DEVELOPMENT OF "ANTI - G" VALVE

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The importance of aeromedical research is well known and does not require to be gone into in any great detail. The discovery of new structural materials, propellants etc., arising from the race for leadership in aviation, has ushered in an age of high transonic and supersonic flying for military and civilian passengers. There is also a great deal of optimism among top-ranking scientists regarding inter-planetary travel in the not-too-distant future. In all these things the limitations of the human system, however, seem to be very much the deciding factor. These limitations have to be removed or reduced to a minimum before high speed and high altitude flying becomes common place.

In many western countries, research in Aviation Medicine has been undertaken for many years now. The United States has even an organisation for work on Space medicine. The research done at the aviation centres have contributed much towards comfortisation and safety in flying. Recognising the importance of aeromedical research a few centres have been established by the I.A.F. for studying medical, physiological and psychological problems.

Development of Anti-G-Valve.

Mechanics :

Before starting on a detailed description of the development of an anti-G-valve, it seems desirable to explain what is meant by the terms 'G' and 'anti-G'. This requires the elucidation of a few fundamental principles without which a proper appreciation of the subject may not be possible. Present day aircraft, mainly the military types, are designed for high subsonic and and supersonic speeds. Added to this, the fighter aircraft are fully aerobatic. These characteristics are dictated by military considerations.

Unaccelerated flight, whatever the speed may be, does not have any effect on the pilot. This does not, of course, include the thermal effect due to air friction at high speeds. This is a separate problem and is not relevant to the subject under consideration. 'Inertia forces', due to accelerations which arise from the change in speed either in magnitude or magnitude and direction effect the pilot.

From Newton's second law of motion

(1) $F = m \times \alpha$

where m = the mass of a body

α = acceleration

F = force on the body.

The same body at rest in earths' gravitational field has a weight given by

$$(2) \qquad W = m \times G$$

Here G is the gravitation constant.

From (1) and (2)

$$(3) \qquad \frac{F}{W} = \frac{\alpha}{G} = n$$

If we say that body suffers a force of 6G, (i. e. n=6) we mean that the body is acted upon by a force due to an acceleration which is six times that due to the earth's gravitation. This would be clear from equation (3). In aircraft engineering, fundamental unit of acceleration is the gravitational constant G and accelerations encountered in manoeuvres etc. are expressed as multiples of 'G'.

Accelerations can be linear or radial and are produced by rectilinear or curvilinear translations of a body. Linear accelerations are met with in jet assisted take-off, crash landing etc. These have no relation to the present subject. The radial or centrifugal acceleration which concern us is produced when a body moves in a curvilinear path, This acceleration is given by

$$(4) \qquad \alpha_R = \frac{V^2}{r}$$

where V=aircraft speed

r=radius of turn.

These are to be expressed in consistent units for calculation purposes. Equation (4) can be rewritten as follows :

$$(5) \qquad n = \frac{\alpha_R}{G} = \frac{V^2}{rg}$$

n=ratio of centrifugal acceleration to G.

Equation (5) shows that $\frac{V^2}{r}$ is the criterion and not V. . It also gives the relation between the speed of the aircraft, the radius of turn and the 'G' imposed during such a turn. For an aircraft flying at say 450 m. p. h. the radius of turn has to be 1100 yards to produce an acceleration of 4 'G'. If 'r' is to be reduced, 'n' naturally increases.

Due to radial acceleration a centrifugal force is created which acts away from the centre of curvature of flight path of an aircraft. This can be of two kinds, one positive and the other negative. The 'positive' centrifugal force acts on the pilot from head to foot. The 'negative' force acts from foot to head. The positive force is encountered in a loop or a bank. The negative force occurs when the pilot does an outside loop or when he levels off after a climb.

Medical Aspects.

Briefly, the physiological effects of varying degrees of positive acceleration on the human body are as follows:-

Cardio-Vascular System.

