ANNOTATED BIBLIOGRAPHY

PHYSIOLOGICAL EFFECTS

ACCELERATION IN AIRCRAFT

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PREFACE

This bibliography was compiled from the literature available in the Bureau of Medicine and Surgery, Washington, D. C., the Technical Information Section of the Bureau of Aeronautics, and the files of the medical department, NAS, Pensacola. For the most part, it includes only the classified reports which have been issued on the subject, no attempt having been made to cover the open literature which has already been very adequately listed in "A Bibliography of Aviation Medicine" by E. C. Hoff and J. F. Fulton, Chas. C. Thomas, Springfield, Ill., 1942, and in the supplemental bibliography by P. M. Hoff, E. C. Hoff, and J. F. Fulton, ibid., 1944, and reviewed by Ham (2).

The papers are so arranged as to present a logical development of the subject matter rather than by author or chronology. A subject and an author index are included to aid in locating individual references, also an index by issuing agency. While many of the sections, particularly the one on decelerative forces in crashes, are known to be very incomplete and some of the classifications are admittedly arbitrary, it is hoped that this compilation of material, which has for the most part not been previously reviewed, will be of aid in further research on acceleration.

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A. REVIEWS AND GENERAL ARTICLES

1. Acceleration and blackout: Summary report No. 3. Office of the Air Surgeon, Headquarters Army Air Forces, Washington, D. C.

Summarizes literature on acceleration in Surgeon General's library part way through 1942. Very good bibliography.

2. Ham, George C. Effects of centrifugal acceleration on living organisms. **War Medicine** 3:30-56 1943.

Review of open literature an acceleration through 1942.

3. Grow, M. C. and H. G. Armstrong. **Fit to Fly: A Medical Handbook for Fliers.** D. Appleton-Century, New York, 387 pp., 1941.

4. Ruff, S. and H. Strughold. **Compendium of Aviation Medicine,** Berlin, 1939. Reproduced under a license granted by the Alien Property Custodian, 1942. 130 pp.

5. Von Diringshofen, H. **Medical Guide for Flying Personnel** trans-by V. E. Henderson. U. of Toronto Press. 102 pp.

B. EFFECTS OF POSTURE ON G-TOLERANCE

6. Stewart, W. K. Final observations on the value of crouching as a preventative of "blacking out." (Farnborough) FPRC No. 177. 10 Aug. 40.

Eleven subjects made 100 man-runs undergoing centrifugal force in planes. Nine subjects were able to raise their blackout thresholds one to two "g" by crouching; two showed no improvement. An accessory rudder bar to facilitate the crouch position is described.

7. Stewart, W. K. An investigation into the effect of a reclining posture on the ability to withstand high "g". (Farnborough) FPRC No. 212. 10 Dec. 40.

One subject made experimental runs exceeding 5 "g" for 10 to 20 seconds. Peak run was 6 "g" for 6 to 9 seconds. This resulted in unconsciousness when subject was unprotected. When cockpit seat was inclined 45° from vertical and feet raised to level of seat, complete visual protection was obtained.

The venous and arterial hydrostatic levels were reduced only one inch by this maneuver, but the decrease in the leg-thigh and thigh-spine angles promoted venous return. Visual fields were not markedly reduced by this procedure, but tilting sufficient to protect from higher values of "g" would produce definite visual impairment.

8. Kerr, C. E., W. K. Stewart, and J. R. Tobin. Note on prone position in aircraft. (Farnborough) FPRC No. 500.

Reclining in a prone position as a protection against "g" has been abandoned by the RAF because: (1) Visual difficulties are apparently insuperable; the blind area above the pilot is too large although the visual field behind him is not affected and the field below him is improved. (2) The position is extremely uncomfortable and produces much fatigue. The Germans report that a prone position raises the "g" threshold to 14 to 17 "g" on the centrifuge. A Heinkel has been reported to have been equipped with reclining seats.

9. Wood, E. H., C. F. Code, and E. J. Baldes. Protection against the effects of acceleration afforded the human by assumption of the prone position. (Mayo Clinic) CAM No. 158. 10 July 43.

Thirty centrifuge runs were made by 3 trained subjects. Vision dimmed at 3 "g" and blackout occurred at 4 to 5 'g" when subjects were sitting upright. In prone position vision was unaffected by 9 "g" for 10 seconds.

10. Dillon, Frederick P. Automatic dive bomber pilot's seat. United States Patent Office No. 2,304,781. Pat. Dec. 15, 1942.

Basic patent on any pilot's seat which automatically places the pilot's body supine, tangential to the arc and perpendicular to the radius of the turn or pull-out, when plane is subjected to "g". Patent describes method using a hydraulic system, and is now assigned to the U. S. Government.

C. ABDOMINAL BELTS AND LEGGINGS AS ANTI-G DEVICES

1. Stewart, W. K. Observations on the efficiency of abdominal belts in the prevention of "blacking out" (Farnborough) FPRC No. 176. 8 Aug. 40.

All tests conducted in planes by a small number of subjects.

a. **Elastic belts** do not raise blackout threshold, may shorten period between blackout and unconsciousness. Although they produce a feeling of confidence at low values of "g", they are potentially dangerous.

b. **Pneumatic belts** inflated at pressures exceeding 50 mm Hg prevent fastening of Sutton harness. Even pressures of 80 to 100 mm Hg (of therapeutic value according to Armstrong) do not elevate blackout threshold.

c. **Hydrostatic belts** are uncomfortably cold even at altitudes as low as 10,000 feet. At 6 "g" belts are a serious hindrance due to increased effective weight. Water does not drain out of belts after exposure to "g" and is very uncomfortable. Hydrostatic belts elevate "g" threshold at least 0.5 "g", but disadvantages outweigh the gain. It is recommended that experiments on belts as anti-"g" devices be discontinued.

12. Stewart, W. K. Final report on effect of abdominal compression on ability to withstand "g". (Farnborough) FPRC No. 300. 27 May 41.

The Valsalva maneuver becomes less effective with increasing altitude. Thus one subject was able to produce only 42 mm Hg rise in blood pressure at 35,000 feet as compared with 65 mm at sea level. Another produced only 10 mm Hg rise at 31,000 feet as compared with 26 mm at sea level.

It is concluded that increased intra-abdominal pressure has 2 effects: (1) an immediate beneficial effect on cerebral circulation which is maximally effective after 60 seconds, and (2) a retardation of blood flow from the lower limbs which leads to a decrease in the minute volume of the heart, hence to syncope. Therefore increased intra-abdominal pressure of long duration will lower the "g" threshold. An increase shortly before exposure to "g" will raise the threshold but will not prevent blackout or syncope if the "g" is applied for a sufficient period of time. The discomforts and dangers of abdominal belts are believed to outweigh the slight protection afforded.

13. Stewart, W. K. Note on Spencer acceleration belt and leggings. (Farnborough) FPRC No. 458. 11 May 42.

Inflation of Spencer belt to 2 to 2.5 psi raises "g" threshold at least 1 "g" for 5 seconds. Structural failure along knee seams occurred in model tested.

14. Andrus, E. C., E. Day, E. Nichols, and S. Scherlis. Studies on the effects of abdominal pressure upon the flow and distribution of blood. (Johns Hopkins) CAM No. 21. 18 Aug. 41.

Effect of Spencer type belt inflated at pressures up to 100 mm Hg studied on 30 male subjects, 16 to 29 years of age. With subject at rest, supine inflation of belt is accompanied by 5 to 6 mm Hg rise in diastolic blood pressure in arms and legs. Venous pressure in arms is not significantly affected, but in legs it usually rises when the belt is inflated, especially if it is adjusted low on the body. Arm volume is unchanged but leg volume increases. Circulation time is not significantly affected. Cardiac output (ballistocardiograph) undergoes transient increase during inflation of belt. Blood flow in arm and calf may increase but usually decreases, particularly with higher belt pressures. This is probably due to peripheral vasoconstriction reflexly provoked by application of pressure to abdomen.

Observations on tilt table. Inflation of belt has no consistent effect on immediate fall of arterial pressure in arms and rise in legs produced by a change from the supine to the erect posture. In over half of subjects, inflation of the belt prevents or lessens progressive fall in brachial arterial pressure during tilting. Increased leg volume on tilting is to some degree prevented by previous inflation of belt. The hypotension produced by sodium nitrite may be very favorably influenced by inflating the belt before or even while tilting. It is concluded that abdominal pressure belts might be valuable in circumstances where pooling of blood in the abdomen occurs.

Effects of inflated belt on respiration. The level of respiration is displaced upward into the complemental air. Tidal air, respiratory rate, and minute volume are little affected. In 13 subjects, vital capacity increased in one, decreased 100 cc in 6, 200 to 500 cc in 5, and 1100 cc in one.

Effects of inflated belt on heart. Upward displacement of the diaphragm raises the heart to a more transverse position. Consequently, the ECG shows shift of electrical axis to the left and a concomitant change in the amplitude of T waves. No significant change in size is apparent on fluoroscopy.

15. Scherlis, S. and E. C. Andrus. Studies on the influence of pneumatic leggings upon the flow and distribution of blood. (Johns Hopkins) CAM No. 115. 18 Feb. 43.

Used from 4 to 34 subjects for different procedures.

a. Inflation of leggings either with or without simultaneous inflation of an abdominal belt produces no circulatory change except a transient, significant rise in venous pressure in arms.

b. Inflation of leggings either with or without a belt has a very favorable effect on circulatory changes produced by 1 "g" on the tilt table. (1) Fall in arterial pressure is prevented. (2) Cardiac acceleration is prevented. (3) Cardiac output is sustained.

c. The mechanism of this action is thought to be as follows: (1) External pressure of leggings is transmitted to veins and opposes hydrostatic congesting pressure there. (2) Normal peripheral resistance in arterioles is increased, and the blood is hindered from flowing into the capillaries. Less peripheral vasoconstriction is necessary to maintain cerebral blood flow.

d. Under gravitational forces greater than 1 "g", belts and leggings would probably be inadequate, might even prove detrimental by opposing venous return from the legs. Also under high gravitational force, more pressure is needed, theoretically, around the calves than around the thighs. This differential is not provided by leggings.

e. It is suggested that the tilt table is a valuable testing instrument for anti-"g" devices.

16. Ferwerda, T. Test of experimental pneumatic stockings and belts for aviators. (Anacostia Naval Airport) CAM No. 28. 24 Sept. 41.

Spencer acceleration belt and stockings tested in plane. When inflated to 1.5 psi pressure, they relieved aching in legs following pull out. Use of belt did not affect initial blackout at 5 "g", but after blackout vision cleared and remained clear for as long as 5 "g" could be held on plane. When inflated to 1.5 psi, apparatus had no effect on "g"-tolerance at forces greater than 5.5 "g". When belt alone was used, very painful pressure was felt in legs.

D. THE FRANKS FLYING SUIT (RAF-RCAF)

17. Franks, W. R. Test flights with hydrostatic suit. (Farnborough) FPRC No. 301. 27 May 41.

In one subject the Franks suit filled with water to heart level increased tolerance 2 "g" in planes.

The following formulae are given which are useful in calculating gravitational forces and hydraulic pressure in suits:

a. Magnitude of accelerating force (G) acting during change of direction:

$G = V^2/15r$ where V = speed in mph.
r = radius of turn in feet.

Length of time (T) in seconds this force acts in a turn of 180°:

$$T = \frac{2.15\ r}{V} = \frac{0.15\ V}{G}$$

A 90° turn takes half as long, a 360° turn twice as long, etc.

b. Magnitude of linear accelerating force (G) acting in straight line (cf. catapult take-offs, deceleration in crashes):

$$G = \frac{(\Delta V)^2}{64(D - V_1)}$$

Where ΔV = change of speed in ft./sec.
V_1 = lowest speed attained in velocity change in ft./sec.
D = distance in feet through which change in speed takes place.

Time (T) in seconds during which linear acceleration acts:

$$T = \frac{2D}{2V_1 + \Delta V}$$

c. Hydrostatic pressure (P) in a water filled suit at any given point:
P = hdG where
P = pressure (× 0.43 to give psi)
h = hydrostatic height of fluid above point in ft.
d = density of fluid.
G = acceleration in G units.

Where the body rests on a support, the pressure (P) on the seat or sole of foot is:

$$P = \frac{M \times G}{A} \quad \text{where}$$

P = pressure in psi
M = weight of portion of body supported by seat (or floor)
G = acceleration in "g" units
A = area of body in contact with seat (or floor) in square inches.

18. RAF Physiological Research Unit. Flight tests on Frank's hydrostatic suit. (Farnborough) FPRC No. 339. 30 July 41.

Four subjects tested FFS in planes. They reported that the suit caused no severe discomfort or inconvenience in climbing in and out of planes. Vertigo occurred when looking back under 6 "g". Complete visual protection was obtained up to 8 to 9 "g" for about 10 seconds.

19. RAF Physiological Laboratory. Devices for protecting pilots from the effects of high acceleration with particular reference to trials of the Frank's suit. (Farnborough) FPRC No. 498. 20 Nov. 42.

At 8 "g", 250 mm Hg aortic blood pressure is needed for clear vision; at 20 "g", 625 mm. The heart has difficulty in contracting against even 200 mm Hg.

Service trials of FFS in planes show one to two "g" increase in tolerance. Farnborough experimental trials always show 2 "g" increase, often 4.5 to 8 "g" increase with experienced subjects when ¾ to 1¾ gallons of water are used in the suit.

Pilots complain of loss of "feel" when wearing suit. The danger of pilot's exceeding "g" load of plane is evident. It is recommended that pilots not be protected beyond 6 "g" and that FFS never be used in planes not cleared for 9 "g".

Advantages of FFS is that pressure **gradient** is produced automatically and independently of any external control.

