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WADC TECHNICAL REPORT 52-317

SECURITY INFORMATION

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**A COMPARATIVE STUDY OF TWO EXPERIMENTAL PNEUMATIC
ANTI-G SUITS AND THE STANDARD USAF G-4A ANTI-G SUIT**

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FEBRUARY 1953

WRIGHT AIR DEVELOPMENT CENTER

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February 1953

RDO No. 695-76

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report presents a phase of a collaborative research project to investigate the problem of finding more effective protection against positive acceleration. It was undertaken by the following group: H. O. Sieker, Capt. USAF (MC) Project Scientist, E. E. Martin, Capt. USAF, O. H. Gauer, M.D., J. P. Henry, M. D., with the technical assistance of R. F. Managan, T/Sgt., R. U. Whitney, J. E. Boothby, A/1C, J. S. Yero, A/2C, J. A. Pettitt, and M. F. Lee. The project is identified by Research and Development Order No. 695-76 entitled "The Principles of Protection Against Acceleration" and was assigned to the Acceleration Section, Biophysics Branch, Aero Medical Laboratory, Directorate of Research. The group acknowledges the support and encouragement given by the David Clark Company. Finally the group wishes to express its appreciation to the laboratory personnel who were subjects for the various studies.

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ABSTRACT

Two new types of pneumatic anti-g suits have been examined which apply pressure to a greater portion of the lower part of the body than the standard C-4A suit. The two suits consist of (1) complete coverage trousers composed of a connected system of circumferential bladders and (2) full pressure trousers. These two types of anti-g suits provide 0.7 to 0.9 g more protection against acceleration than the standard G-4A anti-g suit which afforded 1.8 g protection. A comparative study of the effect of the three types of protection on arterial pressure, venous pressure and vertical heart-to-head distance was undertaken on human subjects. During acceleration the inflation of the two experimental suits maintained mean arterial pressure at eye level and venous pressure at heart level higher than did the G-4A suit under the same conditions. The shortening of the heart-to-head distance was not significantly different with the three types of protection. It is believed that greater protection is afforded by the experimental anti-g suits because they apply greater pressure evenly to a larger portion of the lower part of the body than the G-4A suit is able to do. By this means they increase peripheral arterial resistance and venous return to the heart more effectively than the G-4A anti-g suit.

The two experimental suits have been shown to be an effective and comfortable type of protection against acceleration. Within the limits of blackout or comfort tolerance of the subject, these suits have been demonstrated to be safe for human use. Moreover, they may be incorporated into a combination altitude, anti-g and exposure suit. These new anti-g suits have the disadvantage of being bulky, poorly ventilated and in the case of the full pressure suit, difficult to don. It is concluded that further study, testing, modification and development of these anti-g suits should continue.

The security classification of the title of this report is UNCLASSIFIED.

PUBLICATION REVIEW

This report has been reviewed and is approved.


ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

The pneumatic anti-g suit has been shown to be an effective mechanical means for increasing human tolerance to positive acceleration, (1, 2, 3). The bladder type G-4A anti-g suit now in standard use by the USAF provides approximately 2.0 protection (4). However, in an effort to find more effective and comfortable means for mechanical protection, an investigation of various types of anti-g suits has continued. The purpose of this study is to compare the standard G-4A suit with two new types of anti-g suits, the full bladder trousers and the full pressure trousers.

The principle of an anti-g suit is to apply pressure evenly over as large a portion of the lower extremities, buttocks and abdomen as possible. Three reasons are usually given for the increased positive-g tolerance associated with the application of pressure over this region of the body. First the applied pressure increases the peripheral arterial resistance with an associated elevation in arterial pressure which will increase the tolerance to positive acceleration. Secondly, the application of pressure is thought to increase the amount of blood available to the heart during the exposure of a subject to positive acceleration. Lastly, it is thought that pressure over the abdomen elevates the diaphragm and heart and so decreases the vertical heart-to-head distance. The tolerance to acceleration is increased in this case because the hydrostatic column extending from the heart to the eyes and brain is shortened just as it is when the subject changes from the upright seated position to one of the modified prone or supine positions which also increase g-tolerance. Opinions vary as to which of these three factors is of the greatest importance. Probably all three contribute to the protection afforded by the anti-g suit.

The first types of anti-blackout suits attempted to fill the qualifications for a theoretical anti-g suit. An example of one of the earlier suits was the Frank's Flying Suit (5). With the garment water-filled to heart level, the hydrostatic pressure automatically equalized the internal pressure built up in the fluids of the body by the accelerating force. This type of anti-g suit provided 1.7 g protection. Greater protection was obtained by the use of a combination of air and water pressure in this suit (6). This kind of protection, while having many advantages, proved to be impractical for use in an aircraft and a more usable anti-g suit had to be developed. Based on earlier studies (7, 8) a system of pneumatic bladders which covered the abdomen and portions of the thighs and calves was developed for protection against acceleration. The G-4A anti-g suit now in standard use by the United States Air Force is a modification of these early pneumatic suits. It provides approximately 2 g protection and is reasonably comfortable and practical for use in an aircraft. With this suit, however, pressure is applied only to portions of the lower part of the body. Moreover, the pressure is applied unevenly. It was believed that greater protection against acceleration could be obtained by an anti-g suit which would apply pressure evenly over the entire lower portion of the body. In order to find a more effective pneumatic anti-g suit which could easily be integrated into a combination altitude, anti-g and exposure suit, an investigation of other types of mechanical protection has continued.

SECTION I

DESCRIPTION OF THE TWO EXPERIMENTAL ANTI-G SUITS USED IN THESE STUDIES

It had been suggested that the lower half of the full pressure altitude suit which is being developed by the U. S. Navy would be an effective anti-g suit. The full pressure garment used in these studies (Figure 1) was developed by the David Clark Company for use as a pneumatic anti-blackout suit. A variant of this particular suit was also developed at the suggestion of the U. S. Air Force. This full bladder suit (Figure 2) consists of circumferential bladders which completely cover the lower portion of the body from the waist to the feet.

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Figure 1 - Subject wearing the full pressure anti-g suit. In this particular model the outer reinforcing trousers were attached to the inner trousers and were adjusted to various sizes by the lacing on each leg.



Figure 2 - Subject wearing the full bladder anti-g suit. The outer appearance is quite similar to the standard G-4A anti-g suit. The two inlets for pressurization are visible in this picture.