The forces required for turning an aeroplane are transmitted in a direction parallel to the long axis of the body of the aircrew seated in a normal attitude. The important vessels of the circulatory system are mostly disposed along the long axis of the body, and the arteries and veins are capable of distension and dilation. The vessels dilate due to the increased hydrostatic pressure created by the centrifugal force. So during a positive acceleration the blood from the head, neck, face and thorax tends to flow to the abdomen and legs. This consequently increases the volume capacity of the lower portion of the circulatory system with corresponding drop in the blood pressure. The *right heart* becomes virtually empty. Hence with increasing 'G' the heart is gradually unable to pump sufficient blood to maintain ocular or cerebral circulation. This accounts for the partial or complete loss of vision or even unconsciousness for a very brief period. Although the eye is extracranial yet the circulation to the retina is cut off first, due to the fact that the eye has an internal pressure of approximately 18 mm of Hg. The legs feel much heavier due to the congestion of blood.

Respiratory System.

With moderate acceleration of 2 to 4 'G' the respiration becomes more frequent. At 4 to 5 'G' and above breathing becomes irregular with long slow inspiration and mechanically forced expiration. This has been attributed to traction of the diaphragm with associated sagging of the thoracic viscere. The initial increase in respiration may be caused by reflex effects of the Sinus Caroticus and in part by psychic effect.

Bone Connective Tissue and Muscles.

The muscles of the cheeks and lips are pulled downwards with increasing 'G'. The entire body becomes heavier. At approximately 4 'G' in the sitting position the cervical muscles are unable to support the head resulting in the drooping of the head over the chest. It is with great difficulty that one can raise his arms.

Alimentary System.

The abdominal viscera sag down due to the downward traction. The degree of sagging is proportional to the imposed 'G' .

Central Nervous System.

The orientation in space and the reaction time are both impaired. The increased reaction time is due to a diminution in circulation in the brain.

It may be mentioned here that the degree to which the various physiological effects are imposed on the flier varies directly with the centrifugal force. However, the absolute magnitude of 'G' tolerance depends on the following factors.

(1) Degree of acceleration.
(2) Duration of exposure.
(3) Direction of the force in relation to the long axis of the body.
(4) Psycho-physiological condition of the organism.

Protective Device — 'G' Suit.

It will be appreciated how much of a disadvantage even a temporary loss of control can be in military combat actions. It is therefore, our aim to delay the onset o loss of control or black-out of a pilot. This can be achieved by the application of external pressure on the body. As the internal pressure produced by the congestion of blood is hydrostatic in nature, the correct way is to ensure that the external pressure applied i also hydrostatic. This means that a kind of water jacket has to be worn by the pi during flight. But such an arrangement is both heavy and inconvenient and so has to be ruled out. The other alternative then is to design some kind of suit which, when inflated by air, can apply pressure to the abdomen, thighs & legs. At these places, the external pressure tries to constrict the main blood vessels thus delaying the rus of blood to the legs and feet. Such a suit is called the 'G-suit'. The suit essentially consists of two sets of three inflatable bags made from rubberised fabrics or vinylite nylon fabric. These bags are so placed that they come over the abdomen, the thighs and calf muscles. The suit is worn next to the skin or as close as possible to it.

The 'G-suit' is inflated by a specially designed valve called the anti-G-valve. This valve has to carry out two functions. Inflate the 'G-suit' automatically as the aircraft goes into a manœuvre and regulate the air pressure depending upon the intensity of the manœuvre.

The supply of air for the suit is obtained from the pneumatic system of the aircraft. As the pressure may be of the order of 500 to 600 p. s. i., suitable reducers have to be used before the air can be fed into the anti-G-valve. Where no pneumatic system is provided in an aircraft, the air from the pressure side of the vacuum pump can be used. In the case of Jet aircraft, the air from the turbine casing can be tapped. Due to compression the air is at a high temperature and has to be cooled before it enters the sui

As the anti-G-valve has to admit and regulate air according to the manœuvre, is clear that it has to be actuated by the centrifugal force that acts on the aircraft. " valve is, therefore, mounted vertically in the aircraft.