20. Briggs, F. E. R. The Franks anti-blacking out suit. (Report of plane tests at RCAF Station, Rockcliffe, Ontario, and at Wright Field). FPRC No. 301-A.

Two subjects wearing FFS were completely protected up to 7 "g" in the P-40 and Harvard III for 12 seconds. Fatigue and nausea were relieved. Some respiratory embarrassment was noted during inverted flight, but no other discomfort. An individually fitted suit is necessary.

21. Davidson, S., B. Rose, and W. K. Stewart. Review of the practicability of and necessity for anti-"g" devices in the RAF with particular reference to the FFS Mk III. (RAF Physiological Laboratory) FPRC No. 584. July 44.

The FFS Mk III has been extensively flight tested by the RAF, Fleet Air Arm, and American 8th Army Air Force. It has been tested in Europe, the Mediterranean, and in Southeast Asia. In preliminary trials all three services regarded it favorably. In the final trials, only the FAA have strongly recommended it. The RAF have rejected it, and the 8th AAF at the time of the report was undecided. The chief objections to the suit were its bulk and awkwardness, the difficulty in servicing it, and difficulty in looking back while wearing it.

22. Lamhert, E. H., C. F. Code, E. J. Baldes, and E. H. Wood. The FFS with pneumatic pressurization as an inti-"g" device. (Mayo Clinic) CAM No. 248. 19 Jan. 44.

The FFS, designed to contain water, was inflated with air at 1 psi/"g" and tested on 8 subjects on the centrifuge. Average protection provided was:

Visual symptoms	2.2 "g"
Blood content of ear	2.2 "g"
Amplitude of ear pulse	2.5 "g"

When the FFS was inflated with 4.7 liters of water, less than 1 "g" protection was obtained by all criteria; when fully inflated with water, 1.5 "g" protection was provided.

23. Hallenbeck, G. A., E. J. Baldes, and C. F. Code. The effect of immersion in water on the tolerance of dogs to centrifugal force. (Mayo Clinic) CAM No. 278. 14 Mar 44.

a. When dogs are immersed in water to the junction of the second rib with the sternum so that most of the chest is submerged, "g"-tolerance is lowered. All six dogs on which this was tried died at "g" levels they previously withstood with minimal symptoms.

b. When dogs are immersed in water to the level of the xiphoid process so that most of the chest is above water, tolerance increases up to 3 or more "g".

24. Wood, E. H., C. F. Code, and E. J. Baldes. The protection afforded the human by hydrostatic as compared to pneumatic anti-G devices. (Mayo Clinic) CAM No. 207. 12 Nov. 43.

Nine hundred centrifuge runs were made on 12 subjects to compare the "g" protection afforded by:

a.	Immersion in water to xiphoid process	0.9 "g"
b.	FFS containing 4.7 liters water	0.9 "g"
c.	FFS fully inflated with water	1.5 "g"
d.	Water immersion to 3rd rib at sternum	1.7 "g"
e.	Pneumatic gradient pressure suit	1.9 "g"
f.	Arterial occlusion suit	2.9 "g"

Arterial occlusion (Clark-Wood) suit has 4 pneumatic cuffs, one on each extremity close to the body and an abdominal bladder, which are inflated by "g"-activated valves. All blood vessels are occluded by it.

Conclusion of paper: Pneumatic pressure devices are definitely superior to hydraulic ones in affording "g"-protection.

E. THE COTTON PNEUMATIC SUIT (RAAF)

25. Letter from RAAF Flying Personnel Research Committee to Air Liaison Officer, Australia House, 3 Oct. 41. WAM-101-1 FPRC No. 358(b).

Reports that Cotton suit gives protection up to 9 to 10 "g".

26. Notes on the anti-"g" device from Dr. Cotton, Sidney University, transmitted by Col. C. H. Kellaway of FPRC, Australia. CAM No. 27. 21 Oct. 41.

Photographs of the centrifuge at Sydney. Cotton suit consists of air filled bladders pressurized by a hydrostatic reservoir. Weight of the suit is 30 pounds. Suit protects against 9.3 "g" for 19 ± 1 seconds with no visual symptoms, minimum discomfort.

27. Australian Flying Personnel Research Committee. Blacking-out research at Sydney University during 1941. FPRC No. 358-h. 8 Jan. 42.

Dr. Cotton has been able to withstand 9.5 "g" for 30 seconds in his suit on two occasions.

Cotton suit may be pressurized by (1) hydrostatic system which is too cumbersome for plane use, (2) a column of pistons, (3) Meyer's differential pistons (like U. S. Berger Bros. design) (4) Stevens' ball valve, which has not yet been tested.

Detailed description of electric drive centrifuge at Sydney. Subject's seat is shot out from center of centrifuge to periphery which is revolving at desired speed to obtain very quick acceleration. Radius is 18 feet, maximum speed 60 rpm, maximum force 10 "g".

28. Report No. 2 on "blackout" work at Sydney University. FPRC No. 358-j.

It is reported that Robinson's ball valve device for regulating pressure admitted to pneumatic suits under "g" is unsatisfactory because "hunting" of balls causes fluctuation in pressure and gross wastage of air.

Meyer's differential pistons are satisfactory, providing 3 to 4 "g" protection to trained subjects on the centrifuge. However, the tight fit of the pistons means that the air used must be filtered free of dust.

Pneumatic suits offer good protection but provision must be made for (1) ventilation, (2) reduction in weight.

29. Note on progress of the pneumodynamic suit (extract from the Australian Flying Personnel Research Committee. Report No. FR27 dated December 1942. FPRC No. 407-a.

Six subjects tested the Cotton suit in the Kittyhawk plane in October 42. Five were protected up to 7.5 to 8.5 "g" and one was protected to 10 "g" but buckled his plane during the test. Fatigue was diminshed and pilots were able to read their instruments with ease during high "g" maneuvers although dragging effects on the face and heaviness of the limbs were not affected.

Objections to suit noted were a lack of pressure over the foot and foreleg and a restriction of breathing caused by the suit coming too high up on the chest. Hard soles are needed in the feet of the suit to protect against pressure on the rudder bar. Pressure needs to be emptied completely from the suit when not under "g".

30. Cotton, F. S. and J. H. Tyrer. Experimental results on the amount of protection against "g" afforded by restricting CAAC suit to "legs" plus a belt. RAAF-FPRC-FR(83)(a) (Sydney).

With the convention that the unprotected blackout threshold equals 100, results obtained from grayout data on the centrifuge so far are as follows:

a. The average error of a single test of a series carried out during one centrifuge run is less than 3%.

b. The average error of the mean value of individual tests in one centrifuge run is less than 2%.

c. The capacity of any subject to withstand "g" often shows a progressive change during a series of tests, and if this is not taken into account, serious errors may be introduced.

d. The average "g" threshold using "legs" of suit alone is 121.

e. Average threshold using "legs" plus air belt is 128.

f. Average threshold using whole suit is 134.

g. Values (d) and (f) are probably reliable; value (e) is probably too low.

h. More protection is given by the suit to those with low initial "g"-thresholds than to those with high thresholds.

31. McIntyre, A. K. Preliminary report on KOP anti-G suits. RAAF-FPRC-FR No. 92. June 44.

KOP is Kelly one-piece pneumatic anti-"g" suit. The KOP I and KOP II have 5 gradient pressures, the KOP III has 3 gradient pressures. It is concluded from tests on one subject that 5 pressures are not superior to 3 and that the KOP is still too bulky for practical use. Photographs.

32. McIntyre, A. K. Present position of anti-G suits. RAAF-FPRC-FR No. 93. June 44.

All the anti-"g" suits currently being developed are briefly reviewed with a summary of their advantages and disadvantages.

F. PNEUMATIC PRESSURE SUITS (USA-USN)

33. Navy Department, Bureau of Aeronautics, Washington. Memo from Medical Research Section to Director, Div. Med. Res., Bureau of Medicine and Surgery. Report on research project—anti-blackout suit and attachments. 14 Oct. 42.

The physiological basis of anti-"g" suits is discussed and the history of the Navy pulsating pressure suit and early constant pressure suit is given.

34. Fulton, J. F. Pneumatic and water suits and other agents designed to counteract acceleration in aircraft. (Yale University) CAM No. 15. 22 July 41.

This is a brief review of protective devices which was made preliminary to the commencement of OSRD research. The German methods of combatting "g" are summarized. It is recommended that the effects of adrenal cortical hormones on "g" tolerance be studied and that the relative merits of abdominal belts and pressurized leggings be determined. It is also suggested that a water suit be pressurized with air and that standards of service testing for acceleration be drawn up.

35. Maison, G. L. and C. A. Maaske. Evaluation of anti-G suits. (Wright Field) CAM No. 201. 29 Sept. 43.

Data reported indentical with Wood, Code and Baldes report, CAM No. 207, reference No. 24.

36. Maison, G. L. and C. A. Maaske. Evaluation of anti-G suits, Report No. 1. (Wright Field) Eng-49-696-51A.

Data identical with reference above.

37. Byrne, W. A. Final report on test of anti-"g" devices under simulated combat conditions. (Eglin Field) Proof Dept, AAF Proving Ground Command. Serial No. 4-43-40. AAF Board Project No. (M-4) 205. 3 Nov. 43.

a. Pilots wearing an anti-"g" suit have a definite tactical advantage over those not protected in combat. They are also less fatigued.

b. Guns can be fired without difficulty under as much as 8.8 "g."

c. The Berger Bros. GPS is definitely superior to the Clark-Wood AOS.

d. The instrument vacuum pump installation is more satisfactory than the Cornelius Air Compressor installation from the standpoint of reliability, ease of installation and maintenance, and adequacy at altitude.

e. Photographs of GPS and AOS are included.

38. Scholander, P. F. Final report on test of anti-"g" device for pilots (anti-blackout device). (Eglin Field) Proof Department. AAF Proving Ground Command. Serial No. 7-43-9. 4 Nov. 43.

a. The Berger Bros. gradient pressure suit and the Clark Wood arterial occulusion suit were compared by 24 experienced pilots. Both suits were effective in preventing blackout up to 8 to 9.5 "g" in planes. Both suits effectively prevent "g" fatigue.

b. When 2 to 3 "g" are held continuously for two to ten minutes, the AOS produces severe pain or distracting discomfort in the limbs. No discomfort is produced by the GPS when 2 to 3 "g" are held continuously for 20 minutes. Hence the GPS is preferred by most pilots. Both suits are comfortable when worn outside aircraft and offer good flotation.

c. The GPS pressure equipment operates satisfactorily from the standard instrument vacuum pump with special oil filter in tests up to 33,000 feet. The few failures encountered in the tests could be easily prevented in the future. The AOS requires an electric motor, pump, and switch to power it. Serious failures in the powering devices occurred. Out of 4 pumps tested, one was completely broken in the process and 2 partially broken.

d. Very good photographs of the GPS and AOS are included, also photographs and diagrams of the two valves and graphs of their performance at altitude.

39. Army Air Forces Board. Anti-"g" flying suits—comparative tests of the Clark and Berger models. (Eglin Field) AAF Proving Ground Commend. Project No. 3658-C-422.3. 8 Nov. 44.

After flight tests by 8 experienced pilots, it was concluded that the Clark coverall suit is superior to the Berger Bros. G-2 model, especially in regard to comfort. The Cornelius Clark valve which supplies the pressure also performs better at altitude than the Berger Bros. valve.

Photographs of the Clark suit and Cornelius Clark valve and drawings of the Berger Bros. valve are included.

40. Hallenbeck, G. A., C. A. Maaske, and E. E. Martin. Evaluation of anti-G suits. Report No. 2. (Wright Field) Eng-49-696-51B. 12 Dec. 43.

Pictures of Berger Bros. gradient pressure pneumatic suits. Explanation and photograps of the "g" compensated valves which control admission of air to suits. Positive pressure side of vacuum instrument pump standard in aircraft is used as source of pressure. Suits are pressurized at 1 psi/"g" the maximum pressure attainable being 4 to 4.5 psi.

Thirty-two subjects on the centrifuge obtained the following protection wearing the GPS (gradient pressure suit).

Visual dimming	1.1 "g"
Peripheral light loss	1.6 "g"
Blackout	2.5 "g"
Unconsciousness	2.8 "g"

The M1 breathing maneuver plus the GPS protects vision even at values of "g" where vision would be lost with the suit alone.

Protection remains good even at altitude where pressures obtainable are limited to 4 to 4.5 psi because of the reduced output of the vacuum pump.

The high degree of protection against unconsciousness is thought to be very important because of the period of amentia following unconsciousness.

41. Hallenbeck, G. A., C. A. Maaske, and E. E. Martin. Evaluation of anti-"g" suits. (Wright Field) CAM No. 254. 12 Dec. 43.

a. Centrifuge tests on 32 subjects at Wright Field and the Mayo Clinic show that the Berger Bros. GPS raises the "g" theshold between 1 and 2 "g".

b. To simulate the condition found at high altitudes where the output of the vacuum pump is limited, maximum suit pressures were kept to 4 to 4.5 psi. Protection offered by the suit remained good.

c. Protection offered by suit summates with that afforded by muscle straining maneuvers.

d. Individuals wearing the suit have a very high theshold for unconsciousness, a valuable feature.

Graphs of the performance of the Berger valve when supplied by the B-12 pump are included.

42. Maison, G. L. Evaluation of anti-G suits. Report No. 3. (Wright Field) Eng-49-696-51C. 18 April 44.

A total of 22 Berger Bros. pneumatic gradient pressure suits and 22 hydraulic Franks flying suits were flight tested by 26 pilots of the 9th Air Force in P-47 and P-51 aircraft. Complete visual protection was obtained with both suits.

