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A PRELIMINARY REPORT OF HUMAN RESPONSE TO REARWARD-FACING RE-ENTRY ACCELERATIONS

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JULY 1959

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
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Project 7222
Task 71746

WRIGHT AIR DEVELOPMENT CENTER
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UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

2,[illegible] – November 1959 – [illegible]

FOREWORD

The experiments described in this report were conducted at the request of the Space Task Group of the National Aeronautics and Space Administration, under Project 7222, Task 71746, "Acceleration in Flight." They were designed to supply a basis for comparison of a rigid contoured support and a lightweight, flexible net support.

The authors are indebted to Wing Commander John I. R. Bowring, RAF, and 1/Lt. William Elkins of the Aircraft Laboratory, designers of the net seat, for their enthusiastic and invaluable collaboration in this study.

Tidal volume, electrocardiographic changes, tracking performance ability, and subjective response were evaluated during an acceleration profile designed to encompass several possible rearward-facing re-entry patterns. A maximum acceleration of 16.5 g and a total time of 170 seconds were employed. Subjects faced the center of rotation with the trunk and head inclined 12° in the direction of the centrifuge axis. The subjects were supported with a contoured net system. Two of seven subjects repeated the experiments wearing the MC-2 full pressure suit, both pressurized and unpressurized.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Andres I. Karstens

ANDRES I. KARSTENS
Colonel, USAF (MC)
Asst. Chief, Aero Medical Laboratory

INTRODUCTION

The NASA program for manned space flight has made necessary the evaluation of human tolerance and performance capability during accelerations expected in re-entry of a non-lift body from orbit. Several g-time profiles are possible depending upon the velocity of re-entry (1). The present concept of the first man-in-space capsule involves a method of rotating the seated, forward-facing man through 180° during the orbital phase so that he experiences the resultant inertial force from acceleration in the same direction during both boost and re-entry.

It is apparent that the basic design of the support-restraint system will be a major factor in determining not only physiological tolerance but man's functional ability during the acceleration phases of space flight. Consideration has been given to the principle of net support for these accelerations both by WADC and by several organizations in industry (2). The obvious advantages in weight and comfort have already been established (3). The principle to be described allows use of the full pressure suit, either inflated or uninflated, without modification of the support system. The purpose of this paper is to report the results of preliminary experiments which explore the problem of human response to the accelerations predicted during the NASA re-entry profiles using this system of support. The acceleration profile studied employed a duration and maximum g which was in excess of the several estimated re-entry patterns submitted by NASA.

METHODS

The experiments were conducted in the free-swinging cab of the WADC human centrifuge. The subjects faced the center of rotation with their thorax 21 feet from the centrifuge axis. The support system used is shown in Figure 1 and was developed in the Crew Station Design Section of the Aircraft Laboratory. This particular seat was designed to determine the contour required for maximum body support during acceleration using a reschel nylon mesh under moderate tension as the support. The headrest was made of variable density slow recovery foam. A rigid "cross body" arm rest was employed. The seat's back angle and overall contour were adjustable. Preliminary studies have suggested that the position shown in Figure 1 is one which offers good overall body support and that this degree of body angulation is one which appears to strike an adequate compromise between the cardiovascular and respiratory limitations associated with higher accelerations. In this position the head and trunk are inclined in the direction of the acceleration vector by an angle of approximately 12°, depending on the amount of displacement of the body downward in the nylon net. For example, a 175-pound, 74-inch man increases this angle by 5° at 12 g forward acceleration. The angle obtained during acceleration varied between 11° 30' and 13° 30' in the subject panel used in these experiments. The thighs and trunk form an