History of the Project.

Two types of design were considered, one electrically operated and the other purely mechanical. The latter was finally preferred due to its extreme simplicity. The work was divided into three stages.

(1) Designing a valve to check the principle of operation and the correctness of assumptions made.

(2) Manufacturing a prototype for flight trials.

(3) Makin; the final design based on experience from flight trials.

Checking the Principle of Operation.

Having decided upon a tentative design of a valve, one unit was manufactur for test. As the valve was to be actuated by centrifugal force, it was not easy to arrange for a test. There is no Human Centrifuge in India to enable tests to be conducted. So a whirling arm was built. This consisted of a rotating arm made from an aluminium alloy channel section and swivelling about an axle mounted on ball bearings. The arm was rotated by an 24 volt electric motor through a chain drive. The valve was fixed to the aluminium channel by means of bolts. Air supply was obtained from the compressed air line in the workshops. The pressure was of course stepped down to a small value by means of pressure regulators. The air was taken to the rotating valve through a swival joint (suitably modified) and the hollowed out axle of the whirling arm. From the valve the air was taken to a stationary oxygen bag which served as the suit. When a trial run was made, the valve was seen to inflate and deflate the bag automatically, though the whole apparatus was most elementary in construction.

Author testing the design of the Anti-G Valve

Working Mechanism of Anti 'G' Valve.

The anti-G-valve consists of two units. They are air admission valve and air pressure regulating valve.

Air Admission Valve.

The requirements for this valve, are,

(1) It should not admit air to the suit during level flight.

(2) When a manoeuvre starts, it should snap open and allow air to the suit.

(3) When the aircraft levels off after a manoeuvre, the valve should snap close and at the same time deflate the suit.

(4) Valve action should be fully automatic.

In the case of those aircraft where the air can be tapped at will (this is possible with the pneumatic system), a simple valve which is purely mechanical in action or one which is operated by a solenoid can be used. One such design consists of a piston with a spring loaded poppet head at the top of the piston. The spring is provided to ensure that the valve does not function during bumps in the air or on the ground. The piston moves against and is stabilised with the help of springs. The action of this valve is as follows: The valve is mounted in a vertical position. During level flight, the spring keeps the piston in the 'up' position. So the bottom port is open for the air from the vacuum pump to discharge continuously. The top port is kept closed by the poppet head. So no air goes to the regulating valve and from there to the 'G-suit'. When a manoeuvre starts, the centrifugal force acts on the piston and the poppet which being heavy (made from brass) moves downwards compressing the spring. At about 2½ G and above, the bottom port closes and the top port opens. Air instead of being by-passed, passes on to the regulating valve. When the aircraft levels off, the centrifugal force on the piston is reduced. Spring pushes the piston upwards. The top port closes and the bottom port opens. The air from the vacuum pump is again by-passed and no air is allowed into the regulating side.

Though the principle is fairly simple, some drawbacks compelled us to drop this design.

(1) There is no snap action at 2 or 2½ g.

(2) Due to difficulty of designing a spring, it is impossible to achieve closure of this valve before 3 G is reached.

Since an electrically operated valve does not suffer from these disadvantages, such a valve was designed. This valve consisted of a stainless steel rotor mounted on ball bearing and rotating in the housing. Actually, the rotor does not rotate but only oscillates through 90°. The rotor has a through hole and 2 slots, these having 90° phase difference. The through hole is for passing the air from the inlet to the outlet when the three are in line. When the rotor turns through 90°, the slots come opposite to the inlet and outlet. As the slots communicate with the outside atmosphere, the air is by-passed. The rotor is actuated by a solenoid through a gear mechanism. The solenoid which is a 24 volt electrical circuit, is energised when a micro-switch is closed automatically by centrifugal force. This valve also had one drawback. As the clearance between the rotor and the housing is of the order of 0.002 inches, any trace of oil in the air supply made the rotor stick in the housing.

