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TITLE

ADVANCED +Gz PROTECTION SYSTEMS AND THEIR PHYSIOLOGIC BASES

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ADVANCED +Gz PROTECTION SYSTEMS AND THEIR PHYSIOLOGIC BASES

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INTRODUCTION

This paper discusses the known physiologic bases of advanced methods for protecting against the effects of headward acceleration (+Gz). The topic is preceded by brief descriptions of the physiologic effects of +Gz and of current anti-G systems.

PHYSIOLOGIC EFFECTS OF +Gz EXPOSURE

Rapid pull-out from a dive and tight turns in tactical aircraft produce high levels of +Gz with downward inertial forces[1] acting on the body. These forces can cause unconsciousness which results from the cerebral / neurological consequences of +Gz effects on the cardiovascular system. Although inadequate venous return of more dense blood was originally suspected, the problem is now believed to lie on the arterial side because: (i) blood pressure at heart level is relatively stable; (ii) after several seconds at +Gz, blood pressure increases; and (iii) the decrease in blood pressure at head level is proportional to +Gz level (48).

Figure 1 illustrates the effect of different +Gz levels on systolic arterial blood pressure at different levels of the cardiovascular system according to a simple hydrostatic model superimposed on the cardiac component of intravascular pressure. The difference in blood pressure between head and feet in the upright individual increases with increasing +Gz level.

The adverse consequences of +Gz exposure result from the changes in blood pressure at head level. With increasing +Gz level, blood pressure decreases. At approximately +3 Gz, vision becomes impaired. Retinal perfusion decreases because blood pressure falls below the pressure exerted on the retina by the eyeball (25). +Gz-induced loss of consciousness occurs at approximately +5.5 Gz (11) due to inadequate cerebral perfusion.

Man is most susceptible to the effects of +Gz in the first several seconds of exposure, before cardiovascular reflexes can react to increase blood pressure at heart level. That the body can tolerate +4 Gz at all is due to 4 main events:

(i) Venous return is adequate because the pressure gradient between peripheral and central venous circulations is maintained by gravity-related increases in intra-abdominal pressure acting on the splanchnic vasculature (39,40). As a result, systolic blood pressure at heart level only decreases by 4 mm Hg/+Gz. The diastolic pressure remains unchanged (26).

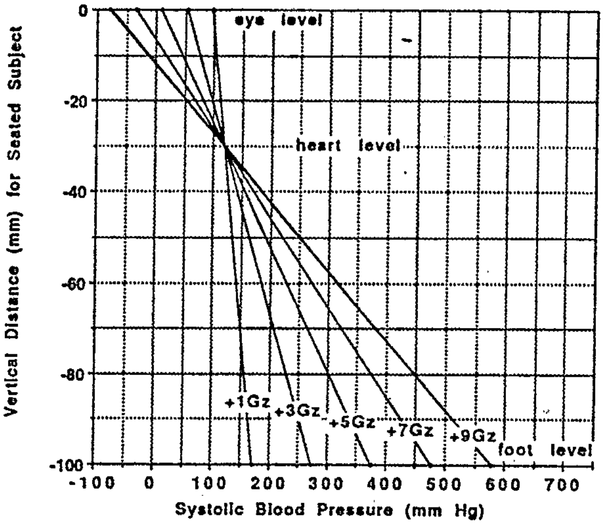
(ii) With near constant heart-level blood pressure, the hydrostatic gradient of approximately 30 cm from the heart to the head can still be overcome.

(iii) Even at very low arterial pressures, an arterial-venous pressure differential in cerebral beds is maintained due to negative pressure on the venous side (20).

(iv) Pericardial pressure gradients provide the heart with some protection against the effects of +Gz (1).

For very short periods of time, man is able to tolerate +Gz levels which would eventually produce unconsciousness. Oxygen stores in nervous tissue are believed to provide up to 5-7 sec of normal function even though cerebral perfusion may be interrupted (44, 50). This can be a problem at +Gz onset rates greater than 1 +Gz/sec as unconsciousness can occur without visual warning signs.

