PART 1 : SECTION 1

CHAPTER 2

PHYSIOLOGICAL EFFECTS OF FLIGHT

Introduction

1. The high performance of modern aircraft in terms of speed, acceleration, and altitude, expose flying personnel to environmental conditions and forces in which the unprotected human body may not be able to function.

2. It is important, therefore, that the physical limitations of the body and methods of extending those limitations are thoroughly understood by all aircrew, and particularly by captains of aircraft who may be responsible for the safety and well-being of untrained passengers.

Accelerations

3. As far as the body is concerned, there are two kinds of accelerations to be considered. These are :—

(*a*) Acceleration acting perpendicularly to the fore-and-aft axis of the aircraft. This kind of acceleration is encountered through :—

(i) Centrifugal accelerations—positive and negative.

(ii) Turbulence.

(iii) Ejection.

(*b*) Linear accelerations.

It is convenient to describe the forces of acceleration in terms of the number of times the force of gravity (*i.e.* the *g*) that is applied.

Effects of Centrifugal Accelerations

4. If the wings of an aircraft are set at an angle of attack greater than that appropriate to the I.A.S. in straight flight they are subjected to an increased loading, and the aircraft moves on a curved path. This increased loading is measured in terms of *g*, and is felt by the pilot as an increase in his weight. It can be shown from the formula

$$\text{Weight} = \text{Mass} \times \text{Acceleration}$$

that, mass remaining constant, weight must increase directly with acceleration. Thus at 4*g* a man is four times as heavy as at the normal 1*g* of level flight.

5. Under these conditions, excess *g*, acting in a head-to-foot direction (with a conventionally-seated pilot), has the following effects :—

(*a*) The blood becomes heavier, and tends to drain from the head and pool in the abdomen and lower parts of the body.

(*b*) The heart is displaced downwards by its increased weight, thus increasing the vertical distance from the heart to the head through which it has to maintain a column of "heavier" blood.

(*c*) Greater muscular effort is required to move the limbs and head.

6. As a result of para. 5, (*a*) and (*b*), the eye and brain are starved of oxygen and partial loss of vision (grey-out) begins, followed later by total loss of vision (black-out). This will eventually be followed by loss of consciousness if the manœuvre is sustained. The effects of black-out disappear as soon as *g* is reduced although, for a few seconds, there may be confusion and some difficulty in focusing the eyes.

7. As loss of consciousness may be followed by dis-orientation (dizziness) for up to 30 seconds, *g* should never be applied beyond the black-out stage, and extra care should be taken with aircraft that tend to tighten (pitch-up) in turns. Tolerance to *g* varies considerably with individuals, but the average pilot will black-out at between 4½*g* and 6*g* after five seconds, greying-out at about 1*g* less, and losing consciousness at about 1*g* greater than his black-out threshold. Owing to the latent period before the symptoms occur, much higher values can be tolerated for very short periods, which explains why a pilot can break an aircraft without blacking-out.

Increasing the *g* Tolerance

8. Tolerance to *g* may vary in the same individual from day to day and is considerably decreased by illness, hunger, fatigue, lack of oxygen, and a

"hang-over". Tolerance to *g* can be increased by the following methods (Fig. 1) :—

(*a*) *Self Protection.* By bracing the stomach and trunk muscles, crouching, and lowering the head as much as possible. Taking a deep breath and shouting, or "bearing down", also help in increasing the threshold. The extra protection given is in the region of 2*g*.

(*b*) *Position.* Raising the legs as high as possible reduces the tendency of blood to drain into them. Provision is made for this in some aircraft by the use of raised rudder pedals. Maximum protection, however, can only be given by having the pilot in the prone position.

(*c*) *Anti-g Suits.* If fitted properly, these suits provide counter pressure to the legs and abdomen by means of air bladders. The amount of air pressure supplied to the air bladders is automatically controlled by a valve, in proportion to the *g* applied, and is normally 1 lb./sq. in. per 1*g* applied in excess of normal gravity. These suits increase the black-out threshold of the normal pilot by about 2*g*, are comfortable to wear, and reduce fatigue considerably in flights where high *g* is repeatedly being applied.

9. **Negative** *g*. When *g* acts in the reverse direction, *e.g.* when entering a dive by pushing the nose down or in an outside loop, excess blood is forced into the head, and *red-out* occurs at a value of about $-2g$ to $-2\frac{1}{2}g$. Negative *g* great enough to produce red-out imposes a strain on the blood vessels of the brain and eyes, and therefore should not be applied except in emergency.

