NASA TN D-345

NASA TN D-345

TECHNICAL NOTE
D-345

PHYSIOLOGICAL EFFECTS OF ACCELERATION OBSERVED DURING A CENTRIFUGE STUDY OF PILOT PERFORMANCE

By Captain Harald A. Smedal, USN (MC), Brent Y. Creer, and Rodney C. Wingrove

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON December 1960

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-345

PHYSIOLOGICAL EFFECTS OF ACCELERATION OBSERVED DURING A CENTRIFUGE STUDY OF PILOT PERFORMANCE [1]

By Captain Harald A. Smedal, USN (MC), Brent Y. Creer, and Rodney C. Wingrove

SUMMARY

An investigation was conducted by the National Aeronautics and Space Administration, Ames Research Center, and the Naval Air Development Center, Aviation Medical Acceleration Laboratory, to study the effects of acceleration on pilot performance and to obtain some meaningful data for use in establishing tolerance to acceleration levels. The flight simulator used in the study was the Johnsville centrifuge operated as a closed loop system. The pilot was required to perform a control task in various sustained acceleration fields typical of those that might be encountered by a pilot flying an entry vehicle in which he is seated in a forward-facing position. A special restraint system was developed and designed to increase the pilot's tolerance to these accelerations.

The results of this study demonstrated that a well-trained subject, such as a test pilot, can adequately carry out a control task during moderately high accelerations for prolonged periods of time. The maximum levels of acceleration tolerated were approximately 6 times that of gravity for approximately 6 minutes, and varied slightly with the acceleration direction. The tolerance runs were in each case terminated by the subject. In all but two instances, the cause was extreme fatigue. On two occasions the subject terminated the run when he "grayed out."

Although there were subjective and objective findings involving the visual and cardiovascular systems, the respiratory system yielded the more critical limiting factors. It would appear that these limiting factors were less severe during the "eyeballs-out" accelerations when compared with the "eyeballs-in" accelerations. These findings are explained on the basis of the influence that the inertial forces of acceleration have on the mechanics of respiration.

---

[1] A condensed version of this report was presented at the Annual Meeting of the Aerospace Medical Association, Miami Beach, May 5-11, 1960, in a paper entitled "Ability of Pilots to Perform a Control Task in Various Sustained Acceleration Fields." This latter paper was subsequently published in the Association's journal, Aerospace Medicine, volume 31, number 11, pages 901-906, November 1960.

INTRODUCTION

Manned satellite or lunar vehicles which employ lift in order to minimize the effects of aerodynamic heating and those of deceleration upon re-entry may require a certain degree of pilot control. The acceleration stresses imposed upon the pilot will vary with the lift and drag of the vehicle. The pilot's ability to tolerate these stresses and at the same time to control the vehicle adequately depends on his position in the vehicle relative to its direction of motion.

A453

Numerous investigations in the past as noted in references 1 through 6 have indicated that man can withstand the magnitude of deceleration required of the vehicle during re-entry if he can be positioned so that the acceleration force is applied in a direction transverse to the spinal axis of the body. Preference so far has been given largely to the placement of the pilot in a position in which these forces are at right angles to the spinal axis, applied from the ventral to the dorsal surface of the body. This direction of acceleration has been variously described as frontward, positive A_X and, more colloquially in the vernacular of the aviator, "eyeballs-in" acceleration. The pilot position is a backward-facing one in relation to the direction of motion of the vehicle.

Of considerable interest, especially in the high lift-drag-ratio vehicle which has the potentiality of being maneuvered to a selected landing site, is the use of the forward-facing seated position. In this position the accelerations would again be applied largely transverse to the spinal axis of the body but in a dorsal to ventral direction. This direction has been described as backward, negative A_X or "eyeballs-out" acceleration. Because of the lift of the vehicle, a great deal of acceleration is probable in the direction which may be described as headward, A_N or "eyeballs-down" acceleration. Varying amounts of a combined headward and backward, negative A_X and A_N or "eyeballs-down and -out" acceleration will also be encountered as the flight path of the vehicle is altered. Figure 1 is presented in order to illustrate the acceleration nomenclature which will be used hereafter.

Some of the lack of interest in the forward-facing position of the pilot, we believe, stemmed from the fact that no adequate anterior support or restraint had been developed. It is much easier to contour a form-fitting posterior restraint away from the functional ventral side of the body. In reference 3 it is stated that positive A_X acceleration is tolerated better than negative A_X acceleration. The difference was said to be so great as to justify rotating the pilot 180° if necessary in order that he face aft during re-entry. However, it was admitted that with an adequate anterior restraint there would probably be little difference, if any, in the tolerance levels.

In the past it has been customary to measure acceleration tolerance largely on the basis of how many g's the individual could withstand without much regard for the many factors which influence these tolerances. For proper evaluation of human tolerance to acceleration, one must exercise care to relate this tolerance to all the appropriate variables. In crash survival (i.e., impact acceleration), human tolerance is based on variables which are quite different from those defining human tolerance to sustained accelerations. The ability of the pilot to control a vehicle flying along an atmosphere entry trajectory depends on human tolerance to sustained acceleration. In particular, five different variables
A are important: the magnitude of the accelerative force, the rate of on-
4 set, the direction in which the acceleration is applied to the body, the
5 duration of the acceleration, and last but most important, the perform-
3 ance ability of the pilot.

In order to explore some of the problems of human tolerance to sustained acceleration, as they relate to the controllability of an entry vehicle, a joint centrifuge study was undertaken by the National Aeronautics and Space Administration, Ames Research Center, and the Naval Air Development Center, Aviation Medical Acceleration Laboratory. The investigation was by no means intended to be a comprehensive study in the field of controllability of re-entry vehicles. Its purpose was to probe into some of the problems by investigating the ability of the pilot to perform a meaningful task while immersed in moderately high varied fields of acceleration for prolonged periods of time and seated in a forward-facing position. The primary purpose of this report is to present and discuss those results which pertain to the effects of acceleration on the cardiovascular, respiratory, and visual functions of the pilot.

NOMENCLATURE

The pilot vernacular "eyeballs in," "eyeballs out," etc., represents effects of inertial forces which are opposite in direction to the accelerating forces.

A_N — acceleration factor, ratio of accelerating force to weight, positive when directed upward along spinal axis, that is, from seat to head

A_X — acceleration factor, ratio of accelerating force to weight, positive when directed forward; transverse to spinal axis, that is, from back to chest

P.E. — pilot efficiency

T — time

METHODS AND MATERIALS

The major piece of equipment used in this program was the NADC, AMAL centrifuge employed as a flight simulator and operated as a closed loop system. Use of this centrifuge as a simulator is described in reference 7. It has a gondola mounted in a double gimbal system at the end of a 50-foot-radius arm. By means of this gimbal system, which can be used up to a radial acceleration of 20g, the relative orientation of the subject with respect to the resultant acceleration vector can be controlled continuously.

Six subjects were used in this study. They were recruited from the various NASA Research Centers; the Naval Aviation Test Center, Patuxent River, Maryland; Edwards Air Force Base, California; and NADC, Johnsville, Pennsylvania. Some had had previous centrifuge experience and all could be considered very sophisticated and highly motivated subjects.

The subjects were required to carry out a relatively complex tracking problem which is described in detail in reference 8. Briefly, certain "flight" information was presented to the subject on an instrument panel illustrated in figure 2. An oscilloscope, 5 inches in diameter, placed in the center of the panel presented these items: a target, a sideslip indicator, an airplane reference, and a horizon. The target was randomly driven by means of combinations of four different sine waves. The target always remained on a line which passed through the center of the airplane reference and was perpendicular to the horizon. Thus, the tracking task was principally to control through the longitudinal mode of vehicle dynamics. Actually in this program the equations of motion described five degrees of freedom with the vehicle forward velocity assumed to be constant. Since the pilot "flew" the centrifuge as a closed loop system the centrifuge was driven in response to the pilot control inputs so that the impressed linear accelerations varied in the same manner as those computed from the equations of motion. The total g field, therefore, consisted of two components, the biased g component and that which resulted from the vehicle maneuvering about a given trim condition. The latter was never more than 0.5g.

The pilot efficiency was calculated as the accumulated tracking error compared with the accumulated excursions of the target and is expressed in the following equation:

$$P.E. = \frac{\int_0^T \theta_i^2 - \int_0^T e^2}{\int_0^T \theta_i^2}$$

where

θ_i^2 square of the target excursions

e^2 square of the tracking error excursions

T interval of the tracking task

A
4
5
3

The entire investigation was divided into three phases, the first of which was devoted to the evaluation of side controllers. In the second phase information was obtained on the combined effects of magnitude and direction of applied acceleration force and complexity of control task on pilot performance. Acceleration versus time profiles used in the first phase were of three varieties. One was 6g positive A_X and zero g A_N and the other was 2g negative A_X and 4g A_N. The duration of each was about 2.5 minutes. In phase 2, runs of 5g to 6g positive A_X and zero A_N, 5g to 6g negative A_X and zero A_N, zero A_X and 4g to 5g A_N, each for 2.5 minutes, were used. The third phase which is discussed in detail in this paper was designed primarily to obtain tolerance to acceleration data. Some of the third phase runs were interspersed in the first and second phases in order to avoid the element of fatigue. Since there were so few subjects and since the time alloted for the program was relatively short, only a few third phase runs were accomplished.

The controller chosen from phase 1 and used for the majority of the phase 3 runs was the two-axis-type side controller illustrated in figure 3. (It was similar to one used and described in reference 9.) Pitch and roll control inputs were made with this controller. Yaw control was made with the set of toe pedals illustrated in figure 4. The toe pedal yaw control differs from the conventional rudder pedals in that control is performed by flexion and extension of the foot about the transverse axis of the ankle joint in contrast to the rudder pedals which are manipulated by flexion and extension of the lower leg at the knee.

One of the most critical elements in carrying out this program and upon which the results that would be obtained depended so greatly was the development of the restraint system. Reference 10 describes this system in detail. Briefly, it consisted of individually fitted styrofoam molds (fig. 5) as the basic component. The molds were constructed so as to hold the individual subject in a sitting position. The spinal axis was approximately 85° to 90° in relation to the thigh axis. The thigh and the lower leg were approximately 90° to each other. It was necessary to omit the lower end of the mold in order to install the toe pedal system for yaw control when the two-axis side-arm controller was being used. The toe pedals were constructed so that the feet were restrained in the device.

The head restraint was incorporated in a protective helmet system as shown in figure 6. The helmet was secured into the mold on either side by 1-inch nylon straps attached to each side of the helmet. A head bumper was incorporated late in the program as a secondary safety feature. The face pieces were individually molded from plaster cast impressions of each subject's face. They were designed so that the major portion of the load would be taken over the malar bone. The chin cup was included in this restraint but only as a minor component since the mandible is an unstable support point and its tolerance to large loadings is poor. The two components of the face restraint were joined together by vertical metallic check straps. The face restraint was attached to the helmet by adjustable 1/2-inch-wide nylon straps fitted into a standard oxygen mask assembly attached to the protective helmet.

A 4 5 3

The torso was held in the mold by two separate components. The upper half of the torso was restrained by a cloth chest plate, fabricated of 6-inch-wide nylon straps crossed over the upper portion of the chest at an obtuse angle so as to cause most of the loading to be taken over the upper rib cage and clavicles. Another separate component was fabricated for the pelvis. It consisted of two slightly crossed 6-inch-wide nylon straps identical with those used for the chest restraint. It was positioned so as to carry the loading over the pelvis and the upper thighs. The extremity restraints were constructed of nylon netting held in place by 3-inch-wide nylon straps. The restraints are illustrated in figure 7. All of the anterior restraint components were extended through the posterior mold by the attached 3-inch-wide nylon straps. The straps were secured to the metal frame which supported the styrofoam molds.

Additional protective devices against the accelerations used in this study consisted of the g suit and elastic bandages for wrapping the legs and arms. The use of the elastic bandages is illustrated in figure 8. It was also found necessary to wrap the forearms in order to prevent the distention of the forearm and hand during negative A_X accelerations.

Time histories of the electrocardiogram, respiration, tracking score, and acceleration were traced on a four channel Sanborn recorder. The electrocardiogram electrodes were positioned on the lateral aspect of the chest. Respiration was measured by means of a chest strap containing a strain-gage device.

Tolerance to accelerations was sampled along four different vectors, namely, positive A_X, A_N, negative A_X, and combined negative A_X and A_N. The rate of onset for all accelerations was approximately 0.1g per second. The duration of all runs was measured as the total time spent at 90 percent of the maximum acceleration. Each tolerance run was preceded by three or four dynamic runs of the routine type used in phases 1 and 2. It was also immediately preceded by a static 1g run intended to be used as a base line.

RESULTS AND DISCUSSION

The data are admittedly meager, but do give considerable insight into the effects of sustained acceleration on the physiological functions of pilots. The results of each test run for each test subject have been tabulated and show the direction of the applied acceleration force, the length of time the applied acceleration was endured, and the pilot tracking efficiency during the run. Because of the inexperience of the majority of the test-pilot subjects with the tracking task, with the pilot controls, and with the operation of the centrifuge, it was believed that, in general, the pilot tracking proficiency had not leveled out at the time these tests were conducted. Therefore, the pilot tracking scores obtained during this phase of the tests should be viewed with caution. Most of the general data obtained from phases 1 and 2 of the investigation are not remarkable when considered from the point of view of time tolerance to acceleration and therefore are not included.