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The full pressure suit is composed of an inner and outer layer as shown in Figure 3. The inner layer is made of an air-tight rubberized material (nylon impregnated with neoprene). It

encloses the feet and extends up the legs and thighs and over the buttocks and abdomen to the level of the umbilicus and is reinforced about the waist by a wide belt. It then returns inwardly over the lower abdomen to the thighs and ends in a rubber-dam seal which becomes air-tight on inflation of the suit. A nondistensible nylon covering fits over the inner garment in order to reinforce it. This outer portion of the suit is supported by suspenders and is held down by straps under the feet. Two air inlets, which are located in the region of the iliac spines, are used to obtain rapid inflation. In these studies the suit was inflated by a dual system of standard g-valves which delivered one p.s.i. per g after 2 g.

The full bladder anti-g suit consists of connected circumferential bladders which cover the entire lower portion of the body. There are five distinct circumferential bladders; one about the abdomen and buttocks, one about each thigh, and one about each calf. The bladders, though connected to maintain a continuous pneumatic suit, are almost completely separated at the gluteal folds and inguinal region and at the knees. No counter-pressure is applied about the feet except for the pressure obtained from the shoes worn with the suit. The bladder system is incorporated into a cotton-nylon flying suit. Two air inlets are also used with this suit. The same dual valve system described for use with the full pressure suit was used in these studies. The standard G-4A anti-g suit (4) which was compared with these two suits, was inflated for these studies by a standard g-valve which delivered 1-1/2 p.s.i. per g after 2 g.

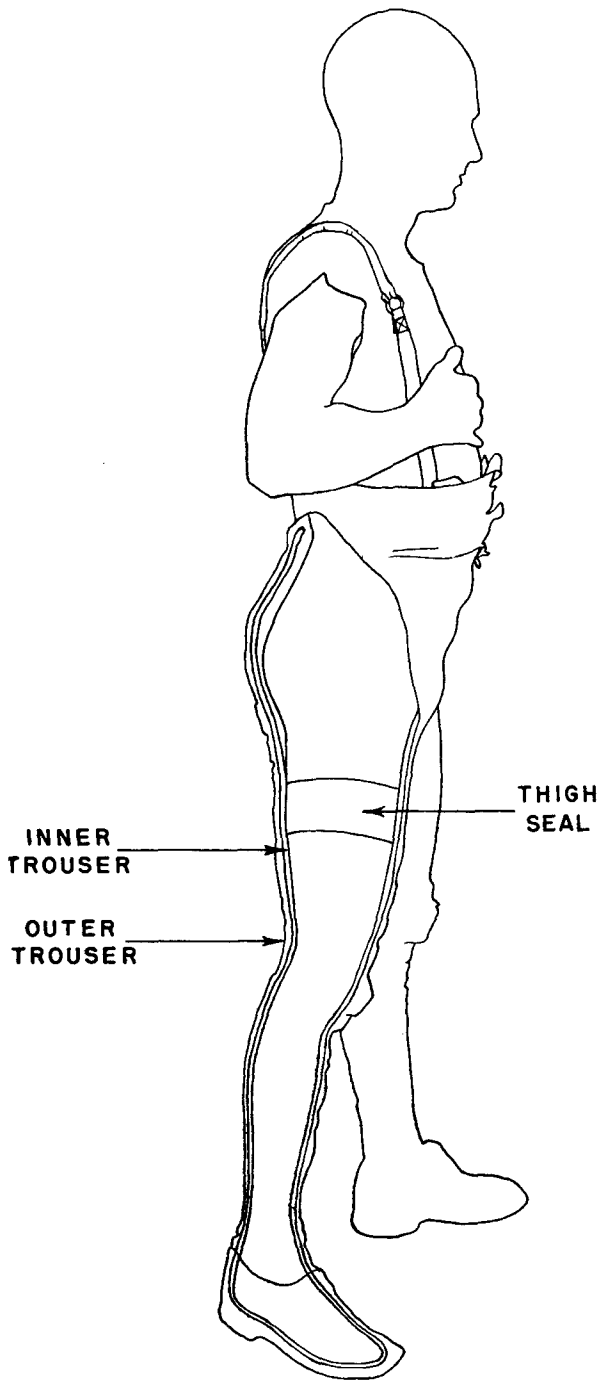


Figure 3 - Diagram of the full pressure anti-g suit. Note that the inner trouser turns inward at the waist to make an air-tight rubber-dam seal at the thigh.

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SECTION II

A COMPARATIVE STUDY OF THE VISUAL SYMPTOMS AND SUBJECTIVE OBSERVATIONS OF SUBJECT DURING ACCELERATION USING THE G-4A, THE FULL BLADDER AND THE FULL PRESSURE ANTI-G SUITS FOR PROTECTION

Methods

In order to evaluate the relative protection afforded by these anti-g suits, the blackout level with each suit was determined for the same individual on the human centrifuge. Sixteen comparative studies were done with eleven healthy men as the subjects. Each subject was exposed to accelerations in increments of 0.3 to 0.5 g until blackout was obtained. In all runs the acceleration was limited to 15 seconds. The blackout level was determined in each individual in the upright seated position without any form of protection. This level was then determined in each of these subjects in the same position when each of the three types of anti-g suits was used as a means of protection. Blackout for these studies was considered to be a loss of peripheral and central vision for 2 - 3 seconds. In addition to determining the tolerance to acceleration with each of the anti-g suits the personal observations of the subject as to the comfort and relative effectiveness of each of the means of protection were noted.

Results

The results of this comparative study are presented in Table I. The average acceleration at which blackout occurred in this group of subjects when no protection was used, was 3.7 g. In this series blackout occurred at a somewhat lower acceleration than has been previously reported (1). An average protection of 1.7 was obtained with the G-4A anti-g suit. The full bladder anti-g suit provided an average protection of 2.4 g. The full pressure anti-g suit afforded an average of 2.6 g protection. It should be noted that all but three subjects showed a significant difference in the protection afforded by the full bladder and full pressure suit as compared to the G-4A anti-g suit. In two of these three subjects blackout was not obtained with the full pressure anti-g suit because the applied pressure became uncomfortable as higher accelerations were attained and the experiment was halted. With the two experimental anti-g suits the subjects in this study were protected to 6.5 or 7.0 g. Further flight studies will be necessary to determine whether the 2.4 to 2.6 g protection will be provided by these suits in the actual flight situation when the subject is less relaxed and has a greater tolerance to acceleration when unprotected.

In general most subjects found the G-4A anti-g suit pressures reasonably comfortable although some of the subjects noted varying degrees of discomfort associated with the inflation of the abdominal bladder. The full bladder anti-g suit which provided an average of .7 g more protection than the G-4A suit was found also to be more comfortable than that suit during inflation. The pressure over the abdomen was more tolerable with the full bladder anti-g suit and accounted for the greater comfort. In general the full pressure trousers were more comfortable during inflation than the G-4A anti-g suit. It should be noted, however, that in several instances the subjects found the abdominal pressure and chest fullness associated with the inflation of the full pressure trousers intolerable at higher accelerations. For this reason the acceleration shown in Table I for the full pressure anti-g suit, while not always representing the blackout level, does for all practical purposes, represent the tolerance limit for the suit in the particular individual. While the full bladder suit and full pressure trousers were more comfortable than the G-4A suit during inflation, the full pressure suit had the disadvantage of being very troublesome to don. The full bladder suit, however, could be put on with the same ease as a G-4A suit. Movement of the legs was not restricted when either of the two experimental suits were inflated. Both suits had the disadvantage of being very poorly ventilated, so that when worn for long periods of time they might

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be uncomfortable. The full pressure trousers gave promise, however, of being easily incorporated into a combination altitude, anti-g and exposure suit.