Figure 1. Effects of +Gz Level on Blood Pressure Calculated According to Hydrostatic Model



CURRENT +Gz PROTECTION SYSTEM

To improve +Gz tolerance[2], anti-G systems must improve or maintain blood pressure at head level. This can be accomplished by increasing arterial blood pressure at heart level or by decreasing the hydrostatic distance between the heart and head. Postural alterations which reduce the heart-head distance are effective +Gz protective measures (14), but this discussion will only consider the near-upright pilot since this is the position of aviators of current and next generation tactical aircraft.

Anti-G Suits

Fighter pilots currently use anti-G suits and anti-G straining maneuvers (AGSMs) to reduce the effects of +Gz. The G-suit, changed little from the early designs of the 1940's, uses five interconnected bladders, one over the abdomen, and one over each thigh and lower leg. It is pressurized at 1.5 psi/+Gz beginning at +2 Gz and confers approximately 1 +Gz of protection.

The main effect of the G-suit is an increase in head-level blood pressure (47, 48, 49). In short duration +Gz exposures of up to 10 sec, the hypertensive effect is produced by increases in peripheral vascular resistance (29) which is evident as an increased heart-level blood pressure. The lower limb vasculature and/or the splanchnic vessels could be the site of the increased resistance. Intra-abdominal pressure increases with G-suit inflation (49) and this helps increase atrial filling pressure (43). The pressurized abdominal bladder of the G-suit also prevents the descent of the diaphragm that normally occurs during +Gz. This confers two benefits (40):

(i) it increases the vertical height of the abdominal contents, resulting in greater hydrostatic pressure against abdominal vessels during +Gz;

(ii) by maintaining diaphragm position, it prevents any further increase in the heart-head vertical distance which would occur if the abdominal contents and lower chest wall were not supported.

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[1] magnitude expressed as multiple of gravitational force.

[2] Tolerance - the capacity to accept the effects of +Gz to a predetermined alteration of some specified physiological function(s); there are +Gz-intensity and/or +Gz-duration components to +Gz tolerance.

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relaxed +Gz tolerance by 0.6 +Gz. Tolerance only increases by 0.2 +Gz when just the leg bladders are used. However, the combined use of the various parts appears to potentiate their individual effects, as +Gz tolerance then increases by 1.2 +Gz. (49). The premier importance of the abdominal bladder for relaxed +Gz tolerance has been verified (7).

Anti-G Straining Maneuvers

Anti-G straining maneuvers of various forms have also been known since the early 1940's. These generally consist of intense muscular contractions of the chest wall (Valsalva maneuver) exerting an expiratory effort against a closed or partially-open glottis. This is coupled with equally forceful tensing of the arms and legs. If the closed glottis method is used, the maneuver is maintained for 3-4 sec, followed by rapid expiration, then rapid and deep inspiration, and initiation of another straining effort. The high intra-thoracic[3] pressure is transmitted directly to the heart and the great vessels (18, 41). If intra-abdominal pressure does not maintain a pressure gradient from abdomen to chest, blood pressure rapidly decreases (3, 40). But the risk of this effect during AGSM is reduced when a G-suit is used (49) due to the increased intra-abdominal pressure effects.

The peripheral muscular tensing component probably contributes to the blood pressure increases with AGSM. The extreme hypertension of high-intensity, resistance exercise is regarded to be the result of mechanical compression of vasculature and powerful pressor responses (30) with increases in total peripheral resistance and possibly cardiac output (32). Similar to the functioning of the G-suit, the cardiac output would then be distributed to a reduced arterial bed.

ADVANCED +Gz PROTECTION SYSTEMS

Compared to the average +Gz tolerance level of +3.7 Gz in relaxed and unprotected subjects, pressurized G-suits, and G-suits combined with straining maneuvers increase mean +Gz tolerance to +5.4 and +8.8 Gz, respectively (33). However, an increase in the number of incidents and fatalities in the current generation of tactical aircraft due to their advanced +Gz capability has renewed efforts to devise better +Gz protective systems.

Improved G-suits.

Our knowledge of the design requirements for improved G-suits has progressed little since WWII when several acceleration laboratories, particularly in the US, had produced G-suits which provided better +Gz protection than current issue G-suits. These superior G-suits, however, were rejected for operations because they were complicated, cumbersome, and uncomfortable, and because their performance actually exceeded what was necessary at that time. It is important to consider this early work.