Specific Results on Each Subject

Since there was so much interest in the tolerance to combined negative A_X and A_N accelerations, the first tolerance runs were made along this vector. The data for the subject R.S. is seen in table 1. His first run was a combined 4g negative A_X and 4g A_N - in other words, eyeballs down and out. This gave a resultant vector with a magnitude of 5.65g. The run was permitted to continue for 5 minutes and 48 seconds when it was terminated by the project engineer. As can readily be seen, the subject's tracking performance was poorer than if he had not attempted to control at all. Nevertheless, this run provides interesting tolerance data. Three days later the same subject made two more tolerance runs at greater acceleration, a combined 5g negative A_X and 5g A_N which gives a resultant magnitude of 7.07g. The first run lasted 47 seconds and was terminated by the pilot because he was unable "to get started" on the tracking problem. After a brief rest period, the run was repeated. This time its duration was 1 minute and 15 seconds and again it was terminated because of difficulties with the tracking problem. Four days later the pilot requested that he be permitted to try a combined 6g negative A_X and a 6g A_N run. This combined acceleration gives the resultant vector a magnitude of 8.49g. He was able to withstand this exposure for only 20 seconds at maximum acceleration. His tracking efficiency during the first 15 seconds was 25 percent. It then fell rapidly to zero by the end of 20 seconds.

On all of these runs this subject's complaints seemed to be about the same. Visual difficulties found were related to changes in the visual fields. There were also changes in the distinctiveness of the objects on the instrument panel, particularly the oscilloscope. The doughnut-shaped target became a solid dot rather than ring shaped. Breathing became difficult and considerable variation in tidal volume was apparent. There was distress and discomfort in the legs due to pooling of the blood and tissue fluids. Tightening and tensing of the leg muscles helped to correct this at first but later during the run it failed. In the end, general exhaustion was the result.

A summary of the data of subject J.W. are shown in table 2. The first run was a 4g negative A_X and 4g A_N. The time for this exposure was 3 minutes and 35 seconds. The run was terminated by the subject because of extreme fatigue. Other more specific terminal events were decreased vision and labored respiration. The subject felt that he could have continued on about 30 more seconds had it been absolutely necessary. Physical examination after the run revealed numerous small petechiae over both forearms, hands, and fingers. Petechiae were also found over the lower legs just below the inner aspects of the knees, around the ankles and over the dorsum of the feet. The subject had felt a slight tingling sensation in the lower legs during the early part of the run but had no real discomfort. The lower legs and feet had been wrapped with elastic bandages prior to the run.

Four days later the same subject was given a combined 5g negative A_X and a 5g A_N acceleration. The time for this exposure was 2 minutes and 42 seconds. Although extreme fatigue again was present at the end of the run, the reason given for the subject's terminating the acceleration was loss of vision. Labored respiration was again a prominent subjective observation. This time early in the run the subject noted painful sensations in the calf of the legs and in the toes which quickly subsided. In comparing his respiration pattern with that in a 6g positive A_X type of run, he noted that, although it seemed more rapid, he felt that he could take deeper breaths. The distortions in vision were blurring and diplopia which he could occasionally correct by moving his facial muscles and by concentrating on focusing his eyes on the target object of the oscilloscope. This became increasingly more difficult to accomplish as the run progressed. It is felt that the diplopia could have been caused wholly or in part by the pressure of the head restraint on the face about the eyes. Opening the eyes wider seemed to correct some of the blurring. This leads one to believe that pressure of the lid margins on the cornea may have caused an astigmatic error in refraction which the subject could correct temporarily by moving his eyelids. He stated he could have continued for a longer period of time from the standpoint of general fatigue and the lack of respiratory difficulty but he terminated the run because he could no longer tell the exact position of the moving target.

Figure 9 is a reproduction of the Sanborn 4 channel recorder tracings of this subject's first run. The top tracing is the electrocardiogram which is not remarkable save for the increase in heart rate to 180 during the final moments of the acceleration. It was 120 at the start of the run. The second line is the respiratory tracing. In addition to the increase in rate, one can see a change in the character of the respiratory pattern. As the acceleration came on, the subject gradually filled his lungs with air and breathed off the top of this larger lung volume. The result was a greater functional residual capacity in the lungs. This is the same process as is usually seen during muscular exercise in which the functional residual capacity is increased and the vital capacity is decreased. This change in respiratory mechanics is a physiological method for increasing the efficiency of oxygenation of the blood through the more thorough ventilation of the alveoli. There is a greater functional residual capacity in the lungs at the end of expiration which prevents large-scale fluctuations in oxygen and carbon dioxide tensions in the alveoli and in the blood.

Subject M.T. made two tolerance runs as is seen in table 3. The first was the combined 4g negative A_X and 4g A_N. The time of this run, 3 minutes and 7 seconds, compares very well with that of subject J.W. This run was terminated because of extreme fatigue. The problems with vision and respiration previously mentioned were present for this subject as well.

The same subject made a second tolerance run later the same day. This time the acceleration vector was changed to the A_N direction or eyeballs down acceleration. The magnitude of the vector was 6g. The run lasted 5 minutes and 13 seconds and was terminated largely because of visual difficulties. At the onset of the acceleration the subject noted marked dimming of the vision which became maximum about the time peak acceleration was reached and then subsequently improved. However, as the run progressed, his vision again became dimmer and dimmer until near the end of the run he began to have trouble telling the exact location of the target on the oscilloscope. The green lines on the oscilloscope disappeared finally and the scope image became completely white. The subject's peripheral vision vanished much earlier since all the other instruments on the panel were no longer visible while he still had fairly good vision of the oscilloscope target. Respiration became gradually more labored and contributed to his general fatigue. The g suit functioned well and its abdominal bladder which was held low over the abdomen interfered very little with his respiratory effort. He felt very little pressure or pain in the legs from pooling of blood and tissue fluids. The wrapping of the legs with elastic bandages appeared to be effective. The couch as the basic support appeared to function well in the chair position.

Subject R.C. was given two severe tolerance runs as is shown in table 4. The first was a 7g negative A_X acceleration which he tolerated for 4 minutes and 47 seconds. There were some visual difficulties. His peripheral vision decreased somewhat and although the image of the oscilloscope became mildly blurred, his visual acuity remained good throughout the run. He noted an increase in the difficulty of breathing toward the end of the run, but felt that this was due to general fatigue. He felt some pain in his forearms, wrists, and hands as a result of pooling of the blood and tissue fluids but this was limited by the elastic wrappings and the gloves. This distress did affect the controllability but not seriously. There was no marked distress in the lower extremities, which also were wrapped with elastic bandages, and as a result, he had no difficulty in operating the toe pedals. The subject's reason for terminating the run was general exhaustion.

The second tolerance run for this subject was made the following day. This was an acceleration in the opposite direction, positive A_X, and the magnitude was 6g. A vector of 1.5g A_N was inadvertently added but did not appreciably alter the magnitude of the resultant vector which increased to 6.18g. It was thought that such a resultant vector might reduce the distressing sensation in the chest as is found when the body is inclined 65° to 70° forward during positive A_X accelerations. However, this pressure sensation was not relieved. The duration of this run was 5 minutes and 57 seconds. Though the pilot terminated the run again because of general exhaustion, some of the contributory factors were a severe pain in the temporomandibular joints, rapidly failing vision, and labored respiration.

Figures 10 and 11 are shown to illustrate the difference in respiration during the last two endurance runs. During the 7g negative A_X acceleration the subject at first breathed at irregular intervals with apparent varying tidal volume. He soon established a regular respiratory pattern which he maintained throughout the run. In contrast is the 6g positive A_X run. As the acceleration came on, the subject's respiration increased in rate and apparently in volume. There appears to be a gradual reduction in the functional residual capacity with an apparent return to normal at the cessation of acceleration. This difference in respiratory pattern was apparent to all subjects when negative A_X and positive A_X runs were compared. It was generally agreed that there was less respiratory distress during the negative A_X accelerations. All subjects complained of the pressure sensation in the chest and throat during positive A_X acceleration. The sensation could possibly have been relieved somewhat by flexing the body forward to about 65° to 70° during this acceleration as has been pointed out in reference 3. The data presented in references 10 and 11 indicate that there is considerable impairment in lung ventilation during positive A_X accelerations. Unfortunately, there are no data available for comparison with the negative A_X acceleration results of this study.

Incidentally, two instances of premature cardiac contractions are seen during the 6g positive A_X run (see inserts 2 and 3, fig. 11).

Subject R.I. made two tolerance runs as is shown in table 5. The first run was a 6g A_N acceleration and its duration was 6 minutes and 27 seconds. The run was terminated by the pilot because of exhaustion and a gradual loss of vision described as "graying out." The symptoms observed by the subject are, for the most part, the same as those described by subject M.T. during his 6g A_N run. Subject R.I. made a second tolerance run the following day. This was at 7g negative A_X acceleration, and was terminated by the pilot after 2 minutes and 45 seconds. The subject had developed an upper respiratory infection and he found it difficult to breathe because of the collection of mucus about the nose and in the throat and mouth. There were no other major difficulties.

Figure 12 is a reproduction of the electrocardiogram, and recordings of respiration, tracking score, and acceleration during the last subject's 6g A_N run. In the electrocardiogram there is a series of what appears to be four extrasystoles (see insert 2, fig. 12) which appeared shortly after the onset of the acceleration. They appear to be ventricular in origin and are probably from the same focus. Each is coupled with a regular beat, producing, in effect, a transient bigeminal rhythm. The rate reached 180 per minute toward the end of this run. The respiration pattern appeared to be more regular in rate and of greater volume during acceleration.

A
4
5
3

Subject J.H. was the least experienced of all. He had only a short period of indoctrination since he did not participate in the phase 1 and 2 portions of the program. His two runs are summarized in table 6. His indoctrination consisted of three 2-1/2-minute exposures to 4g in each of the three basic vectors and then the 1g static run. His first tolerance run was a 7g negative A_X which he terminated after 2 minutes and 23 seconds because of extreme fatigue. A second similar run the following day lasted 3 minutes and 48 seconds. It, too, was terminated because of extreme fatigue. His more specific complaints were similar to those of the subjects that preceded him and were restricted to visual disturbances, respiratory difficulties, and the pooling of blood and tissue fluids in the extremities, particularly the forearms and hands.

Throughout these series of tests, the test-pilot subjects were able to maintain control over the simulated entry vehicle. However, it should be noted that for all but one of the runs presented, the pilot's tracking performance was worse in a high sustained g field than in the earth's constant 1g field (static run). This result is believed significant, even though it was noted that the pilot's tracking scores for this phase of the investigation are of questionable value. This reduction in pilot's tracking performance with increased g is consistent with the results reported in reference 11. Reference 11 also reports on the results of the present investigation and deals specifically with the ability of the pilot to perform in a high sustained acceleration field.

From these data and those of the studies of tolerance to acceleration previously made by others, it is possible to construct time tolerance to acceleration boundaries, the derivation of which is shown in reference 11. In addition, it is possible to relate these boundaries to the accelerations anticipated during atmosphere entry from circular or parabolic orbits. Figure 13 illustrates these boundaries and requirements. The dashed curve on the right illustrates the maximum g's and the length of time during which they would have to be endured by an occupant of a ballistic vehicle entering the earth's atmosphere from a lunar mission. Note that this is not a time history but rather each point on the curve represents an atmosphere re-entry trajectory with a different initial entry angle. The curve shows, for example, that by proper drag modulation, the vehicle could encounter a maximum of 10g's during entry. This 10g level would have to be endured for about 1-1/4 minutes. The left-hand dashed curve illustrates the ballistic vehicle entry from circular orbit with a constant initial entry angle (γ_e) of -5°. Note that the negative A_X, or eyeballs out, and the positive A_X, or eyeballs in, boundaries are shown to be one and the same. It was demonstrated in this study that with suitable restraint, the tolerance to eyeballs out accelerations is at least as good as the tolerance to eyeballs in accelerations. As is seen in figure 13, man, if properly restrained, is capable of withstanding the acceleration stresses required of re-entering from circular velocity. However, in an entry from parabolic velocity (lunar mission), man's tolerance to acceleration as presently understood could be exceeded.

A
4
5
3

General Effects

It would appear that the major distressing physical limitations encountered involve mainly three body systems - visual, cardiovascular, and respiratory - of which the latter seemed to be the most severe. In two instances a physiological end point was established and both instances concerned the loss of vision which prohibited continuation of the tracking task. These events occurred on one of the 6 A_N tolerance runs and on one of the diagonal, or combined, negative A_X and A_N tolerance runs. On all other occasions the subject terminated the run because of exhaustion.

In no instance was there any prolonged incapacitation after any of the tolerance runs. Rapid recovery to a prerun state in a matter of a few minutes was the rule. There was some residual fatigue but this was no greater than that seen after the routine phase 1 and 2 exposures. The question of rate of recovery once the acceleration is over is yet an open one and of considerable importance since the pilot having flown the re-entry must still be able to make a landing. This is a problem for future investigation.

Visual disturbances were minimal during the positive A_X runs. They were somewhat more prominent during the negative A_X and combined negative A_X and A_N accelerations. There appeared to be two distinct factors involved in their etiology. During the A_N and combined A_N negative A_X accelerations, the problem of graying out or blacking out was foremost. This is largely a hemodynamic problem and can be prevented to a degree, or at least delayed, by the use of certain mechanical supports, such as the g suit. Better protection than that offered by the g suit is required for more severe and prolonged A_N accelerations and this might be afforded by the use of a water filled half-suit for the abdomen and lower extremities.

The visual disturbances encountered during the negative A_X accelerations were of a different sort. They had to do with the problem of visual acuity and were not so severely incapacitating. As pointed out by White in reference 12, they are probably due to mechanical effects on the occular components. It has been thought that lens displacement and/or tilting of the receptors in the retina, thus reducing their optical efficiency, were the etiological factors. However, since so much of the refraction of light takes place anterior to the crystalline lens, it would appear that other mechanical effects are responsible. The pressure of the eyelids on the cornea or other distortions of the corneal surface could account for the loss of acuity. This is substantiated in part by the comments of the subjects that facial movements and varying the lid opening often restored visual acuity. Tears, which sometimes became excessive, may also have been a factor.

The cardiovascular symptoms not related to visual disturbances were occasional cardiac arrhythmias, electrocradiographic changes similar to those pointed out in reference 4, petechial hemorrhages, and blood and tissue fluid accumulation in the extremities. These findings appeared mostly during the A_N negative A_X and combined negative A_X and A_N accelerations. There was no serious loss in the ability to use either the side controller or the toe pedals because of the pooling effect, but there was considerable discomfort. Leg and arm wrappings with elastic bandages and the use of tight fitting gloves for the hands helped to reduce these symptoms a great deal. However, a much better solution to this problem would be a seat that could be adjusted so that the pilot's forearms and particularly his lower legs could be placed at right angles to the direction of the acceleration.

