MIN^{-1})

Subject run number	Pre-G	Start G	Mid G	End G	Avg. peak G	Start 1 G	Mid 1 G	End 1 G	Avg. 1 G	Post G
A1	63	91	91	97	96	68	66	65	67	60
A2	78	79	70	74	72	65	64	61	63	68
A3	67	103	121	128	119	95	90	89	90	67
A4	65	71	77	84	78	57	55	56	57	57
B1	90	132	131	131	132	98	90	86	89	78
B2	85	91	98	93	93	88	75	74	75	72
B3	95	143	151	153	148	106	93	92	94	86
B4	74	120	112	102	111	78	69	66	71	69
C1	58	68	70	77	70	61	60	63	61	57
C2	57	65	64	59	62	56	54	53	54	53
C3	58	71	80	82	76	62	62	61	62	56
C4	56	63	66	72	68	60	58	61	58	54
D1	90	135	148	151	144	84	80	79	82	78
D2	84	101	98	87	97	71	73	71	71	71
D3	89	157	168	161	163	105	108	107	108	92
D4	66	102	104	108	105	71	69	68	70	68
E1	72	92	78	81	82	63	64	63	65	65
E2	70	96	85	90	90	73	67	63	67	65
E3	61	76	78	76	75	61	60	57	61	55
E4	68	87	95	103	97	70	73	73	73	63
F1	71	84	85	82	84	65	65	62	64	63
F2	67	105	116	128	115	71	62	61	63	58
F3	72	99	89	97	95	72	64	69	68	65
F4	63	122	135	149	133	77	73	75	74	62
G1	80	78	86	82	84	77	74	71	74	70
G2	71	95	91	91	92	74	75	71	73	67
G3	70	84	83	77	80	73	74	74	74	72
G4	75	96	100	104	99	80	83	81	82	70
H1	89	118	130	121	122	95	80	77	85	75
H2	69	119	123	122	121	77	80	77	79	66
H3	71	127	128	133	129	96	80	80	86	73
H4	60	129	129	140	133	92	81	89	87	70

TABLE 6.– INDIVIDUAL AVERAGE RESPIRATION RATE VALUES DURING SPECIFIED PORTION OF FLIGHT SIMULATION (MIN^{-1})

Subject run number	Pre-G	Peak G	1 G	Post G
A1	18.7	20	19.3	16.8
A2	19.2	20	20.5	21
A3	18.8	15.9	16.4	19.2
A4	19.4	16.5	17.1	18.3
B1	18	21.8	16	15.
B2	15.2	19.5	16.7	11.8
B3	16	20.2	15.5	16.5
B4	---	---	---	---
C1	20	18	16	19
C2	20.3	22.2	18.8	20
C3	18.6	20.2	17.8	18.3
C4	19.2	13.5	17.3	17.8
D1	19.7	21.5	19.2	19.3
D2	18.2	20.5	18.5	18.3
D3	17.6	20.7	16.8	18.6
D4	16.6	21.3	17.7	16.9
E1	19.7	23	19	20.5
E2	20.7	21.3	19.2	20.5
E3	19.4	21.2	19.5	18.5
E4	20.6	21	19.9	20.2
F1	18.3	22.5	16.3	17
F2	17.5	22.5	15	12.8
F3	16	---	---	---
F4	15	26.8	20.2	13.8
G1	24.3	25.3	23.7	21.8
G2	22.9	23.6	22.4	25
G3	21.9	24.5	---	---
G4	24.4	23.5	22.3	25
H1	7.7	17.5	16.8	21.3
H2	12.6	13.3	12.4	18
H3	17.8	18.3	18.9	21
H4	9.7	12.4	9.5	9

TABLE 7.– INDIVIDUAL AVERAGE BLOOD PRESSURE VALUES (SYSTOLIC/DIASTOLIC) DURING SPECIFIED PORTION OF FLIGHT SIMULATION (mmHg/mmHg)

Subject run number	Pre-G	Peak G	1 G	Post G
A1	122/65	140/98	130/80	---
A2	125/69	160/90	135/75	110/55
A3	120/69	165/90	98/62	---
A4	130/80	150/85	120/80	120/75
B1	155/77	175/115	155/95	---
B2	126/83	185/135	140/100	---
B3	153/78	210/130	130/105	135/80
B4	132/80	175/120	---	130/82
C1	127/80	120/85	120/85	135/80
C2	126/79	140/97	120/75	135/75
C3	112/72	110/80	95/60	90/60
C4	117/72	135/95	110/75	115/70
D1	115/85	---	---	---
D2	102/67	135/100	97/67	---
D3	113/69	150/100	115/80	105/77
D4	95/68	120/100	---	97/70
E1	138/80	165/115	135/93	125/85
E2	125/77	155/105	130/90	120/70
E3	113/72	170/120	---	110/80
E4	120/77	160/100	130/85	120/80
F1	125/85	175/110	140/95	---
F2	112/84	160/120	---	105/80
F3	112/80	160/110	---	115/85
F4	125/85	160/105	105/80	---
G1	115/87	162/100	122/92	---
G2	98/62	125/100	---	100/60
G3	107/69	150/90	---	85/65
G4	115/70	130/90	120/70	120/70
H1	128/85	170/118	135/95	---
H2	112/62	130/85	---	---
H3	112/65	175/130	---	120/75
H4	115/60	160/105	105/70	110/65