(i) Knowing that the problems with +Gz exposure affected the arterial system more dramatically than the venous side, efforts concentrated on increasing blood pressure at heart level. Arterial Occlusion Suits were produced to increase vascular resistance. These suits consisted of an abdominal bladder and a cuff on each upper thigh. Inflated to arterial occlusive pressures, e.g. 325 mm Hg at +5 Gz, these provided an average of 2.1 +Gz of protection above the normal tolerance point (45). The addition of arm cuffs increased the protection to 2.9 +Gz. Ischemic pain made these suits unacceptable.

(ii) Most of the G-suits used by NATO countries today are minor variants of the USAF G-3A G-suit. In contrast, the G-4A incorporated larger bladders, and more extensive and better fitting fabric pressure on the body surface into a coverall garment. The G-4A provided approximately 2.0 +Gz of protection, double that afforded by the G-3A (31). pressure to all body surfaces below the chest and provides approximately 2.4 (28) to 3.2 +Gz of protection to visual symptoms (10). In a comparison with the G-4A coverall, the 0.9 +Gz extra protection provided by the Full-Pressure-Half-Suit was due to improved blood pressure at eye level (43). This was attributed to increased peripheral arterial resistance and venous return. A possible benefit due to greater reduction in the heart-head distance was ruled out.

Several types of G-suits applying more uniform pressure to the lower body compared to the standard suit have been investigated recently by the USAF (8, 21, 22, 23). According to impedance plethysmographic measurements, the latest USAF uniform pressure G-suit displaces more blood from the calves and thighs into the abdomen than does the standard suit (23).

With counter-pressure exerted to the entire body surface below the umbilicus except for the ankles and toes, Prior of the RAF has observed that +Gz tolerance compared to the unprotected condition is increased by 2.9 +Gz, a 1.3 +Gz increase above that provided by the standard G-suit (36). Gluteal region coverage was speculated as the main reason for the improvements.

G-suits with greater pressure in the lower leg bladders and less pressure in the abdominal bladder (48), or suits inflated from the bottom bladders upwards (6), offer no better +Gz protection than single pressure suits.

The anti-G valve is an important component of +Gz protective systems because G-suit performance also depends on receiving the correct pressure at the appropriate time. How fast the G-suit should be inflated is currently unresolved. If the rate of G-suit pressurization is improved so that the delay is reduced to only 0.5 sec, significant improvements in +Gz tolerance over the standard conditions have been recorded (13). In contrast, a mean delay of 2.0 sec in pressurization with no deterioration in protection has also been observed (5). Although cerebral blood pressure decreases with +Gz onset, the cerebral ischemic reserve time could offer a buffer period before +Gz protective systems must be fully activated.

Positive Pressure Breathing

The AGSM effectively increases blood pressure, but it requires concentration and proper instruction to ensure it is performed correctly, disturbs respiration, and is fatiguing due to the muscular effort. Two physical characteristics are associated with the AGSM. Tolerance of high +Gz levels requires high intra-thoracic pressures, therefore muscle contraction will be of high intensity. Sustained aerial combat maneuvers require repeated AGSM, therefore endurance capacity is important. The procedure of positive pressure breathing during +Gz (PBG) has the potential to reduce much of the physical stress of performing the AGSM.

PBG uses a modified breathing regulator to increase the pressure of gas delivered to the oxygen mask and lungs. As with the AGSM, the increased airway pressure from PBG is transmitted to the left ventricle and thoracic systemic arteries (16). The benefits and optimum use of pressure breathing have been well studied in relation to reducing the hypoxia from exposure to the very low barometric pressures of altitude (16). The hypertension with pressure breathing and the potential role for +Gz protection were recognized as early as 1944 (24).

Interest in PBG was revived in the early 1970's with investigations conducted in the US and UK (27, 42). Pressure levels up to 40 mm Hg did not alter +Gz tolerance compared to tests using straining maneuvers, but the subjects reported less fatigue with PBG. Arterial blood pressure was also more stable with PBG. During the AGSM, inspiration between strains causes intra-thoracic pressure to drop with subsequent decreases in heart-level blood pressure. Because PBG provides consistent levels of airway pressure, the respiratory-related fluctuations in blood pressure are reduced and head-level pressure is more sustained.