The respiratory symptoms and findings were of major interest and importance. The method used in recording the respirations of the pilot did not yield accurately much more than the respiration rate; however, it was possible to obtain certain objective impressions from a study of the respiratory patterns. Subjectively the negative A_X accelerations were the best tolerated when evaluated from the point of view of lung ventilation. The objective evidence gathered concerning respiration supports this observation but is not conclusive and requires further investigation. It has been shown in previous studies described in references 13 and 14 that there is marked impairment of lung ventilation during positive A_X accelerations.

The reasons for the subjective and objective evidence in support of the relative ease of respiration in the negative A_X as contrasted with the positive A_X accelerations can be found in an examination of the mechanics of respiration as pointed out in reference 15. During negative A_X accelerations the inertial forces of acceleration assist in increasing the anterior-posterior diameter of the chest which normally occurs during inspiration. During positive A_X acceleration these same forces tend to prevent the expansion of the chest by keeping it compressed. Exhalation by the same token is enhanced by the positive A_X but hindered by the negative A_X accelerations. However, this reduction in exhalation during negative A_X acceleration leaves the chest expanded with a larger functional residual capacity which is an advantage. This method of respiration is seen during muscular exercise in which the functional residual capacity is increased by maintaining the lungs in an inflated condition and breathing off the top of a larger lung volume. The result is more efficient oxygenation of the blood in the lungs.

If, therefore, negative A_X accelerations are more favorable toward adequate lung ventilation when compared with positive A_X acceleration and since respiratory function seems to be the most critical factor in tolerance to prolonged transverse acceleration, it would appear that the forward-facing seated position might be preferable in an atmosphere entry vehicle.

A453

An exceedingly important factor regarding the forward-facing seated position is that of the performance of the restraint system and, in particular, its anterior component. The system used in this study was satisfactory for the demands of this program but it would be largely unsatisfactory in an entry vehicle. In particular, the controller arm restraint would have to be markedly improved. As previously pointed out, an adjustable seat might advantageously be incorporated. In general, some of the major difficulties of the forward-facing seated position would be resolved if the seat, restraint, and protective system were integrated and automatically operated, yet completely controllable by the pilot. This is for the most part, an engineering problem.

Appended to this report are the recorded post run questions by the project engineer and the pilot's answers, the medical officers comments and the over-all comments of the pilots. The questions, answers, and comments are added because they express so well in the pilots own words some of the material which has been presented in the report.

CONCLUDING REMARKS

The results of this study demonstrated that a well-trained subject such as a test pilot can adequately carry out a control task during moderately high accelerations for prolonged periods of time. The maximum levels of acceleration tolerated were approximately 6 times that of gravity for approximately 6 minutes, and varied slightly with the direction of the applied acceleration force.

The limitative physiological factors grouped themselves about three body systems, namely, visual, cardiovascular, and respiratory. Most of the tolerance runs were terminated because the subject became exhausted but this incapacitation due to extreme fatigue was of short duration. Rapid recovery in a matter of a few minutes was almost always the rule.

This recovery rate can be of some importance in the high lift-drag-ratio class of vehicle since the pilot must follow an approach procedure and carry out a landing maneuver following an atmosphere entry.

The visual difficulties were not critical during the horizontal accelerations although minor decrements in visual acuity were seen. It is believed that these are the result of distortions in the corneal surface and hence result in transient astigmatic refractive errors. The critical visual symptoms were those that resulted from the A_N or headward accelerations. In two instances the tolerance runs were brought to an end because the pilot could no longer see the instrument panel distinctly since he was graying out.

It was obvious from the subjective observations and the limited objective findings that the negative A_X, backward or eyeballs out acceleration caused the least embarrassment in regard to adequate respiratory function. The positive A_X frontward or eyeballs in accelerations were the most distressing from the respiratory point of view. On choosing a pilot position for re-entry this can be a critical factor when accelerations are moderately high and prolonged.

A special restraint system is required for the forward-facing seated position. The system used in this study proved to be adequate in meeting the demands of this program. It is conceivable that with certain improvements and modifications, the tolerance to acceleration levels obtained in this study might be considerably extended either in magnitude or in time of tolerance or both.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Aug. 8, 1960

APPENDIX A

TEST PILOT'S POST RUN COMMENTS

Subject: R. S.

Acceleration Vector: $-A_X = 4$ $A_N = 4$

A453

Pilot's Comments

The apprehension and perhaps the unfamiliarization with the G field itself makes about the first minute somewhat uncomfortable; first 30 seconds at least before you can relax and take full advantage of the restraint system. Restraint system worked very well, the tensing of the lower legs was fairly important - I feel that the toe pointing method is better than the toe pulling method for tensing the lower legs since you don't fatigue quite so easily. It would be worth a try to use the toe pulling, I think, for the first couple of minutes until you get worn down and then use the toe pointing—pressing method.

The blurring in vision occurs fairly significantly, but is not due to anything physiological. I think it is due more to the sweat coming off your cheeks and down out of your helmet. This is fairly noticeable and I kind of think that the moisture in your eyes over your eyeballs might be causing some of this too because it gets to a constant level and stays there. It seems like you might be looking through a windshield on a rainy day. At about 5 - a little over 5 minutes is when I noticed a cramping in the top of the calf of my leg and sort of when you tense too long, your arms start to shake or something, other than that I think you could go a considerable long way under the restraint system that we have for a long period of time. Breathing felt like they were coming in very short.- It was real comfortable to take real short breaths, but every so often, I couldn't guess at the period, you felt like you wanted to get one good one, then you can go back to a short breath business again. You had to take a good one every once in a while, had to take time out to try to get one good breath in. That is all.

Medical Doctor's Comment

The run was terminated because of the fact that respiration became irregular and the pulse rate was getting very high. On examination after the run, the subject had some petechiae over his ankles and toes and up on the inner aspect of his knees.

3H

Questions by Observer and Pilot's Answers

Question: Any difficulty in walking or standing upright after you got out of the gondola?

Pilot: I would say no, and considering that you have been strapped into one place and you are a bit numb in some cases, if you were strapped right here in that sofa for about 1-1/2 hours, you probably, first time you stood up, would be leary about where you stepped.

A
4
5
3

Question: During the first minute your performance went down considerably and then came up again, was that due to this apprehension, unfamiliarity, or what?

Pilot: I didn't know exactly what the restraint was going to do for me. Once I discovered it was doing a good job up top here I didn't worry about anything up top. I could see OK and I was breathing fairly good and then I concentrated on trying to keep my legs tight - I didn't do anything with yaw control, I was pressing too hard to feel anything. Just like, I guess, if you push as hard as you can with both feet, you can't very well get a differential there that is significant and I think if the centering force were equal to that pressure you were pushing, I might have been flying the whole hop in a constant yaw. I made one or two constant changes in yaw and mechanical type changes, it didn't get me anywhere as far as tension was concerned because this tingling sensation builds up in your feet, if you keep it real tense you feel good except it is just tense.

Question: The effect was to prolong the run in essence. You didn't use yaw control. You had your muscles flexed very tight to prevent pain down the extremities of the limbs.

Pilot: In trying to use the yaw control, you need variations of force down there and tension variations in your legs.

Question: These were worse set of dynamics you have been controlling today. Could you have controlled that, do you think, during a period of six minutes if you had to - if your life depended upon it?

Pilot: I think I could do a lot better if I did it again but not today, maybe tomorrow or Monday.

Question: I notices you still have signs of pressure on your face - a slight indentation. Were there any pains during the run itself?

Pilot: Everything is just trying to squeeze out between the restraint straps, I am glad they molded them to our faces.

Question: If we asked you to talk while making the ride, to count say, could you have spoken or not?

Pilot: Except for my breathing, I would have been able to say yes or no, I wouldn't like to carry on a conversation.

Question: In the right hand with which you were holding the controller, do I understand that you did or didn't feel a tingling very severely in that hand?

Pilot: No, I got the same feeling in both my hands that I had when we had that left strap too tight. As a matter of fact, the blood vessels felt like they were out the same. What felt real good was just getting a hold on that left controller a bit tighter and consciously getting a hold of the right-hand controller tighter. This would be akin to if your foot goes to sleep when you just hang it somewhere, it wouldn't go to sleep if you just had it resting on something. Do you know what I mean?

A453

Question: Did you do any tensing of your pelvic and lower trunk area?

Pilot: The G suit did pratically everything. It varied in periods. When I let the G suit do everything, it seemed like it was filling up my chest too, and when I forced my stomach out against the G suit it seemed to give me some more room in my chest. There were a couple of times when I wanted to get that deep breath so I forced the G suit out, took a deep breath and then relaxed again and took little short breaths.

Question: It has been 20 minutes since you came out. Do you have any tingling now in either the foot or hands?

Pilot: No, I feel just like before I went in.

Question: Is that calf muscle still stiff?

Pilot: It has been stiff for three days - since the first run.

Question: Any further suggestions about supports?

Pilot: What really got to me that was worse than anything was the zipper in my G suit which was right underneath the big straps that go into the couch, and I would have liked to have been rid of the whole shooting match.

Question: Before the runs, could you perceive this pressure or did it appear during the runs?

Pilot: It was slight when we started; however, on the -2 +4 run, I thought it was the long zipper that went down and I thought it couldn't get any worse than that or it is going to have to go in my leg. But this thing is the cross zipper in the lower pocket. I am going to have to leave it open so that it is out here in the fat rather than on the bone.

Question: One thing a man could always do before a ride like this is make sure there are no uncomfortable points at all anywhere before he makes the high G runs for a long period.

A 4 5 3

Pilot: You could take all kinds of hard points, let's say in the lateral axes of the body, but you can't take them in the longitudinal - either behind you or in the couch or in front of you between you and the restraint straps - on this type of run. If you had anything in your pockets that was underneath these restraint straps this would really compound the situation.

One thing, I have tried variations of eating, and different time intervals, and different types of food, and time interval and type of food I had today was the most comfortable of any of the runs that I have made. At 10:00 AM, it was roughly seven hours since I ate a real good meal and it was pretty high protein type, a lot of milk, butter, eggs, cereal and banana.

Question: Let's go over this again, in other words, you ate about that time?

Pilot: At 10:00, about seven hours ago, I had eggs, a lot of milk, butter, cereal, bananas, and this is the most comfortable I have been as far as the middle is concerned.

Question: You feel this is definitely better than a heavy meal closer to the runs?

Pilot: Definitely. I feel really strong about that particular point. As a matter of fact, I am going to look out for it in the future, because I felt real good when I got out as far as just a tinge of anything in the stomach, burping, gas or anything you might have that you couldn't get out.

Acceleration Vector: $-A_X = 5$ $A_N = 5$

Question: Are the eyes watery?

Pilot: It feels like you are looking through a glass of water.

Question: Are your eyes moist now, tears in them?

Pilot: Yes, they are moist now.

Question: Was this g effect on eyeballs or was it due to the tearing?

Pilot: I would say that the water or the moisture is getting in front. Everything else is going in that direction. As a matter of fact, my nose was dripping and I got the scope at about 1 inch at 7 o'clock, with some 7 or 8 shots, so you can see which way things are going in my head.

Question: At the time we hit IC stop, you say you were maintaining visual recovery, is that right?

A453

Pilot: Yes, it is not clear, but you can tell where the horizon is and you can see the dot and tell where the wings of the airplane are. It is not like it is now, of course, but you can tell what is going on.

Question: Well, we ended up that this arbitrary criterion of stopping the run, it says zero if you got to that low. Now we have to decide whether to give you half a minute to recover from the initial phase and then have that the beginning of your period here that we stick to that criteria. What do you think about that?

Pilot: I think you take that first 30 seconds or so under advisement and if the trend continues, beyond, say 45 seconds (it is hard for me to tell in here, I guess it is about 45 seconds or so), "debend," then stop it; otherwise give me a chance to get positioned and recuperate, get in a situation where I am all set to begin the tracking task.

Question: I wonder if it would be better if we not gave you the tracking task right away but let you kind of stabilize out, then start the actual measurements, give you a chance to get onto this thing and get a feeling for it and then actually start measuring your efficiency.

Pilot: Let's start the recording and go right from the beginning but take integrated error from 1 to 5 or 6, whatever the case may be, instead of from zero to 6. Can you do that? Your are integrating this tracking error aren't you, and you are doing it from a total contour, right?

Question: We whip you up, start tracking and start to measure you from the instant you start to track.

Pilot: You can cut the limits then and take the first one under visual advisement so to speak and then use after 1 minute.

Question: Does ACL understand how we might want to run this? We would like to give him the tracking. Let him run for 45 seconds, till he kind of gets on to the dot, gets squared away, and then at that point start the measurements of his tracking efficiency, ACL, we will have to delay until the problem starts automatically - about half way to the top - and we will start the tracking right away and then wait 45 seconds and start integrated pilot performance, I think this will give the pilot a little better shake on it.

Question: Can you describe your breathing technique?

Pilot: Really grunt breathing. The hyperventilation sounds after the run was over was trying to get back to a normal level. Trying to keep your chest cavity tight and tensed against the restraint straps is a pretty lousy feel for normal breathing naturally.

Question: Can you describe your visual field this time?

Pilot: The visual field becomes somewhat restricted. I think the blurriness was about the same as it was on the run on Saturday and the first one this morning, and also, this run. It is not that you can't see; it is just that they are not clear, the end of the lines are not clear, the width of the lines are not clear as they are now, neither is the little circle. The circle appears more solid.

Question: The circle - could you tell the center of it or not?

Pilot: No, you could tell the center because you could see the circumference, you can't see any hole in it at all. That will give you an idea of the blurriness of the lines.

Question: Are you experiencing any vertigo or disorientation right now?

Pilot: No, none at all.

Question: Did you in any part of the run?

Pilot: None, I had not thought of it till you just mentioned it.

Question: What about breathing?