Eighty percent of the pilots thought anti-"g" protection desirable in P-51 aircraft, but only about 40 percent thought it necessary in P-47's, probably because the latter planes are less maneuverable. Protection was especially desired for combat flying

Of the 17 pilots who tested both types of suit, 11 preferred the GPS, one the FFS, and 5 had no preference. The GPS was preferred because it is lighter, less cumbersome, can be worn over ordinary clothing, fitting is less critical, and it does not need to be serviced with water prior to take off.

43. Maaske, C. A., G. A. Hallenbeck, and E. E. Martin. Evaluation of anti-G suits. Report No. 4. (Wright Field) Eng-49-696-51D. 10 June 44.

Purpose: To determine the results of tests made on the Material Command centrifuge to determine the efficacy of a single pressure anti-"g" suit in preventing the symptoms caused by exposure to radial acceleration.

Duplicates reference No. 44.

44. Maaske, C. A., G. A. Hallenbeck, and E. E. Martin. Evaluation of anti-G suits. Report No. 4. (Wright Field) CAM No. 348. 10 June 44.

The efficacy of a single pressure pneumatic suit (G-2) was compared with that of a gradient pressure suit (G-1) with a view to lightening and simplifying anti-"g" protection. The G-1 suit plus oil filter and valve weighs 15.5 lbs., the G-2 assembly weighs 8.5 lbs.

In the G-2 the oil filter has been removed and the abdominal bladder simplified. It is pressurized at 1 psi/"g" for values of "g" over 2. There are one abdominal, 2 calf, and 2 thigh bladders. Air is metered to the suit by a 2 unit single pressure "g" activated valve. Pressure source is the positive pressure side of the B-12 vacuum instrument pump rotating at 3,000 rpm and working on -5 inches Hg intake.

Twenty experienced subjects who tested the G-2 by 10 second exposures on the centrifuge obtained an average protection of 1.2 "g" against visual dimming and peripheral light loss and of 1.9 "g" against blackout. This compares favorably with the performance of the G-1 suit.

45. Maison, G. L., and C. A. Maaske. Evaluation of anti-G suits. Report No. 5. (To report the status of anti-"g" devices for fighter planes in the various theaters.) (Wright Field) Eng-49-696-51E-1. 11 Aug. 44.

Two models of the anti-"g" suit have been shown to be necessary, a cut-out suit (G-3) consisting only of the cloth covered bladders to be worn with reguler officer's clothing in cold climates, and the G-4, a very light weight coverall for wear in tropical localities where a minimum of clothing is desirable. G-suits are now optional in the 9th Air Force for P-47's and P-51's; they are mandatory in the 8th AAF for P-51's.

The G-3 is a cut-out G-2 (single pressure) suit. Comparative weights:

G-2 suit	6 lbs.
G-2 plane installation	4 lbs.
G-3 suit	2¼ lbs.

(Plane installation interchangeable with G-2).

The G-4 coverall is made of rayon marquisette; probably is too porous to protect against sunburn. (NB this has been replaced by solid weave nylon at a later date.) Total number of "g" suits delivered to date is 3500. 6600 are on order.

Photographs of G-1, G-2, and G-4 suits are included.

46. Maaske, C. A., Anna Lou Roach, E. E. Martin, and G. L. Maison. Evaluation of anti-G suits. Report No. 6. (Wright Field) TSEAL-3-696-51-F. 16 Nov. 44.

a. Tests have been made on the Wright Field centrifuge of the efficacy of the G-3 (cutaway) and G-4 (coverall) anti-"g" suits. Eleven subjects tested the G-3, 10 subjects the G-4. Protection was determined relaxed with maximum "g" lasting 10 seconds.

b. Protection offered was as follows:

Graying	1.0 "g"	1.0 "g"
Peripheral light loss	1.05 "g"	1.14 "g"
Blackout	1.26 "g"	0.9 "g"

c. The G-3 is pressurized at 0.86 psi per "g" in maneuvers exceeding 2 "g". The G-4 is pressurized at 0.88 psi/"g". The slightly greater protection against blackout offered by the G-3 is thought to be due to the better fit obtained with adjustable lacings, which are not incorporated in the G-4.

d. The G-3 has been reported to offer 2 "g" protection in planes, quite adequate for the aircraft now being flown.

47. Maison, G. L. Report to the Air Surgeon on status of anti-"g" devices as of 1 November 1943. (Wright Field).

Comparison of operation and construction of hydraulic suits (FFS), gradient pressure pneumatic suits (GPS), and Clark-Wood arterial occusion suit (AOS). Pressurizing devices for GPS and AOS at present time consist of:

a. Positive side of vacuum instrument pump. Performance of this pump falls off badly at altitude, must be used with oil filter.

b. Cornelius Co., electrical pump operating on 24 volts DC and using 35 amps. Current model has been shown to be unreliable in service tests at Eglin Field.

c. Tanks of compressed gases. These give excellent performance at all altitudes and temperatures but are least satisfactory source of pressure because of limited period of usefulness, unsatisfactory valves, and added complication of installation and servicing.

d. Combination pump and tank units. Still in developmental stage and designed for use with AOS.

Average protection offered to relaxed subjects on centrifuge is reported as follows:

FFS	0.7 "g"
GPS	1.3 "g" to 1.5 "g"
AOS	2.0 "g" to 2.5 "g"

Both FFS and GPS have proved acceptable to pilots for operational use. AOS should theoretically prove more valuable, but 20 out of 25 experienced combat pilots who flight tested both GPS and AOS preferred the GPS as the AOS proved too uncomfortable. Further operational testing of both GPS and AOS is suggested.

48. Maison, G. L. Report to the Air Surgeon on status of anti-"g" devices as of 25 March 1944. (Wright Field).

Continuation of reference No. 47. Simplification of the three pressure GPS suit (G-1) into the one pressure (G-2) suit is reported. Service tests in the ETO have been performed and are reported in reference No. 42.

49. Maison, G. L. Evaluation of anti-G suits. (Wright Field) CAM No. 309. 18 April 44.

Duplicates data of reference No. 42.

50. Lamport, H., E. C. Hoff, E. J. Baldes, A. R. Sweeney, C. F. Code, and E. H. Wood. Tests of protection against the effects of acceleration afforded the human by the use of the latest model of the gradient pressure suit (GPS) when inflated by three different pressure arrangements. (Mayo Clinic) CAM No. 187. 25 Aug. 43.

No significant differences were found between the protection offered by gradient pressure and single pressure anti-"g" suits when tested on the centrifuge.

Type of inflation of Suit	No. Subjects	Protection in "g" units offered to Vision	Ear Opacity	Ear Pulse
3 gradient pressures	3	1.3	1.6	1.6
Gradient pressure in legs, single pressure over abdomen	7	1.2	1.3	1.4
Single pressure	6	1.2	1.4	1.2

51. Henry, J. P., W. G. Clark, W. H. Tracy, and D. R. Drury. Determination of the effect of time of inflation on the "g" protection gained from the Clark G-4 suit. (University of Southern California) CAM No. 398. 1 Dec. 44.

a. A quantitative measure in terms of "g" units has been made in th course of over 700 centrifuge runs of the protection afforded by a Clark G-4 coverall when rapidly inflated (in less than 0.1 sec) by 5 psi at various times relative to the onset of an acceleration cycle of constant pattern.

b. The pressure could be applied any time less than two minutes before the attainment of maximum "g" without involving the loss of more than 20 percent of maximum protection.

c. With the acceleration pattern used, the optimum time of rapid inflation lay between the start of acceleration and the attainment of 3 "g".

52. Irving, L. Evalutoin of means of reducing pilot fatigue during long fighter missions—anti-"g" suit. (Eglin Field) AAF Board Proj. 4018-C-360.2. 7 Dec. 44.

Two pilots tested the anti-"g" suit on three 5 to 7 hour missions, inflating it in level flight to test it as a means of relieving fatigue. Both agreed that it had no value as such and actually increased their discomfort. Pressure is applied by the "g" suit to parts of the body which do not tire on sitting and is not applied where it might be of value. This finding does not, of course, affect the value of the suit as an anti-"g" device.

53. Meakin, L. W. Report on bladders, vinylite coated nylon—anti-blackout suit—endurance test of. Naval Air Experimental Station, Philadelphia. 9 Feb. 45.

Anti-"g" suit bladders (nylon) were exposed to up to 24 hours at 100° F. and 100% relative humidity and up to 24 hours at 120° F. dry, following which leakage was tested. Bladders met BuAer specifications and were actually improved as far as leakage was concerned by weathering.

54. Maaske, C. A. A report on the introduction of anti-"g" equipment to FEAF and a survey of aero-medical problems in SWPA including continental Australia. (Wright Field). Memo report TSEAL-696-51h. 24 Feb. 45.

The visit of Capt. Maaske and Dr. Baldes of the Mayo Clinic to the Southwest Pacific area and Australia is reported. Tropical climatic conditions interfere with the use of either the G-2 or G-4 coverall anti-"g" suits; the G-3 functions very satisfactorily, preventing blackout and fatigue. However present flying tactics do not indicate a need for anti-"g" equipment. (It is recognized that this situation may change at any time.)

The centrifuge at Sydney is described. No physiological recordings have been made on it to date. A brief description is also given of the six-pressure gradient Australian suit.

55. Aviation Equipment Office, Marine Aircraft Group 91, 9th Marine Aircraft Wing, Fleet Marine Force, USMCAS, Cherry Point, N. C.

A total of 14 tests of the current anti-"g" suit (G-4) were made by Marine aviators. It was found to prevent blackout under high "g" and to reduce pilot fatigue. The suit is uncomfortable only if improperly fitted. Sticking of the pressure regulator valve may occur in new equipment but is easily corrected. It is concluded that the G-4 is a valuable and practical piece of equipment.

Tables of the pressure provided by the valve from 2 to 8 "g" and of the permissable maximum acceleration of the F4U from 10,000 to 30,000 feet are included.

56. Herrington, L. P., H. Lamport, and E. C. Hoff. Analytic studies of pressure transmission factors in anti-"g" suits. (Yale) CAM No. 129. 10 Dec. 42.

a. Directly underneath pressurizing air bladders, the pressure is the same as in the bladder, irrespective of the surface curvature and friction.

b. At points removed from the air bladder, skin pressure is proportional to the curvature of the surface.

c. When the air bladder is pressurized through a range of pressures to a peak (acceleration) and returned to the starting point, ascending and descending pressure curves at skin not beneath bladder are different.

d. This difference is greater as distance from bladder increases.

e. The difference is greater in proportion to the curvature of the skin.

f. The greater the friction between cloth and skin, the greater these discrepancies should become.

This is "Capstan" type of pressure. Analysis of these factors should permit design of suits which would depend less on bladder and more on cloth pressure. Limiting factors would be inequalities of pressure permissable to give proper physiological effect.

57. Lamport, H., E. C. Hoff, and L. P. Herrington. Review of methods of applying air pressure to the extremities for protection against acceleration with measurements of the effective pressures on the skin. (Yale) CAM No. 228. 24 Nov. 43.

When pressure is exerted on a curved body surface by cloth, the tension of the cloth over the curved surface equals the pressure exerted on the surface times the radius of curvature of the surface. The same relation applies to a curved bladder surface.

The pressures exerted by the GPS, Berger Bros. long tube suit, and the pneumatic lever suit have been measured on th subjects under 1 "g" and the results tabulated in a series of graphs. The pressures vary greatly and depend to a large extent on the location where they are measured (i.e., under bladder or under cloth of suit, etc.)

58. Lamport, H. and L. P. Herrington. Pressure exerted on the lower extremity by the latest models Berger single pressure anti-"g" suit and pneumatic lever anti-"g" suit. (Yale) CAM No. 294. 27 March 44.

a. The pressures imparted to the tissues of the leg by latest models pneumatic Berger single pressure suit and Yale pneumatic lever suit were measured during inflation with acceleration.

b. Berger SPS gives maximum pressure on calf, the PLS gives gradient pressure decreasing from ankle to the thigh.

c. The PLS gives much more uniformity of pressure at any given level than the Berger SPS.

d. Berger SPS is painful over the thighs without acceleration when inflated higher than 7 psi. The PLS is not painful.

e. It is thought that uniformity of pressurization and provision of gradient pressure might give added "g" protection to PLS.

f. Further development of PLS and its trial in centrifuge and plane seems indicated.

59. Lamport, H., and L. P. Herrington. Centrifuge tests of the pneumatic lever anti-"g" suit. (Yale) CAM No. 368. 14 June 44.

a. Nine male subjects tested the PLS inflated to 1.14 to 1.85 psi on the Wright Field Centrifuge.

b. Overall protection against all visual symptoms was 1.38 "g".

c. Roughly equal protection was obtained against all visual symptoms.

d. The PLS suit offers promise of cooler anti-"g" device than those suits where pressurized bladders cover large areas of the body.

60. Lambert, E. H., E. H. Wood, E. J. Baldes, and C. F. Code. Comparison of protection against the effects of positive acceleration afforded by the standard gradient pressure suit (GPS) and a simplified single pressure suit. (Mayo) CAM No. 308. 27 May 44.

a. The GPS inflated to the standard three pressure gradient afforded an average protection of 1.5 "g" in 21 subjects.

b. The simplified single pressure suit inflated with 1.25 psi offered 1.4 "g" protection in 13 subjects. A comparison of the SPS and GPS on 8 subjects revealed no significant difference between the two suits.

c. The GPS modified for a single pressure of 3 psi plus 1 psi/"g" afforded an average protection of 1.8 "g" in 6 subjects.

d. The SPS inflated with a two pressure gradient afforded an average protection of 1.8 "g" in 6 subjects.

Conclusion: There is no significant difference between the GPS and SPS when either is inflated by either single or gradient pressure.