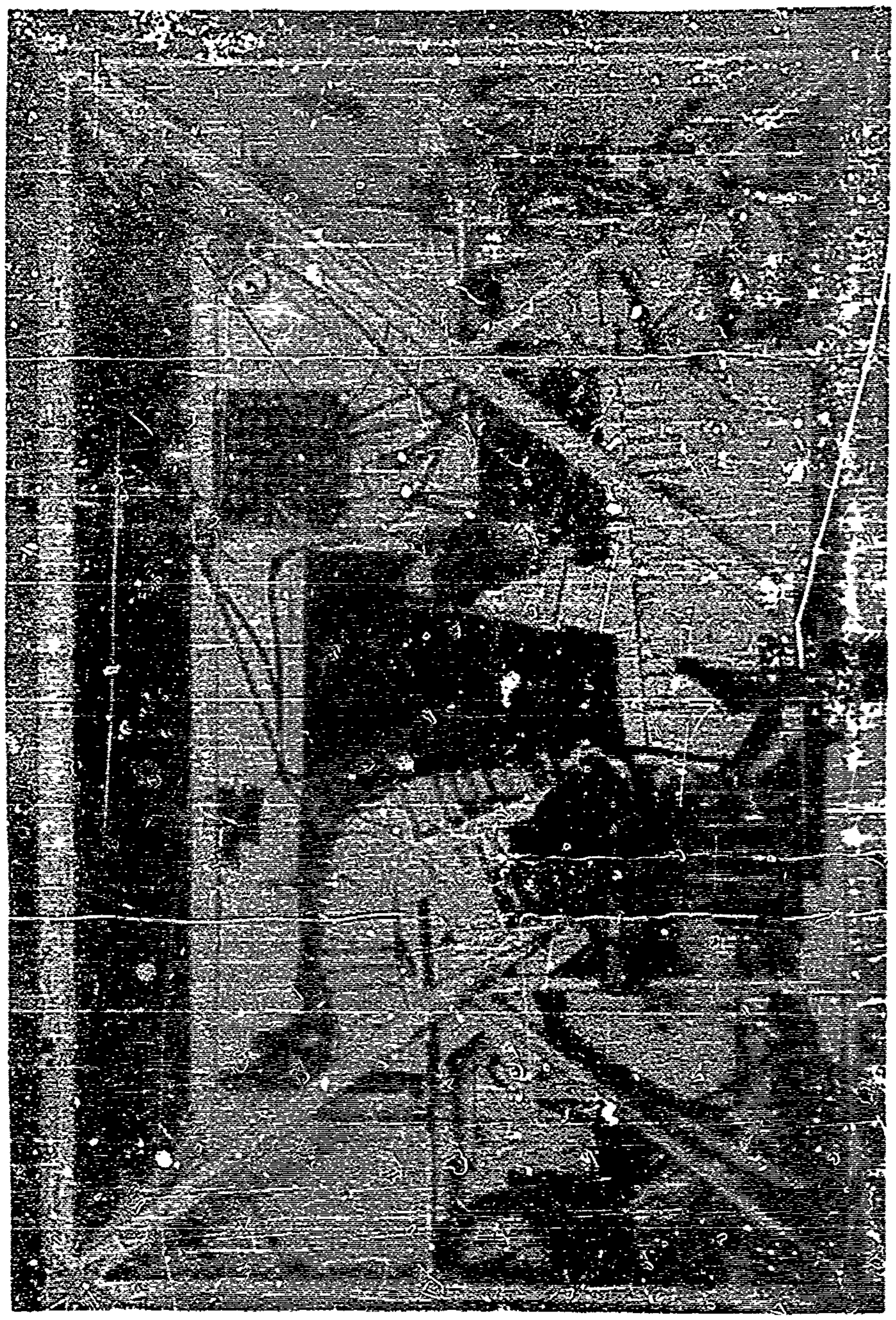

FIGURE 1 - Subject Positioned in Net Support System

included angle of 100° and the angle at the knees is approximately 100°. The studies conducted with this seat are the basis for design of a lightweight tubular titanium and dacron mesh system currently under construction in the Aircraft Laboratory.

The acceleration profile which was tested is shown in Figure 2. Basically, the curve involves two rates of onset, viz., the subject is accelerated at a rate of 0.14 g/second to 8.5 g, then to 16.5 g at 0.32 g/second. The decay of acceleration is a mirror image of the onset. The total time of acceleration is 170 seconds. The subject is above 8.5 g for 50 seconds. The area under the curve represents a change in velocity of approximately 24,500 miles per hour. This profile was chosen because it envelopes the several calculated re-entry profiles submitted by NASA.

Velocity of air flow was measured continuously with a low resistance wire mesh pneumotachygraph and a 0.5 psi differential transducer. Tidal volumes were determined by planimetry from the respiratory curves recorded. Electrocardiographic tracings were recorded throughout each centrifugation using a modification of Lead II

During experiments with the pressurized MC-2 suit, absolute helmet pressure and helment-suit differential pressure were also measured using Statham strain gage differential transducers.