Accelerations Due to Turbulence

10. Rapidly alternating vertical accelerations of the aircraft may occur at high speed in turbulent conditions, such as those experienced in cloud, at low level in hot climates, and over uneven terrain. These accelerations, usually of the order of $1\frac{1}{2}g$ to $2g$ but occasionally up to $3g$ in high-speed aircraft, are governed in amplitude and

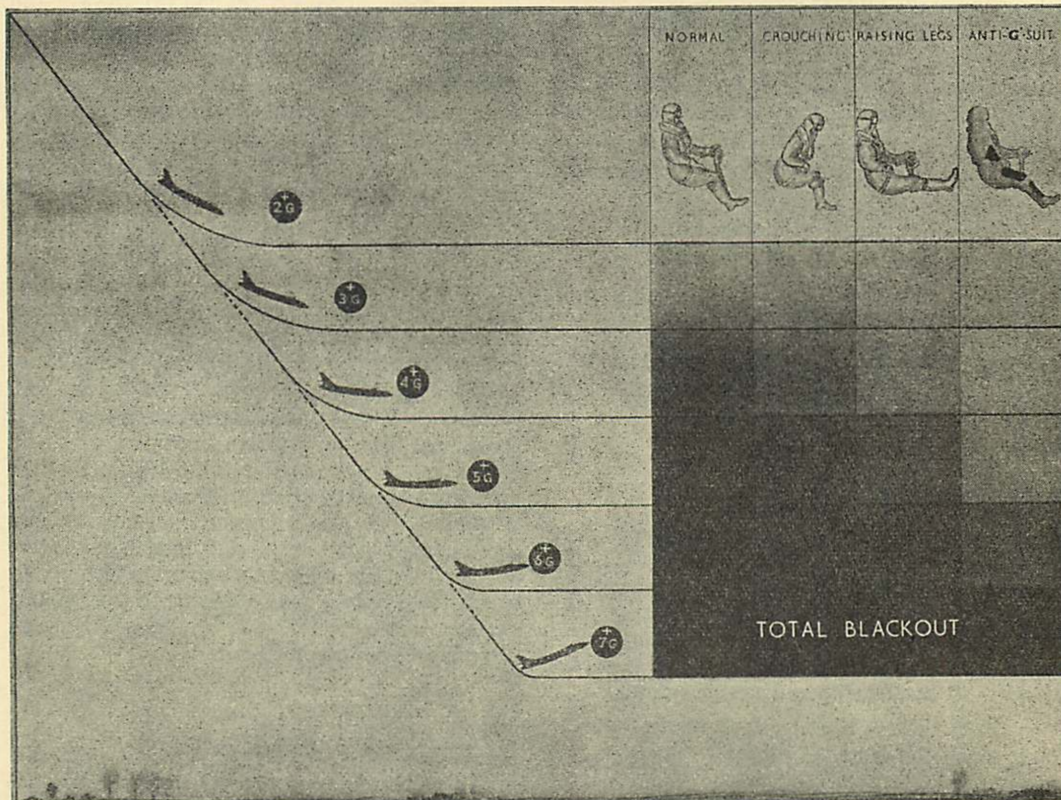


Fig. 1. Relationship between g and Black-Out

frequency by the wing loading and speed of the aircraft as well as by the amount of turbulence. Their major effect is to hasten the onset of fatigue in the individual, but serious injuries and concussion can occur as a result of being thrown against the cockpit canopy or cabin roof if the harness is inadequate or loose. It is the duty of captains to ensure that they and their crews and passengers have their harnesses secure when there is a possibility of flying into turbulent conditions.

Accelerations During Ejection

11. For ejection it is necessary to give the body an acceleration large enough to clear the tail of the aircraft in such a way that the spinal column is not subjected to more than 25*g*, and at no time must the rate of rise of *g* exceed 300*g* per second. These limitations must not be exceeded under any conditions of temperature and through the full weight-range of aircrew. In addition, the transmission of energy from the seat to the man during ejection is affected by the elastic properties of the equipment stowed in the seat pan, and it is essential that no unauthorized equipment should be placed in the seat pan. After ejection a number of other accelerations act on the seat and occupant, but these are of a complex nature and need not be described here. They may, however, lead to some dis-orientation and confusion and for this reason it is advisable that aircrew should know the ensuing drill so well that it becomes automatic.