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[3] Intra-thoracic pressure is loosely defined as the pressure around the heart, i.e. intra-pleural pressure.

relaxed individuals. End-expiratory lung volume is determined by the balance of forces (38) tending to deflate the lungs (i.e. static recoil of respiratory system), and forces tending to inflate the lungs (e.g. pressure breathing). PBG at approximately 20 mm Hg would move the respiratory system to near total lung capacity.

Due to the inflating effect, exhalation is more difficult with pressure breathing. Normally passive exhalation now requires expiratory muscle contraction, the intensity of which will be proportional to the airway pressure. The effort required for expiration and the sensation of lung overdistension are reduced by garments which encompass the thorax[4] and contain a bladder for pressurization (16). The standard procedure applies pressure to the outside of the chest at the same level as the airway pressure.

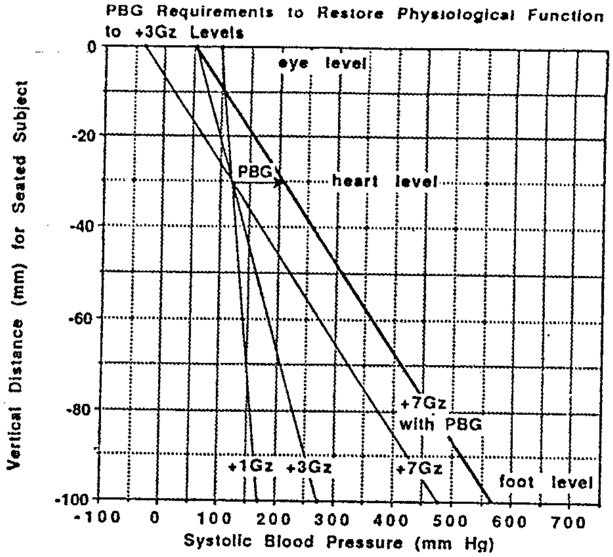
At low pressure levels, thoracic counter-pressure garments make PBG easier. They also allow greater pressures to be used. The maximum pressure breathing level without thoracic counter-pressure is generally regarded as 30 mm Hg. With pressure breathing equipment limited to a "partial-pressure ensemble" (self-tightening oro-nasal mask, helmet, thoracic garment, and G-suit), 80-90 mm Hg airway pressure will probably be the maximum tolerable. While these are certainly high pressures, the risk of burst lung syndrome is remote in healthy lungs because thoracic counter-pressure garments control the pressure gradient between the chest wall surface and alveolar space.

<u>PBG Schedules</u>

Design engineers of PBG regulators must know at what +Gz level PBG should begin, how much pressure is required at different +Gz levels, and the maximum pressure output required from the regulator. The requirements of the PBG schedule have only received attention recently. On a physiologic basis, PBG should begin at +Gz levels causing a deterioration in physiologic function. For example, if visual impairment is not to exceed the loss of peripheral vision, then PBG should begin between +3-4 Gz. PBG could start at a lower +Gz level should pilots require verification of the proper functioning of the PBG system.

As AGSM intensity increases with increased +Gz, so too must the PBG level. An example of PBG proportional to the +Gz level is shown in Figure 2. If head-level blood pressure is to be maintained at some specified level, e.g. equivalent to the pressure normally obtained at +3 Gz, heart-level pressure must increase enough to translate the BP-height line to the point where head-level pressure is the same as the pressure at +3 Gz. Since head-level blood pressure decreases by approximately 22 mm Hg / +Gz in average man, the PBG schedule would be expected to at least match this requirement if it is to be the sole source of intra-thoracic pressure increases. Therefore Figure 2 shows 88 mm Hg PBG restoring head-level blood pressure at +7 Gz to the +3 Gz equivalent. Any deficiency in the amount of pressure supplied to the airways must be made up by supplemental AGSM.

The amount of PBG delivered at different +Gz levels is being addressed from two perspectives: (i) subjective satisfaction with the protection provided by the level of PBG given; and (ii) measurement of +Gz tolerance with different levels of PBG. Subjective ratings of PBG schedules during in-flight trials (2, 12, 17, 19, and USAF Tactical Life Support System trials) and in the centrifuge (35, 37) indicate PBG beginning at approximately +3-4 Gz and increasing at approximately 5-15 mm Hg/+Gz is superior to the standard G-suit and AGSM system at conferring +Gz protection. In contrast, measurements of +Gz tolerance show that greater PBG levels are required to produce protective benefits. Average PBG schedule requirements of approximately 18 mm Hg/+Gz (15), 26 mm Hg/+Gz (9), and 32 mm Hg/+Gz (34) have been reported. PBG requirements significantly greater than 22 mm Hg/+Gz show that the blood pressure increase for increases in intra-pulmonary pressure can be less than unity (16).