Estimates of performance were made through the use of a dual pursuit tracking task which had been previously standardized (4). The task consisted of an Instrument Landing System indicator mounted 77 cm directly in front of the subject's eyes. It was connected to an oscillator which gave full-scale deflection of both needles every 20 seconds. The needles did not cross the center target area at the same time. The ILS indicator was illuminated with a source of white light which gave 10 foot lamberts reflected luminance. The subjects were instructed to attempt to keep both needles on a circular target area 3.5 mm in diameter in the center of the indicator with a control mounted on the arm support. The two dimensional control was adjustable for arm lengths of the different subjects. It was a small knob which could be moved through full scale (15 mm top to bottom and 12 mm side to side) with only finger and wrist movements. Its sensitivity was such that one millimeter movement of the control caused a 2.5 mm deflection of the indicator needles. Each needle moved 15 mm on either side of the center of the indicator during full-scale deflection. Performance was remotely recorded as percent time off target. During the experiment, while acceleration was constantly changing, the entire display was recorded using motion picture cameras. This allows analysis of tracking performance ability as an instantaneous function of acceleration. Furthermore, the film record includes a measure of the distance off target of each needle so that the degree of error as well as absolute error can be assessed.

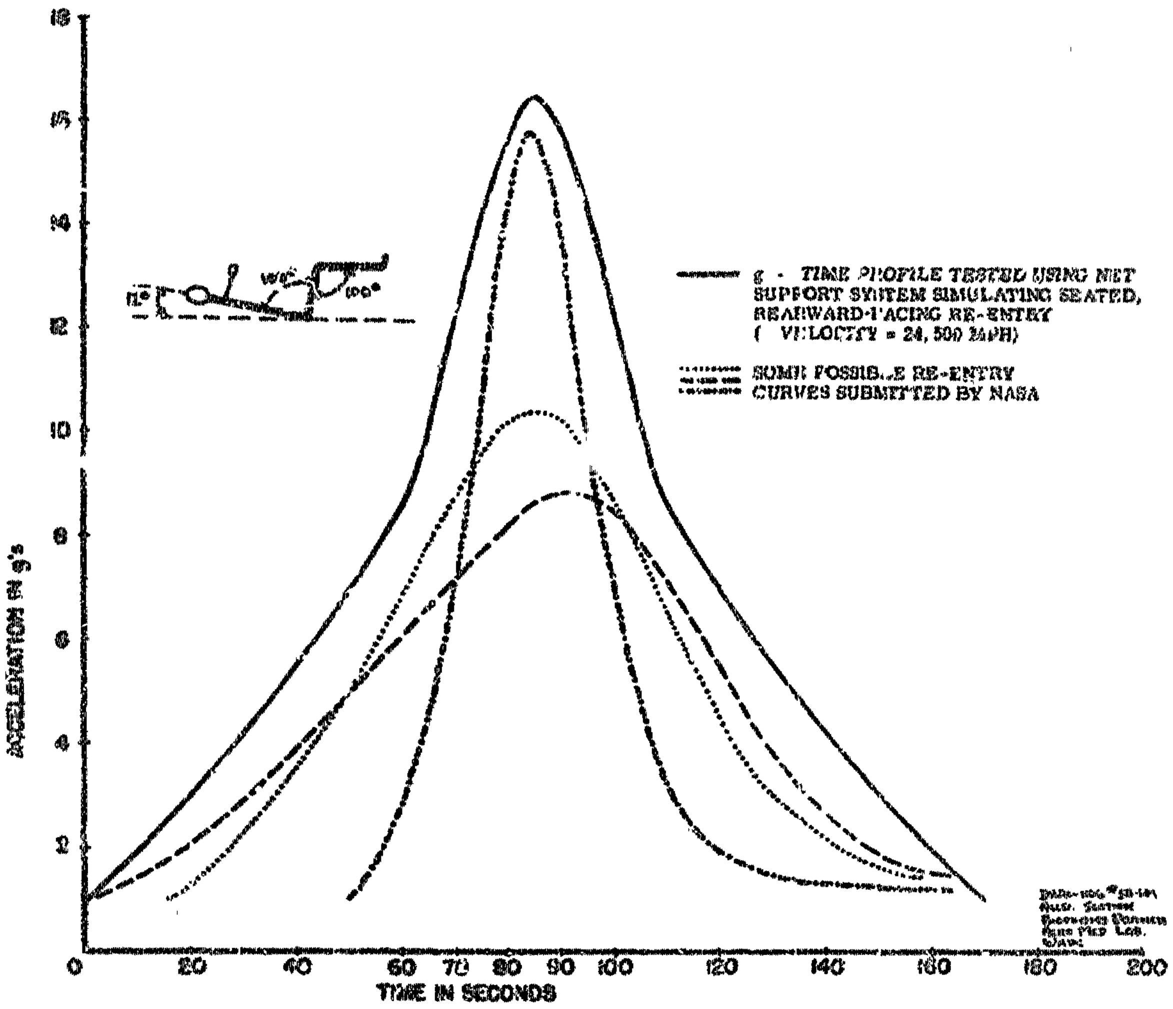

FIGURE 2 - Re-Entry Acceleration Profiles

In addition to this task, the subjects were required to repeatedly respond to a center light (77 cm eye to light distance, luminance in excess of 10,000 foot lamberts, white light) by squeezing a trigger-grip switch to extinguish it within 3 seconds after the light was turned on by the central observer. The subjects were told to give the center light priority over the tracking task and it was assumed that they were at blackout when they failed to answer the light.

Another switch located above the trigger was connected to the power supply of the centrifuge and allowed the subject to terminate the experiment at any time during the acceleration that blackout, severe dyspnea, chest pain, or any other symptom associated with loss of a critical faculty appeared.

The subjects practiced tracking at one g until their performance reached an apparent plateau. They were then given several practice sessions at low and intermediate accelerations prior to the actual experiments.