Linear Accelerations

12. Linear accelerations are encountered along the line of flight, as in take-offs, assisted take-offs, deck landings, ditchings, and crashes. The same unit of measurement is used but reference is usually made to accelerations and decelerations according to the direction in which the force is imposed. Values that may be expected are 4*g* for a catapult launching and 3*g* for an arrested landing. In wheels-up landings or ditchings the force may exceed 10*g*. Provided that aircrew are protected by a correctly fitting harness or assume their correct crash positions, they can withstand these forces up to the standard strength of the aircraft.

13. The standard "Z"-type harness protects the wearer up to decelerations of 25*g* if correctly and tightly fitted, with the lap belt as low as possible and the shoulder straps locked. A high lap belt may allow the wearer to slip forward under the harness. The parachute quick-release box should never be directly behind the "Z" harness quick-release box, as it would then be driven back into the wearer during a severe deceleration and possibly cause internal injury.

Effects of Altitude on Man

14. The whole of the body's activity depends on the production of energy by a process which is, in effect, controlled combustion of material taken in as food. For this, as with other forms of combustion, oxygen is necessary. In order to bring the oxygen to every portion of the body where it is needed there exists a highly efficient transport system, the blood stream. Oxygen from the air enters the blood by passing across the surface of the lungs, and gaseous waste-products are eliminated by a reverse flow, from blood to the atmosphere. The passage of oxygen into the blood stream is governed by the *partial pressure* exerted by that gas (*i.e.* total pressure × volumetric proportion of individual gas in mixture). Although the composition of the atmosphere remains constant from sea level to altitudes as great as we can anticipate reaching with piloted aircraft in the near future, the pressure exerted by the air (and therefore that part due to the oxygen) falls progressively as one ascends. In order to maintain the required pressure of oxygen in the gas mixture breathed, it is necessary to increase the proportion of oxygen in that mixture. However, there is an altitude limit beyond which the total pressure is so low that breathing 100 per cent. oxygen still results in a lower partial pressure of oxygen within the lungs than when breathing the usual 21 per cent. oxygen at sea level. This limit corresponds to 33,700 feet above sea level.

Effects of Oxygen Lack

15. A shortage of oxygen supply to the tissues is termed *anoxia*. This may result from many causes, but the one with which we are concerned is insufficient transfer of oxygen from the inhaled gas mixture to the blood stream. The body shows the effect of oxygen lack in a sequence dictated by the sensitivity of various parts of the body to reduction of oxygen supply (and hence energy production). The most sensitive tissue is that part of the eye concerned with night vision. Reduction of the ability to see dimly illuminated objects can be detected at about 4,000 feet. Next to be affected are those parts of the brain associated with judgment, self-criticism, and the accurate performance of mental tasks. At altitudes above about 10,000 feet errors in

judgment become apparent to an observer but often not to the person suffering from oxygen lack, because, at the same time as the loss of ability has taken place, lack of appreciation of this alteration in skill has occurred. A man at this stage is often under the impression that he is in full possession of his faculties, or even flying more accurately than usual. At a later stage, or with exposure to a higher altitude, more gross changes in behaviour may be observed. General clumsiness and trembling may be noticed, breathing becomes rapid, vision becomes indistinct, questions or instructions may be ignored, and appreciation of any alteration in aircraft attitude or behaviour may not be noted or realized until after some delay, and when realized no corrective action may be taken. It is this effect of interfering with the normal action of the brain that is most to be feared in aircraft, for the brain controls the aircraft. Loss of this control is more to be feared than, for example, engine failure, or loss of R/T above cloud. Mood changes are common, and can take the form of hilarity, pugnacity, or drowsy apathy. Finally, consciousness is lost and the unsupported man will collapse. Individuals vary in their resistance to oxygen lack. The fact that one man has withstood certain conditions does not imply that others will react in the same way. Moderate and severe anoxia is accompanied by marked blueness of the face (particularly the lips) and the finger-nail beds.

Hyperventilation (Over-Breathing)

16. Although the mechanism of its action is different, over-breathing produces symptoms somewhat similar to those of oxygen lack. By over-breathing, or *hyperventilation,* is meant respiratory effort out of proportion to the work being done, and it is so common that some consideration must be given to its consequences.

17. Normal breathing maintains a constant partial pressure of carbon dioxide in the lungs, and it is this pressure which ordinarily provides the stimulus to breathing. Over-breathing, resulting from apprehension or excitement, may so reduce the level of carbon dioxide in the blood stream that the proper uptake of oxygen is reduced, and, in addition, the delivery of oxygen to the body cells is impaired.