An important question that will need to be answered is: once the required intra-thoracic pressure increase for each +Gz level is known, should that pressure be produced entirely by the regulator while the pilot remain reasonably relaxed, or should a portion of the intra-thoracic pressure increase come from AGSM? The only PBG system that is operational, albeit in the very early stages, is the Combat Edge programme of USAF. It produces 12 mm Hg/+Gz beginning at +4 Gz and has been well-received by aircrew.

Although the maximum tolerable airway pressure is approximately 90 mm Hg with partial pressure ensembles, maximum pressures in the 60-70 mm Hg range will be more acceptable to aircrew. With such levels of PBG, what is the maximum +Gz-intensity tolerance that could be expected? This will depend greatly on the maximum intra-thoracic pressure that can be developed. Recent experiments using limited-coverage thoracic garments have shown that the maximum intra-thoracic pressure from the simultaneous use of PBG and maximum AGSM is not different than the intra-thoracic pressure from maximum AGSM alone. The average of these pressures was approximately 140 mm Hg (4).

Although PBG is unlikely to increase +Gz-intensity tolerance above levels attained with AGSM, PBG would be of value during repeated exposures to moderate +Gz levels and in replacing poorly-performed AGSMs. Ineffective AGSMs could occur from lack of knowledge or practice in proper AGSM techniques, the inability to execute a strong AGSM due to muscular fatigue, or from concentration being diverted elsewhere, such as aircraft control.

FINAL REMARKS

What improvement in +Gz tolerance can be expected from the combination of full coverage G-suits and PBG? Relaxed subjects reached +8.3 Gz with these counter-measures[5] compared to +3.6 Gz without +Gz protection (36). Of this increase, 2.9 +Gz of protection was due to the full coverage G-suit. Therefore, we would expect most pilots to be able to conduct flying tasks at +10 Gz when a well-executed AGSM is added to PBG and greater coverage G-suits. Significant improvements in +Gz-duration tolerance will also be realized.

Carbon dioxide and some pharmacologic agents have also conferred hypertensive effects, but these will not be reliable components of any +Gz protective system. Should +Gz protective

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[4] Such garments vary from those covering the entire trunk (called jerkins) to those just covering the rib-cage (called pressure vests or waistcoats).

[5] PBG schedule = 9 mm Hg/+Gz beginning at +2 Gz, with 60 mm Hg ceiling.

systems fail, or reach their limit during flight, unconsciousness-avoidance monitors which measure some standard level of physiologic function such as head-level blood flow, could intervene to reduce the aircraft's +Gz level. We must also be cautious about how far we are willing to push +Gz tolerance. The body has limitations (46), and if exceeded, serious consequences could result without having reached the +Gz tolerance endpoint.