Pilot: I was really grunting there the last couple 10 seconds or so.

Question: Was this due largely to breathing difficulties, was your IC stop due to breathing difficulties?

Pilot: Yes, I was just bushed, I am really bushed to tell you the truth. It was even work to breathe and it even got to be work to even just ride along tensing my legs and trying to keep the blood out of there and concentrating on this concentration, I didn't think we were getting much out of it. I don't think I could have gone much beyond when I stopped it anyway.

Question: In looking at your breathing again, you went into the same type when I stopped you before. I was about to stop you now, because you got to breathing shallowly and then taking deep breaths and then going back to shallow breaths which is what looks like what we call a Cheyne-Stokes type of breathing. Your heart action remained fairly good from what I could see.

Pilot: The visual description of the target, the horizon and the lateral position of the airplanes wings has already been mentioned in comparison to the 4 by 4 run. There is only a slight deficiency in sight which could be stated that whereas a dark area could be seen in the middle of the target doughnut under 4 by 4 run. There was little to no shading whatsoever, the target doughnut appeared fairly solid on the 5 by 5 run. The most uncomfortable factor encountered was breathing, for which I stopped the run. This was particularly so in that the G suit felt like it was occupying the majority of the chest cavity or the torso. In this particular run, the G suit inflation pressure was on high which was probably a mistake since in the previous runs, the G suit inflation valve had been set on low. The rate or lag in the G suit inflation was fairly noticeable. It seems like the body is more acutely sensitive in g or transients in the g fields and there is somewhat of a friction band so to speak where if you transit back and forth, nothing happens whatsoever and the only time you get a good inflation of the suit is when you make a large excursion which complicates the breathing factor. The breathing I think was hyperventilated during the run due to the grunting and the exertion involved in tensing the various parts of the body and also trying to maintain some area in the chest cavity which seemed to be restricted due to the G suit. Practically no useful effort could be gained as far as yaw control is concerned. The legs feel like a couple of stumps, and even the yaw indicating pip is fairly imperceptible. The most perceptual of the scope indications is the lateral indication and next in order is the pitch indication and practically imperceptual is the yaw indication. The pencil controller feels real good inasmuch as practically no effort is involved in twisting or turning or rotating the arm or wrist. It is more or less just finger movements, which is good since the least effort that is needed or expended needlessly is definitely a factor in prolonging the tolerance of the g. General controllability of this controller felt real good - yaw control was practically nil, lateral control was satisfactory. It didn't tend to be any massed overbalance of the controller. Pitch control was good. There is some difficulty in integrating the pitch and lateral combination. I tended to sense a pitch variation - started a correction, sensed a lateral variation, and started to correct, and so forth. I didn't consciously try any two axes corrections, there were probably some but the sensing is such that it seemed that one predominated and then the other, and corrections were made accordingly. The leg position is such that you can just feel the blood running right down your legs, and under this particular g field, no amount of tensing or tightening or twisting of legs seemed to be effective in preventing

A453

this. About the only thing that could be done is let it go down there and live with it.

Question: I would like to summarize some of these things we were talking about at one time, especially the visual disturbances. You said at first they were rather acute on their onset but then you became accustomed to them - is that right?

Pilot: It seems like the first 30 seconds - 45 seconds the whole face is pressing forward very tightly against the restraint, and it is more of a focusing problem. It seems like you are looking through a glass of water.

A453

Question: The markings are indistinct then for a while but did they become better as time went on?

Pilot: They improved appreciably after about 45 seconds and you can get the general idea of where you want to do. You can see the excursions in lateral and longitudinal; yaw excursions are practically imperceptual.

Question: No dimunition of visual fields?

Pilot: I would say no, I didn't consciously make much other visual effort other than an occasional check of the longitudinal g indicator which was the only one which was showing anything.

Question: Did you have any difficulty with vertigo and disorientation?

Pilot: None as a matter of fact I hadn't even thought about it until you mentioned it after the run was over.

Question: Your major difficulty on that run then was breathing?

Pilot: Right, and I think like I said I wish I hadn't had that G suit put on high position. I would like to try it again with G suit on in low position and see what differences there are.

Question: Would you describe the effectiveness of the restraint system including the face restraint?

Pilot: I thought it was real good. I didn't have any pressure points like I did on the 4 by 4 run where the zipper was digging into my shin bone. That was also the wrong positioning of the buckle as we found out today. The buckle with the attachment on it was, or has a tendency on me anyway to lay right on the shin bone and we got that around to the side so that the buckle was more vertical and the strap was across the bone. Other than that, the restraint I though was real good.

Question: I wonder if it would be a fair question to ask you to what degree the acceleration as such influences your ability to operate the hand controller and also your ability to operate yaw control?

Pilot: The acceleration field through the visual blurring I think was the only real significant factor other than the inability to control yaw. The effect of the g field on the longitudinal and lateral control was basically the hazing of the vision whereby it was previously described that the center of the target couldn't be picked out and the horizon line and the wings of the airplane lines were about twice as wide. The pencil controller in its physical makeup is enough dissociation between the normal stick grip normal control with which we usually fly an airplane, so there is no real awareness of trying to put in positive forearm displacements fore and aft or to the side. The dissociation is between a normal type of control is such that you have a hold of this little pencil, your hand is flat, you can make very minute corrections.

A
4
5
3

Question: What are your general comments?

Pilot: It is pretty much the same, the same problems are here. I noticed in yaw control it is extremely difficult to move the feet under any accelerative forces. There is no natural coordination involved, the pilot has to actually think about moving it and apply a real conscious effort to move it.

Question: This vertigo you reported, when did that first begin?

Pilot: It begins when you make a rapid correction or I gave a full down pitch full control and let it come back to zero, and when that happened, the thing was oscillating back and forth and this gives you a confused feeling.

Question: When did the oscillation back and forth start after your pull-down in pitch?

Pilot: I pushed it full down and then let it go, that started the oscillation.

Question: Did it persist after the end of the run?

Pilot: No.

Question: Did you have a disorientation feel to it at the same time?

Pilot: It is hard to explain. A little bit of disorientation when this occurred, you are not exactly sure of what is going on, it seems to be moving quite fast.

Question: On your panel, during that period, were you able to make out the display all right or was it sort of unclear?

Pilot: You could make it out all right. It is a little hard to dope it because things are moving fairly fast.

Question: In other words, you feel it is interpretation rather than being able to see what is there?

Pilot: Right. This time I attempted to rotate my head forward a bit as we started into the run. I didn't have the blurring of vision I had before.

A453

Question: To what do you attribute this?

Pilot: I don't know. It may be anything from lack of oxygen to these cheek plates and the way they push against my cheeks.

Question: Any trouble getting your breath this time?

Pilot: No, I didn't have any trouble.

Question: Any other comments you want to make? You are in good shape for the next run?

Pilot: No, I can't think of any. Yes, I feel good today, that is, for anything up to two minutes.

Acceleration Vector: $-A_X = 6 \; A_N = 6$

Question: I wonder if you could summarize for us while he is getting the picture, any pains or unusual feelings that you had?

Pilot: It didn't feel bad at all. I don't know when you came up on g now since there is a little bit of confusion and this indicator here has not been working. I started to grayout - I guess in about 4 or 5 seconds, I'm not sure - and then I closed up my stomach a little bit tighter in my chest and my vision felt pretty good. It is much easier to pick up motion of the blip and the wings of the airplane than it is to monitor the constant position and then about that time a real surge hit my feet and I tried various turning in and turning out, etc., with my feet but it didn't do any good so I just thought well you got to live with it. The pain and the tingling started to ease off and I felt like I could really get down under this and see what was going on and tracking when the thing stopped. There is sort of a gray level here which it don't appear to be getting any worse, but you don't appear to be getting any better either but at least you can hold your own. That's about it.

Question: What about restraints, did you feel comfortable in those all the time?

Pilot: Real good.

Question: What would you say was your most severe problem then as far as physical well being is concerned?

Pilot: A pain in my lower right leg.

Question: Nothing else? Except your vision, is that it? A

Pilot: Slightly, but this wasn't any worse than the 4 by 4 - even better 4
than the 5 by 5 run. This might be because my head was out much higher 5
than it was in any of the other ones. I don't feel beat at all right 3
now. A slight graying out was experienced at the onset of the run. There was no difficulty in the breathing in the situation which was really a comfort to experience. The flow of blood into the legs is practically unimpeded with binding from the toes to knee and undoubtedly the most discomforting of all the experiences. There is no appreciable effect of relieving this situation. When completely relaxed, I get a better feel of the rudder pedals. Might as well not expend the energy if you are not doing anything worthwhile.

Question: During the graying did the whole panel gray consistently or was there a periodic or segments that were graying and other segments that were clear?

Pilot: It felt like a peripheral-type graying that came in from the side - sort of a conical pattern, which came in from the sides. The tensing of the chest sort of just opened this back up made the visual perception clear. Visual acuity was about the same. On this particular run the head restraint was much tighter, much tighter than it was in the 5 by 5 run. I had practically no latitude in my head, fore and aft movements at all.

Question: Let us go over this matter of straining and relaxing again. Can you describe your straining procedures and relaxing procedures on this run?

Pilot: I wasn't up there very long and I tried several things in real quick order, probably didn't give them a real good test under those conditions. First, I tried to do the old stand by of trying to point my toes, and consequently tensed the muscles up the back of my leg, which didn't help this feeling in the lower leg. But I tried to do this thing in conjunction with a twist end; likewise this didn't help very much even with the twist out. But I did all of these things very quickly in order to find a position which would relieve the situation. Well, I tried relaxing and it seemed like it didn't make any difference. Therefore, I just went back to the relaxed position to try to maintain a good feel of the yaw control.

Question: What about the visual situation in this run?

Pilot: The visual perception decreased appreciably with a graying area which started in the peripheral field. The tensing of the stomach muscles of the chest brought this thing back - brought the visual perception back quite a bit, as a matter of fact, more than I had expected from it - and when I got this back, it sort of put my mind off that. The ease of breathing was a real joy. There was no difficulty in breathing at all this time.

A453 Question: When the g came on, did you have any tendency to have double vision or difficulty focusing your eyes on the object to give proper demarcation of all the numbers on the dials?

Pilot: I didn't look at any other dials except the scope and the onset of g was coupled with this widening of the horizon line and the solidifying the blip. The widening of the horizon line made the yaw fly almost imperceptible. I would say that the yaw indication you could barely see a little chip, top and bottom of each of the line sticking out from the horizon line. You know what I mean.

Question: I have one final question, that is to do with the control itself. How much effect do you believe the g field had on your ability to operate the controller?

Pilot: I don't think that the g field had any real adverse effect as long as you can see what you are doing and your not really uncomfortable as far as the legs are concerned. Of course, you didn't have the breathing problem this time. The g field, except for the discomfort in the lower legs, has no adverse effects at all.

Subject: J. W.

Acceleration Vector: $-A_X = 4$ $A_N = 4$

Pilot's Comments

The initial rotation to the -4g A_X caused no sensations that were bad except a pressure against the restraint device. This was more noticeable in the face than anywhere else. Then as the normal g of 4 was put on, the G suit inflating caused no discomfort. There were some feelings of slight tingling in the legs at this time and in the arms, but no discomfort. The problem of tracking was carried out with no deterioration as near as I could tell on the first part of the run, the vision was good and the breathing cycle did not appear too difficult. Towards the end of the run, the first noticeable effect was a deterioration or blurring of vision such as under normal accelerations. Throughout the run, a tingling and pain sensation in the arms when the arms were being held against the restraint devices. Pulling the arms back into the mold would help this sensation but made tracking more difficult. Towards the end, when the vision became worse, the breathing also was more difficult; as the breathing difficulty increased, the vision difficulty seemed to increase. Towards the last 30 seconds of the run, the impressions I had was of wanting to be through with it because it was becoming uncomfortable, however, I could still carry out the tracking task at this time. I do not feel that I could have carried on a tracking test over another 30 seconds or so because mainly of deterioration in vision but the physiological point was reached to where I did not desire too much to continue the tracking at this point.

A453

Medical Doctor's Post Run Comments

In observing the monitoring system during this run, it was obvious that the subject was holding his own and breathing very well until the last part of the run, when his control started to deteriorate. His pulse rate didn't change markedly. Physical examination after the run showed numerous petechiae over both arms, hands and fingers and over the lower legs, concentrated just below the inner aspects of the knees and over the area below the calf of the leg down to the toes. These areas were wrapped with elastic bandages before the run.

Acceleration Vector: $-A_X = 5\ A_N = 5$

Questions by Observer and Pilot's Answers

Pilot: I am having to help my restraints in order to stay as comfortable as possible, that is, by using my stomach muscles slightly, by tensing my legs by stiffening my arms; these restraints in this position are unsatisfactory.

A453

Question: What is unsatisfactory?

Pilot: The complete restraint requirement since you consider the restraint is made so the pilot is able to fly his vehicle and not worry about his physical conditioning and if you have to spend part of your mental effort on physical effort restraining yourself so to speak, that is, tightening your stomach muscles, tensing your legs, stiffening your arms, then to me this is unsatisfactory.

Question: How much does that influence your rating?

Pilot: I would say this would influence it to a certain percentage, not 100 percent, but under this g field it influences it 25 percent. Under higher g fields I am sure it goes up. As far as I am concerned in the 4 by 4 it had some effect on it.

Medical Officer: You seemed to do very well, in fact, you were breathing so well I picked up some tracings here I didn't expect to get. It worked out very well. I could monitor your respiration as well as your pulse range. Your pulse rate got up but it was regular and there was nothing to worry about even though it was kind of fast.

Pilot: You are forced to breath real rapidly in the g configuration, almost like you are running a mile and you are on the last quarter stretch and about to die.

Question: On your tracking at the very last, what happened to your tracking?

Pilot: It was just a matter of trying to see the thing. I was blurry and as long as I could see it, I could track all right but I was continually focusing my eyes even I tried pulling my head back away from the scope. This seemed to clear it up as long as I could hold my head back a little, but it was just for a few seconds and then I would have to do something else. Mainly I was just trying to focus my eyes opening my eyelids wider - anything to try to focus under normal conditions - and I usually when I could do something, refocus for a moment but I couldn't hold it so it was a continuing process or refocusing to see what the thing was because the vision would get so blurry that I could see more than one presentation.