TABLE I

Name	Without Suit	G-4A	Full Bladder	Full Pressure
J.R.	3.6	5.6	6.5	6.5
R.M.	3.8	5.6	6.2	6.2
E.M.	3.5	4.8	5.6	5.8
H.S.	3.3	4.6	5.6	5.6
R.S.	4.0	4.8	6.2	*6.7
R.P.	4.8	5.8	6.5	6.5
J.B.	4.6	6.5	6.5	*6.5
C.W.	3.8	6.2	7.0	*6.2
C.D.	4.2	5.2	5.4	
R.M.	3.8	4.6	5.8	*6.7
R.L.	3.2	4.6	5.6	*5.8
J.R.	3.5	5.4	6.2	6.2
E.M.	3.3	5.2	5.8	6.2
J.R.	3.2	5.0	6.5	*6.2
J.H.	3.2	6.2	6.5	6.5
E.M.	3.5	5.6	5.8	
AVERAGE	3.7	5.4	6.1	6.3

* Not Blackout

The full bladder and full pressure anti-g suits are a more effective means of protection against positive acceleration than the G-4A anti-g suit. Since pressure is applied more evenly over a greater portion of the lower extremities with these two suits, they more closely resemble the theoretically perfect pneumatic anti-g suit. The following studies were undertaken in order to determine the comparative effect of the different anti-g suits on the three factors which account for the increased tolerance associated with applied pressure over the lower part of the body.

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SECTION III

A COMPARATIVE STUDY OF THE ARTERIAL AND VENOUS PRESSURES IN SUBJECTS AT ONE G WITH THE INFLATION OF THE THREE ANTI-G SUITS

The effect of each of the three anti-g suits on arterial and venous pressure was first determined at one g using the pressure in each of the suits which was equivalent to the pressure developed by the anti-g valve at 3, 4, and 5 g. In these studies the subject was in the seated posture but was placed on the platform of the human centrifuge in the right lateral recumbent position with the dependent arm extended 90° at the shoulder as shown in Figure 4. This particular position

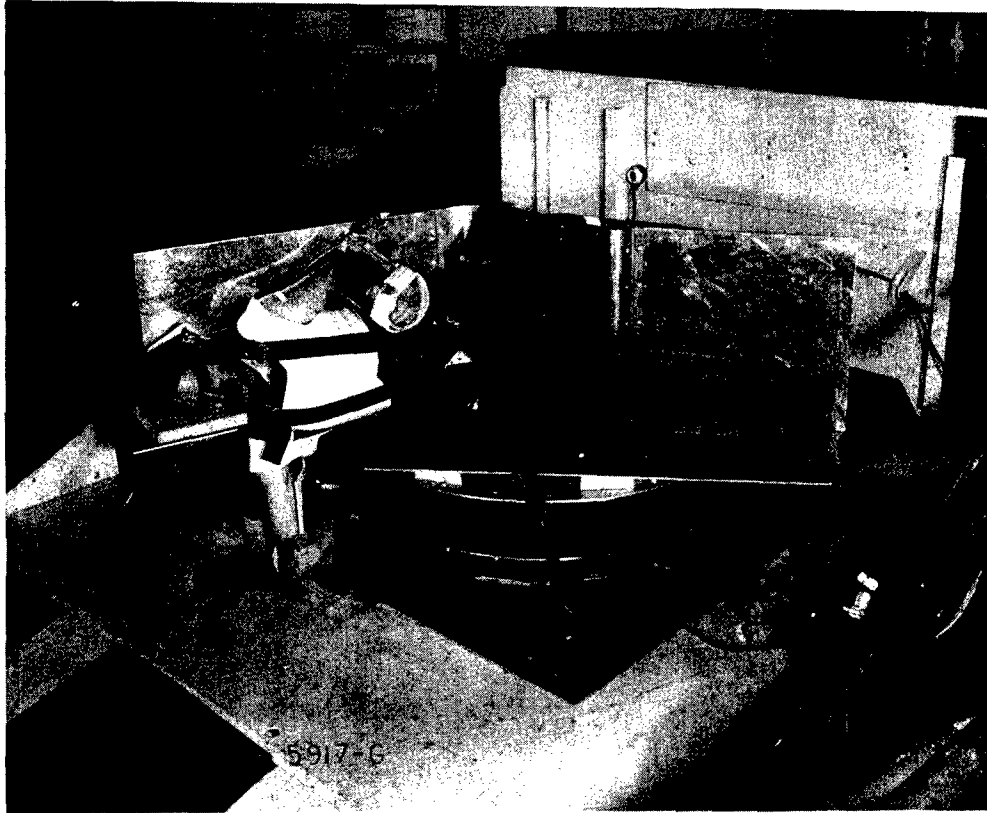


Figure 4 - Subject in the conventional seated posture but in the right lateral recumbent position. Note the arterial pressure transducer at eye level and the venous pressure transducer at the level of the anticubital vein.

was chosen because it has been demonstrated that a venous pulse pattern similar to the central venous pulse (Figure 5) can be obtained from a needle in the anticubital vein of the dependent arm (9). It is believed that in this position with the dependent arm extended, the venous system remains patent and the central venous pulse is transmitted to the anticubital vein. The venous pressure is obtained by correcting for the hydrostatic column extending from the venous needle to the middle of the sternum. Observations (9) from studies done at the Aero Medical Laboratory have shown that consistent venous pressures within the normal range can be obtained by this method. It was necessary to obtain accurate pressures in a proven patent system because it is believed that a

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pressure change in the venous system is uniformly reflected throughout the venous and pulmonary circulation (10, 11). This permits forming conclusions about pressures within the heart and in the lung circulation from a safe and technically simple determination. While the recumbent position might affect the arterial and venous pressures and the kinds of changes observed with inflation of the anti-g suits, it was thought that this study did represent a comparison of the effect of the three suits under the same conditions.



Figure 5 - Venous pulse pattern obtained from needle in anticubital vein of dependent arm of subject in the lateral recumbent position.