Pressure Regulating Valve.

Pressure regulating valve which was first evolved consists of a piston which operates in the housing and is kept floating by two springs. It has the inlet connection to the G-suit and the outlet to the atmosphere. In level flight, no air is admitted into it by he air admission valve. But when 'G' acts, air starts coming into the small chamber of the pressure regulating valve. But as the piston moves down under 'G' the outlet to atmosphere is throttled. The back pressure in the chamber increases and the air flows through to the "G" suit. This arrangement which may be called the 'constant leakage system' has one disadvantage that due to the constant leakage the rate of inflation of the G-suit is slow. So this was discarded in favour of the present system which works on the principle of a safety valve.

Final Design.

The principle of operation is as follows. Air from a pump or the turbine casing enters the valve body. In level flight, the piston in the regulating valve lifts up under the least pressure and the air passes into free air through ports provided on the regulating valve housing. A certain amount of back pressure develops in the valve body, but this is not sufficient to lift the flapper valve in the air admission valve. The compression of the spring can be varied so that the flapper can lift up at any required 'G'. In the design of pressure regulating valve, there seems to be a relation between the area of the valve port, the moving brass weight which is actuated by 'G' and the compression value of the spring.

Let W be the weight of the brass wt. in pounds.
N is the 'G'.
R is the upward load exerted by the spring.
A is the area of the valve port.
P is air pressure in p. s. i. in the valve body.

Considering the equilibrium of the piston and brass weight.

$$P.A. = NW - R$$

$$\text{or} \quad P = \frac{NW}{A} - \frac{R}{A}$$

As per medical requirements, P should be zero at 1½ G and beyond that P shoud vary at 1 p. s. i. per G.

$$\text{or} \quad P = N - 1.5$$

$$\text{So if} \quad \frac{NW}{A} - \frac{R}{A} = N - 1.5$$

$$\frac{W}{A} = 1 \text{ and } \frac{R}{A} = 1.5 \text{ (Numerically)}$$

So for a fixed valve port area A, W & R are known. The equation holds good as long as the valve remains closed. But as the safety valve piston rises, the pressure slightly drops. This is accounted for by reducing the port area somewhat. The design based on this calculation has given excellent results. When the aircraft goes into a manoeuvre, the centrifugal force acts on the moving brass weight of the regulating valve and the valve port is closed. The back pressure of the air in the valve body rises to the particular value automatically determined by the regulating valve. In an ordinary safety valve the pressure at which the valve should blow off is set by a spring. In this case the settings are automatically governed by the 'G' acting on the moving piston.

'G' Tolerance Afforded.

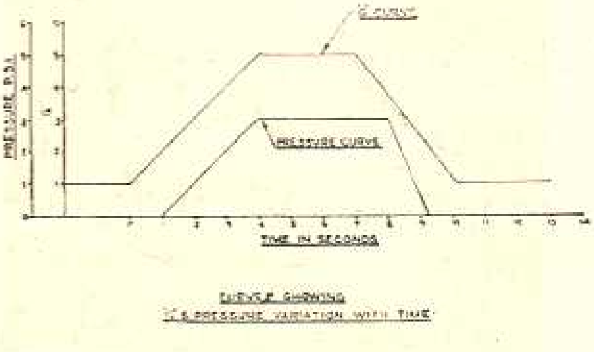
Now we come to the actual requirements for the valve and a discussion of the tolerance afforded by the 'G' suit.

The requirements of the valve are.

(1) In normal flight and in bumps, the valve should not inflate the suit.

(2) In a manoeuvre, the valve should start functioning at about 2 G. The pressures should be such that at $1\frac{1}{2}$ G it is zero and from then on the pressure varies at the rate of 1 p. s. i. per 'G'. Thus at 2 G. pressure is $\frac{1}{2}$ p. s. i., at 4 G. it is $2\frac{1}{2}$ p. s. i. etc.