Question: We noticed that your pilot efficiency suddenly dropped and we were afraid that this was something so that is why we pushed the IC up there.

Pilot: You pushed it? So did I. I thought I stopped myself. I noticed that mainly I couldn't see well enough to find the presentation to continue tracking. My physical condition, outside of an increase in breathing, I think was not much different than when I started. That was about the only discomfort.

Question: How did your restraint system hold up that time, particularly on the face?

Pilot: Very good on the face, in fact, I looked at myself once - it looks horrible. I even had red eyeballs I noticed which are gone now. That was quite interesting to me.

Question: On looking at the scope could you see the lines? How did they appear when they got blurred? Were they widened? Could you tell yaw, for example?

Pilot: I could still pick them all out. Mainly I seemed to get a dual presentation and a blurred presentation, and it seemed to be vertically displaced rather than horizontally. I had a dot up and a dot below and I didn't know which one to chase. The initial discomfort as I came up to the g field was after I got -5 which was fairly good, and then when they put the +5 on, I got quite a painful sensation in my legs, in the calfs and down into the toes. This lasted for about 15 seconds during which I wasn't sure whether I would continue the run or not. At the end of this time the pain let off and from that time on, my lower legs and toes were no problem. The pain remained in my right arm but of a very minor nature - just annoying but not to where it would stop me from doing anything. My breathing was difficult and had to be forced to where I was breathing more rapidly than under a transverse 6g load, but I could seemingly breath deeper. My chest would fill up but I had to keep breathing more rapidly. The principal problem was with vision and I seemed to get a distortion of the presentation. This included a dual presentation to where I saw two steering dots and was not really able to tell which one was the correct one. The distortion in vision if I didn't correct for it would keep me from tracking, it got bad. The only correction I could do was to move my eyelids to open my eyes wider and try to force a better vision this way. I also tried pulling my head back into the mold slightly, this seemed to help a small amount, however, there wasn't sufficient room to move it back. The problem with time continued to be vision. I kept having to make corrections continually and it seemed to be getting more and more difficult at the end of the run to correct to where I could see to track. The only reason I stopped myself at this time interval was vision although my breathing to me had become slightly more difficult at this point. I do feel I could have gone further as far as breathing and body discomfort, but no further as far as tracking ability with decreasing vision. I have another comment, after I got out of the vehicle, I had quite a painful feeling behind both knees; in fact, it was quite difficult to walk until I had stood up and allowed my legs to return to normal. This discomfort was not apparent when I was in the couch and making the runs, only after I got out and stood up. There was no dizziness on the acceleration stopping, however, as I didn't stand up. On getting out of the gondola there was a slight dizziness; this went away shortly after I got out and was seated in the lounge.

Subject: R. C.

Acceleration Vector: $-A_X = 7$

Questions by Observer and Pilot's Answers

Question: You have just finished an eyeballs-out run of 7g in the negative A_X direction in the neighborhood of 5 minutes 10 seconds. We would like to get a fairly complete recording of your observations A
during this run. Take this list of questions and use them as a guide- 4
line going down through the various things noted here and add any other 5
observations you can think of for this run. 3

Pilot: First, there were some visual disturbances. The peripheral vision area this was cut down in clarity. There was some slight blurring in the peripheral area, however, right on the scope itself, and on the instrument panel there were only very minor fuzziness, blurring of vision. This didn't seem to handicap reading of the instruments or analyzing the scope display. It was possible to see the tracking display clearly, and I felt as though this did not at all detract from the capability of tracking. As the run progressed, with the fan and wind blowing in the cab, there was some eye watering which caused 20 or 30 percent loss in eye acuity. During this watering period, I still could track well, but there was a definite loss of vision along with this eye watering. This started after a minute or minute and a half of being at this level. After the initial straining this eye watering business stopped and the normal vision returned until about 4-1/2 minute point and from then on blurring increased slowly and gradually until additional eye straining and facial expressions would not help and again my eyes started to water and this caused me to want to stop the run. Along with this, I noticed that my breathing rate increased after about 4-1/2 minutes and I just felt as though I was becoming fatigued and wearing down and this was the reason for stopping the run. Your next questions are in regard to vertigo and disorientation and nausea and I experienced none of these while in the g field or while slowing down, or even after getting unstrapped; and then after moving out of the chair, and particularly while climbing up the ladder, I had a feeling of more or less complete loss of balance but this did not cause undue disorientation other than not being able to feel as though I could stand upright with any degree of steadiness. There was no nausea; however, there was a heavy fatigue feeling connected with this. Next question is connected with breathing, and I found that this was unrestricted although you did have to more or less strain against the g forces as they affected the inhalations and exhalations; however, it was fairly easy to breathe, I thought, off the top of my lungs, with short panting breaths although I did not mean to intimate they were shallow breaths. They were moderate deep breaths of short duration. On this 7g run I used the same breathing technique that I used on previous runs of 6g level. After about

H

A453

4-1/2 minutes, I noticed that the breathing rate seemed to increase slightly and I did have a feeling of not being able to get enough breath. I had a feeling though that this shortness of breath was due to fatigue - not due to any other associated reaction due to g. just a matter of getting tired and then resultant feeling is one of not getting enough breath. On the area of your questioning here of support restraint systems, I feel as though the localized pressure areas of being on the straps is resulting in a support system that is not very comfortable. Pressure points are high, particularly on the lower points of the legs and at the hips and across the shoulders and across the chest. These straps ought to be wider or more straps or maybe some kind of a net or possibly even some kind of a Fiberglas arrangement to reduce the loads so that you do not have any localized high-pressure points. The legs and arms were wrapped with ace bandages, my feet were taped, and I felt as though this was sort of indirect part of restraint and that they did a good deal in keeping down the pain due to blood pooling. I wore gloves that were tight on my hands so that my fingers and up to the palms of my hands were fairly well supported, but going between the hands and wrists where the ace bandages started were exposed and these did swell and cause some pain. This was true on both right and left hands. This blood pooling in the hands did somewhat affect controllability but not real seriously. On the helmet, early in the run after about two minutes, I noticed a sharp pain above the right eye, which at first I thought was a sinus pain, but after about one minute it went away, so I surmised that my hat was pinching me, the rubber molding maybe around the hat was pinching my forehead. After I got out of the centrifuge, everybody noticed a very sharp mark on my forehead from some sharp part of the helmet. Perhaps a better more form fitted or a hard mold inside the hat would reduce the pressure point. The face restraint was good, such as it is, but it results in high localized pressure points on the cheek bones and "hat" on forehead and somewhat on the chin. Although the chin is comfortable relatively speaking, but the cheek bones get sore after a run like this. As far as the controller was concerned, the operation of the controller in this acceleration field, as this blood pooling accumulated in the right hand and the pain became of higher intensity, it did detract from my ability to use the side-arm controller. However, this was maybe I lost 30 percent of my controller effectiveness so I felt as though I was still able to move the controller in a positive mode of operation and I could track within certain limits. These limits I would estimate as being half as good as I did statically. I thought that I was deteriorating towards the end of the run, however, even at the end when I pushed the stop button. I was still tracking good. On this particular run, I had taped my right hand down to the arm rest about 1/2 way between the elbow and the wrist, and this helped a good deal in keeping my hands from sliding forward on the controller and my one g adjustment of the control stick in the fore and aft direction was OK even at the 7g load. As far as toe pedals are concerned, I don't believe I operated them because I felt that it wasn't necessary to do that in order to continue the tracking job; however, I did feel that they could be operated, but it is my guess that because of blood pooling in the feet and the fullness in the feeling of the muscles, you don't expect to be more than 50 percent efficient compared with 1g operation on the toe pedals.

My comments in regards to comparison of this run with other runs that were made just previous to this felt as though the 7g is an order of magnitude greater than the 6g runs as far as straining against additional force is concerned. You do have to work harder and you very definitely have less margin to work with at 7g as you do at 6g. There is more eye distortion requiring more muscular effort in the face and around the eyes in order to keep focused on the instrument panel. There is more probability of eye watering and which has to be fought off with greater vigor, and this results in more fatigue at 7g than at 6g. Again, I would like to say it requires a great deal more effort at 7g for this length of time than it does for 6g for 2-1/2 minutes. In comparing the 6g runs with the 7g runs, or vice versa, this is in the strap directions $-A_X$, the straining is the same, it helps to tense leg muscles, stomach, and the left-hand grip can be increased and the arm muscles can be strained to assist in the circulation. It is advantageous to strain harder with the higher g levels. This straining results in a very fatigued feeling at the end of a run like this.

Acceleration Vector: $+A_X = 6$ $A_N = 1.5$

Question: Well, we just finished a run which was positive 6 A_X, for approximately 6 minutes. We would like now to have a recording of your observations made during that run.

Pilot: The reason for stopping the run at the end of near 6 minutes was a jaw pain in the jaw sockets and also eye watering, heavy tears forming in the eyes which blurred the vision and I was not able to cure this tearing from the eyes. Also, after about 5 minutes I could see that I was fatiguing because when I would strain and grunt and try to clear up my peripheral vision, I could no longer do so. So, I became concerned about losing forward vision in the onset of blackout. After about 6 minutes this did come about that I could no longer clear up my vision with grunting and straining and blinking my eyes and trying to dry up the tears and stop the tears from coming, I could no longer control that. Also, this jaw pain was at a very high level and may have been causing the tears for all I know but just the combination of these three pains just made me give up. I found that I could interpret the display pretty well, not quite completely clearly, but with only a minor loss in vision. This was most noticeable after about 3 or 4 minutes, somewhere in there. The clarity of the instrument panel was slightly reduced. There was no vertigo or disorientation or nausea during the run and only after becoming unstrapped where I could start to move my head around did I notice any disorientation and then again it was a case of becoming unbalanced. It was very difficult to stand up without having a tendency to fall over sideways. It seemed to me that I was always falling off to the left. This persisted, I'm estimating now, about 15 to 20 minutes. Is that how long it's been since I got out of the gondola, 30 minutes? Well, after about 30 minutes I'm in pretty good shape as far as this disorientation or unbalance is concerned. I do not feel as fatigued from this run as I was yesterday when undergoing acceleration into the straps A_X. I was tired after that. This run, physically and muscularly, I do not feel so tired. This jaw pain cleared up immediately on coming back toward 1g. The tears continued to stream out of my eyes for approximately 2 or 3 minutes after getting out of the gondola. Once they dried up, vision was restored to normal.

On the breathing during the run, there was some fullness in the throat which impaired breathing slightly, although I did find that I could swallow saliva anytime that I wanted to during the run and it would seem to go on down and not block breathing in any way. In the chest area, there was a certain amount of restriction or heavy feeling around the chest which did impair breathing somewhat. However, it was extremely labored breathing. On the support and restrains systems, they were very good. I had no pressure points or serious restraint pains during the run. I did not notice any severe pain due to blood pooling or that sort. I thought that the restraint system was quite effective for the g in this direction. I might mention that the G suit was not inflated during this run. I was always able to operate the controller and also the toe pedals. This controller was the pencil displacement type controller, which the control stick height was reduced so it was a little shorter. That made it a little bit easier to operate. My tracking score was somewhere around 4 to 4-1/2. There were times when I would grunt and strain and allow the tracking area to become excessive. I'd divert attention from tracking and so, therefore, my score was not as good as it was under 1g condition. The overall controllability of the machine in this g field, I thought, was about 3 to 4 - 3-1/2 I would say because I could not satisfactorily and with great quickness damp any oscillations. During this run, I did have the forearm again taped, this is the right-hand forearm, to the arm rest. This tape was about half way between the elbow and the wrist. I thought that this helped some to steady the hand so that that controller could be operated more precisely. In comparing this g field with the one yesterday, I do not feel that I am as fatigued. However, there was a great deal more localized pain which was the reason for stopping the run. It was the pain and eye watering and inability to clear up vision with grunting, and so forth, that was the reason for stopping the run. After coming back to 1g, of course, all the discomfort factors went away, so the end result is a feeling of less fatigue. The straining procedures are a little bit different for this. I tried more abdominal and chest and shoulder straining which did help to restore vision peripheral vision and vision clearness on this run whereas in the g field throwing you into the straps, this type of straining has no effect and doesn't help much. In regards to clearing up the point on this straining, I feel that this straining is not required in the g field, putting you into the straps. That is a $-A_X$ in this program. The last question here is to compare these two g fields from a physiological difficulty in tolerating them for 2-1/2 minutes, and at the end of 2-1/2 minutes, it is kind of a toss up as to which one is the easiest and I think there was a little more fatigue yesterday at 7g than there was today at 6g. However, this jaw pain was beginning to manifest itself and this reached quite intense values after about 5 minutes today; whereas, yesterday there were no extreme local pain areas, although, there were many moderate pain areas. The one today resulted in a local pain in the jaws that was just a little too much.

A
4
5
3

Question: Do you feel now that after this you could have landed an airplane? Suppose you had been in this field for 6 minutes and your task was now to make a landing. Do you think you could have done that?

Pilot: I have been thinking about this sort of question and I presume that you mean land after a practical length of time would come about, after you would be at 1g. I think that you could land the airplane rather sloppily, but safely. Assuming now that you would be at 1g and not be required to guide the aircraft very precisely over a period of a couple of minutes. This several minutes would allow you to get your strength back from such an ordeal and you should be able to guide the airplane down to sloppy but safe landing. I feel that if it were necessary to precisely navigate or precisely control the aircraft on something like a GCA type of landing, anything that would require an extreme amount of concentration, would result in some very sloppy inaccurate flying.

Subject: R. I.