Methods

Three experiments were done in different individuals. Each subject was in the seated posture but in the right lateral recumbent position with the dependent arm extended and the other arm flexed and supported at the level of the heart. An indwelling needle was inserted into the radial artery of the flexed arm through a local procainized area and connected by vinylite tubing to a Statham pressure transducer mounted at eye level. This transducer actuated a Heiland galvanometer in a recording oscillograph. Another indwelling needle was placed in the anticubital vein of the opposite, dependent arm. Venous pressure was recorded from the vein in the same manner as reported for the arterial pressure. The venous recording gauge, however, was placed at the level of the venous needle. The pressure obtained was corrected for the hydrostatic column extending from the gauge to the middle of the sternum. Both needles were kept patent by periodic rinsing with small amounts of 0.5 cc heparin and 10 cc saline solution. The mean pressure was obtained from the oscillograph record by planimetry.

Each of the three suits which were carefully fitted on the subject was used in a single experiment in the same individual. Pressures of 1, 2, and 3 p.s.i. representing the pressure applied at 3, 4, and 5 g were used in the full bladder and full pressure anti-g suit. Dual valves were used to obtain fairly rapid inflation although, as shown in Figure 6 the inflation time was slower with these two suits than with the G-4A anti-g suit. Pressures of 1-1/2, 3 and 4-1/2 p.s.i. were used in the G-4A suit representing the pressures used at 3, 4, and 5 g.

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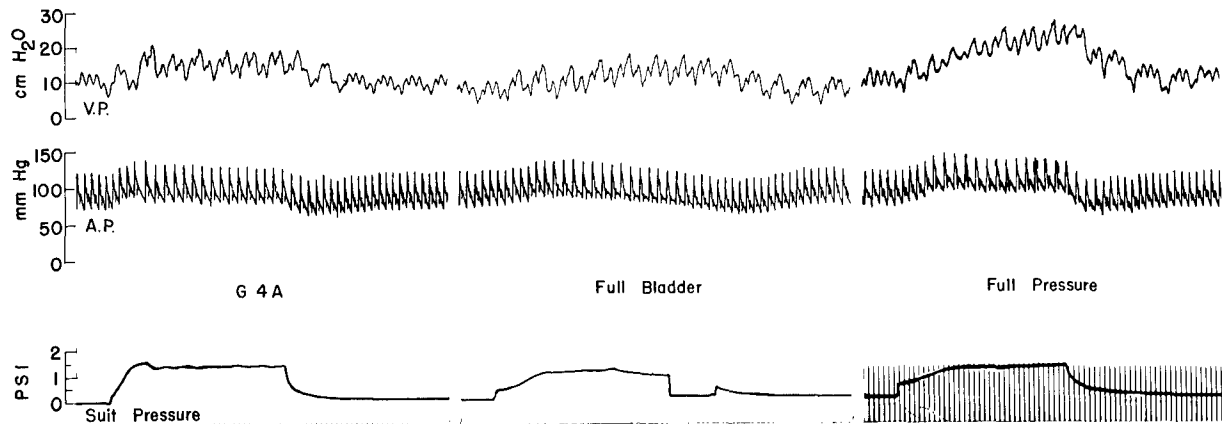


Figure 6 - Record of arterial and venous pressure obtained at one g when each of the anti-g suits was inflated with a pressure equivalent to that used at 3 g.

Results

Figure 6 is an example of the record obtained when the suits were inflated with pressures equivalent to those used at 3 g. In this particular case it can be seen that the rise in arterial pressure was approximately the same for all three suits. In Figure 7 experiments on three

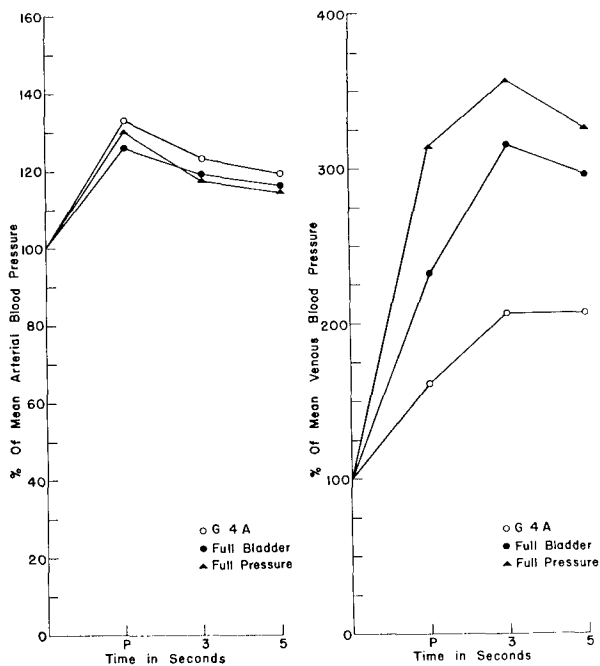


Figure 7 - The average percent change of mean arterial and venous pressure for three subjects at 1 g using each of the three types of anti-g suits inflated with the pressure equivalent to that used at 4 g. All three subjects were in the right lateral recumbent position.

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subjects are summarized. The various suits were inflated on each subject with the pressure equivalent to that used at 4 g. It is evident that the average percent increase in mean arterial pressure was the same for all suits when they were inflated. It is probable that as a result of slower inflation of the full bladder and full pressure suits, compensating mechanisms may have begun to lower the arterial pressure and thus higher peak pressures were not obtained. But at the end of 5 seconds the arterial pressure was unquestionably the same with all three suits and was approaching the resting control value. The reason for this is that the compensating mechanisms initiated by the carotid sinus which was stimulated by the higher arterial pressure, lowered that pressure toward its normal value. As other authors (3) have pointed out, it is difficult to use studies of this nature to evaluate the effect that an anti-g suit will have on the arterial pressure when the subject is exposed to acceleration since under these circumstances the compensatory receptors will be affected in a different manner.

The venous pressure in Figure 6 is markedly higher with the full pressure suit than with the other two suits. Figure 7 shows that in experiments where greater pressure was used, the average percent increases in mean venous pressure for three subjects was greater with the full bladder and full pressure anti-g suit than with the G-4A anti-g suit. The full pressure suit also was associated with a somewhat greater rise in venous pressure than the full bladder suit. It should be noted that three seconds after peak inflation, the venous pressure no longer increased. It is believed that this rise in venous pressure is the result of redistribution of blood into the upper portion of the body and particularly into the thoracic viscera. In view of previous studies (10, 11) it seems likely that this same rise of pressure occurs uniformly throughout the great veins, right heart and pulmonary circulation. However, the arterial and venous pressures probably are not affected in the same fashion by the inflation of an anti-g suit at one g as they are when the protected subject is exposed to acceleration (3). For this reason pressure studies were also done when subjects were protected and exposed to acceleration.