TABLE 8.– ANALYSIS OF VARIANCE (Compared with Zero G_z – pre-acceleration phase)

	Source of variation																Total
	S	G	SG	B	SB	GB	SGB	R	SR	GR	SGR	BR	SBR	GBR	SGBR	Error	
(a) Change in heart rate during beginning peak G_z																	
Sums of Squares	2793.78125	4975.03125	195.03125	1092.78125	63.28125	712.53125	9.03125	225.09375	70.09375	614.34375	463.34375	103.59375	141.09375	18.34375	166.84375	1577.65625	11644.21875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	2793.78125	4975.03125	195.03125	1092.78125	63.28125	712.53125	9.03125	75.03125	23.36458	204.78125	154.44791	34.53125	47.03125	6.11458	55.61458	75.12648	---
F	37.18770	66.22206	2.59604	14.54589	0.84233	9.48442	0.12021	0.99873	---	---	---	---	---	---	---	---	---
(b) Change in heart rate during mid peak G_z																	
Sums of Squares	4584.03125	6022.53125	344.53125	1755.26125	7.03125	69.03125	1.53125	308.59375	367.84375	689.84375	974.84375	131.59375	54.84375	130.34375	85.84375	2455.15625	15547.71875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	4584.03125	6022.53125	344.53125	1755.28125	7.03125	69.03125	1.53125	102.86458	129.28125	229.94791	324.94775	43.86458	18.28125	43.44791	28.61458	116.91220	---
F	39.20917	51.51328	2.94692	15.01367	0.06014	0.59045	0.01310	0.87984	---	---	---	---	---	---	---	---	---
(c) Change in heart rate during end peak G_z																	
Sums of Squares	7050.78125	5330.28125	488.28125	2674.03125	9.03125	185.28125	30.03125	140.34375	363.09375	1297.09375	837.09375	47.34375	212.34375	234.59375	27.84375	3019.40625	18827.46875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	7050.78125	5330.28125	483.28125	2674.03125	9.03125	185.28125	30.03125	46.78125	121.03125	432.36450	279.03125	15.78125	70.78125	78.19791	9.28125	143.78125	---
F	49.03824	37.07214	3.39600	17.90240	0.06281	1.28863	0.20887	0.32536	---	---	---	---	---	---	---	---	---
(d) Average change in heart rate during peak G_z																	
Sums of Squares	4728.78125	5330.28125	282.03125	1696.53125	9.03125	236.53125	11.28125	198.59375	255.09375	869.59375	725.84375	70.84375	87.34375	102.84375	46.09375	2157.65625	14650.71875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	4728.78125	5330.28125	282.03125	1696.53125	9.03125	236.53125	11.28125	66.19791	85.03125	289.86450	241.94791	23.61458	29.11458	34.28125	15.36458	102.74553	---
F	46.02420	51.87846	2.74495	16.51196	0.08790	2.30211	0.10980	0.64429	---	---	---	---	---	---	---	---	---
(e) Change in heart rate during beginning 1 G_z																	
Sums of Squares	630.12500	210.12500	8.00000	722.00000	6.12500	66.12500	4.50000	413.50000	171.37500	322.37500	245.50000	54.50000	33.37500	303.37500	69.00000	1199.50000	3260.00000
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	630.12500	210.12500	8.00000	722.00000	6.12500	66.12500	4.50000	137.83333	57.12500	107.45833	81.83333	18.16666	11.12500	101.12500	23.00000	57.11903	---
F	11.03179	3.67872	0.14006	12.64027	0.10723	1.15767	0.07878	2.41309	---	---	---	---	---	---	---	---	---
(f) Change in heart rate during mid 1 G_z																	
Sums of Squares	871.53125	0.78125	0.03125	657.03125	22.78125	16.53125	0.78125	257.34375	118.09375	82.34375	225.09375	41.09375	79.34375	225.09375	141.84375	912.90625	2739.71875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	871.53125	0.78125	0.03125	657.03125	22.78125	16.53125	0.78125	85.78125	39.36458	27.44791	75.03125	13.69792	26.44791	75.03125	47.28125	43.47173	---
F	20.04822	0.01797	0.00072	15.11399	0.52405	0.38028	0.01797	1.97326	---	---	---	---	---	---	---	---	---
(g) Change in heart rate during end 1 G_z																	
Sums of Squares	882.00000	1.12500	6.12500	1058.00000	24.50000	55.12500	21.12500	300.50000	91.00000	241.37500	294.37500	63.00000	42.50000	262.37500	90.37500	1085.00000	3433.50000
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	882.00000	1.12500	6.12500	1058.00000	24.50000	55.12500	21.12500	100.16666	30.33333	80.45833	98.12500	21.00000	14.16667	87.45833	30.12500	51.66666	---
F	17.07097	0.02177	0.11855	20.47742	0.47419	1.06694	0.40887	1.93871	---	---	---	---	---	---	---	---	---