REFERENCES

1. Avasthey P, Wood EH. Intrathoracic and venous pressure relationships during responses to changes in body positions. J. Appl. Physiol. 37:166-175, 1974.
2. Bagshaw M. A flight trial of positive pressure breathing during acceleration using RAF Hawk aircraft at a tactical weapons unit. Royal Air Force, Institute of Aviation Medicine. IAM Report No. 637, 1984.
3. Bjurstedt H, Wood EH, Astrom A. Cardiovascular effects of raised airway pressure. Acta Physiol. Scand. 29:190-201, 1953.
4. Buick F, Hartley J, Pecaric M. Maximal intra-thoracic pressure with PBG and AGSM. In: Preprints, AGARD Aerospace Medical Panel 71st Symposium. High altitude and high +Gz protection for military aircrew. 29-30 April 1991, Pensacola, FL.
5. Burton RR. Anti-G suit inflation rate requirements. Aviat. Space Environ. Med. 59: 601-605, 1988.
6. Burton RR, Jaggars JL, Leverett SD. Advances in G-protection research. In: Preprints of Annual Meeting of Aerospace Medical Association, pp 29-30, 1976.
7. Burton RR, Krutz RW. G-tolerance and protection with anti-G suit concepts. Aviat. Space Environ. Med. 46:119-124, 1975.
8. Burton RR, Parkhurst MJ, Leverett SD. +Gz protection afforded by standard and preacceleration inflations of the bladder and capstan type G-suits. Aerospace Med. 44:488-494, 1973.
9. Clere JM, Lejeune D, Tran-cong-chi D, Marotte H, Poirier JL. Effect of different schedules of assisted positive pressure breathing on G-level tolerance. In: Proceedings of SAFE Symposium, Las Vegas, NV, 1988.
10. Cochran LB. A study of the half-pressure anti-blackout suit. U.S. Naval School of Aviation Medicine, Pensacola, Florida. Research Report No. NM 001 059.15.03, 20 July 1954.
11. Cochran LB, Gand PW, Norsworthy ME. Variations in human G tolerance to positive acceleration. U.S. School of Aviation Medicine, Naval Air Station, Pensacola, Florida, Research Report NM001 059.02.10, 31 August 1954.
12. Cresswell GJ, McPhate D, Harding RM, Farrer E. Positive pressure breathing with and without chest counter-pressure - an assessment in air combat manoeuvring flight. Aviat. Space Environ. Med. 59: 480, 1988.
13. Crosbie RJ. A servo controlled rapid response anti-G valve. Naval Air Development Center, Report NADC-83087-60, 1983.
14. Crossley RJ, Glaister DH. Effect of posture on tolerance to positive (+Gz) acceleration. In: Adaptation and Acclimatisation in Aerospace Medicine. AGARD-CP-82, pp 6-1 to 6-6. AGARD, Neuilly-sur-Seine, France, 1971.
15. Domaszuk J. The application of positive pressure breathing for improving +Gz acceleration tolerance. Aviat. Space Environ. Med. 54:334-337, 1983.
16. Ernsting J. Some effects of raised intra-pulmonary pressure in man. AGARDOgraph 106. The Advisory Group for Aerospace Research and Development. NATO. Technivision Services, England, 1966.
17. Glaister DH, Lisher BJ. Pressure breathing as a means of enhancing tolerance to sustained positive accelerations. In: Proceedings of a Symposium on Biomedical and Biophysical Aspects of Oxygen Systems, 17th Meeting of Air Standardization Coordinating Committee, Working Party 61, Farnborough, Hants, November 8-12, pp 138-144, 1976.
18. Hamilton WF, Woodbury RA, Harper HT. Arterial, cerebrospinal and venous pressures in man during cough and strain. Am. J. Physiol. 141:42-50, 1944.
19. Harding RM, Cresswell GJ. Royal Air Force flight trials of positive pressure breathing. In: Proceedings of a Symposium. High G and high G protection - aeromedical and operational aspects. Royal Aeronautical Society, London, pp 62-71, 1987.
20. Henry JP, Gauer OH, Kety SS, Kramer JJ. Factors maintaining cerebral circulation during gravitational stress. J. Clin. Invest. 30:292-300, 1951.
21. Krutz RW, Burton RR. The effect of uniform lower body pressurization on +Gz tolerance and protection. In: Preprints of Annual Scientific of Aerospace Medical Association, pp 62-63, 1974.
22. Krutz RW, Burton RR. A comparison of uniform pressure anti-G suits. In: Proceedings of 25th SAFE Symposium, Las Vegas, NV, pp 50-53, 1987.
23. Krutz R, Burton RR, Forster EM. Physiologic correlates of protection afforded by anti-G suits. Aviat. Space Environ. Med. 61:106-111, 1990.