Acceleration Vector: $A_N = 6$

Pilot's Comments

A453

There were no problems physiologically other than vision and right at the beginning of the run vision was blurred about the time I got to 6g and dimmed quite a bit. I seemed to get it back quite a bit but as the run progressed it got dimmer and dimmer and for the last, I would say, minute and a half, I was having trouble telling just where the target was and the scope. The only things I could recall seeing was the scope face and, incidentally, the contrast between the display and the base of the scope makes it almost completely blend together. I could notice out of the corner of my eye the angle of attack indicator moving up and down. That was yellow and black which seemed to be better but the face of the scope looked like it was completely white and I couldn't see the green lines on it. It was very, very dim. Everything else was completely gone, all peripheral vision. I terminated the run when I felt that that thing was getting so bad that I couldn't really tell where the doughnut really was but even at this time other than the breathing getting labored there was no physiologically effects. I felt no pooling, no pains, nothing else.

Questions by Observer and Pilot's Answers

Question: Do you think your field vision changed, anyhow could you see out of the complete field of your eye?

Pilot: No, the only thing I could see was the scope face and then I recall the angle of attack I could see motion in the angle attack indicator and I could read the numbers. I could tell the position of it; however, none of the other instruments or anything else in the panel I did not notice and I do not recall seeing it, no.

Question: I wonder if you could outline your method of straining for this, how you prepared for the run and how you were held up for the point of your straining throughout the run or if there was straining involved?

Pilot: No, there was no straining. I think the G suit did a very good job. The bladder on my stomach was positioned down very low. It did not interfere to any extent with my breathing. There was no requirement that I could determine and I could not detect myself doing any straining during the run. In fact it seemed quite normal, fairly relaxed actually.

Question: Now, lets take your method of breathing, did you tend to take big deep breaths with a bunch of small ones in between or just what procedure did you use?

Pilot: I think breathing was probably pretty normal especially during the beginning of the run probably slightly deeper than normal. Near the end of the run it became faster and I noticed a feeling like you had run a distance and your breathing is heavier and more labored, still fairly deep.

Question: Now, one question about your support. So far as I know this A
is the first time that the contour couch type support system has been 4
used for a A_N type run for any substantial period of time. I wonder 5
if you could describe this type of support for running A_N run like 3
this for a long duration? You might compare it with other supports you have had in other piloting experiences.

Pilot: The couch worked very well. There are no pressure points. I'm pretty sure there are no petechiae or anything else. I felt no pooling. My legs are wrapped. It was quite comfortable, the only part that had any uncomfortable aspect to it was the head. I think having the head supported is a help but in this type of run the way it is supported sort of means you are pulling on your chin and the sides of your ears and the sides of your head. I think you could have a little better support for the head, but the idea of having the head supported I think is a help and, of course, being strapped securely in your seat undoubtedly is a help.

Question: Now about your use of the controller did your hand get tired and fatigued in this operation or were you able to maintain good controllability without having any interference in this regard?

Pilot: There is no problem at all using the controller there was no fatigue involved. The only problem, of course, was trying to figure which way the target was or where the target was to figure out which way to move the controller but moving the controller itself is no problem.

Question: Were you able to have a feeling within your hand of just where the controller was and just exactly what position you were maintaining, that is you have an input here of a stick sensitivity on your hand?

Pilot: Yes, I was able to tell the position of the stick at all times and there was no problem in moving it or telling where it was.

Question: Would you say, now taking this field of acceleration as it is, somewhat independent of the vehicle dynamics, would you say there was an effect of this acceleration on your ability to operate the stick or would you say that it is a subject that you can't really cover yet?

Pilot: The lack of vision definitely reduces the ability to control. I think vision could be improved by a better display, I mean more prominent, possibly larger. Would an 8-ball help out? No, I don't think so, I think on an 8-ball - I think the lines would probably be too small on it, maybe a variation between white and black as there are on some of them it might help.

Question: Now, when you decided to stop the run, what were the primary things that led you to decide. What was the primary reason that you decided to stop?

A453

Pilot: I stopped the run because I felt that my vision had deteriorated to the point that I couldn't really tell where the target was and I was sort of guessing around once in a while. I could barely get a glimpse of it, this was primarily when it was at the extreme from the horizon line and the cross indicating the airplane, the reference line. Once in a while I would get a glimpse of it but it had got to the point that I couldn't do an efficient job of tracking due to the lack of vision.

Question: In other words, it was not pain or discomfort and it was the fact that you felt that you couldn't see well enough to maintain a good tracking performance.

Pilot: That is correct.

Question: One other thing, we haven't checked you on is that of the vertigo, nausea, or disorientation. You have been out now about 15 minutes. What aftereffect do you have now and did you have any sensations of this type during the run?

Pilot: No sensations during the run. Immediately following the run I felt somewhat dizzy and there is a mild vertigo now but it is rather slight.

Question: The question is now what do you mean by a mild vertigo?

Pilot: I would say a slightly unsteady, probably couldn't stand on one foot if I wanted to, probably a slightly unsteady gait. No double vision, no blurring. The question is, being subjected to this for 6 minutes, could I make an approach landing? I think yes, if I had sufficient time if I had to recover my vision which presumably you would have. I think within a minute or two minutes you would be sufficiently recovered in vision and I feel that the vertigo is probably coming from the rotation of this thing and not from the g field. The g field itself, I don't think has any lasting effects of any nature that would hinder to any great degree the ability of the pilot to land.

Question: Are there any final points that you would want to make on the record here?

Pilot: Only that I think this was probably the easiest of the bunch.

Acceleration Vector: $-A_X = 7$

Question: You just finished a $-7\ A_X$ run with tracking task. Would you summarize that run? A453

Pilot: I didn't have any pressure points I can think of or noticed during the run, the support system was good, it is still you are hanging from various straps, it might be more desirable to have larger coverage over the body to restrain you into or back into the mold or seat. Also, the cheek pieces could be bigger and cover more area.

Question: Your use or feel of the foot pedals under these conditions as your feet are taped, could you use your foot pedals effectively when you wanted to use them? Could you feel where they were? What control did you have over your feet?

Pilot: I did not use the foot pedals during the run; the dynamics were not that bad that I had to. I think you could use them alright. You wouldn't have much feel in them. It would be mechanical pushing on one or the other.

Question: Effects of this acceleration field on the short pencil controller, what effects if any, do you think the g field had on the motor activity of operating the controller. This independent of any visual problem you had?

Pilot: I think a g field this high reduces the ability to make fairly large precise motions of the controller not to any serious degree, but there is some reduction.

Question: Is there a difference in the direction, forward and backward motions as compared with the sideward motions?

Pilot: None that I noticed on it.

Question: Blurring of vision in your left eye, in the beginning or later in the run?

Pilot: I noticed some blurring and also some double vision late in the run after a few minutes, partially due to some tearing in the left eye and, I don't know, fatigue or something.

Question: Let us take your vision for the first 23 seconds, that is the period of time from beginning until you received the tracking task. Did you have any vertigo or visual problems during that specific segment up to and prior to beginning of tracking?

Pilot: None that I can recall - perhaps very slight blurring of vision but easily ignored. This is not anything like it was on first few times we went to this A_N.

A453

Question: What about segment after that including the blurring of left eye, could you see the scope blurred in vertical or horizontal mode or in both directions?

Pilot: It seemed to me in both directions, I can see the inside of the dot, it was just fuzzy, there is one thing - it seemed to me - I am not sure of this - perhaps when I relaxed, my vision seemed to split into two images and I think it might require some tensing of some kind to keep the vision focused on the scope.

Question: You have had a number of runs in different fields. How much practice if any do you think the experience you had helped you in making runs of this type? Do you feel there has been a physiological adaptation conditioning here which is significant or not?

Pilot: Yes, the runs are easier to make, the standard g fields we are running, at first they were trying. I felt that 2-1/2 minutes you pretty well had it and was ready to quit, during the latter days program running these same g fields, there is no problem at all, not particular fatigue or at the end of 2-1/2 minutes, I felt like 1g, could go on a lot longer.

Question: As an informal opinion, how much of practice or how much increase do you think might occur as a result of assume that you were going to repeat this for a period over a years time, do you think your ability to endure runs would continue to rise or would there be a level off here relatively soon?

Pilot: I think after 2 or 3 weeks, there would be a leveling off. I felt in the $-A_X$ direction, I felt better actually during the middle of the program than I did towards the end, this is probably due to a cold, the $+A_X$ seemed to be getting easier every time I tried it. I think the same would go for the A_N, this seemed endurable as time went on. This also may have been due to better protection, the G suit and so forth, but the $+A_X$ I think at least 3 weeks, I am still getting to feel more comfortable with each ride.

Question: Compare $-A_X$ and A_N, I know the magnitudes in these modes are not the same necessarily, what could you now indicate the primary physiological effect of each one and relative difficulty of each one?

Pilot: Physiological I think the normal was actually as comfortable as any of the others with the exception that vision became a problem, deteriorated and just about gone at the end. I had previously thought that the $-A_X$ was more comfortable than the $+A_X$, but in these last few days, the $+6\ A_X$ has been easier than the $-6\ A_X$ but I still feel this is partially due to the cold in my head. One other thing, I have learned to breathe well in the $+A_X$ direction, until I got this cold, breathing was no problem in the $-A_X$, this may be one reason I have reversed my opinion here. I think it gave me some advantage although when we were running fields of minus and plus A_X at the same time, when we first started running with same magnitude I liked the $-A_X$ better at first, it wasn't until just recently that I have felt comfortable in $+A_X$ field.

A 4 5 3

Subject: J. H.

Acceleration Vector: $-A_X = 7$

Questions by Observer and Pilot's Answers

Question: Describe your feelings throughout this run, ability to see, breathe, general welfare, ability to track and so forth, if you will.

A 4 5 3

Pilot: I think this first thing was force of the windup, I had a feeling that I was definitely going to 7g, I was sort of expecting about what I got, a tremendous windup, it took me a couple of seconds to get oriented which I might add happens after every run, but this time it took the breath out of me and I did not start my tracking exercises on time. It looked like I was a little behind then I caught it on a 4 negative g run, I noticed I had a tingling in my fingers which I thought over a period of time was disconcerting but in the 7g run I did not notice any discomfort at all as far as tingling or hanging up in the straps. One thing that did bother me was I was perspiring a bit and I was dropping quite a bit of perspiration onto the instrument panel and it was also streaming up my chin strap into my nose and it was becoming a problem to breath and I could hear myself breathing extremely hard, at least I thought I was and that became a real problem. I didn't have any loss of vision over the time period of the run, I could see just as well at the end as at the beginning but perspiration was becoming a problem.

Question: In comparing the various g fields you went through, how would you compare the positive transverse and the normal g field and negative g field as to their tolerability?

Pilot: I think it is easier to operate in a negative g field. I am surprised I am making this statement but the 4 negative g field seemed very easy, I was very relaxed I had no trouble shifting around on controller and I thought I tracked better on that phase than on any other phase. At 7 negative g, I think it was psychological, I was expecting a big windup there and I got it. I think the 4 positive g would be more discomforting over a long period of time than 4 negative. I don't know what g forces I had here, I thought I had been in the gondola only a total time of around 15 minutes maximum. I lost track of all time while I was in there.

Question: During the buildup on negative 4 and 7 did you notice any trouble adjusting your vision right from the outset?

Pilot: In the negative 7g run I got behind the airplane just a bit it took me a while to get my senses, I had the feeling that my breath had just been sucked out of me for a second. On the 4 negative g run I had no trouble at all, was very relaxed all the way through and I just felt that it was so easy that I didn't believe I was getting 4 negative g's.

Question: At 7 negative g did you notice any difficulty in your hands, forehands, lower legs and toes?

Pilot: No, on the negative g I didn't notice any tingling, hanging up in the straps, one thing I did fail to mention, on the 7 negative g, rudder controls seemed to be extremely deliberate, I mean rudder movement had to be thought out, I thought I had more stable rudders on 7 negative g condition because it was so hard to reach the rudders. More positive forced gradients.

A
4
5
3

Question: How well were you able to feel the position of the stick with your hands and the position of your feet during this last run?

Pilot: I could feel my hand position well, I found that with stick control that was no problem but with rudder control, I had to think about it before I could act, sometimes I had to say well we arrive on the right side of the scope, so, therefore, you must need a right rudder, it was extremely deliberate because I had to reach up to touch my rudders.

Question: Any vertigo or disorientation?

Pilot: Towards the end of the 7 negative g run, before I hit the stop button I was getting slightly nauseated from all this water in my nose, I felt as if I was going to get in trouble there if I didn't do something about it.

Question: In your opinion was this perspiration due to heat generated due to being confined in the gondola or due to excitement or uncertainty that you were experiencing making this run?

Pilot: I don't think it has anything to do with the gondola or such. I generally give off a lot of perspiration when I am doing something, when it is difficult I really seem to perspire more than normal, especially in flying or hard studying or anything like that, I just generally tend to sweat. I don't notice it while it was going on, until it started to get to be a problem of navigation.

Question: After you leave this g field, do you think you could go down and make a landing now, say for example, a jet making a critical landing giving a minute or two between let us say 3 minutes to go from here to landing approach and make a landing, could you do it with a reasonable degree of accuracy?

Pilot: I don't think you could go from 7 negative g to a normal landing unless you had a couple of minutes at least to reorientate yourself, as I was being clanked around from negative g's back to static condition, it really got to me at a moment there, I felt worse then at that period, I think that is the problem the arm rotating going around in circle makes it harder on you. It is hard to exactly cut it out, I always tend to see light out of the gondola I think you do better if you had a black cockpit except for your instruments. I think if you had visual break through to a point where you can get it off the gages and relax for just a minute and then go down to a visual landing I don't think you would have any trouble making that, but if you have to come down on instruments I think you will need at least 2 minutes to reorient yourself. I think coming out of negative g, I was a little woozy and I don't think I could have made a good instrument approach or flown instruments down maybe to 30 seconds before visual landing, I think you need more time to get set up than that. I think it can be done but I think you should have 1-1/2 or 2 minutes to reorient yourself.

REFERENCES

1. Lombard, C. F.: Human Tolerance to Forces Produced by Acceleration. Douglas Aircraft Co., Rep. ES-21072, Feb. 27, 1948.