Note: S = Use of G-suits; G = max G_z level; B = bed rest; and R = replicates.

TABLE 8.– ANALYSIS OF VARIANCE (Compared with Zero G_z – pre-acceleration phase) – Concluded.

	Source of variation																Total
	S	G	SG	B	SB	GB	SGB	R	SR	GR	SGR	BR	SBR	GBR	SGBR	Error	
(h) Average change in heart rate during 1 G_z																	
Sums of Squares	731.53125	13.78125	0.03125	871.53125	13.78125	63.28125	3.78125	365.59375	86.59375	243.34375	265.09375	38.59375	27.34375	262.84375	80.34375	1004.15625	3067.46875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	731.53125	13.78125	0.03125	871.53125	13.78125	63.28125	3.78125	121.86458	28.86458	81.11458	88.36458	12.86458	9.11458	87.61458	26.78125	47.81696	---
F	15.29857	0.28821	0.00065	18.22639	0.28821	1.32341	0.07908	2.54856	---	---	---	---	---	---	---	---	---
(i) Change in heart rate post flight (post simulation zero G_z)																	
Sums of Squares	18.00000	45.12500	18.00000	200.00000	1.12500	200.00000	0.12500	221.12500	15.75000	18.12500	232.75000	33.75000	6.12500	110.75000	29.12500	446.37500	1149.87500
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	21	31
Mean Squares	18.00000	45.12500	18.00000	200.00000	1.12500	200.00000	0.12500	73.70833	5.25000	6.04167	77.58333	11.25000	2.04167	36.91666	9.70833	21.25595	---
F	0.84682	2.12293	0.84682	9.40913	0.05293	9.40913	0.00588	3.46766	---	---	---	---	---	---	---	—	---
(j) Average change in respiration rate during peak G_z																	
Sums of Squares	0.55125	130.24957	0.49005	3.82261	23.70155	8.10029	3.06280	43.34915	15.68540	6.76166	21.41431	17.83957	4.63055	22.02661	46.16847	134.52657	347.85327
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	19	29
Mean Squares	0.55125	130.24957	0.49005	3.82261	23.70155	8.10029	3.06280	14.44972	5.22847	2.25389	7.13810	5.94652	1.54352	7.34220	15.38949	6.40603	---
F	0.08605	20.33234	0.07650	0.59672	3.69988	1.26448	0.47811	2.25564	---	---	---	---	---	---	---	---	---
(k) Average change in systolic blood pressure during peak G_z																	
Sums of Squares	1152.00000	1275.12500	0.50000	465.12500	338.00000	36.12500	162.00000	3448.62500	393.75000	203.62500	212.25000	5.12500	1131.25000	896.12500	68.25000	2910.37500	9787.87500
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	20	30
Mean Squares	1152.00000	1275.12500	0.50000	465.12500	338.00000	36.12500	162.00000	1149.54150	131.25000	67.87500	70.75000	1.70833	377.08325	298.70825	22.75000	138.58928	—
F	8.31233	9.20075	0.00361	3.35614	2.43886	0.26066	1.16892	8.29459	---	---	---	---	---	---	---	---	---
(l) Average change in diastolic blood pressure during peak G_z																	
Sums of Squares	94.53125	1471.53125	34.03125	30.03125	38.28125	185.28125	69.03125	660.59375	318.09375	1049.09375	652.09375	329.59375	449.84375	484.84375	48.59375	3332.15625	5915.46875
Degrees of Freedom	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	20	30
Mean Squares	94.53125	1471.53125	34.03125	30.03125	38.28125	185.28125	69.03125	220.19791	106.03125	349.69775	217.36458	109.86458	149.94791	161.61458	16.19791	158.67410	—
F	0.59576	9.27392	0.21447	0.18926	0.24126	1.16768	0.43505	1.38774	---	---	---	---	---	---	---	---	—

Note: S = Use of G-suits; G = max G_z level; B = bed rest; and R = replicates.

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