18. Carbon dioxide lack also has the effect of reducing the blood supply to the brain. Feelings of unreality, light-headedness, trembling, and lack of judgment may result.

19. At low altitudes, serious over-breathing leading to incapacity is rare, since the washing-out of carbon dioxide decreases the stimulus to breathing and so limits the hyperventilation. When a man is already anoxic, however, even a moderate degree of over-breathing is dangerous, for the ill-effects of the two conditions are additive. Disaster may then result from the combination of two relatively minor causes. Thus, although some increase in the breathing rate is a normal consequence of oxygen lack, *any attempt to fight anoxia by voluntary over-breathing is to be avoided at all costs.*

Time of Useful Consciousness

20. The time for which useful consciousness is maintained after deprivation of added oxygen decreases with altitude. There is always a wide variation in the resistance to anoxia in the lower altitudes, but representative times of useful consciousness at rest are :—

22,000 feet ...	... 10–15 mins.
25,000 feet ...	... 4–5 mins.
30,000 feet ...	... 2–3 mins.
35,000 feet ...	... 1–1½ mins.
40,000 feet ...	... less than 1 minute
50,000 feet ...	... 15 seconds

21. No practical use should be made of these figures, since the mental and physical efficiency is adversely affected at a much earlier stage. The period during which consciousness is maintained is shorter than para. 20 would suggest if, before exposure, relatively dense air has been breathed (as in the case of the failure of a cabin pressurized to less than 10,000 feet).

Factors Predisposing to Anoxia

22. Physical activity markedly accelerates the onset of the effects of oxygen lack, and a mildly anoxic person may become very much more severely affected if he moves about in the aircraft.

23. Certain types of injury or illness may predispose to anoxia ; in particular, passengers suffering from chest disease or injuries, or recent blood loss, should be given oxygen and/or flown at minimum altitude.

Other Effects of Oxygen Lack

24. Resistance to cold is very much reduced by anoxia. Frost-bite of the extremities is more probable under such conditions.

25. Prolonged mild anoxia, such as may be experienced during exposure at 8,000 to 10,000 feet for several hours, may give rise to general lethargy and fatigue out of proportion to the work performed. For flights of this type oxygen should be used whenever possible.

26. Proneness to airsickness may be accentuated by anoxia.

Detection and Treatment of Anoxia

27. The recognition of anoxia in oneself may be very difficult. It is, however, greatly facilitated by having once experienced the symptoms of the condition in a decompression chamber. It is a golden rule to check oxygen equipment if any abnormal sensation (even of excessive well-being and confidence) is noticed in flight, or if mental or physical tasks appear to become unduly difficult. Slurring of speech and slowness in appreciating instructions or replying to questions may be detected during use of R/T or intercom. For the pilot alone in an aircraft it is most important to think of anoxia if such alteration in response is noticed, and the pilot should be instructed by other aircrew or ground controllers to check his oxygen equipment. If no fault is found or improvement is not noted on correction, an immediate descent should be ordered. Lives have been saved by quick recognition of anoxia in the pilot of one aircraft of a formation and the swift action of his colleagues on noting a slowness or lack of response over the R/T. Where possible, in the case of a crew member of a multi-seat aircraft, another member of the crew should be sent to investigate any suspicion of anoxia, always ensuring that adequate provision is made for the supply of oxygen to both afflicted and helper.

28. The treatment of anoxia follows three lines :—

(*a*) *Administration of Oxygen.* Use a walk-around or emergency oxygen set, or correct the fault in the crew member's oxygen equipment, or use the emergency flow from the aircraft regulator.

(*b*) *Reduction of Altitude.* This facilitates recovery and allows more time to be devoted to the correction of the original cause. It is worth remembering that where considerations of range or operational hazard preclude descent to below 10,000 feet, it may still be worth while bringing an anoxic person to an altitude below 20,000 feet although consciousness may not be recovered until a lower level is reached.

(*c*) *Resuscitation.* Promptly applied measures may save the life of a person who has apparently stopped breathing following prolonged anoxia, and administration of oxygen and/or reduction of altitude should be accompanied by the use of artificial respiration for at least an hour before hope is abandoned. An effort should always be made to see that the victim's airway is not obstructed by the tongue, tight clothing, or an abnormal position of the head.