61. Wood, E. H., E. H. Lambert, C. F. Code and E. J. Baldes. Factors involved in the protection afforded by pneumatic anti-blackout suits. (Mayo Clinic) CAM No. 351. 24 Aug. 44.

Field tests show that a suit giving 1.5 "g" protection on the centrifuge gives ample protection in aircraft.

a. Three types of experiments were carried out on FFS, GPS and AOS. Variation in blackout threshold was determined.

(1) With leg and abdominal bladders inflated to the same pressure.

(2) With abdominal bladder pressure only varied, with and without constant pressurization of leg bladders.

(3) With leg bladder pressure only varied, with and without constant pressurization of abdominal bladders.

b. In general, as pressure increases, suit protection increases. The most important factor affecting the amount of protection afforded by the suit is the amount of pressure applied to the abdomen and trunk.

c. Pressurizing leg bladders alone gives very little protection. (Average 0.2 "g"). However, pressurizing abdominal bladder alone gives 50 percent less protection than is afforded by abdominal plus leg bladders.

d. High pressures in suit, which uniformly give greatest protection, may also cause considerable discomfort. The most important factor is abdominal pressure. Hence the optimum suit pressure is the highest abdominal pressure the subject can stand comfortably. This varies with subject, type, and fit of suit. In general, the larger and more efficient the abdominal and trunk bladders, the lower is the optimum pressure.

e. Arm bladders are not necessary. When used alone they offer no protection at all although when used with a complete suit they increase protection 0.6 "g".

f. Recommended pressures for suits are as follows:

FFS	½ to 1 lb/g
GPS and Mark V AOS	1 to 2 lb/g

62. Clark, W. G., J. P. Henry, and D. R. Drury. Determination of the most satisfactory single constant pressure with which to inflate the standard gradient pressure suit. (U. of Southern California) CAM No. 356. 1 Sept. 44.

a. A quantitative measure in terms of "g" units of the protection offered by the Navy Gradient Pressure suit (inflated to uniform constant pressures of 1 to 10 psi) against visual symptoms was made by 400 centrifuge runs on 14 subjects.

b. These protections were contrasted with subjective estimations of comfort at rest, at 2.5 "g", and at maximum acceleration.

c. The highest single pressure throughout the suit which was comfortable to the average subcjct during acceleration at 2.5 "g" was 5 psi.

d. The average protection afforded by 5 psi was 1.3 "g".

e. Protections of 1.85 "g" are obtainable by using pressures of 7 to 10 psi.

63. Wilkins, R. W. Bimonthly progress report No. 17 to the CMR-OSRD on Contract OEMcmr-143. 2 Oct. 44.

An anti-"g" suit has been constructed out of cotton netting which works on the principle of the "Japanese finger trap". Tests at the Wright Field Centrifuge show that it gives a protection of ½ to 1 "g". The experimental model is now being strengthened and simplified.

G. CARDIOVASCULAR EFFECTS OF GRAVITATIONAL FORCE

64. Rose, B., W. K. Kerr, and W. A. Kennedy. The effects of acceleration on the pulse rate, electrocardiogram, electroencephalogram, and the ear opacity. (RCAF, Toronto) Report No. 6 File No. A.H. 100-5.

72 subjects—690 centrifuge runs. EKGs taken by means of 2 chest electrodes, one to left of apex, one over base of heart 1 inch below sternal notch. EEGs taken by 2 electrodes 2 inches apart transverse to sagittal suture, 1 inch anterior to midpoint between occiput and nasion. Ground electrode on mastoid process. Ear photoelectric cell on upper ear below helix.

Pulse Rate Changes—Preceding run, pulse may be elevated to 90-130 beats per min. (average 95). With onset of acceleration, the rate increases for 4-10 sec. after maximum "g" is attained. If the run is short, it may increase even when "g" decreases. The maximum pulse attained was 195 to 220, followed by bradycarida. During recovery the pulse may rise slowly and evenly or fluctuate wildly.

There is no linear correlation between increases in pulse and the amount of "g" at values of "g" less than 3 on 5 second runs. On longer runs, G = K pulse. On reparted runs, pulse response is usually identical except for recovery period. There is no apparent relation between the pulse response and the severity of symptoms. There is no relation between the maximum pulse response and "g" tolerance. However, the average rate of increase of pulse correlates with a high "g" threshold.

EKG Responses—As the heart rate increases, the PR interval decreases from 0.07 to 0.06 sec. The P wave is frequently superimposed on the T wave, may be biphasic, notched or absent. The QRS complex diminishes in amplitude and the main deflection is down. QRS diminishes in duration with "g" and becomes normal as "g" is removed. Right axis deviation occurs, the electrical axis shifting from 90° at the beginning of the run to a maximum of 150° at the height of "g". It returns to normal suddenly.

The gradient of the ST segment disappears. It is isolectric at height of "g" and overcompensated on recovery. The T wave diminishes in amplitude or disappears altogether. It returns to normal very rapidly, often in a biphasic form. Following exposure, sinus arrhythmia is very common as is an increase in the amplitude of the T wave. Rare complications are ventricular extra systoles and lengthened PR interval with or without heart block. No permanent changes have been observed.

Ear Opacity—387 observations on 40 subjects. Opacity begins to decrease at 2 to 3 "g" and continues to decrease until just after "g" decreases. Following this, reactive hyperemia occurs for 5 to 15 seconds. Ear opacity decreases inversely with "g". It is not related to duration of "g". Reactive hyperemia lasts longer after long runs. On repeated runs to just below threshold, ear reactions are the same. Visual symptoms follow ear reactions approximately.

EEG Reactions—530 runs on 62 subjects. A muscle filter is used to take out frequencies of more than 30/sec. Readings are taken from motor areas. Most frequent change in EEG is 16 to 26/sec. waves of 10 to 50 microvolts, probably muscular in origin. These waves last for the duration of the run. Sometimes high, slow (60 to 90 micro-volt, 2 to 6/sec.) waves appear during deep blackout. 5 to 14/sec., 30 to 90 micro-volt waves appear early in the run unaccompanied by symptoms in rare cases, and diminish before the maximum "g" is attained. The origin of these is unknown.

When consciosness is lost, 1.6 to 6/sec., 50 to 180 micro-volt waves usually appear at about the time conscicusness is lost or 1 to 2 seconds before. In all probability they are due to cerebral apoxia. The EEG may remain normal for the entire run, even through consciousness is lost. Convulsive seizures occur in 69% of those who lose consciousness and are not accompanied by seizure discharges. Instead slow high waves of unconsciousness remain unchanged.

EEGs taken without muscle filters show the same pattern. In no case have grand mal or petit mal patterns been seen, nor have large random spikes been observed.

Discussion—It is concluded that no physiological measurements are of as much value as the simple signal system. Pulse increases compensate for the blood pressure drop. In those with rapid response, hydrostatic pressure determines the blackout threshold. In those with slow response, the pooling of blood is the limiting factor.

65. Ham, G. C., and E. M. Landis. Objective measurements of circulatory changes in man during acceleration in the centrifuge and in the plane. (U. of Virginia) CAM No. 67.

In 8 plane tests (maximum 2.5 "g" for approximately 5 seconds) and 27 centrifuge runs on 8 subjects it was found that "g" well below the graying level diminishes the blood content of the ear consistently and strikingly. At high "g" this blanching is even more marked at the time that grayout, blackout, and unconsciousness appear. Reactive hyperemia follows short exposures to "g".

When 4 "g" was maintained on the centrifuge for 45 seconds, vascularity of the ear decreased, then increased and, after a brief compensatory rise, stabilized at a level lower than normal but definitely above the minimum. It is thought that this reaction was due to a carotid sinus reflex becoming active 11 to 13 seconds after the onset of "g".

Measurements were made by means of a photoelectric ear unit (modified oximeter) and a portable self-contained oscillograph. The apparatus is offered as a safe method for objective study of circulatory adjustment to "g" in the plane and in the centrifuge and for evaluating the protection offered by anti-g devices.

66. Wood, E. H., E. H. Lambert, and R. E. Strum. Systolic blood pressure in man during exposure to high accelerations of the centrifuge. (Mayo Clinic) CAM No. 338. 4 Aug. 44.

a. An instrument has been developed which records systolic pressure in humans using finger opacity pulse as an indicator. It has been used on 3 subjects in over 100 centrifuge runs in which the forearm was supported at brain level.

b. In control runs for 15 seconds at maximum "g" with subjects unprotected, the maximum decrease in systolic pressure averaged 28 mm Hg per "g" above 1 "g" and occurred within the first 7 seconds after exposure.

c. In centrifuge runs which did not produce unconsciousness, systolic pressure rose during exposure, the maximum recovery taking place 12 seconds after the onset of "g". The average recovery was 35 mm Hg above the lowest blood pressure level.

d. Blood pressure varied inversely as the maximum "g" attained. Clear vision persisted to 56 mm Hg; peripheral lights were lost at 39 mm Hg, and blackout occurred at 19 mm Hg.

e. Blood pressure varied directly with ear opacity, (although ear opacity changes lagged behind blood pressure) and inversely as the changes in the heart rate.

67. Davenport, H. W. Environmental temperature and the vardiovascular effects of inflating a pneumatic suit (GPS). (Harvard) CAM No. 332. 31 July 44.

a. Tilting normal subjects from recumbency to 70° reduces blood content of the ear. There is great variation in the same subject on repeated tests at the same enviromental temperature.

b. Inflation of a pneumatic suit to 3 psi on a tilted subject increases the blood content of the ear but with considerable variation. The magnitudes of these 2 changes cannot be correlated with each other or with heighth, weight, or physical fitness of the subject.

c. Effects produced at 25° C by inflation of ankle, leg, and thigh bladders to 3 psi are not significantly modified by mild exercise, by fit of GPS, or by additional inflation of the abdominal bladder.

d. Tilting to 70° and return to recumbency decreases and increases respectively the blood content of the ear by approximately equal amounts at 25° C and 40° C, but at 3° these changes are larger in extent and slower in development.

e. Inflation of ankle, leg, and thgh bladders increase the blood content of the ear by approximately equal amounts at 40° C and 25° C but has little or no effect at 3° C.

f. Heart rate is increased by tilting to 70° and decreased by inflation of the suit. Changes in heart rate are more pronounced at 40° C and 25° C and less pronounced or absent at 3° C. Similarly, decrease in blood pressure is greater with tilting at 40° C and 25° C and less at 3° C. Inflation of suit tends to raise blood pressure slightly more at 40° C and 25° C than at 3° C.

g. Inflation of the abdominal bladder in addition to leg bladders does not add significantly to the cardiovascular effects of the suit at any of the temperatures tested, but it must be emphasized that these observations involved a force of only 1 "g" on the tilt table and that results may well be different at higher "g".

h. It is concluded that inflation of the pneumatic suit (GPS with equal pressure in all bladders) has more effect on the circulation to the head at high environmental temperatures than at low. However, the differences at 1 "g" are not great and the responses of any one subject are extremely variable.

68. A comparison of the changes in pulse rate and in blood pressure resulting from anoxia, increased intrathoracic pressure and change in posture. Project 115, Report No. 1. (Randolph Field) 2 Feb. 43.

Fourteen male subjects exposed to anoxia for 30 minutes at a simulated altitude of 18,000 feet had an average pulse rate of 89 as compared to 75 at sea level. There was no consistent change in blood pressure.

Rising suddenly from a lying to a standing posture caused the pulse rate to increase from 70 to 90. There was also a decrease in both systolic and diastolic blood pressure at the end of 2 minutes which had no relation to the change in pulse rate.

The Valsalva experiment (40 mm Hg pressure) caused the pulse rate to increase from 82 to 115. Blood pressures could not be measured.

69. A study of the Valsalva procedure by means of the electrocardiograph, arteriograph, and teleroentgenograph. Project No. 116 Report No. 1 (Randolph Field) 2 Feb. 43.

Used 14 male subjects aged 21 to 45 years, 64 to 75.5 inches in height, and weighing 140 to 208 lbs.

a. Valsalva experiment (40 mm Hg pressure) increased the heart rate in 13 subjects by an amount which varied on repeated tests.

b. Ten subjects showed constant alteration of the T wave. There were 3 cases of premature systole or shift of the pacemaker and one case of electrical alternans, none of these changes being reproducible on repeated tests.

c. In the arteriograms, the amplitude of the pulse wave deflection was reduced and the dicrotic notch was deepened.

d. The size of the cardiac silhouette was reduced in all subjects during the maneuver.

70. Rushmer, Robert F. Physiology of increased intrathoracic pressure in relation to the effect of centrifugal forces. (Randolph Field) CAM No. 234. 10 Nov. 43.

Similarities of circulatory changes resulting from increased intrathoracic pressure (cf. Valsalva maneuver) and from positive radial acceleration indicate that compensation to these stresses is based on similar mechanisms.

a. When intrapulmonic pressure is elevated to 40 mm Hg after forced inspiration (Vl maneuver), intragastric pressure is equal to intrapulmonic pressure.

b. When intrapulmonic pressure is elevated to 40 mm Hg after forced expiration (Ve maneuver) intragastric pressure is higher than intrapulmonic by 8 to 23 mm Hg.

c. When intrapulmonic pressure is maintained at 40 mm Hg while a leakage of air occurs through a manometric valve, (Ml maneuver) intragastric pressure is 35 to 50 mm Hg higher than intrapulmonic. Repeated performance of the Ml maneuver during centrifugation will raise blackout threshold 3 "g".