SECTION IV

A COMPARATIVE STUDY OF THE ARTERIAL AND VENOUS PRESSURES AND HEART-TO-HEAD DISTANCE WITH THE INFLATION OF EACH OF THE THREE ANTI-G SUITS DURING EXPOSURE OF THE SUBJECT TO ACCELERATION

As was pointed out earlier in this paper, there are three means by which an anti-g suit is thought to increase tolerance to acceleration. These are: (1) by increasing the peripheral arterial resistance and maintaining arterial pressure in the head region (2) by making blood available to the heart and (3) by shortening the vertical heart-to-head distance. The following experiments were designed to determine which of these factors may be more effectively altered with the two experimental anti-g suits and account for the greater protection provided.

Methods

Six experiments were done on five different subjects. Three experiments were done in different subjects in the seated posture but placed in the right lateral recumbent position on the platform of the human centrifuge so that the force of acceleration was through the long axis of the body. Three experiments were done in different individuals in the conventional upright seated position in the cab of the human centrifuge. Direct arterial pressure measurements were made from an indwelling needle placed in the radial artery. The pressure recordings were made in the manner described in Section III. In the experiments with the subject in the right lateral recumbent position the upper arm was flexed and supported so that the radial needle was at heart level. In the studies in which the subject was in the upright seated position, the radial arterial needle was at the level of the first or second rib. The Statham pressure transducer was placed at eye level in both types of experiments in order to record a pressure equivalent to arterial pressure at that level.

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Venous pressure was measured by means of a needle in the antecubital vein of the dependent arm in each subject in the lateral recumbent position. The venous gauge was placed at the level of the needle. These three studies were done to determine the venous pressure accurately before and after the exposure to acceleration. It was also hoped that this position would avoid the collapse of the vein observed when venous pressure was recorded in the conventional fashion during the exposure to positive acceleration. The venous pressure was also measured from the antecubital vein of each of the subjects in the upright seated position. The arm was extended at almost a 90° angle from the body so that the needle was at the level of the third rib. It was believed that collapse of the vein during acceleration would be at a minimum in this position. The venous pressure transducer was placed at the level of the third rib. The pressures were recorded in the same manner as the arterial pressures. In two experiments in the upright seated position esophageal pressure and respiration were recorded simultaneously with the venous pressure. The esophageal pressure was recorded by means of a miniature manometer (12). Respiration was recorded by a "hot-wire" respirometer.

In each experiment the subject was exposed to positive acceleration first without protection and then with each of the three types of anti-g suits. Each subject in the right lateral recumbent position was exposed to 3 g without protection and to 3, 4 and 5 g with each of the three types of protective garments. Each subject in the upright seated position was exposed to his blackout acceleration unprotected and then exposed to accelerations in increments of .3 to .5 g until blackout occurred with each of the three anti-g suits. All runs were for 15 seconds with 5 to 10 minute intervals between. All pressure records were planimetered where necessary.

Nine experiments were also done in which chest X-rays were obtained on the same subject using each of the anti-g suits at a given acceleration. The purpose of these studies was to determine whether there was any difference in the extent to which these three suits shifted the diaphragm and heart. An X-ray of the chest was obtained at the acceleration at which blackout occurred in the subject without protection. A similar chest X-ray was then made of the same subject using each of the three anti-g suits at the same acceleration. The X-rays for each subject were developed simultaneously to insure uniformity in their density. The elevation of the heart and diaphragm was determined by measuring the distance between these organs and some constant bony structure in the upper thorax. The change in this distance when one of the types of protection was used was compared to the distance between the same points when no protection was worn. This was then expressed as the percent change.

Results

a. Arterial Pressure

Figure 8 presents the effect on arterial pressure at eye level in the subjects exposed to 3 g with and without the various types of g-protection. These subjects were all in the right lateral recumbent position but exposed to 3 g in the vertical axis of the body during the period of acceleration. At peak acceleration the percent fall in mean arterial pressure was about the same in all the situations except that it was maintained at a slightly higher level by the full pressure suit. It can be seen that ten seconds after peak acceleration was reached the full pressure and full bladder anti-g suits maintained the arterial pressure at a higher level than when no protection or the G-4A anti-g suit was used. Fifteen seconds after peak acceleration the arterial pressure was essentially the same in the protected and unprotected states. This is believed to be due to the reflex compensatory mechanism which is initiated by the carotid sinus and usually becomes evident 10 to 15 seconds after peak acceleration (13). Figure 9 presents the same type of data as Figure 8. In this case, however, each subject was exposed to 4 g with each of the types of protection. While the percent change in mean arterial pressure at eye level was approximately the same at peak g, at 5, 10, 15 seconds after peak g the full bladder and full pressure anti-g suits maintained this pressure at a slightly higher level than did the G-4A anti-g suit.

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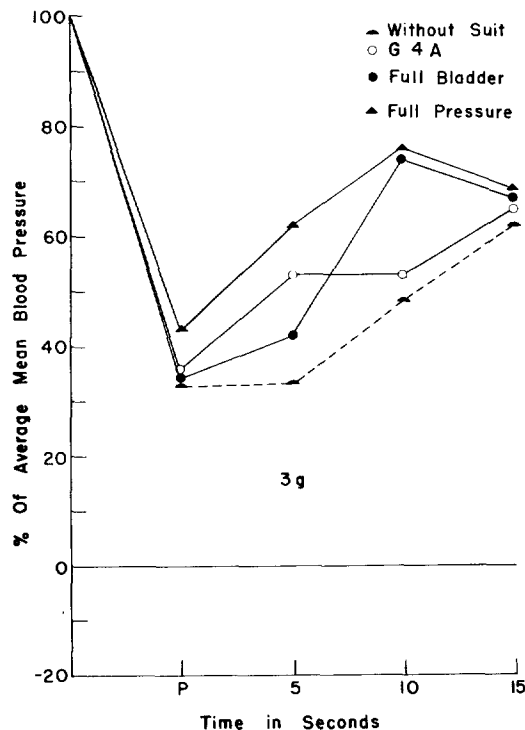


Figure 8 - The average percent change of mean arterial pressure at eye level for three subjects exposed to 3 g without and with the three types of protection. During the control period these subjects were in the right lateral recumbent position. The intervals at which points are shown are control, P (peak acceleration) and 5, 10, and 15 seconds after peak acceleration.