24. Lambert EH. Subcommittee on Acceleration of the National Research Council. Self-protective maneuvers combined with anti-blackout suits. February, 1944. Cited in: Wood EH, Lambert EH. Some factors which influence the protection afforded by pneumatic anti-g suits. J. Aviat. Med. 23:218-228, 1952.
25. Lambert EH. The physiologic basis of blackout as it occurs in aviators. Fed. Proc. 4:43, 1945.
26. Lambert EH, Wood EH. Direct determination of man's blood pressure on the human centrifuge during positive acceleration. Fed. Proc. 5:59, 1946.
27. Leverett SD, Burton RR, Crossley RJ, Michaelson ED, Shubrooks SJ. Physiologic responses to high sustained +Gz acceleration. USAF School of Aerospace Medicine, SAM-TR-73-21, 1973.
28. Lewis DH. An analysis of some current methods of G protection. J. Aviat. Med. 26:479-485, 1955.
29. Lindberg EF, Wood EH. Measurement of cardiac output during headward acceleration using the dye dilution technique. Aerospace Med. 30:817-834, 1960.
30. MacDougall JD, Tuxen D, Sale DG, Moroz JR, Sutton JR. Arterial blood pressure response to heavy resistance exercise. J. Appl. Physiol. 58:785-790, 1985.
31. Martin EE. Evaluation of the anti-G suit, report No. 7. Air Command Memorandum, Report No. TSEAA-689-2B, November 20, 1947.
32. Miles DS, Owens JJ, Golden JC, Gotshall RW. Central and peripheral hemodynamics during maximal leg extension exercise. Eur. J. Appl. Physiol. 56:12-17, 1987.
33. Parkhurst MJ, Leverett SD, Shubrooks SJ. Human tolerance to high, sustained +Gz acceleration. Aerospace Med. 43:708-712, 1972.
34. Pecaric M, Buick F. Determination of a pressure breathing schedule for improving +Gz tolerance. Submitted for publication to Aviat. Space Environ. Med. 1991.
35. Prior ARJ, Bass JA, Tervit J. Positive pressure breathing and chest counter-pressure for enhanced +Gz tolerance using NGL anti-g module and regulator 1654E000. Royal Air Force, Institute of Aviation Medicine, Aircrew Equipment Report No. 537, 1986.
36. Prior ARJ. Centrifuge assessment of the +Gz acceleration protection afforded by full coverage anti-G trousers. Royal Air Force, Institute of Aviation Medicine, Aircrew Equipment Report No. 572, 1988.
37. Prior ARJ. The optimisation of a positive pressure breathing system for enhanced G protection. In: Preprints, AGARD Aerospace Medical Panel 71st Symposium. High altitude and high +Gz protection for military aircrew. 29-30 April 1991, Pensacola, FL.
38. Rahn H, Otis AB, Chadwick LE, Fenn WO. The pressure-volume diagram of the thorax and lung. Am. J. Physiol. 146:161-178, 1946.
39. Rushmer RF. The nature of intraperitoneal and intrarectal pressures. Am. J. Physiol. 147:242-249, 1946.
40. Rushmer RF. A roentgenographic study of the effects of a pneumatic antiblackout suit on the hydrostatic columns in man exposed to positive radial acceleration. Am. J. Physiol. 151:459-468, 1947.
41. Sharpey-Schafer EP. Effects of coughing on intra-thoracic pressure, arterial pressure and peripheral blood flow. J. Physiol. 122:351-357, 1953.
42. Shubrooks SJ. Positive pressure breathing as a protective technique during +Gz acceleration. J. Appl. Physiol. 35:294-298, 1973.
43. Sieker HO, Martin EE, Gauer OH, Henry J. A comparative study of two experimental pneumatic anti-g suits and the standard USAF G-4A anti-g suit. Wright Air Development Center, WADC-TR-52-317, 1953.
44. Stoll A. Human tolerance to positive G as determined by physiological endpoints. J. Aviat. Med. 27:356-67, 1956.
45. Wood EH. Development of anti-G suits and their limitations. Aviat. Space Environ. Med. 58:699-706, 1987.
46. Wood EH. Maximum protection anti-G suits and their limitations. SAFE J. 18:30-40, 1988.
47. Wood EH, Lambert EH. The effect of anti-blackout suits on blood pressure changes produced on the human centrifuge. Fed. Proc. 5:115-116, 1946.
48. Wood EH, Lambert EH, Baldes EJ, Code CF. Effects of acceleration in relation to aviation. Fed. Proc. 5:327-344, 1946.
49. Wood EH, Lambert EH. Some factors which influence the protection afforded by pneumatic anti-g suits. J. Aviat. Med. 23:218-228, 1952.
50. Wood EH, Sturm RE. Human centrifuge non-invasive measurements of arterial pressure at eye level during Gz acceleration. Aviat. Space Environ. Med. 60:1005-1010, 1989.

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