71. Rushmer, R. F. Physiology of increased intrathoracic pressure in relation to the effect of centrifugal forces; arterial pressure, venous pressure, and finger volume during increased intrapulmonic pressure. (Randolph Field) CAM No. 233. 1 Dec. 43.

a. In normal subjects venous return from arm to thorax fails in 75% of men performing V1 breathing maneuver, in 100% performing Ve maneuver and in 22% performing M1 maneuver. Venous return from legs fails to occur in all subjects performing all three types of breathing maneuvers.

b. Rapid increase in venous pressure is usually accompanied by a rapid increase in finger volume. Poor compensation of arterial blood pressure occurs during V1 maneuver.

c. Individuals displaying a rapid increase in venous pressure during V1 maneuver do so on subsequent days.

d. Abdomino-thoracic gradient in pressure produced during Ve and M1 maneuvers apparently facilitates maintenance of arterial blood pressure.

72. Rushmer, R. F. Physiology of increased intrathoracic pressure in relation to the effects of centrifugal forces. (3) Two cases of circulatory failure during increased intrapulmonic pressure. (Randolph Field) CAM No. 267. 16 Jan. 44.

a. Two subjects performing Ve and V1 maneuvers while suffering from primary neurogenic shock (arterial puncture) developed visual and cerebral disturbances and poor circulatory compensation to the maneuvers.

b. A third subject having poor tolerance to rapid changes in posture and to centrifugal force demonstrated a subjective and circulatory response to increased intrathoracic pressure.

c. Improvement in tolerance to increased intrathoracic pressure on repeated trials by subject 3 was associated with a reduction in the rate of increase in venous pressure, especially during the V1 maneuver.

d. Correlation of circulatory response to increased intrathoracic pressure with tolerance to "g" on the human centrifuge may lead to the development of a simple test for detection of poor tolerance to "g".

e. People with poor tolerance to "g" have no business in fast planes.

73. Rushmer, R. F. Physiology of increased intrathoracic pressure in relation to the effect of centrifugal forces. (4) Comparison of physiological response to increased intrapulmonic pressure and to applied centrifugal forces. (Randolph Field) Project 160. Report No. 4. 1 Aug. 44.

a. During neurogenic peripheral circulatory failure in 5 subjects during arterial puncture, grayout occurred at 65 mm Hg systolic blood pressure, blackout at 40 mm, and unconsciousness when the pressure was too low to measure.

b. On the basis of these observations, it is predicted that a subject blacking out at 5 "g" would develop a systolic pressure of 140 mm Hg at heart level during the application of "g".

c. Deductions from results of the Valsalva maneuver and the protective value of the semi-prone position in aircraft suggest that venous pooling in the extremities and the thoracic-abdominal gradient in pressure produced by "g" are not the most important factors producing blackout, but rather that blackout is due to the fall in blood pressure above the heart level provided the exposure to "g" is relatively short.

d. Theoretical considerations and a few service observations make the crouching position seem as effective in "g" protection as any of the mechanical devices now available. Practical difficulties in its use, however, are introduced by the great strain put on the lower part of the back, by the greatly increased weight of the head under high "g", and by the limitation of the visual field.

e. It is recommended that further attempts be made to overcome the difficulties of the crouching position in the human centrifuge and to make precise measurements on the relation of position of the body to blackout threshold.

74. Rushmer, R. F. A study of the role of intra-addominal pressure in tolerance to centrifugal forces. (Randolph Field) Project 316. Report No. 1. 9 Sept. 44.

a. Intra-abdominal pressure in both dogs and man as measured by a balloon inserted rectally is sufficient to support a column of blood from any level in the abdomen to a level a few cm. below the dome of the diaphragm.

b. The combined effect of intra-abdominal andintra thoracic pressure in dogs is sufficient to elevate blood above the dome of the diaphragm.

c. The increase in intra-rectal and intra-abdominal pressure during positive "g" in man on the centrifuge varies directly as the magnitude of "g". However, it fails to reach the levels predicted on the basis of a column of fluid of constant height, probably because of protrusion of the anterior abdominal wall and compression of intestinal gas resulting in descent of the diaphragm.

d. The use of pneumatic anti-"g" devices which apply pressure to the anterior abdominal wall increases the pressure within the abdomen to a level consistent with the elevation of the diaphragm to its normal position.

e. A hypothesis is presented to explain the effectiveness of anti-"g" devices in terms of maintenance of normal heart-brain distance, normal position of diaphragm, and reduction in the differential between abdominal and thoracic pressure.

75. Wilkins, R. W., C. K. Driedland, and S. E. Bradley. Estimations of cardiac and vasomotor reserve especially in response to strains designed to simulate those of acceleration. CAM No. 177. 1 Sept. 43.

a. Release of occlusion of circulation in the limbs is followed by intense local hyperemia and fall of systemic arterial blood pressure, rise in pulse rate and cardiac output and fall in venous pressure. Reocclusion reverses this.

b. External compression of the abdomen raises intra-abdominal pressure slightly, but not enough to occlude circulation, although blood flow and kidney functions are retarded.

c. Abdominal muscular straining raises intra-abdominal pressure much higher than does external abdominal compression.

d. Valsalva maneuver causes initial sharp rise in arterial pressure followed by a fall in the arterial and pulse pressure plus a rise in pulse rate.

e. Release of Valsalva strain is followed by brief further fall in arterial pressure, then a rise into hypertensive levels for one half minute or more.

76. Von Diringshofen, H. The effect of the centrifugal forces on the blood circulation of the aircraft pilot. **Luftfahrtmedizin** 6: 152-165, 1941. (R.T.P. Translation No. 1680).

Reactions to "g" may be divided into 3 categories depending on cardiovascular tone of pilot.

a. In those with high blood pressure and normal or increased minute volume of heart, blackout threshold is high and recovery very rapid.

b. In those with normal or low blood pressure and adequate circulation, visual difficulties occur at moderately low values of "g" accompanied by insufficient filling of the right auricle. The left ventricle is definitely flattened.

c. In those with weak cardiovascular systems, the whole circulation fails under "g". Muscle tone is lost and the heart beats empty. A long period of recovery is necessary. This is very dangerous.

77. Young, C. A. Hypotension in aviation, with a review of 159 fatal crashes. **U. S. Naval Medical Bulletin** 39:222-235. 1941.

Upper limits of hypotension taken as 110 mm Hg systolic blood pressure, 70 mm diastolic. Believes that 10% of cadets 18 to 25 years old are hypotensive. However, in 159 fatal crashes, 45.9% of the pilots were hypotensive. Of the pilots involved in crashes clearly due to pilot error, 85.6% were hypotensive.

Individuals with low blood pressure also tend to have higher than average standing pulse rate. It is suggested that they are more susceptible to blackout and fatigue and have less emotional stability.

78. Schroeder, H. A., and O. Horwitz. Analysis of crashes from the viewpoint of certain physiological disturbances. Research Report, Naval Air Station, Pensacola, Florida. 22 Feb. 43.

Of 30 crashes occuring in the past 6 months at Pensacola in two-seated trainers, 19 were due to obvious causes (4 fatalities). The remaining 11 (8 fatalities) were due to a combination of vertigo and acceleration.

79. Holt, J. P. The effect of centrifugal force on the carotid blood pressure of dogs and the use of a water suit in modifying this effect. (U. of Louisville) CAM No. 63. 11 Aug. 42.

Normal healthy dogs with a resting blood pressure of 150-160 mm Hg were placed under sodium barbital anaesthesia, their tracheas cannulated, the carotid arteries exposed and blood pressure recorded directly. They were placed on a 7.15 ft. radius centrifuge and subjected to various values of "g" of from 30 seconds to 10 minutes.

Between 4.28 and 5.63 "g", if the dogs were centrifuged unprotected, in an empty plethysmograph, or in a loose canvas suit, blood pressure fell 98% of its original value. If the dogs were protected by a water filled plethysmograph or a canvas suit containing a water filled abdominal bladder and tubes down the hind legs, blood pressure fell only 44% at the same value of "g."

H. MISCELLANEOUS REFERENCES ON PHYSIOLOGY OF "G"

80. Beeler, D. C. Data on accelerations for medical research. Memo report for Aero Medical Lab., Wright Field. (NACA, Langley Field, Va.) 23 July 1942.

Discussion and series of graphs showing the time history curves of several aircraft during various maneuvers. Graphs were compiled from NACA flight tests from 1927 to 1942. A formula is given by which approximate time histories can be constructed for turns of various amounts performed at varying speeds and angles of bank.

81. The physiolo .cts of high accelerations. Navy Department, BuAer Technical Note ... 25 Jan. 41

Warning to flight personnel to avoid excessive "g" in maneuvers, maintain physical fitness.

82. Effect on flying personnel of high centrifugal forcess. War Department. AAF Technical Order 00-25-12. 6 Nov. 41.

Forces greater than 4 "g" may cause fractures in personnel standing in aircraft, 5 to 6 "g" produce grayout in seated personnel. 6 "g" produce blackout or unconsciousness. German crouch position is recommended as an anti-"g" measure.

83. Schroeder, H. A. High accelerations in intermediate training; incidence of symptoms and an estimate of tolerance to "g". Research report, Naval Air Station, Pensacola, Florida. 19 March 43.

Questionnaire submitted to students and instructors showed that one-half had either grayed or blacked out, one-eighth did so frequently. The "g" involved was never over 6 and was usually less than 5 "g" applied for less than 4 seconds. Pilots were very ignorant as to the cause of blackout. In 165 cases, Immelman turns, split S's, sharp pull outs and pull ups were the most frequent causes of blackout.

84. Maison, G. L., and C. A. Maaske. Description of the Materiel Command human centrifuge, techniques employed therewith and results of studies of normal "g" tolerance of human subjects. (Wright Field) Eng-49-696-4D. 11 Oct. 43.

a. The Wright Field centrifuge, which was placed in operation 15 March 43, is driven by a 180 HP motor driven in turn by a 250 HP AC-DC motor generator set. Automatic control is provided by a photoelectric scanning device. The safety factor is 3, and failure of any part of the driving mechanism or opening of the doors to the centrifuge room automatically stops the centrifuge. The system of signal lights and the recording mechanism are described.

b. Standard operating procedure is given. For 10 second exposures the following average thresholds have been determined in 772 centrifuge runs on 35 normal male subjects:

Clear vision	4.0 "g"
PLL	4.5 "g"
Blackout	5.0 "g"

85. Rose, B. W., W. K. Kerr, and W. A. Kennedy. The average blackout threshold in aircrew trainees as determined by means of the centrifuge. (RCAF-Toronto) 14 Dec. 42.

One hundred and twenty-four normal, physically fit aircrewmen were studied in upright position on 1568 centrifuge runs, usually of 25 seconds duration with 5 seconds exposure to maximum "g". Occasional runs were performed with up to 30 seconds exposure to maximum "g". Blackout threshold ranged from 2.5 to 9 "g".

Percent of Subjects	Vision Clear at
100	2 "g"
80	4 "g"
20	6 "g"
2 to 3	9 "g"

Slightly higher values of "g" can be withstood by all subjects with 2 seconds maximum exposure.

86. von Diringschofen, H. The JU-89 equipped for medical flight research. **Flugsport 35:** 108 - 111, 1943. (Source—**J. Royal Aeranautical Soc. 47:** 416 - 417, 1943).

Acceleration tolerance was determined in a JU-89 on 22 subjects in 200 plane runs, the highest acceleration used being 8.5 "g" for 3 seconds.

% Subjects	Grayout	Blackout	Collapse
80	5 "g"	5.5 "g"	6 "g"
50	6 "g"	6.8 "g"	7.5 "g"
20	6.5 "g"	7.5 "g"	8.0 "g"

When subjects became anoxic, collapse occurred in 2 to 3 seconds at 3 "g".

87. Kennedy, W. A., W. K. Kerr, W. R, Martin, B. Rose, and W. R. Franks. Relation of blackout threshold to age, weight, body measurements, and cardiovascular tests. Proc. 13th M eting Ass. Comm. Aer. Med. Res., Ottawa, 1944.

In 1568 centrifuge runs on 124 subjects, no statistically significant correlation was found between "g" threshold and age, weight, body measurement, resting pulse and blood pressure, and response of pulse and blood pressure to tilting. Only factor which even looks promising is heart to seat measurement, for which P is only 0.04 for over 1000 subjects. Good distribution curve for blackout threshold is included.

88. Rose, B., and W. R. Martin. The determination of the blackout threshold in aircrew trainees and factors concerned in its variations. CNRC - CAM. C-2205.

Eighty-eight subjects were given at least 10 runs each on the RCAF centrifuge at Toronto.

a. Average blackout threshold was 4 to 6 "g". Range was 3.5 to 9 "g".

b. Average grayout level was one "g" below the blackout level; the average level of unconsciousness was one "g" above it.

c. The blackout threshold is inversely related to the time of exposure to "g".

d. At the blackout threshold, increasing the time of exposure to "g" may prolong blackout without producing unconsciousness.

e. In any one man, the blackout threshold may vary by plus or minus one "g" in any one day.

f. Continued exposure to acceleration does not increase the tolerance to "g".

g. Frequent daily exposure to threshold "g" may reduce the tolerance to "g".

89. Williams, M. M. D., E. J. Baldes, R. K. Ghormley, and C. F. Code. Are the intervertebral disks compressed or displaced during positive acceleration? (Mayo Clinic) CAM No. 255. 18 Feb. 44.

Anterioposterior and lateral X-ray pictures were taken of the lower spinal region in 4 subjects before and during exposure to 2 to 6 "g". No significant change was detected in the measurements of the lumbar intervertebral spaces and the total length of the lumbar spine. It is concluded that there is no compression or displacement of the lumbar spine under these values of "g".

90. Firestone, Charles. Air speeds and their traumatic effects on the brain. **J. Av. Med.** 6: 45 - 48, 1935.

No data. The writer confuses angular and radial acceleration. He proposes a metal helmet to cushion the brain.