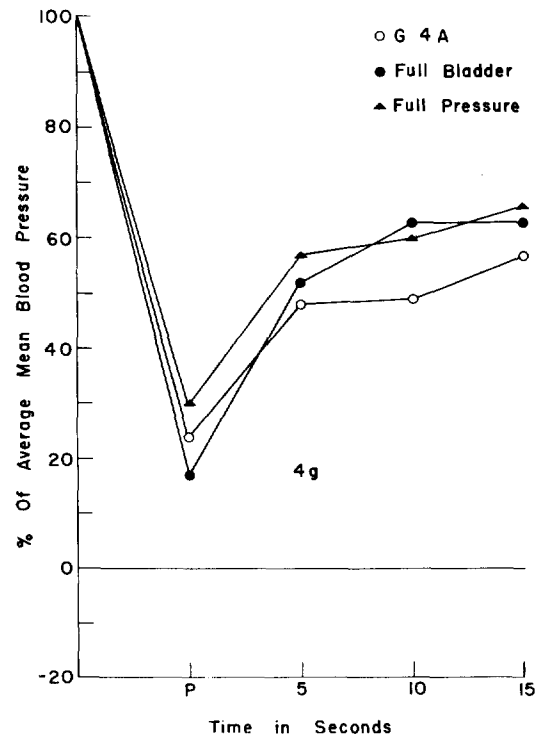


Figure 9 - This chart presents the same type of data as Figure 8 except that the three subjects were exposed to 4 g.

When the subject was in the conventional upright seated position and exposed to positive acceleration the changes in mean arterial pressure at eye level were similar to the findings reported for the subject in the right lateral recumbent position. Figure 10 is a comparison record of the arterial pressure in a subject exposed to 5.2 g with each of the three types of anti-g protection. The mean arterial pressure and the diastolic arterial pressure at eye level with the two experimental suits was higher than with the G-4A suit at 5, 10 and 15 seconds after peak acceleration. Figure 11 presents the average results of three experiments carried out at 5.2 g in three different subjects. The full pressure suit was more effective in maintaining arterial pressure at eye level than the other two suits. The full bladder suit was more effective than the G-4A suit but less effective than the full pressure suit. When compared to the arterial pressure at 3.2 g, which was blackout for two of the three subjects, the pressure was much higher at 5.2 g with all the types of protection. At a given acceleration the full pressure suit maintained the mean arterial pressure 10 to 20 mm Hg higher at eye level than did the G-4A suit. The full bladder suit maintained this pressure only 5 to 10 mm Hg higher at eye level than the G-4A suit. The difference in maintaining arterial pressure at eye level with the two experimental suits would seem to be critical enough to allow approximately one g more protection than the G-4A suit.

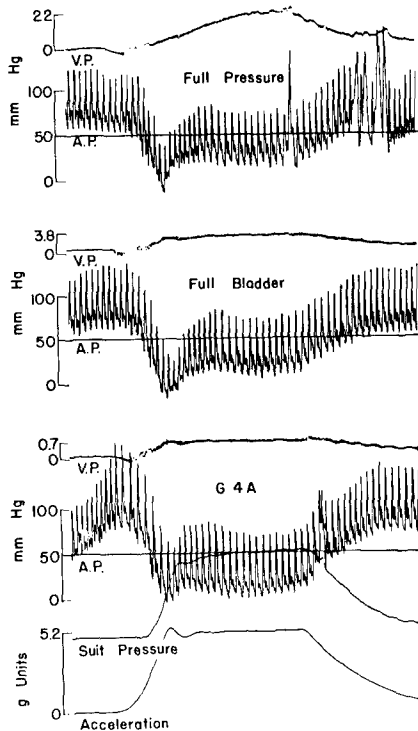


Figure 10 - These are actual records from the same subject in the upright seated position comparing the effect of the three types of anti-g suits on arterial and venous pressure during exposure to 5.2 g. The period of acceleration is 15 seconds. The venous calibration is not linear but has been corrected for the effect of the acceleration in the venous gauge. The calibration only applies to the pressure during acceleration. The resting venous pressure was 4 to 5 mm Hg.

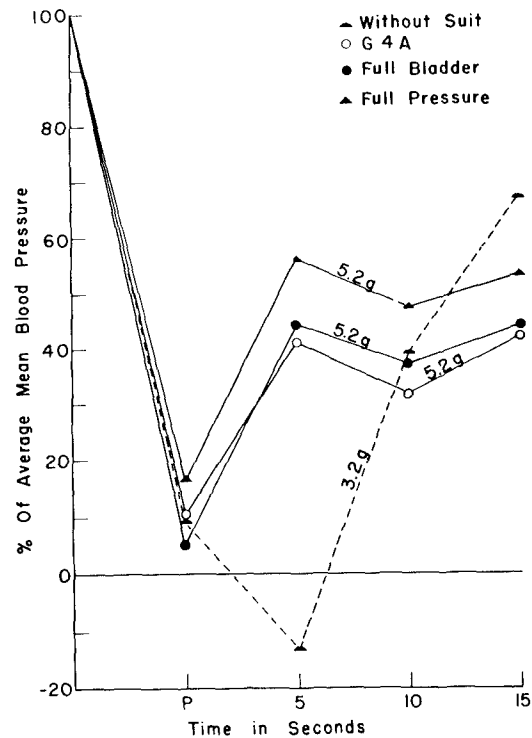


Figure 11 - This chart presents the average change in mean arterial pressure at eye level for three subjects exposed to 5.2 g with each type of protection. All these subjects were in the upright seated position. The average percent change in mean arterial pressure is also presented for the three subjects exposed to 3.2 g without any protection. It should be noted that at 10 to 15 seconds after peak acceleration the arterial pressure had returned to 60% of the control value when no protection was used.

Figure 12 demonstrates the advantage of the full bladder and full pressure suits in a somewhat different fashion. The percent change in mean arterial pressure at eye level five seconds after peak acceleration is plotted against acceleration for the same subject without protection and with the various types of anti-g garments. Blackout occurred at 3.3 g when the subject was unprotected. The ends of the lines representing the various suits are the points at which blackout occurred for 2 to 3 seconds during the run although at 5 seconds the mean arterial pressure was at or just above the critical level for blackout. For example at 4 g with the G-4A suit the arterial pressure was 50% of the control value and with the full pressure suit 70% of the control value. The same level of mean arterial pressure as was shown at 4 g with the G-4A suit was not reached until 6.5 g with the full pressure suit. It is believed that the difference in mean arterial pressure at eye level at a given acceleration accounts for the greater protection afforded by the experimental suits as compared to the G-4A suit. It is possible that greater arterial pressure can be maintained at eye level by the experimental suits because greater pressure can be applied in these suits. Only a limited pressure can be forced into the relatively small bladders of the G-4A suit which at higher accelerations become more round and hard but do not apply much more pressure