These experiments involved seven young adult male subjects. Six were experienced centrifuge riders, the other was given two indoctrination sessions at low acceleration prior to beginning the experiments. The acceleration profile shown in Figure 2 was also studied with two of the seven subjects wearing MC-2 full pressure suits. Both subjects were centrifuged, first with the suit ventilated but not inflated, and on another day, with the suit pressurized at 3 psi. The anti-g bladders were not activated in either of the tests.

RESULTS

With an overall trunk and head angle of 17° in the direction of the acceleration, blackout was experienced by two subjects at 12 g when no straining maneuvers or protective equipment were used. By using the standard Air Force anti-g suit (CSU-3/P) inflated to 5 psi, loss of vision was prevented in both subjects at 12 g. When the back angle was changed to 12°, only one of four subjects experienced blackout at 16.5 g without anti-g suits. Dyspnea appeared only at higher levels of acceleration in this position. All subjects maintained some degree of ventilation throughout the acceleration profile.

Results from experiments enveloping the NASA re-entry acceleration curves are shown in Tables I and II. Five of seven subjects were able to withstand the entire profile shown in Figure 2. Two subjects experienced severe substernal pain associated with inspiratory dyspnea and were forced to terminate the experiment at 13.5 and 16.0 g respectively. The pain was an intense ache over the lower third of the sternum, which radiated bilaterally along the costal margin and into the epigastrium. It persisted for 4 to 6 hours after the experiment. One of these subjects experienced a sharp chest pain which radiated to the top of the scapula one hour after the experiment. Standard electrocardiograms taken 24 hours after the experiment failed to reveal a deviation from the normal in any of the seven subjects.

TABLE I

TIDAL VOLUMES AND RESPIRATORY RATES OF SIX SUBJECTS EXPOSED TO 16.5 G ACCELERATION PROFILE

TIDAL VOLUME IN CC's

	Subj. 1	Subj. 1a	Subj. 1b	Subj. 2	Subj. 2a	Subj. 2b*	Subj. 3	Subj. 4	Subj. 5	Subj. 6
CONTROL	500	500	940	550	425	760	675	400	425	650
8 g	250	200	350	225	175	170	575	350	275	400
16.5 g	100	50	90	100	175	0	300	100	200	100**
8 g	200	200	240	500	425	-	425	375	375	
POST RUN	475	650	530	750	300	-	700	850	625	950

RESPIRATORY RATE IN CYCLES/MIN

	Subj. 1	Subj. 1a	Subj. 1b	Subj. 2	Subj. 2a	Subj. 2b*	Subj. 3	Subj. 4	Subj. 5	Subj. 6
CONTROL	26	25	20	20	18	18	17	23	24	15
8 g	50	60	30	44	36	46	18	41	36	30
16.5 g	99	78	45	64	48	0	27	60	57	60
8 g	54	69	38	42	30	-	38	43	39	60
POST RUN	24	30	30	30	30	-	25	22	25	24

"a" with MC-2 full pressure suit uninflated
"b" with MC-2 full pressure suit pressurized
* aborted ride at peak (16.5)
** aborted ride at 13.5 g.