91. Lambert, E. H., E. H. Wood, and E. J. Baldes. The protection against the effects of acceleration afforded by pulling against a weighted control stick and the influence of this on the effectiveness of pneumatic anti-blackout suits. (Mayo Clinic) CAM No. 265. 12 Feb. 44.

a. Pulling against a force of 19 pounds per "g" applied to a mock airplane control stick increased the average "g" tolerance of 12 subjects 0.7 "g".

b. In 8 subjects (4 wearing GPS, 3 wearing AOS, and 1 wearing a modified GPS) the protection of the stick was added to the protection offered by anti-"g" suits as follows:

	Threshold	Protection Offered By		
		Stick	Suit	Stick + Suit
Ear Opacity		+0.5	+1.4	+1.9
Ear Pulse		+0.6	+2.0	+2.6
Clear Vision	2.9 "g"			
Dim Vision	3.4 "g"			
Peripheral light loss	3.9 "g"	+0.7	+1.2	+1.8
Blackout	4.7 "g"			

c. Pulling on a weighted stick speeds the time of recovery of vision and is twice as effective during recovery period as during maximum acceleration. Cardiac acceleration is greater when pulling on the stick, reaches a maximum later, and lasts longer.

92. Maison, G. L., C. A. Maaske, G. A. Hallenbeck, and E. E. Martin. The effect of taping the body on "g" tolerance in man." (Wright Field) CAM No. 204. 29 Sept. 43.

Ih has been reported that Japanese pilots sometimes tape their bodies to increase their "g" tolerance. In 416 10-second centrifuge trials on 18 subjects, taping the body with 2 and 4 inch Ace bandage from the ankles to the xiphoid process and from the axillae to the wrists gave the following protection:

Clear vision	0.8 "g"
Grayout	0.5 "g"
Peripheral light loss	1.2 "g"
Blackout	1.1 "g"

Unavoidable variations in tightness of bandages produce very variable results. The process is exceedingly uncomfortable and time consuming and is not considered practical.

93. Davidson, S., and W. K. Stewart. Note on some physiologic effects of low values of centrifugal forces encountered in flight. FPRC No. 573. 29 Feb. 44.

Used 6 experimental subjects.

a. Operational tests show that values of 2-1/2 to 3 "g", if frequently repeated, cause fatigue, GI disturbances.

b. Immediate fatigue is increased by factors such as unsuitable aerodynamic properties and structural design of aircraft.

c. Reduction in frequency of exposure and alleviation of monotony of flight patterns help symptoms somewhat.

d. Protection afforded by anti-"g" suits (FFS) is extremely important.

e. In the design of anti-"g" devices it is important to have full protection against the lower values of centrifugal acceleration as well as to prevent blacking out at higher values.

94. Wood, E. H., E. J. Baldes, and C. F. Code. Changes in the external appearance of the human being during positive acceleration. (Mayo Clinic) CAM No. 391. 18 Oct. 44.

Photographs and text.

95. Hallenbeck, George A. The effect of repeated short exposures and of prolonged exposures to increased "g" on human subjects. (Wright Field) Eng-49-696-56. 5 Feb. 44.

a. During 60 second exposures to positive "g," 6 subjects who suffered either PLL or blackout during first 10 or 15 seconds of the run showed varying degrees of improvement thereafter.

b. When 6 subjects were given 6 rapidly repeated 10 second exposures to 4.2 "g", vision improved during second and following trials. Improvement was consistent when interval between exposures was 10 seconds or less, and was less marked when interval was 15 to 30 seconds.

c. Thus repeated exposures to "g" are probably not responsible for unfavorable symptoms reported by pilots during rat race maneuvers.

d. Vision improves even though pulse rate drops on repeated exposure to "g".

96. Hallenbeck, G. A., and R. L. Engstrom. The response of normal dogs to prolonged exposure to centrifugal force. CAM No. 279. 3 Mar. 44.

a. The reaction of dogs to "g" is graded as follows:

Grade 1 response: Dog is conscious. Pupils of eyes fail to react to light. Slight ataxia is present. Pulse is 100 to 200.

Grade 2 response: Dog is limp and unconscious. There is a weak, irregular pulse, often bradycardia. Severe ataxia is noted when consciousness returns.

Grade 3 response: Death. Only postmortem pathology is gross distention of the vessels below the heart, occasional hemorrhage into colon.

b. Unanesthetized dogs withstand exposure to 8 or more "g" for 5 or more minutes with Grade 1 response.

c. Unlike rats when subjected to 2 to 12 "g" forces, dogs do not respond to "g"-time values of 80 "g"-minutes in a constant fashion.

d. General nembutol anesthesia does not appreciably lower "g" tolerance.

e. The work of Holt (reference 79) showing that carotid blood pressure is zero at 5 "g" is questioned because of the survival of dogs exposed to over 5 "g" for 8 minutes. Maybe blood gets to brain some other way than by carotid arteries.

97. **Lambert, E. H. (Mayo Clinic) Acceleration Conference of the Committee on Aviation Medicine, Rochester, Minnesota. 23 Feb. 44.**

a. In 215 centrifuge trials in which peripheral light loss occurred, it took place an average of 6.4 seconds after the maximal "g" was reached. Recovery averaged 12.7 seconds after the attainment of maximum "g". Where blackout also occurred, peripheral light loss developed after 5.8 seconds, recovery after 15.5 seconds. Blackout occurred at 7.9 seconds, recovery after 15 seconds. If subject became unconscious, peripheral light loss occurred at 6.8 seconds. If symptoms are going to appear on a given centrifuge run, they happen before the tenth second. In only one out of 181 cases did peripheral light loss occur after this time. The time for peripheral light loss remains constant in a given individual over a period of a year and a half.

b. "Variations of intraoccular pressure". 200 observations on one subject whose resting blood pressure averaged 110/80 show that extraocular pressures of 50 mm Hg cause peripheral dimming beginning nasally, of 55 mm Hg result in peripheral light loss, and of 65 mm Hg cause blackout. First areas of the retina to become insensitive to light are those most remote from the origins of the retinal blood vessels. Application of 30 mm Hg negative pressure to the eyes will clear vision of a subject riding the centrifuge at blackout level. Naturally this is a very hazardous procedure.

98. Watt, G. E. Investigation into the effect of altitude and anoxia on "blacking out" threshold. FPRC No. 213.

Plane tests were made at 10,000 and 15,500 feet with and without oxygen. Failure to use oxygen at 10,000 feet lowers "g" tolerance by 0.5 "g". This was confirmed at 15,500 feet, where complete blackout occurred at 5.9 "g" as opposed to 6.9 "g" at 10,000 feet using oxygen. Tolerance was constant from 20,000 to 32,000 feet when using oxygen.

99. Jones, B. F., F. D. Chapman, R. E. Mitchell, H. H. Jasper, and A. Cipriani. The effect of repeated exposure to loss of atmospheric pressure upon tolerance to positive acceleration in monkeys. CAM#104. Jan. 43.

Used 9 **Macaca mulatta** monkeys. One half received a diet rich in iron and copper and one half a diet poor in these elements. Four hours daily exposure to a simulated altitude of 25,000 feet produced polycythemia in the Fe-rich animals which increased their "g" tolerance by 2.3 "g" (49%). Protection lasted 30 days. It was measured by extinction of brain potentials and retinograms. Desoxycorticosterone reduced recovery time in all animals and reduced extinction time and "g" threshold in polycythemic aninmals although raising it in the controls.

100. Stewart, W. K. Influence of drugs on ability to withstand centrifugal force. (Farnborough) FPRC No. 338. 11 Aug. 41.

a. **Cycliton** (like coramine and camphor) produces a rise in respiratory rate and blood pressure. 2 cc injected in human subjects have no effect on blackout threshold but alleviate fatigue due to "g" in flight tests.

b. **Benzedrine.** 25 mg injected have no effect on "g" tolerance.

c. **Glucose.** Injection of 80 gms in 500 cc water has no effect on "g" tolerance.

d. **Ephedrine** and **adrenaline.** Have synergistic effect on the sympathetic nervous system. Ephedrine alone has no effect on "g" tolerance but ephedrine plus adrenaline produce a slight improvement.

e. **Arenal cortical extract (eschatin).** When 10 cc (250 dog units) are injected, they produce a very variable rise in blood pressure and in "g" tolerance.

Conclusion: None of the drugs tested have any immediate application to the problems of "g".

101. McIntyre, A. K. Effect of anti-malarial drugs on "g" tolerance. RAAF-FPRC. FR-71.

a. Centrifuge tests were performed on a group of 33 aircrew trainees to determine blackout thresholds before and after anti-malarial drugs (quinine, atebrine, and "A.S.I.") in suppressive doses.

b. Before treatment, blackout threshold averaged 4.9 "g" for 5 seconds, range 3.6 to 6.2 "g".

c. No adverse effect on resistance to "g" was observed with any drug.

d. In most cases, "g" tolerance improved progressively with successive centrifuge runs whether or not drugs were taken.

AVERAGE "G" TOLERANCE

	Quinine		Atebrine		Atebrine & ASI	
	Before	After	Before	After	Before	After
Drug	5.1	5.4	4.7	5.2	4.7	5.5
Control	5.2	5.6	4.2	4.2	4.2	4.7

102. Lamport, H., E. C. Hoff, and L. P. Herrington. Statistically valid tests of drugs and other factors affecting the resistance of mice to acceleration. (Yale University) CAM No. 298. 15 Mar. 44.

a. Mice were studied in the laboratory centrifuge and resistance to acceleration measured objectively in terms of the fatal spin number (FSN), the number of spins of equal duration but progressively higher top speed required to cause death.

b. **Ergonovine**, throughout its dosage range, reduces the resistance of mice to acceleration.

c. **Pitressin** increases resistance of mice with low initial resistance, but is without effect on mice of average or high initial resistance.

d. **Pitressin plus atropine** give greater protection than pitressin alone.

e. **Dilantin** is without effect on "g" tolerance.

f. **Preliminary tilting** of mice in which they are not maintained in a head up position has no effect on "g" tolerance. Head up tilting protects mice if continued for 4 days prior to testing. It has no significant effect if continued for only 2 days.

g. Experiments with humans to determine on the centrifuge the effect of sleeping in beds titled head up are suggested.

103. Jasper, H., M. Clinton, Jr., A. Cipriani, and G. W. Thorn. The effect of desoxycorticosterone acetate and adrenal cortical extract upon "g" tolerance in monkeys. CNRC-CAM. C-2244.

In eleven **Macaca mulatta** monkeys, tolerance to positive acceleration between 3.0 and 6.9 "g" was not appreciably altered by adrenal cortical extract or by pretreatment with desoxycorticosterone acetate as measured by threshold of extinction of the EEG.

Recovery time of brain potentials was accelerated 21% by adrenal cortical extract administered the night before exposure and 48% by four days pretreatment with desoxycorticosterone acetate.

104. Jasper, H. A. A. Cipriane, and E. Lotspeich. Physiological studies on the effect of positive acceleration in cats and monkeys. C-2225. (Summary of report presented to the CAM). 28 Sept. 42.

a. **Blood pressure** in the cat drops to zero from the norm of 120-140 mm Hg in 1.5 seconds when 7 "g" is applied. Hence latencies in production of symptoms must be attributed to factors other than blood pressure.

In the monkey, a fall to 50-60 mm Hg is necessary to extinguish retinal response to light. A level of 25 mm is necessary for extinction of spontaneous cortical electrical activity. Recovery begins as soon as "g" is removed, and blood pressure rises to 20 to 30% above normal during reactive hyperemia.

b. **Intracranial pressure** begins to fall as soon as positive "g" is applied. It decreases 15 mm Hg per "g". During reactive hyperemia, intracranial pressure is two to three times normal.

c. **Electroretinogram.** The "b" wave, associated with ganglion cell activation and discharge of impulses along the optic nerve, is reduced to half normal amplitude in 10-12 seconds after the onset of positive "g" and is absent after 20-40 seconds exposure. Extinction of the "b" wave precedes extinction of the EEG at 3-4 "g", but cortical activity disappears first at 6-8 "g".

d. **Occipital cortical response to light stimulation** disappears before spontaneous brain waves, which may persist indefinitely at very low values of "g". At the threshold, both cortical and retinal response to light dro pout before spontaneous cortical activity, and above the threshold cortical response may persist after loss of spontaneous electrical activity.

e. **Electroencephalogram.** The initial change under "g" is excitatory. This phase is followed by depression and delta waves and finally by extinction of all electrical activity.

105. Britton, S. W., V. A. Pertzoff, et al. Physiological studies on high centrifugal forces. (University of Virginia). Report to the CAM.

Work was carried out on normal young male and female **Macacus rhesus** monkeys which were not anesthetized. Constant and striking changes in the ECG were observed under high "g" and consisted of a fall of about 50% in the R-S potential and an increase in heart rate of 10 to 30 beats per minute. Voltage decreases are much more marked than the reciprocal frequency changes.

Complete protection against cardiac changes is afforded by a low pelvic belt pressurized to 75 mm Hg or higher.

Desoxycorticosterone and benzedrine injections give slight or partial protection against "g" effects.

The appearance of delta waves in the EEG is fairly common under "g". The potential of these delta waves is somewhat reduced by applying a cervical cuff inflated up to 75 mm Hg.

106. Britton, S. W., and E. L. Corey. Centrifugal and gravitational effects on animals and their alleviation. (University of Virginia) CAM No. 40. 2 Feb. 42.