(3) When the aircraft levels off, the valve should automatically deflate the suit.

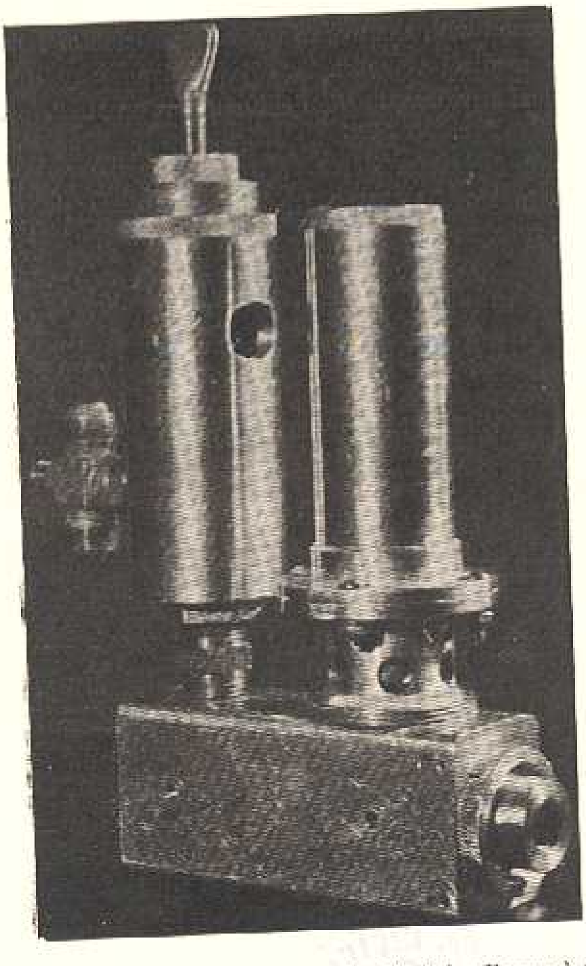


CURVE SHOWING
'G' & PRESSURE VARIATION WITH TIME

If an oscillogram of the 'G' and pressure variation against time were to be taken, the curve would be like the one shown. The time lag in the building up of pressure at the start of a manoeuvre is necessary as some time has to elapse before the blood can flow down to the places where pressure is applied. When the aircraft starts levelling off, the air pressure in the suit remains for a short time. This is necessary, otherwise, the sudden removal of the pressure will result in the blood still flowing downwards due to the initial momentum. This will result in the pilot blacking-out temporarily.

The tolerance afforded by the suit is a bit difficult to specify without a test on the Human Centrifuge. The tolerance afforded is about 2G. In other words, if without the G suit the pilot blacks out at say 5G, the suit helps him to stand accelerations upto 7G.

The valve has been flight tested in a Jet aircraft. This test, of course, can only show the pilot's reactions after using the G-suit. A more comprehensive test could be done in a Human Centrifuge. Unfortunately, in India, we do not have a C[illegible] and so a detailed evaluation cannot be done.



Anti-G-Valve designed at the Aviation Medicine Research Centre.

Special Features of the Anti-G-Valve.

The anti-G-valve designed at the Aero Medical Centre has the following outstanding advantages.

(1) The design is very simple.

(2) Maintenance problem is practically nil.

(3) There is very great flexibility of adjustment both as regards the 'G' at which the suit should start functioning and the rate of pressure increase with 'G'.

Conclusion.

An attempt has been made to explain briefly the working of the anti-G-valve designed at the Aviation Medicine Research Centre. The tests so far conducted have proved very satisfactory. It is hoped that, when the test programme is completed, this anti-G-valve will be accepted as standard equipment for the Indian Air Force.

We must provide more facilities at the various research centres in India. It should then be possible to proceed with the work in a more satisfactory manner. Having had so late a start in aero medical research, we have a long way to go before we can be self sufficient in the technical advances in the field of Aviation Medicine.

Acknowledgement.

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