TABLE II

TIDAL VOLUMES AND RESPIRATORY RATES OF SUBJECTS WITHOUT PRESSURE SUITS SUCCESSFULLY COMPLETING ACCELERATION PROFILE EXPRESSED AS PERCENT OF CONTROL VALUES

	TIDAL VOLUME		RESPIRATORY RATE/MIN	
	Mean	Standard Error	Mean	Standard Error
CONTROL	100%		100%	
8 g	66%	9	165%	10
16.5 g	31%	6	272%	37
8 g	75%	10	198%	11
POST RUN	139%	21	118%	13

Blackout was approached in three of 12 experiments. The subjects were unable to see the tracking task at 16.5 but could still see the center light during the peak of the acceleration profile. One subject repeated the experiment and was able to prevent blackout by straining maneuvers at peak acceleration. In the remaining experiments, the subjects apparently were able to perform the tracking task throughout the experiment.

Only two subjects have been through this profile in the full pressure suit. Both subjects were able to endure the entire experiment and subjectively felt that the uninflated suit did not impair tolerance. One subject felt that the suited run was more tolerable than his previous non-suited exposure. Tracking ability during both the pressurized and unpressurized suited experiments appeared to be as good or better than in the shirt-sleeves experiments.

With the MC-2 suit pressurized at 3 psi two subjects attained a peak acceleration of [illegible].5 g. One subject voluntarily aborted the experiment at this point because of severe dyspnea. Tidal volume had begun to decrease markedly at [illegible] g and respiration had ceased entirely at [illegible] g. The other subject successfully completed the profile.

By using the motion picture records of the tracking task monitor display, it was possible to define target sizes other than the 3.5 mm target which was recorded automatically. Measurements were made to determine the percent of time each subject was able to keep both indicator needles within a target of 7.0 mm. diameter.

The data from the tracking task seems to be quite variable. It appears that the overall score as well as the score based on moment to moment changes in tracking ability (at different levels of acceleration) is critically related to the degree of learning which the subject has undergone.

Figure 3 shows the tracking scores of two subjects who were most experienced with this task. One subject was a naval pilot. Both had practiced the task a number of times during transverse acceleration of more than 1 g. Figure 4 is a graph of three scores of a less experienced subject during the same acceleration, first wearing conventional flying coveralls then the uninflated MC-2 full pressure suit and finally MC-2 suit inflated to 3 psi.

Table III shows the tracking ability of each subject immediately before and after the acceleration. There was no gross detriment in the time required to extinguish the center light when it was presented, except when marked loss of vision or blackout at the higher accelerations occurred.

DISCUSSION

The experiments reported in this paper represent a special effort to supply information about human reactions to a specific series of accelerations using the