Used light duty, 6 ft. radius centrifuge capable of producing up to 50 "g".

a. **Effects** on rats are uniform and constant under given conditions.

b. Within "g" and time limits, "g" x time = constant effect.

c. **Orientation.** Dystaxia and convulsions frequently follow exposure to high forces. Chronic disorientation (vertigo, tonic-clonic head movements) may occur after a few exposures.

d. **Respiration** is suppressed and **heart beat** slowed at high "g". During recovery, pulse rate rises and asphyxial gasping occurs 30 seconds after stopping centrifuge. Electrocardiagrams show increased prominence of P waves.

e. **Tolerance** is increased by widely spaced exposures. Several close exposures, however, are invariably fatal. Six rats exposed to 25 "g" once every 15 minutes survived an average of 22 exposures. Respiration fails before the heart fails.

f. **Sex.** Females are markedly superior in "g" tolerance. Blood pooling the male sexual appendages does not explain the difference.

g. **Age.** Young but nearly full grown rats are significantly more susceptible to "g" than fully mature animals.

h. **Posture.** Animals survive better in loosely fitted cages than when tied down by arms and perineum.

i. **Lethal limits** are 50 "g"-minutes for mature males; 60 "g"-minutes for mature females; 44- "g"-minutes for adolescents. (All animals full fed and not bound down.)

j. **Blood and tissue chemistry.** In 6 rats following exposure to high "g" there was no change in water content of brain, liver, kidney, spleen, or leg muscles. Serum NaCl was unaffected. Blood sugar increased 25 to 100%. Liver, muscle, and heart glycogen significantly decreased. Forty rats showed no variation in water intake or urine output for 12 hours after centrifugation.

k. Loose fitting **adhesive straps** raise the lethal "g" dose 50% or to 70 "g"-minutes

l. **Forced exercise** for 4 hours preceding exposure had no effect on the response of male rats.

m. **Alcoholism.** Animals exposed 2 to 3 hours after recovery from moderate alcoholism show no effects on "g" tolerance. Severe alcoholism reduces resistance.

n. **Anoxia, oxygen, carbon dioxide.** Previous exposure to low barometric pressure (nduced prostration every 2 to 3 days at 320 mm Hg for one month previous to testing) significantly improves "g" tolerance. Oxygen administration immediately before testing is not beneficial. Carbon dioxide inhaled just before exposure to "g" allows 50% survival of the normal lethal dose.

o. **Pitressin** given to fed rats produces extraordinarily good protection against normally lethal "g". **Postpituitary extract** is moderately effective.

p. **Cortico-adrenal extract** and **adrenalin** are moderately effective. **Desoxycorticosterone** is of no value.

q. **Benzedrine sulphate** and **normal saline** do not increase "g" tolerence.

r. **Photographs** of rats being centrifuged show marked abdominal protusion, arching of th lower dorsum, flexion of head on chest, penile extrusion. Scrotum and testes retracted but not intra-abdominal.

s. **Nomograms** are included in the paper for easy calculation of "g", speed of centrifuge, etcet.

107. Britton, S. W., E. L. Corey, and G. A. Stewart. Gravitational effects on animals and their alleviation. (University of Virginia) CAM No. 41. 3 Mar. 42.

a. At smaller radii of rotation of a centrifuge, greater speeds are necessary to produce vertigo. Vertigo may become chronic as one rat had persistant vertigo for over 2 months.

b. Within limits of 2 to 8 minutes and 6 to 25 "g", "g"t = K and 50 "g"-minutes normal lethal limit.

c. Longest survival of any one animal was 120 "g"-minutes.

d. When rotated at 25 "g" and allowed slight freedom of movement in small cages, rats withstand "g" much better than when outstretched and loosely tied. A simple abdominal strap affords great protection against "g" forces.

e. Mature animals resist "g" better than young individuals.

f. A previous short fasting period (12 hours) enables male rats to withstand "g" better than fully-fed animals.

g. Female cats, rabbits, and rats withstand "g" much better than male animals.

h. In cats, glycogen level of liver, muscle, and heart is greatly decreased one hour after centrifugation. Rats show similar results. In rats blood sugar levels are elevated. Hyperglycemia is proportional to the severity of exposure and persists for 2 to 4 hours. No glycosuria has been observed.

i. Serum electrolyte and water content are not significantly affected one hour after exposure of cats and rats to "g".

j. In cats, significant delay in gastric emptying time occurs on exposure to low "g". Marked interruption of gastric digestion follows moderately severe "g".

k. In cats, cardiac activity may be significantly disturbed by exposure to relatively low "g." Profound cardiac changes are observed after high "g" and consist of prominent and/or inverted T waves, absence of P waves, complete heart block, arrhythmia, and fibrillation.

l. Decerebrate rigidity may occur after centrifugation of cats. Very slow, high voltage waves are seen in EEG records.

m. Effects of high "g" on the central nervous system.

1. Vertigo and dystaxia observed in 25 cats and 100 rats.
2. Brief unconsciousness is very common.
3. Pseudo-affective or quasi-emotional states are very common in cats.
4. Decerebrate rigidity observed in 20 cats.
5. Tolerance may be built up in rats and cats by repeated exposure but eventually the central nervous system may be permanently affected.

Conclusion: "G" effect on animals are often referred to the central nervous system. The disturbances produced are usually temporary, occasionally permanent.

n. Breathing CO_2 or CO_2/O_2 (5%-95%) for brief periods improves resistance to high "g". Previous exposure to anoxia (25,000 feet for 2 to 3 hours) is also beneficial. Oxygen per se is not effective.

o. Pitressin and post-pituitary extract markedly affect "g" resistance. Adrenalin is of some benefit. Paredrine is ineffective.

p. In male rats, cortico-adrenal extract, desoxycorticosterone, and estradiol (diproprionate and benzoate) have a beneficial influence. Glucose-saline is also helpful. Benzedrine and amyl nitrite have no significant effect.

q. Arteriographic studies made with injection of diodrast or skiodan show pooling of blood in splanchnic vessels of cats and possibly in jugular veins.

r. In cats, EEG's show more or less complete suppression of activity during normal unconsciousness produced by exposure to "g" During decerebrate rigidity, high voltage slow waves appear, although frequency is not reduced to the level of delta activity in man.

s. Factors which influence "g" tolerance are:

animal species	position
sex	mechanical aides
individual differences	pressor drugs
age	hormones
food	respiratory gases
	pre-exposure to "g"

Rats and guinea pigs have greater tolerance than dogs, cats, mice, and rabbits, i.e., size of the animal is not the determining factor.

t. Female resistance is superior to male with respect both to "g" and anoxia. In the case of rats exposed to simulated altitudes of 22,000 feet, females survive longer than males at 16° C, and their survival time approximates that of males at 32° C. Survival time of both sexes greatly decreases at high temperatures.

u. Postmortem findings after centrifugation to near lethal point are: Right auricle and right ventricle are dilated and full of blood. The rest of the heart is normal. The bases of the lung show severe hemorrhagic extravasation. The upper halves are pale. The liver is dark and deeply congested. The kidneys have ecchymotic patches but are normal on section. The spleen is small, hard and contracted, and pale in color. Rectal prolapse and bleeding are found. There are no gross changes in the brain. In rats, one testis (always the left) may be markedly distended with venous blood. There is also evidence of intra-abdominal retraction of one testis.

108. Britton, S. W., E. L. Corey, and G. A. Stewart. Physiological studies on high gravitational forces. (University of Virginia) CAM No. 56. 10 April 42.

In 18 male rats mortality rate at 25 "g" was reduced 50% by suitably spaced and graded previous exposures to "g". Amyl nitrite inhaled during profound shock following centrifugation in dogs and cats restores normal rate and rhythm of heart, improves A-V conduction, alleviates bundle branch block. Shock gradually disappears and animal recovers. When centrifugation is continued until death, findings are extreme cardiac dilatation, subintemal hemorrhages in left heart, congested lungs, and lobal tears in liver.

Desoxycorticosterone greatly increases resistance to "g", as do glucose-saline injections. Exposure of rats for 5 minutes to 5° C (icewater) increases tolerance. Atropine and pilocarpine do no good. Female rats are much more resistant than male rats. Castration of females and injection of testosterone propionate does not reduce resistance. High gravitational forces inhibit oestrus activity markedly. In dogs, blood concentration and blood sugar are increased by exposure to "g", return to normal levels within 3 to 4 hours following exposure. In frogs, dilation of vessels of web and gross hemorrhage occur on centrifugation.

I. TILTBOARD STUDIES ON THE CARDIOVASCULAR SYSTEM

109. Graybiel, A., and R. McFarland. The use of the tilt table test in aviation medicine. **J. Av. Med.** 12:194-211 1941

a. The tilt table test provides a good method of testing the functions of the peripheral vascular system.

b. Out of 91 subjects tested, 9 collapsed or fainted, 13 responded poorly, 58 responded fairly well and 11 well.

c. When the subject's response was correlated with changes in blood pressure and pulse, the most important items in order of significance were (1) fall in systolic blood pressure (2) fall in pulse pressure (3) increase in heart rate.

d. The wide variation in response is due to individual differences and to a number of factors which render an individual physically unfit.

e. Response to tilting may be improved by training.

f. It has been noted that there is correlation between fainting and "blacking out" in pull outs from dives. Consequently a method of testing this susceptibility should be of value in aviation medicine.

g. Results so far warrant further exploration of the possibilities of the tilt board and standardization of the procedure.

110. Taylos, C., S. C. Allen, and V. E. Hall. A study of orthostatic insuffiiciency by the tilt board method. (Stanford University) CAM No. 1.

Out of 91 healthy male subjects aged 18-28, 20 were fainters and 71 non-fainters. The accumulation of blood in the lower part of the body causes cerebral anoxia. It can be prevented by leg bandaging and, to some extent, by physical training.

111. Ham, G. C., and J. C. Hortenstine. Objective determination of circulatory changes preceding, during and following greying, blackout and syncope on the tilt table. (University of Virginia). CAM No. 54. 28 May 42.

Thirty tilt table observations were made on 14 male subjects 20 to 30 years of age and on one 41 years old. In 14 cases, sodium nitrite was given in addition to tilting.

It was demonstrated that objective changes do occur in ear opacity, the rate and amplitude of pulse in the temporal artery, and blood pressure in the brachial artery prior to grey or black out and syncope. As confusion frequently precedes these symptoms, an individual's subjective recollection of blackout is unreliable. Objective criteria should be used in judging protection on the centrifuge or in the plane.

112. Ham, G. C., and J. L. Patterson, Jr. Observation on the ability to predict syncope in subjects given nitrite on the tilt table. (University of Virginia). CAM No. 139. 8 June 43.

Twenty subjects were tilted and given nitroglycerine in a total of 58 exposures. In 35% of the observations fainting occurred. Three consistent fainters and 6 non-fainters were tested. The pulse pressure and, to a less extent, ear temperature and body height showed significant correlation with fainting. Ninety-one per cent of the cases having a pluse pressure of 36 mm Hg or better were non fainters. With pulse pressures of less than 36 mm Hg, fainters and non-fainters were equally divided.

113. Landis, E. M., J. L. Patterson, Jr., and G. C. Ham. Studies on the circulatory changes induced by tilting and nitroglycerin administration in a series of young male subjects. (University of Virginia) CAM No. 190. 13 July 43.

Fifty-eight subjects were tilted and 20 given nitroglycerin. Twenty subjects fainted (35%). A combination of the fall in ear temperature and the lowest pulse pressure recorded in the first 3 minutes after tilting to an upright position has statistically significant value in predicting fainting. A simplified tilt test is described and its possible value as a test for "g" tolerance is discussed.

J. DECELERATIVE FORCES IN CRASHES.

114. DeHaven, H., Mechanical analysis of survival in falls from heights of 50 to 150 feet. **War Medicine 2:586-596. 1942.**

Seven cases of free fall in which height of fall was exactly known and speed conservatively estimated are analyzed. It is concluded that the human body can tolerate and expend forces up to 200 times gravity for brief intervals **during which the force acts in transverse relation to the long axis of the body.**

115. Rushmer, Robert F. Internal injury produced by abrupt deceleration of small animals. (Randolph Field) Proj. 241, Report No. 1. 1944.

a. This article is mainly a description of an apparatus to produce abrupt deceleration in mice. The same type of internal injuries occur as those found in humans in aircraft accidents.

b. The lungs, liver, spleen, and mesentery are most frequently affected by large forces applied transversely through the body and in that order.

c. Decelerative forces developed at the upper end of the carriage of the apparatus are undoubtedly greater than those developed in the pilot compartment of aircraft. The forces calculated at the abdominal surface of mice ranged from 153-227 "g". It is entirely possible that forces of this magnitude may occur in airplane crashes.

d. In spite of the fact that data obtained in this way cannot be directly applied to the problem of aircraft accidents, fundamental investigation as to the mechanism of action of these forces, the effect of position on internal injury, and the incidence of injury to various tissues can be carried out.

116. Rushmer, Robert F. Comparison of experimental injuries resulting from decelerative forces applied to the ventral and dorsal aspects of rabbits during simulated aircraft accidents. (Randolph Field). Proj. 301, Report No. 1. 8 October 44.

a. Rabbits (under nembutol anaethesia) receives less internal damage when moderate decelerative force is applied to the back by a flat surface than when they face the force and are supported by a web harness (Sutton type).

b. When subjected to decelerative force of 300 to 400 "g", there is no difference in the degree of internal injury whether the dorsal or ventral surface is exposed.

c. The location of internal injury bears little relation to the site of the application of decelerative force. Thus trauma is probably due to (1) high pressure waves transmitted through solid viscera and fluid elements of the body and to (2) the tearing of tissues such as the lungs, liver, mesentery, intestinal tract, and blood vessels (especially the lungs) from sudden distortion or displacement.

d. Most severe injuries result when the animals are loosely attached and are allowed to continue to travel forward and decelerate against a flat surface which has completely decelerated at the time of impact of the animal.