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. Bondurant, S., Clarke, N. P., Blanchard, N. G., Miller, I. T., Hersberg, R. R., and Hiatt, E. P.: Human Tolerance to Sonic Accelerations Anticipated in Space Flight. USAF MJ. vol. IX, no. 8, Aug. 1958.

4. Webb, M. G.: Some Effects of Acceleration on Human Subjects. NADC-MA-5812, Sept. 1958.

5. Miller, Hugh, Riley, M. B., Bondurant, S., and Scott, E. P.: The Duration of Tolerance to Positive Acceleration. WADC-TR-58-635, Nov. 1958.

6. Roman, J. A., Coermann, R., and Ziengenrusher, G.: Vibration, Buffetting and Impact Research. Journal of Aviation Medicine, vol. 30, no. 2, Feb. 1959.

7. Clark, Carl, and Woodling, C. H.: Centrifuge Simulation of the X-15 Research Aircraft. Presentation at the Aero-Medical Association Meeting, 27 April 1959, Los Angeles, California.

8. Sadoff, Melvin: The Effects of Longitudinal Control-System Dynamics on Pilot Opinion and Response Characteristics as Determined From Flight Tests and From Ground Simulator Studies. NASA MEMO 10-1-58A, 1958.

9. Sjoberg, S. A., Russell, Walter R., and Alford, William L.: Flight Investigation of a Small Side-Located Control Stick Used With Electronic Control Systems in a Fighter Airplane. NACA RM L56L28a, 1957.

10. Smedal, H. A., Stinnett, G., and Innis, R.: A Restraint System Enabling Pilot Control While Under Moderately High Acceleration in a Varied Acceleration Field. NASA TN D-91, 1960.

11. Creer, Brent Y., Smedal, Harald A., Captain, USN (MC), and Wingrove, Rodney C.: Centrifuge Study of Pilot Tolerance to Acceleration and the Effects of Acceleration on Pilot Performance. NASA TN D-337, 1960.

12. White, William J.: Acceleration and Vision. WADC TR-58-333, Nov. 1958.

13. Zechman, Fred W.: The Effects of Forward Acceleration on Vital Capacity, WADC TR-58-376, Dec. 1958.

14. Cherniak, N. S., Hyde, A. D., and Zechman, F. W.: The Effects of Transverse Acceleration on Pulmonary Function. WADC TR-59-347, June 1959.

15. Gauer, O., and Ruff, S.: The Limits g Endurability for Centrifugal Forces in the Back to Chest Direction. (Die Ertraglichkeitsgrenzen fur Flichkrafte in Richtung Rucker-Brust). Luftfahrtmedizin, vol. 3, no. 3, 1939, pp. 225-230.

TABLE 1.- TOLERANCE DATA; SUBJECT R.S.

ACCELERATION A_X A_N	T AT 90 % MAX ACCELERATION	P.E.%
STATIC	——	57
-4 4 (5.65)	5'48"	-10
STATIC	——	39
-5 5 (7.07)	47"	0 -10
-5 5 (7.07)	1'15"	0
STATIC	——	55
-6 6 (8.49)	20"	25 for 15"

TABLE 2.- TOLERANCE DATA; SUBJECT J.W.

ACCELERATION A_X A_N	T AT 90 % MAX ACCELERATION	P.E.%
STATIC	——	25
-4 4 (5.65)	3'35"	35
STATIC	——	50
-5 5 (7.07)	2'42"	45

TABLE 3.- TOLERANCE DATA; SUBJECT M.T.

ACCELERATION A_X A_N	T AT 90 % MAX ACCELERATION	P.E.%
STATIC	——	75
-4 4 (5.65)	3'7"	50
STATIC	——	82
0 6	5'13"	53

TABLE 4.- TOLERANCE DATA; SUBJECT R.C.

ACCELERATION A_X A_N	T AT 90 % MAX ACCELERATION	P.E.%
STATIC	—	79
-7 0	4'47"	45
STATIC	—	83
+6 1.5 (6.18)	5'57"	58

TABLE 5.- TOLERANCE DATA; SUBJECT R.I.

ACCELERATION A_X A_N	T AT 90 % MAX ACCELERATION	P.E.%
STATIC	—	70
0 6	6'27"	50
STATIC	—	75
-7 0	2'45" *	63

* SUBJECT HAD UPPER RESPIRATORY INFECTION HAMPERING BREATHING DURING RUN

TABLE 6.- TOLERANCE DATA; SUBJECT J.H.

ACCELERATION A_X A_N	T AT 90 % MAX ACCELERATION	P.E.%
STATIC	—	40
-7 0	2'23"	25
STATIC	—	60
-7 0	3'48"	55

A
4
5
3

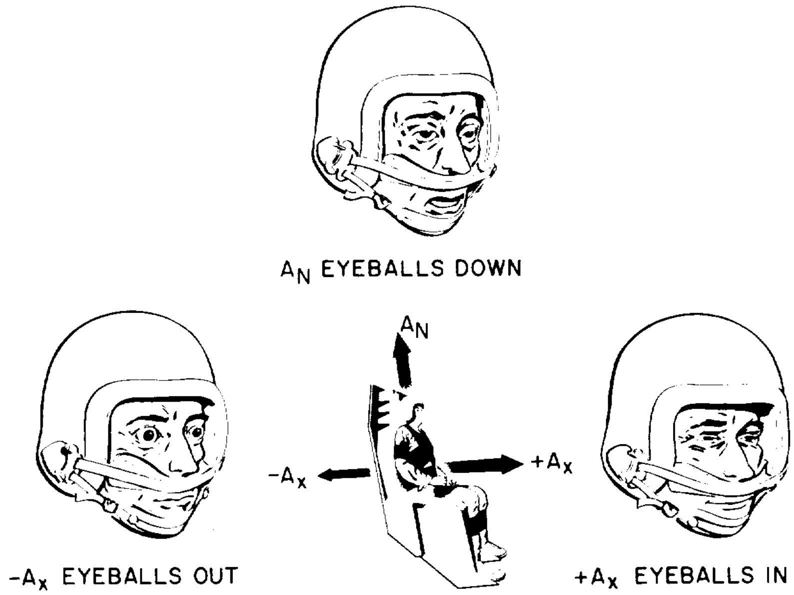


Figure 1.- Acceleration vectors and pilot vernacular for impressed acceleration.

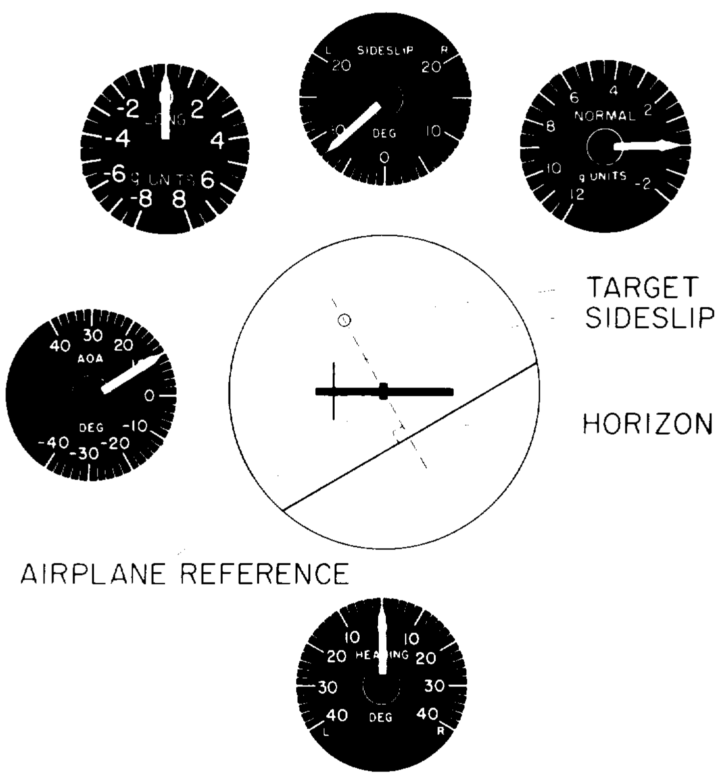
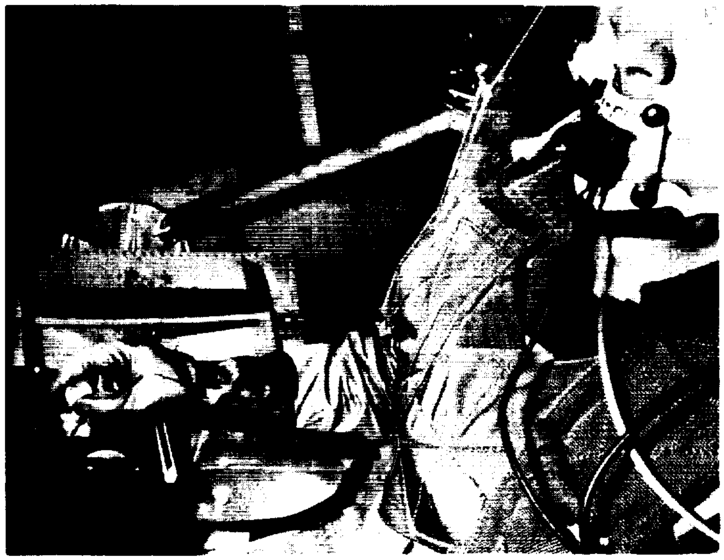
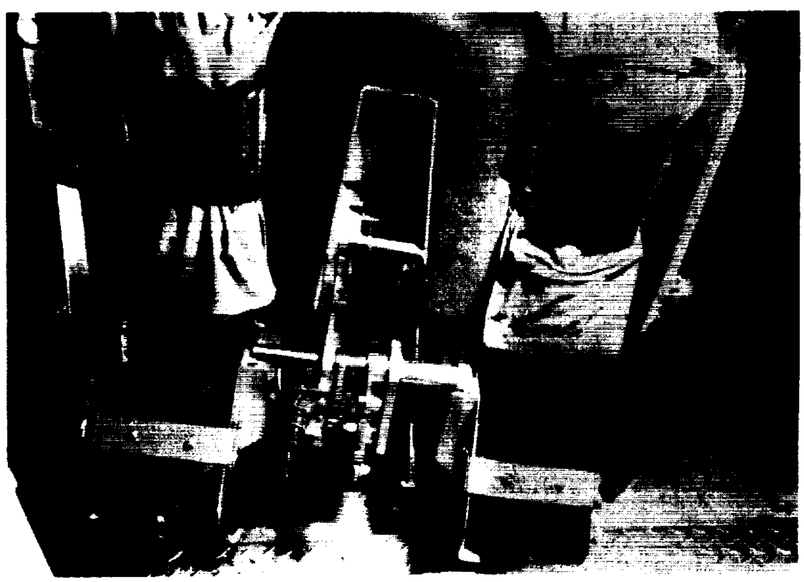


Figure 2.- Pilot instrument display.



A-25822

Figure 3.- Two-axis side controller used for the test.



A-25976-25

Figure 4.- Toe pedals used for yaw control.

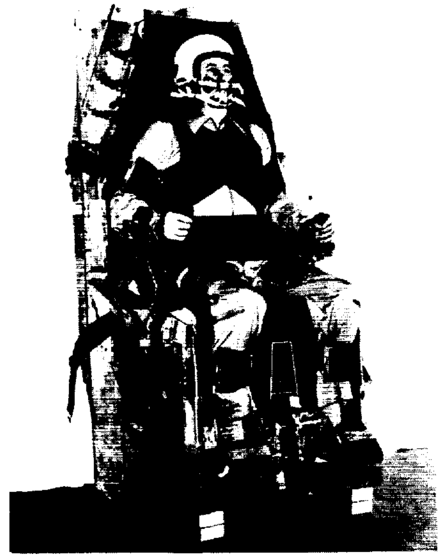
A
4
5
3

A-25976-26

Figure 5.- Typical body mold used for the tests.

A-25982

Figure 6.- Detail of head restraint system.



A-26251

Figure 7.- Over-all view of restraint system.

A-25976-24

Figure 8.- View of arm and leg wrappings.

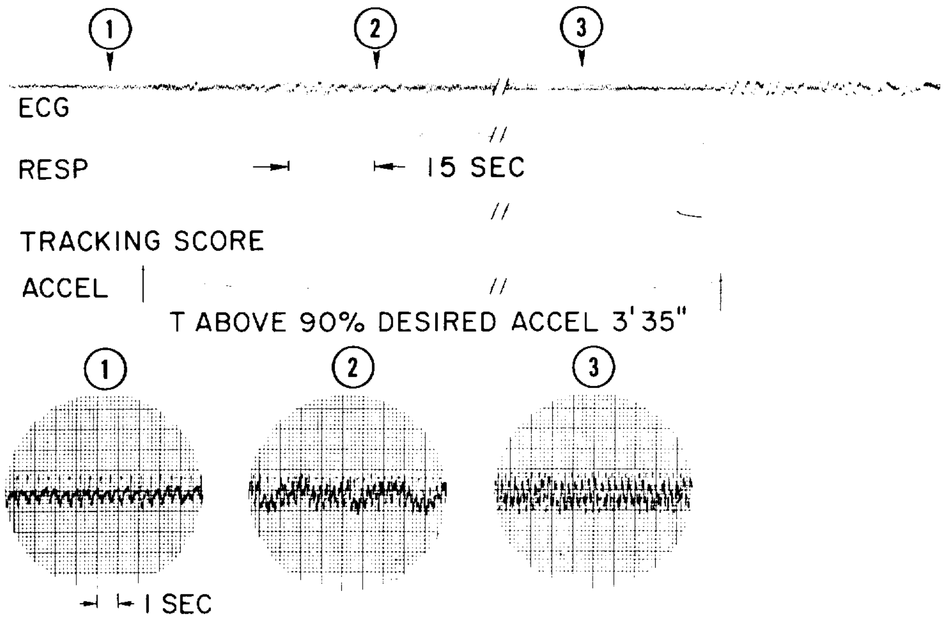


Figure 9.- Sanborn recorder data; subject J.W.; acceleration $-A_X$=[illegible]. A_N=[illegible].