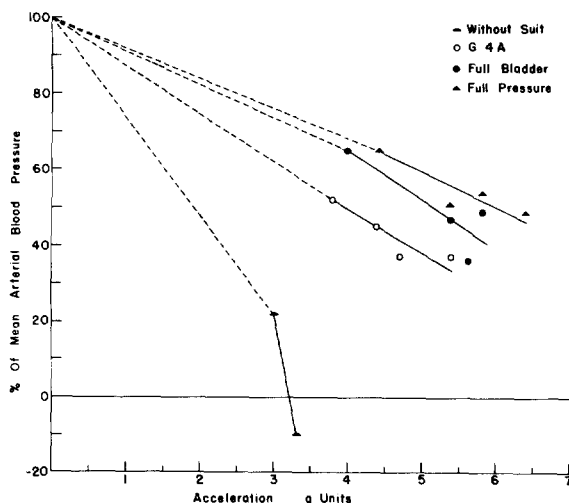


Figure 12 - This chart presents the percent change in mean arterial pressure at eye level plotted against acceleration when each of the anti-g suits was used for protection against acceleration by a single subject. The pressure was determined 5 seconds after peak acceleration in each case.

to the extremities. These two experimental suits more closely resemble the perfect anti-g suit in that they are capable of applying greater pressure evenly to a larger portion of the lower part of the body than the G-4A anti-g suit. The greater rise in arterial pressure can in part be attributed to a more effective increase in peripheral arterial resistance when these two experimental suits were used.

b. Venous Pressure

The second factor which may explain the greater g protection given by the new anti-g suits, is that they may provide a more adequate supply of blood for the heart. This might account for the greater protection afforded particularly in the latter part of the 15 second acceleration. In the studies done at one g it was noted that the full bladder and full pressure anti-g suits caused a greater rise in venous pressure as measured in these experiments than did the G-4A suit in a comparable situation. During acceleration the same difference in venous pressures with the various suits was noted (Figure 10). With the G-4A suit the venous pressure decreased as compared with the control. The full bladder suit maintained this pressure at the control value but the full pressure suit increased the pressure approximately 18 mm Hg over the control value. This same result was observed in all three subjects in the upright seated position. In two experiments in which esophageal pressure and res-

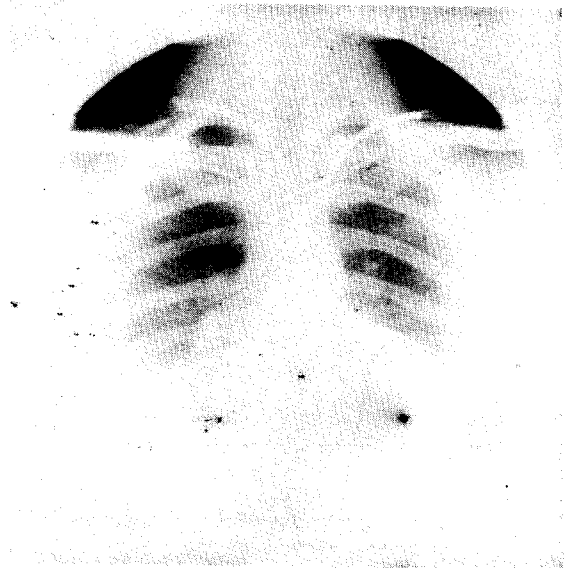
piration were recorded, the venous pressure elevation occurred even though there was no alteration of esophageal pressure or respiration. It therefore seems unlikely that the rise in venous pressure was the result of increased intrathoracic pressure.

Figure 13 presents four chest films of the same individual at the same acceleration. The first is a control taken at acceleration with the subject relaxed and without a suit. There is a marked difference in height of diaphragm and density of lung fields between it and the three other pictures which were taken at the same acceleration but wearing g-suits. It should be noted that the lung fields even in the upper portions are more dense in the last two films, than they are in the second film. The subject was wearing the full bladder suit and the full pressure suit respectively when films 3 and 4 were made. Film 2 was taken while the subject was exposed to the same acceleration and using the G-4A suit for protection. The difference in lung density was observed despite no appreciable difference in the level of the diaphragm in the three suit protected X-rays. This must mean that, in lungs compressed by the same amount, there is greater engorgement of the pulmonary vessels when the experimental suits are inflated during acceleration. The same picture was observed in all nine subjects. It seems evident that the greater venous pressure observed with the inflation of the full bladder and full pressure suit is related to a greater engorgement of the large veins in the thorax. It is believed that this demonstrates that more blood is made available to the heart when these two suits are used. Moreover, based on other studies (10, 11), it is believed that the rise was of similar magnitude throughout the venous system, right heart and pulmonary circulation.

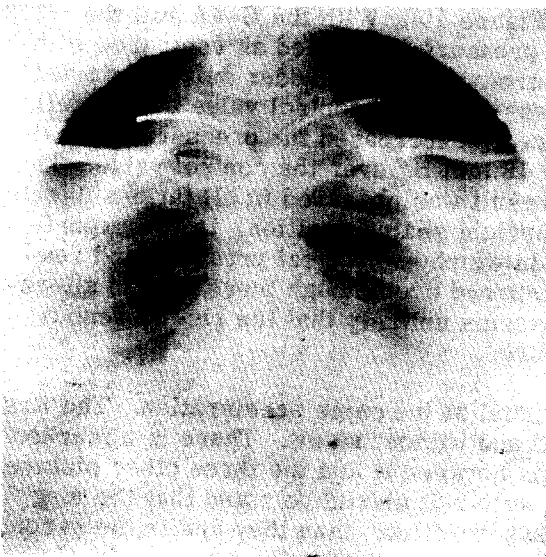
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Film 1



Film 2



Film 3



Film 4

Figure 13 - A comparison of the chest X-rays in the same subject exposed to the same acceleration. The first: without protection and others when wearing each of the three pneumatic anti-g suits being tested. In the second film the G-4A suit was used, in the third the full bladder and in the fourth the full pressure suit.

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Venous pressure measurements were also made in the three experiments in which the subject was in the right lateral recumbent position. The venous pattern observed at one g was not obtained during acceleration because the vein apparently collapsed. However, very good venous pulse patterns were obtained before and after the exposure to acceleration. Planimetry of these pressure records revealed that the venous pressure was consistently 2 to 4 cm of water higher 20 to 30 seconds after the exposure to acceleration without protection than it was before. Figure 14 presents an example of the increased venous pressure after the subject was exposed to positive acceleration without protection. This finding occurred in all three subjects.