Previous discussions of forces involved in aricraft accidents assume forces of 3 to 60 "g". There are no reliable measurements. The work of DeHaven indicates that one can survive 200 "g" for brief periods of time. It has been assumed that decelerative forces are constant. Actual measurements on rabbits show that with average decelerative forces of 130-140 "g", peak forces of 400 "g" may be reached. The type of injury produced experimentally in rabbits is very similar to that actually found in aircraft crashes.

Conclusions. (1) Forces encountered in aircraft crashes may be much larger than previously suspected. (2) The body can survive higher decelerative forces than has been previously assumed.

K. INSTRUMENTS OF VALUE IN STUDYING ACCELERATION.

117. Ham, G. C., and E. M. Landis. Apparatus for the study of changes in the peripheral circulation during acvceleration. (University of Virginia) CAM No. 48. 23 April 42.

Descripition of a modification of Millikan's oximeter to record ear opacity and pulse amplitude changes in response to circulatory changes. Duplicates appendix to CAM No. 44.

118. Ham, G. C., and J. L. Patterson, Jr. Quantitative determination of changes in blood content of the human ear with a modified oximeter. (University of Virginia) CAM No. 140. 26 May 43.

a. The oximeter has been modified so that the opacity of the ear tissue and of the blood in the human ear can be measured separately.

b. Both the opacity of the ear tissue alone and that of the blood alone differ from individual to individual. These two variables would necessitate a large number of curves if all situations were to be covered.

c. One variable can be eliminated if the effective opacity of the bloodless ear tissue of all individuals is made the same by varying the intensity of the incident light.

d. A method of obtaining empiric curves with an artificial ear to simulate a decrease or increase in blood content of the human ear has been described. This method can be used to calibrate recording instruments in terms of percentage change in blood content.

e. The properties of photocells which may produce errors in results are discussed.

119. Ham, G. C., J. L. Patterson, Jr., and E. M. Landis. Quantitative measurements of changes in blood content of the human ear with a modified oximeter. (University of Virginia) CAM No. 188. 10 June 43.

a. A modified oximeter ear unit is described which allows separate measurement of both the thickness ("opacity") of the bloodless ear and of the blood in the human ear.

b. It is calibrated with sheets of tracing paper to represent the bloodless ear and glass chambers of known thickness to represent the blood contained in the ear.

c. A method for the measurement of percentile changes in the blood content of the ear with the cathode ray oscillograph and this ear unit is described. It is adaptable to use in either the centrifuge or aircraft.

120. Nyboer, J., S. Bagno, and L. F. Nims. The impedance plethysmograph, an electrical volume recorder. (Yale University) CAM No. 149. 10 June 43.

Circuit diagrams of an impedence plethysmograph; explanation of its operation and derivation of the necessary equations. Satisfactory records are obtained of changes in pulse volume as well as the large, slow changes resulting from redistribution of blood. The method depends upon the fact that the electrical impedance of any part of the body is a function of its volume.

121. Sturm, R. E., and E. H. Wood. An instantaneously recording cardiotachometer applicable to the study of heart rate changes in human beings during exposures to acceleration (Mayo Clinic) CAM No. 371. Sept. 44.

For human centrifuge studies of acceleration a record of instantaneous heart rate is necessary. The circuit diagrams and an explation of the operationof a suitable cardiotachometer are given. The instrument is activated by the R wave impulse of the ECG but can be adapted for activation by ear opacity, volume, or pressure pulse impulses. By appropriate modification the instrument can be used to record the instantaneous rate of occurrance of any phenomenon which produces or can be caused to produce changes in electrical potentials.

122. Crescitelli, F., and E. Gardner. The application of a hot wire and thermocouple for recording surface pulsations in the human body. (University of Southern California) CAM No. 37[illegible] 15 Sept. 44.

It is possible to obtain pulse records from the surface of the body by means of a nichrome hot wire and a copper-constantin thermocouple which are lined up with an adapter through which a small current of warm air is driven by body pulsations. Variations in emf thus produced are suitably amplified and recorded by a galvanometer or cathode ray oscillograph. The chief limitation of the method is a failure to follow slow changes.

123. Sturm, Ralph. Description of a device for measuring blood pressure under increased "g". (Acceleration Conference, Rochester, Minn. 23 February 44.

An inflatable cuff covers the wrist of the subject. Cuff pressure and finger pulsations are recorded. Systolic blood pressure is taken as that pressure just below the cuff pressure which cuts off finger pulsations. Blood pressure at any level of the body may be determined by anchoring the hand at that level.

Trial runs show that blood pressure is well maintained at heart level during 5 to 6 "g" on the centrifuge. This does not look as if venous return were impaired.

124. Viteles, M. S., and O. Backstrom, Jr. An analysis of graphic records of pilot performance obtained by means of the R-S ride recorder. CAA Division of Research, Washington, D. C. Report No. 23. Nov. 43.

R-S ride recorder records movement of aircraft in 3 dimensions. Useful for mapping "g" patterns of aerial maneuvers.

125. Hallenbeck, G. A. The Lindquist-Ryan tensiometer. (Wright Field) CAM No. 310. 8 April 44.

Description of an apparatus for recording "g" produced in opening shock of parachute jumps by stylus writing on moving clear film.

126. AAF Material. Instruments on the human centrifuge at RCAF No. 1 Initial Training Center, Toronto, Canada. (Wright Field) Memo report Exp-M-49-695-16A. 21 Sept. 42.

Description of Canadian equipment including color motion picture cameras, signal system, accelerometers, and electroencephalographs.

127. Jobes, H. W. Human centrifuge of the Aero Medical Unit at the Mayo Clinic's Aero Medical Laboratory (Wright Field) Memo report EXP-M-49-698-5. 24 Aug. 1942.

The superstructure and driving mechanism of the inertia-type centrifuge at Mayo Clinic is described. The superstructure is judged to be quite satisfactory in operation but the clutching and braking mechanism gives a somewhat non-linear acceleration to the centrifuge, partly because of manual control.

128. Herrington, L. P., H. Lamport, and E. C. Hoff. Human centrifuge. Report of the Yale Aeromedical Research Unit. 30 Oct. 1942.

A relatively inexpensive, 20 foot radius human centrifuge is described as follows. The centrifuge is driven through a reduction gear by a DC motor receiving power from an AC activated motor generator. If the current fails or the maximum speed is exceeded, the brake stops the centrifuge. The speed is controlled electronically.

Radial acceleration is proportional to the square of the rate of rotation. The control keeps the constant rate of change of the electric current proportional to the square of the rate of rotation. (This is a modification of the electric tachometer where the voltage is proportional to the revolutions per minute). A direct reading of the electric accelerometer is thus produced.

A more elaborate device permits the duplication of the "g" effect of any air maneuver by means of a photo cell following a "g"-time curve (called programming). The centrifuge gives a radial acceleration of 14 "g" in 5 seconds for the average-weight subject. Manufactured by Frank Hrubitz & Co., Salem, Oregon. Safety factor 12x.

129. Guillemin, Victor, Jr. "Motor drive and control for the human centrifuge." (Wright Field) Report No. EXP-M-49-695-16. 15 Sept. 42.

An AC motor drives a DC generator which drives a DC motor. Two series fields, F1 and F1' are connected in series with each other and with armatures. The motor field F2' is fed by the electronic exciter which generates field F2' under special control from ABC. Before operation the AC motor is turned on "set" and the DC generator is brought up to full speed. The tubes in ABCD are warmed up. The current in F2 is zero and OR is open so current in F1 is zero also. The motor does not turn over although the field F2 is excited. Equipment is "ready"

To start, close OR and start current in F2. The generator produces current larger than but proportional to the current in F2. This gives a proportional torque in the DC motor and a proportional rate of speed increase in the centrifuge. The current for F2 is produced by thyratron unit B, but the output of B is controlled directly by A.

A receives two potentials, Es and Ea, from the centrifuge drive. Es comes from the tachometer generator and is directly proportional to the speed of the centrifuge. Ea is a potential drop across 2 series fields and is directly proportional to the rate of speed increase or acceleration of the centrifuge. Es' produces a counter potential to Es. When Es is equivalent to Es' the safety limit is reached and the current cut off. Ea' opposes Ea and is the safety limit for acceleration. During deceleration the motor feeds the current back to the generator. Thus the current through F1, F1', and the potential Ea are reversed. Ea'' opposes this so the rate of deceleration is controlled. This device, A, is not used in an ordinary run because the maximum values are not reached. Instead the present speed control C is used.

A heavily inked graph of the run is drawn through a photoelectric scanning device. The scanner causes the potentiometer to rotate and introduces a varying potential, similar in action to Es, into A. Safety devices automatically open the relay OR and apply emergency mechanical brake if the scanner fails to operate. The scanner also automatically returns the device to "ready" position at the end of the run. The recording "g" r[illegible] is actuated by a tachometer generator and draws a record of time v[illegible] of "g" on a moving strip of paper. This record is compared with the graph introduced into C to check the performance of the entire equipment.

L. REPORTS OF MEETINGS AND CONFERENCES ON ACCELERATION

130. Minutes of the 1st meeting of the subcommittee on acceleration. NRC. Washington, D.C. 28 Sept. 1942.

131. Minutes of the 2nd meeting of the subcommittee on acceleration. NRC. Washington, D.C. 2 Dec. 1942.

132. Minutes of the 3rd meeting of the subcommittee on acceleration. NRC. Washington, D.C. 29 March 1943.

133. Maaske, C. A. Reports of the committee on aviation medicine, National Research Council, on radial acceleration and its effect on the human and animal organism. (Wright Field). Memo Report ENG-M-49-696-36. 8 April 1943.

Report and summary of the 3rd meeting of the subcommittee on accele acceleration, CAM-NRC. Washington, D.C. 29 March 1943.

134. Maison, G. L. Conferences and tests at the centrifuge of the Mayo Aero Medical Unit. (Wright Field) Eng-660-11Y 24 April 43.

Report of conference held by Army representatives, Mayo Clinic group, and suit manufacturers. The difference between types of acceleration encountered in centrifuges and planes is explained.

135. Army Air Forces Conferences on acceleration at the Montreal Neurological Institute. (Wright Field) Memo Report Eng-49-696-4B. 14 June 43.

Purpose: To report conferences on the effects of radial acceleration on the physiology of animals, held by Dr. H. Jasper (Montreal Neurological Institute) and Lt. C. A. Maaske (Wright Field).

a. Safety of human subjects can be greatly promoted by preliminary centrifuge studies of animals. It was concluded that animal experimentation is vital to the elucidation of physiological changes occurring under "g".

b. In animals the normal cardiac response to "g" unprotected is tachycardia superseded by bradycardia when "g" is removed. Failure to obtain tachycardia indicates poor or depressed cardiac reflexes and is a very grave sign. However, bradycardia with protection under "g" is a usual though not invariable response. With protection, form of the ECG is the best index of the subject's condition.

c. Results of animal experimentation indicate that physiological events immediately following "g" exposure are as significant as results obtained under "g". Futhermore, these events vary with the duration of the exposure. The important indices are blood pressure, ECG, EEG, and respiration. Therefore all centrifuge studies should conform in "g"-time relationships to flight maneuvers.

d. Three types of episodes are seen in monkeys under high positive "g".

(a) **Cortical fit** associated with sensitization of the cerebral cortex by ischemia followed by return of enough blood to produce convulsions. (This response is frequently seen where external anti-"g" protection is used.)

(b) **Decerebrate attack**—complete abolition of cortical brain waves. Extensive clonic spasms followed by decerebrate rigidity lasting many hours.

(c) **Gasp reflex** initiated by medullary anoxia. This can be differentiated from a cortical fit by its occurrance during rather than after "g" exposure.

e. Movies show that there is no drainage of blood from brain vessels under "g" unless air is allowed to enter the skull artificially.

f. Where skll defects exist, the brain is pressed down on its base under "g" and an unusual type of blackout occurs produced by blockage of the optic nerve at the geniculate level.

g. Animals immersed in water to the neck are partially protected from "g". The same amount of protection is conferred by immersion only to the xiphoid process, but if the water is lowered further, protection decreases sharply.

h. The feasibility of raising intra-pulmonary pressure as a protective device was discussed. This project is especially important because Dr. Jasper has noted right heart failure and pulmonary engorgement of animals exposed to high "g" while protected.

136. Minutes of the 4th meeting of the subcommittee on acceleration. NRC Washington, D.C. 17 Sept. 43.

137. Minutes of the 5th meeting of the subcommittee on acceleration. Feb. 23-24, 1944, at the Mayo Aero Medical Unit, Rochester, Minn., Bull. Subcommittee on acceleration. CAM.

138. Knowlton, G. C. and G. A. Hallenbeck. Meeting of the National Research Council Subcommittee on Acceleration, Rochester, Minn. 23 and 24 February, 1944. (Wright Field) Memo Report Eng-49-696-59. 11 March 1944.

139. Hallenbeck, G. A. Meeting of National Research Council subcommittee on acceleration. Washington, D.C. 7 June 1944 (Wright Field) Memo Report Eng-49-696-51E. 22 June 1944.

140. Proceedings of the 13th meeting of the associate committee on aviation medical research. National Research Council of Canada, Ottowa. 25 Feb. 44.

141. Proceedings of the 14th meeting of the associate committee on aviation medical research, NRC, Canada. 29 Sept. 44.

142. Progress report of the RAF Physiological Laboratory. Jan. 43 to Jan. 44. FPRC No. 563. 21 Jan. 44.

144. Minutes of the 1st meeting of the Acceleration Section of No. 2 Flying Personnel Research Unit held at the old Medical School, Sydney University. RAAF, FPRC. F. R. No. 78. 29 March 44.

143. Minutes of the 13th meeting of Flying Personnel Medical Officers, Farnborough. 6 Feb. 44.

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