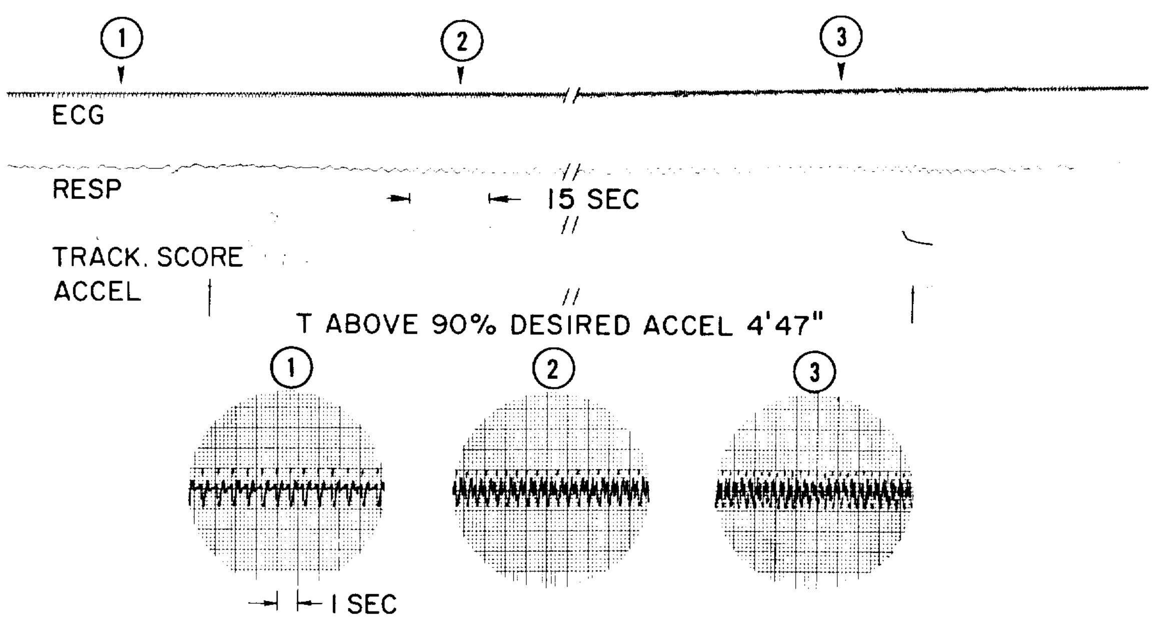


Figure 10.- Sanborn recorder data; subject R.C.; acceleration $-A_X$=[illegible], A_N=0.

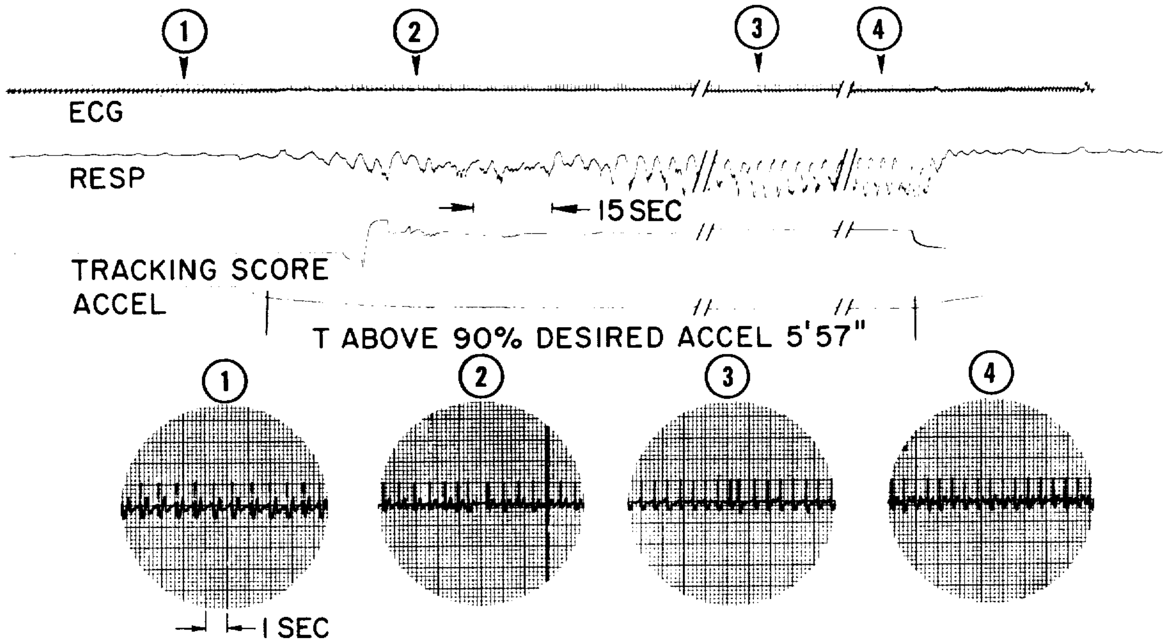


Figure 11.- Sanborn recorder data; subject R.C.; acceleration A_X=6, A_N=1.5.

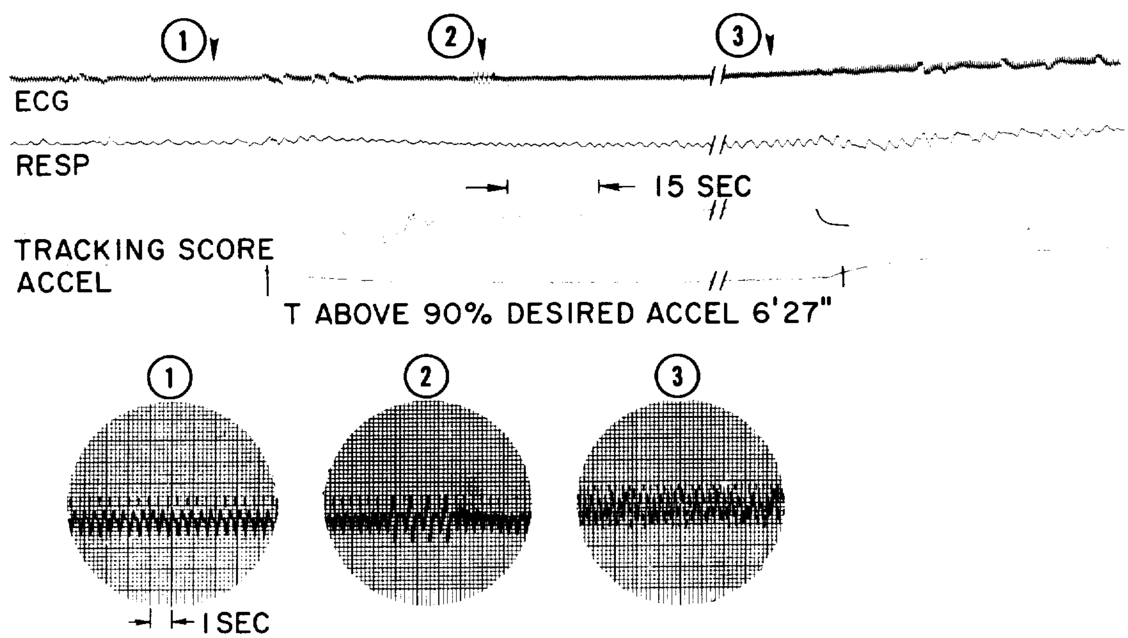


Figure 12.- Sanborn recorder data; subject R.I.; acceleration A_X=0, A_N=6.

A
4
5
3

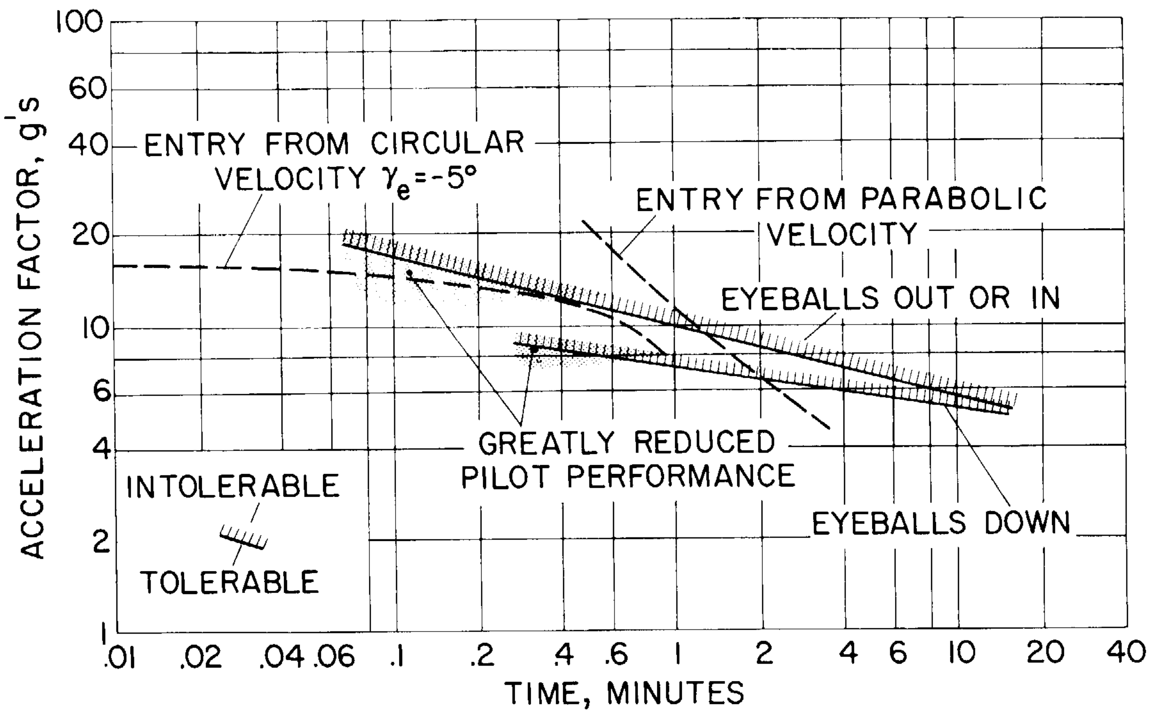


Figure 15.- Time tolerance-to-acceleration boundaries.

NASA TN D-345
National Aeronautics and Space Administration.
PHYSIOLOGICAL EFFECTS OF ACCELERATION OBSERVED DURING A CENTRIFUGE STUDY OF PILOT PERFORMANCE. Harald A. Smedal, Brent Y. Creer, and Rodney C. Wingrove. December 1960. 57p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-345)

An investigation has been made in an attempt to establish meaningful human tolerance to acceleration boundaries typical of those which might be encountered by a forward facing pilot flying an atmosphere entry vehicle. The experiment was accomplished utilizing the Johnsville Centrifuge as a flight simulator and operated as a closed loop system, with a representative control problem. The physiological effects of these accelerations on the circulatory, respiratory, and visual systems are discussed.

Copies obtainable from NASA, Washington

I. Smedal, Harald A.
II. Creer, Brent Y.
III. Wingrove, Rodney C.
IV. NASA TN D-345

(Initial NASA distribution: 8, Behavioral studies; 34, Piloting.)

NASA

NASA TN D-345
National Aeronautics and Space Administration.
PHYSIOLOGICAL EFFECTS OF ACCELERATION OBSERVED DURING A CENTRIFUGE STUDY OF PILOT PERFORMANCE. Harald A. Smedal, Brent Y. Creer, and Rodney C. Wingrove. December 1960. 57p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-345)

An investigation has been made in an attempt to establish meaningful human tolerance to acceleration boundaries typical of those which might be encountered by a forward facing pilot flying an atmosphere entry vehicle. The experiment was accomplished utilizing the Johnsville Centrifuge as a flight simulator and operated as a closed loop system, with a representative control problem. The physiological effects of these accelerations on the circulatory, respiratory, and visual systems are discussed.

Copies obtainable from NASA, Washington

I. Smedal, Harald A.
II. Creer, Brent Y.
III. Wingrove, Rodney C.
IV. NASA TN D-345

(Initial NASA distribution: 8, Behavioral studies; 34, Piloting.)

NASA

NASA TN D-345
National Aeronautics and Space Administration.
PHYSIOLOGICAL EFFECTS OF ACCELERATION OBSERVED DURING A CENTRIFUGE STUDY OF PILOT PERFORMANCE. Harald A. Smedal, Brent Y. Creer, and Rodney C. Wingrove. December 1960. 57p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-345)

An investigation has been made in an attempt to establish meaningful human tolerance to acceleration boundaries typical of those which might be encountered by a forward facing pilot flying an atmosphere entry vehicle. The experiment was accomplished utilizing the Johnsville Centrifuge as a flight simulator and operated as a closed loop system, with a representative control problem. The physiological effects of these accelerations on the circulatory, respiratory, and visual systems are discussed.

Copies obtainable from NASA, Washington

I. Smedal, Harald A.
II. Creer, Brent Y.
III. Wingrove, Rodney C.
IV. NASA TN D-345

(Initial NASA distribution: 8, Behavioral studies; 34, Piloting.)

NASA

NASA TN D-345
National Aeronautics and Space Administration.
PHYSIOLOGICAL EFFECTS OF ACCELERATION OBSERVED DURING A CENTRIFUGE STUDY OF PILOT PERFORMANCE. Harald A. Smedal, Brent Y. Creer, and Rodney C. Wingrove. December 1960. 57p. OTS price, $1.50.
(NASA TECHNICAL NOTE D-345)

An investigation has been made in an attempt to establish meaningful human tolerance to acceleration boundaries typical of those which might be encountered by a forward facing pilot flying an atmosphere entry vehicle. The experiment was accomplished utilizing the Johnsville Centrifuge as a flight simulator and operated as a closed loop system, with a representative control problem. The physiological effects of these accelerations on the circulatory, respiratory, and visual systems are discussed.

Copies obtainable from NASA, Washington

I. Smedal, Harald A.
II. Creer, Brent Y.
III. Wingrove, Rodney C.
IV. NASA TN D-345

(Initial NASA distribution: 8, Behavioral studies; 34, Piloting.)

NASA