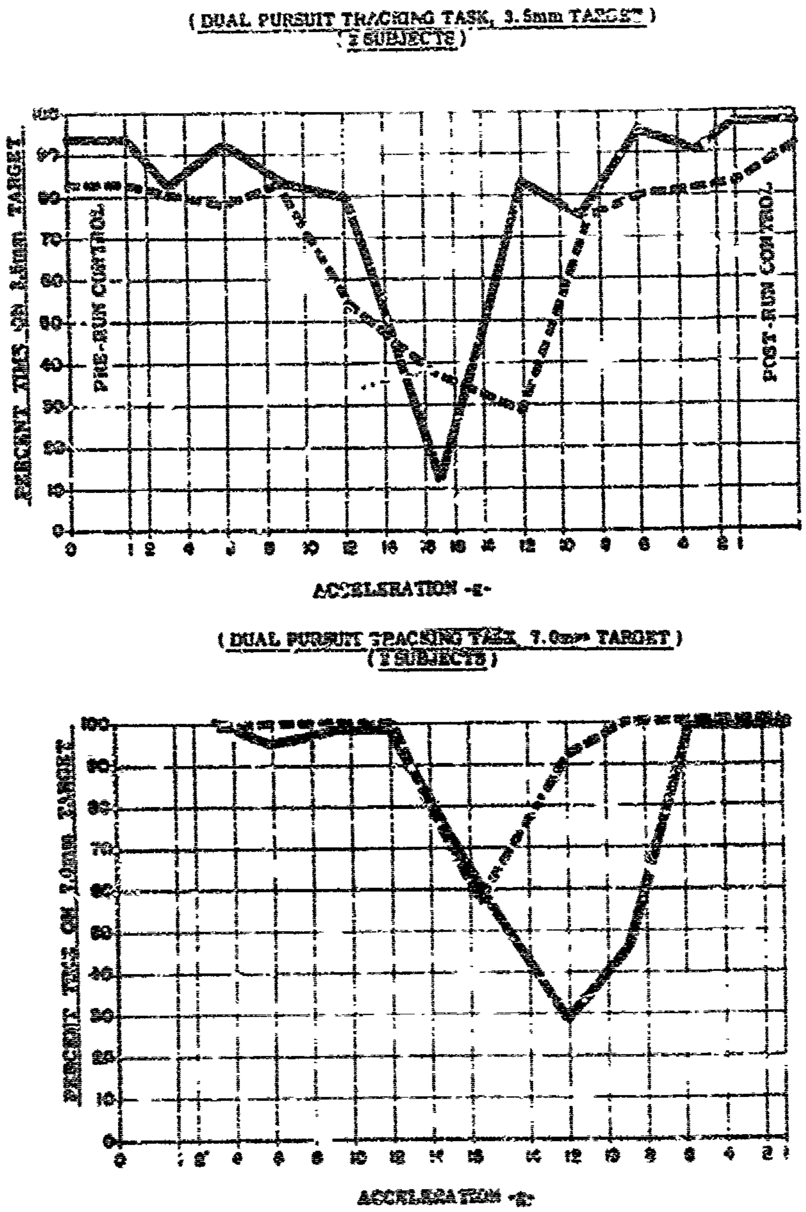

FIGURE 3 - Performance Score During Simulated Rearward Facing Re-entry

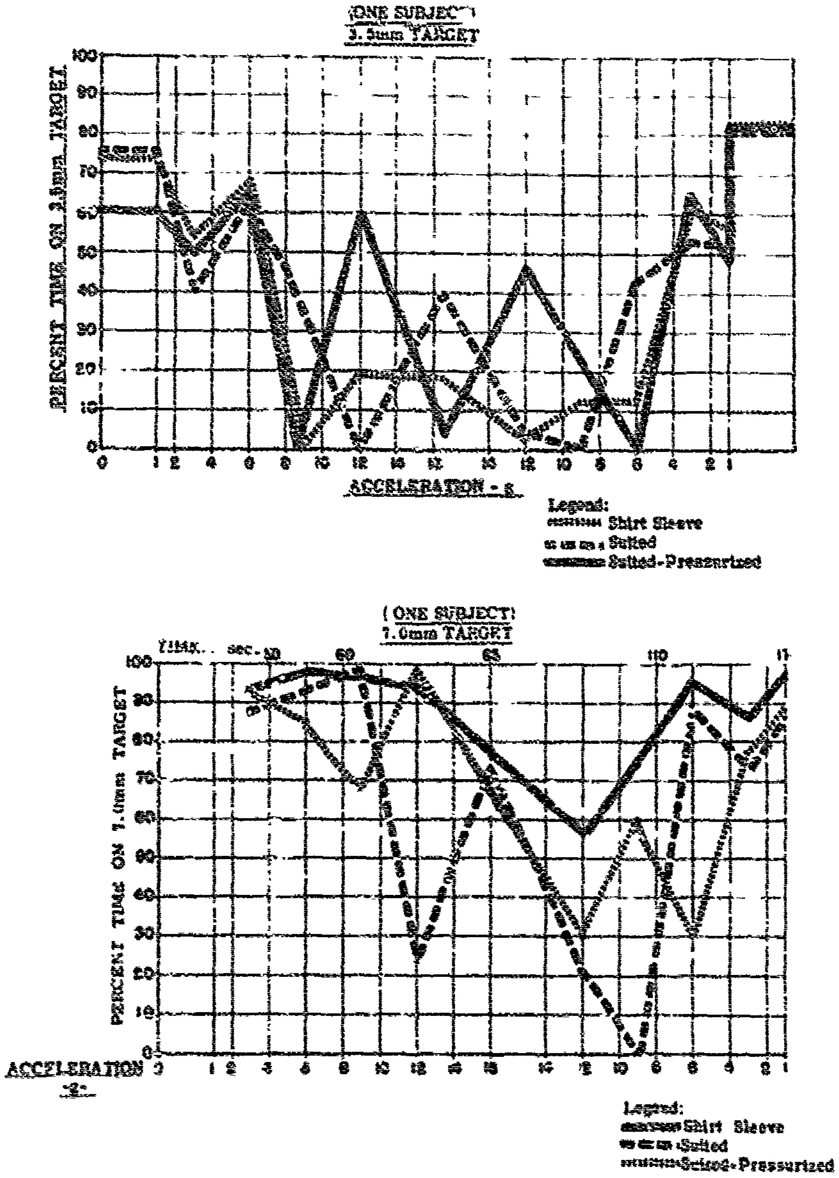

FIGURE 4 - Comparison of Tracking Ability During Acceleration in Shirt Sleeves and in Full Pressure Suit