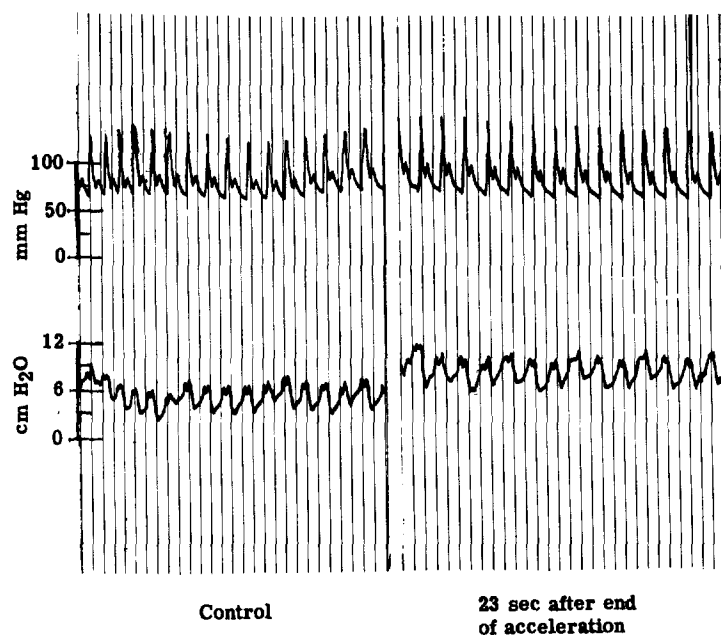


Figure 14 - Actual record of venous and arterial pulse before and after exposure of a subject to positive acceleration of 3 g without protection.

From this limited number of observations it would appear that the venous tone had increased during the exposure to positive acceleration. It is suggested that the body may try to compensate for the fall in arterial pressure and decrease in venous return to the heart by an increase in venous tone as well as by the generally accepted compensatory mechanisms involving the carotid sinus, and aortic arch regions as the receptor areas and the heart and arterial system as effector organs (14, 15). This rise in venous pressure was also noted after exposure to acceleration with the protective devices. In this situation the pressure might remain high for a short period immediately after the acceleration as a result of the venous engorgement associated with the applied pressure over the lower portion of the body.

It seems evident that the venous pressure was elevated more when the full pressure or full bladder suit was inflated than when the G-4A suit was pressurized. This was true both at one g and at higher accelerations. A greater volume of blood was also provided in the thoracic region by the two experimental suits. It is believed that this accounts in part for the greater g tolerance observed with the inflation of these suits particularly during the latter portion of a 15 second period of acceleration.

c. Vertical Heart-to-Head Distance

The third factor which might have accounted for the increased protection afforded by the experimental suits is that they might have elevated the diaphragm and heart more effectively than the G-4A suit and so resulted in a greater shortening of the vertical heart-to-eye distance. From the study of comparable chest films of nine subjects it is concluded that the three suits do not differ in their ability to elevate the heart and shorten the vertical heart-to-eye or heart-to-head distance. In nine subjects the distance between the heart and diaphragm and the upper thoracic bony structure was shortened by twenty percent when the G-4A and full bladder anti-g suits were inflated at the same acceleration as that achieved in the unprotected state. This distance was shortened by an average of twenty-five percent when the full pressure anti-g suit was inflated at the same acceleration. This difference cannot be regarded as significant in view of the exact method used.

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It seems evident that the increase in protection provided by the experimental suits was not related to a greater shortening of the heart-to-head distance but rather was afforded because the mean arterial pressure at eye level was better maintained with these suits. It is believed that the arterial pressure reached a higher level for two reasons. First, there was a greater increase in peripheral arterial resistance. Second, there was a better supply of blood available to the heart. It is also believed that both these effects resulted from the more even application of a greater pressure over a larger portion of the lower part of the body.

SECTION V

RELATIVE SAFETY OF THE TWO EXPERIMENTAL ANTI-G SUITS

When investigation of the two experimental anti-g suits began, it was believed that they might be potentially dangerous. This belief was based in part on earlier studies by Jasper (16) in which animals were protected against positive acceleration of 10 to 12 g by counterpressure applied over the lower part of the body to the level of the heart. Some of these animals showed damage and dilatation of the heart, pulmonary vessels, and great veins.

However, these suits have been demonstrated to be safe at least when used within the limit of blackout or comfort tolerance. First, it is unlikely that the rise in arterial pressure at heart level would result in any damage to the heart or vascular system when the full bladder or full pressure suit is inflated during acceleration. At 6.5 g when the mean arterial pressure at eye level is about 30 mm Hg the arterial pressure at heart level is approximately 180 mm Hg which is well within the range that the normal human heart will tolerate. Secondly, within the acceleration range in which it is anticipated the suits will be used, the venous pressure does not rise more than 20 to 30 mm of Hg. It is most likely that this rise in pressure persists throughout the pulmonary circulation as well. However, this pressure rise also is well within the range tolerated by the normal heart and lungs. Lastly, although the lungs appear congested in the chest X-rays of each subject wearing the inflated full bladder or full pressure anti-g suit during exposure to acceleration, there was no marked dilatation of the heart. Moreover, there have been no adverse effects in 20 to 30 subjects who have used the two suits at accelerations as high as 6.5 g. While this acceleration is lower than pilots can withstand using the G-4A in flight, it should be pointed out that the present series of experiments was done in relaxed subjects with a low tolerance to acceleration. It seems most unlikely that there is any danger associated with the use of these two experimental anti-g suits by healthy individuals within the comfort tolerance and blackout limits.

SECTION VI

SUMMARY

The principle of the pneumatic anti-g suit is to apply pressure evenly over as large a portion of the lower part of the body as possible. Two experimental anti-g suits have been developed which do this more effectively than the standard USAF G-4A anti-g suit. The first of these experimental suits, which was developed at the request of the U. S. Air Force, consists of complete coverage trousers composed of connected systems of circumferential bladders; the second, independently developed by the David Clark Company, is a full pressure garment which encloses the feet and extends upward to the waist. These suits provide 0.7 to 0.9 g more protection than the standard G-4A anti-g suit which provides 1.8 g protection.

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The pneumatic anti-g suit increases tolerance to positive acceleration (1) by increasing peripheral arterial resistance (2) by making blood available to the heart and (3) by shortening the heart-to-head distance. A comparative study of the three anti-g suits was done to evaluate the effect of each of them on these factors. The two experimental anti-g suits maintained arterial pressure at eye level higher at a given acceleration than the G-4A and kept this pressure above the critical blackout level for approximately one g more than the standard anti-g suit. These two suits also maintained a greater amount of blood in the thoracic viscera than the G-4A suit. The decrease in heart-to-head distance was the same with all three suits.

The full bladder and full pressure anti-g suits were not only more effective but in general were more comfortable with inflation during acceleration than the G-4A suit. These two suits have been shown to be safe when used within the limits of comfort, tolerance, and blackout. They can also be incorporated into a combination altitude-anti-g and exposure suit. However, other features still remain to be investigated. Actual flight tests will be necessary to determine if the suits provide the same protection against acceleration as they do on the human centrifuge. The comfort and heating effect of the experimental suits when worn for long periods of time will also have to be established. It is recommended that development, testing and modification of the full bladder-full pressure anti-g suits be continued in an effort to provide a more effective mechanical means for protection against positive acceleration in the upright seated posture.

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