TABLE III

PRE-RUN AND POST-RUN CONTROLS --TRACKING TASK-- 16.5 G PROFILE

% of Time Off Target

Subject No.	Pre-Run Control	Post-Run Control
1	29	43
2	27	26
3	16	8
4	6	3
5	27	34
6	26	17
7	26	31
8	15	17
9	6	15
10	28	10
11	34	18
Average	22%	20%

net support system. Because of the urgency of the request for this information, it has been necessary to sacrifice several important physiological measurements which had been planned for the overall study. Since the net system of support and restraint is being considered for several weapon systems, this laboratory is planning an extended series of both basic and applied studies to objectively select optimum body positions with respect to both physiological tolerance and performance ability. It is probable that a considerable portion of this information will be available in time to be of use to NASA during selection of their support system for the manned space capsule.

It is not possible to entirely explain the increase in tolerance which the net system provides in comparison to the rigid system previously used in this laboratory (8). The subject panel includes members who participated in both studies. The earlier rigid system was not contoured to body shape. The net support was contoured to the dorsal surface of the body to some degree and became even more close fitting under acceleration. It may be that the net support reduces distortion of the chest wall under acceleration. At any rate it reduces respiratory effort and chest pain. It definitely is more comfortable and prevents the formation of dermal petechiae in dependent areas.

The versatility of the net support system is illustrated by the fact that subjects ranging from 145 pounds to 175 pounds were comfortably supported throughout the acceleration. The degree of body displacement is related to the stretch of the reschel nylon net so that heavier subjects have a slightly greater back-angle than lighter subjects.

The two tests using flying coveralls which were terminated involved short, lightweight subjects who apparently displaced the net support least of any of the panel. A limited number of experiments have been done comparing dacron and nylon for net support. Dacron is supposed to undergo less stretch so that it should be possible to pre-position the subject at the desired body angle without marked changes during the acceleration. Preliminary results indicate that the particular dacron net used underwent almost as much stretching as the nylon net. Furthermore, it failed to return to its original shape after the acceleration. Further studies are necessary to define its usefulness as compared to nylon and other materials.

The loss of vision in seated forward acceleration appears to have a more complex etiology than the usual blackout in seated headward acceleration. Despite a very slow rate of onset of the positive g vector, loss of vision occurred when this component reached about 3 g; a point considerably below the threshold for seated positive acceleration. However, the eye is about 10 cm in front of the heart in this position so that is probable that a portion of the hydr[illegible] column acts in preventing adequate retinal perfusion. The anti-g suit and straining maneuvers appear to aid in prevention of loss of vision in forward acceleration showing, at least, that this blackout, as in positive g, is opposed by compression of the lower part of the body. If the occupant of the space vehicle is required to perform any critical tasks, it appears worthwhile to supply him with functional anti-g bladders which function during peak acceleration above 13 g.

The performance measurements in this study essentially confirm and extend those of Preston-Thomas (6), which explored man's ability to perform similar tasks during three-stage forward accelerations characteristic of the launch phase. It appears doubtful that man will be mechanically able to make more than wrist and finger movements during acceleration greater than 12 g. One subject whose hand slipped off the tracking control at peak g was unable to reach the instrument again until the acceleration was reduced to about 10 g.

Performance ability during acceleration as indicated by the dual pursuit tracking task appears to be a function of learning to do the task during acceleration. The numerous sessions of practice at 1 g did not seem to make up for lack of experience of most of the subjects with the task during acceleration. We do not yet have data on a large enough number of trained subjects to present a statistically significant picture of performance ability during the acceleration profile. It is apparent from Figure 3, however, that at least some people can be expected to exert rather critical control over such a task during accelerations of up to 12 g. Actually, the two subjects whose scores are shown in Figure 3 continued to do well on this task until loss of vision from the positive g vector occurred.

There is an indication, based on the experience of two subjects during 12 g accelerations in a slightly different position, that use of the anti-g suit in this situation may extend performance ability by raising the threshold for loss of vision. There is no apparent evidence of impaired performance immediately after the simulated deceleration. This would indicate that the occupant of a space vehicle could be expected to make similar critical adjustments shortly after re-entry, or for that matter, after boost since the force vector acts in the same direction (except for the possible influence of zero g state).

Every subject decreased tidal volume and increased respiratory frequency progressively in a manner directly related to the magnitude of acceleration. At peak acceleration ventilation became inadequate in almost every subject. That is, tidal volume was approximately equal to or less than the expected anatomic dead space (100 -- 175 cc) near peak acceleration, and it is therefore improbable that any new air reached the alveoli during this period. However, the duration of inadequate ventilation was usually relatively brief (10 -- 15 sec) in this acceleration profile, and it is not expected that serious levels of arterial oxygen depletion lasted for a significant duration of time. In more prolonged accelerations above 10 g of forward acceleration, serious arterial desaturation with resultant cerebral hypoxia would be expected to impair tolerance and performance.

During return from peak acceleration and in some cases, continuing after, completion of the acceleration profile, an impressive increase in ventilation occurred which would suggest that inadequate oxygenation did exist near peak acceleration.

It should be noted too, that the ratio of total minute ventilation to tidal volume increased proportionally to the accelerative force. Therefore, breathing became progressively less efficient, so that the demand for oxygen increased progressively because of the increasingly inefficient work of respiration itself.

Almost identical results prevailed in the same subjects with and without the MC-2 full pressure suits. Pressurization of this suit during acceleration did not alter the general respiratory pattern.

Dyspnea and chest pain were present in those subjects unable to tolerate the profile of acceleration, and were cited as the reasons for aborting the attempt, although their respiratory frequency and tidal volumes were within the range of those seen in the subjects who did tolerate the acceleration profile.

Direct measurement of arterial saturation and its changes due to acceleration, accelerative changes in pulmonary blood flow and distribution, and similar studies are urgently needed. While complete studies will require more elaborate instrumentation than is currently available, some studies of arterial saturations during acceleration are currently in progess.

SUMMARY

This report covers a series of experiments which evaluate variations in respiratory rate and flow, electrocardiographic changes, tracking performance ability, and subjective response during an acceleration profile which completely envelopes the several predicted re-entry profiles of the NASA manned space capsule. On the basis of these tests, it is possible to say that any of the re-entry acceleration curves submitted by NASA should fall within the tolerance limits using the net support system described with a forward inclination of the trunk and head of 12°.

Preliminary impressions indicate that subjects were able to perform critical tracking maneuvers throughout all except the peak accelerations of the 16.5 g curve. There appeared to be no decrement in tolerance in two subjects wearing the uninflated MC-2 full pressure suit. With the suit pressurized to 3 psi, both subjects reached 16.5 g. One aborted the experiment at this point; the other completed the profile.

The electrocardiograms recorded during acceleration show only mild tachycardias with occasional extra systoles. Respiratory rate increases with acceleration, tidal volume decreases. It appeared that all subjects were able to maintain air flow during all stages of acceleration, however, ventilation near peak acceleration did not seem adequate to maintain oxygenation.

BIBLIOGRAPHY

1. NASA Chart of Re-Entry Acceleration Profiles, submitted to WADC 1 Dec 1958.

2. Ballinger, E. R. and Dempsey, C. A., The Effects of Prolonged Acceleration on the Human Body in the Prone and Supine Positions, WADC TR 52-250, July 1952.

3. Hertzberg, H. T. E., A Prone Position Bed for Pilots, Memorandum Report MCREXD-695-71 D, Air Material Command, 25 June 1948.

4. Zuidema , G. D., Cohen, S. I., Silverman, A. J., and Riley, M. B., Human Tolerance to Prolonged Acceleration, J. of Avia. Medicine, 25: 439-481, December 1956.

5. Clarke, N. P., and Bondurant, S., Human Tolerance to Prolonged Forward and Backward Acceleration, WADC Technical Report 58-267, July 1958.

6. Preston-Thomas, H. R., Edelberg, R., Henry, J. P. Miller, J., Salzman, E. W., and Zuidema, G. D., Human Tolerance to Multistage Rocket Acceleration Curves, J. Avia. Medicine, 26: 390-398, October 1955.