Protection from the Effects of Oxygen Lack at High Altitude

29. Below 40,000 feet administration of oxygen is sufficient to combat the effects of anoxia. By breathing 100 per cent. oxygen, sea-level conditions may be maintained up to 33,700 feet ; and at 40,000 feet only a minor degree of anoxia (equivalent to breathing air at 10,000 feet) is experienced. It must be remembered that exercise is very poorly tolerated under either condition. With increase of altitude a well-fitting mask becomes more and more important ; above 33,700 feet any air dilution during inhalation becomes a serious hazard and excessive air dilution introduces a serious danger of sudden anoxia at any altitude above 25,000 feet.

30. Above 40,000 feet, in order to maintain efficiency for more than a short time, more than the simple administration of oxygen is necessary. Pressure greater than that prevailing at these heights is needed to saturate the blood oxygen-transport mechanism, and this may be achieved in a number of ways. A pressure cabin is obviously a convenient and comfortable means of protection and involves no stresses on the man (other than the remediable effects of insufficient ventilation or inadequate temperature control), but the pressure cabin is a relatively large target and provision must be made for protection of the occupants in the event of perforation or structural failure of the cabin shell or failure of the cabin air supply. By careful design and fitting, a mask may be produced to seal against the face with a pressure difference of some 12 to 15 inches of water. Thus, conditions inside the lungs may be reduced to an equivalent of 40,000 feet while flying at 44,500 feet. The discomfort is quite noticeable and at pressures in excess of about 12 inches of water other effects make it impracticable. However, the system is relatively simple and light and is quite sufficient for the protection of personnel during an emergency rapid descent from 50,000 feet to less than 40,000 feet following loss of cabin pressure.

31. To protect the crews of aircraft forced to descend from altitudes greater than 50,000 feet, the higher pressure applied to the lungs (and hence the circulation) must be countered by pressure applied to the body. Protection of short duration can be given by a simple garment known as a partial-pressure suit, or a limited-cover garment can be worn in conjunction with a pressure headpiece (a mask could not seal against the pressure necessary at such altitudes). Complete counter-pressure, and therefore a complete and continued protection, can be given by a close-fitting inflated suit (the full-pressure suit) or by a more complex and bulky apparatus in the form of a pressure capsule.

Other Effects of Reduced Pressure

32. Exposure to high altitudes (reduced pressures), in spite of effective measures to combat oxygen lack, may lead to the production of various signs and symptoms. These may be conveniently classified as being due to :—

(*a*) Changes of pressure within the ears and sinuses.

(*b*) Expansion of gases in the abdominal organs.

(*c*) Change believed to be due to the release of gas from solution in the tissues of the body, so-called *decompression sickness*.

Each of these will be dealt with in subsequent paragraphs.

The Ears and Sinuses

33. That portion of the ear internal to the drum (the middle ear) is an air-containing cavity with bony walls. It is sealed off from the outer ear by a membrane, the ear-drum, but communicates with the atmosphere by a tube (the Eustachian tube) which opens into the back of the nasal passages. The walls of the lower part of this tube are not rigidly supported, and consequently it is much easier for air to pass from the ear to the atmosphere than in the reverse direction. During ascent, therefore, air automatically escapes and the pressures on the inner and outer sides of the ear-drum are maintained at the same level. During descent, if air does not re-enter the middle ear the drum will be bulged inwards by the relatively higher atmospheric pressure; this gives rise to pain and deafness and, if the pressure difference becomes too great, rupture of the drum may take place. The healthy Eustachian tube may be opened quite readily by simple manœuvres, such as swallowing, yawning, moving the lower jaw, or drawing upwards the soft part of the palate. If difficulty is experienced, raising the pressure in the throat by holding the nose, closing the lips and blowing forcibly often succeeds. If, however, the opening and lining of the Eustachian tube is swollen (as may occur when one has a cold) or if the opening of the tube does not take place frequently enough during descent, the relatively low pressure in the ear may altogether prevent equalization of the pressures by causing the tube to collapse. The lesson to be learned is to avoid flying if one has a head cold or catarrh. If an ear should become painful it may be relieved by re-ascent and gradual descent where this is practicable, with careful attention to measures to open the Eustachian tube. If conditions prohibit such a climb and slow descent, lesser degrees of pain may be relieved by an immediate ascent and slow re-descent in a decompression chamber after landing. In any case the medical officer should always be consulted if persistent pain and/or deafness occur.

34. The sinuses (located in the forehead and in the bones to either side of the nose) are cavities lined with membrane which communicate with the space behind the nose by fine passages. These may be obstructed during descent in the same way as the Eustachian tubes, and the result may be quite severe pain. This usually relieves itself quite rapidly ; but if it should persist, or occur several times, it should be reported to the medical officer.

The Abdomen

35. The stomach and intestines always contain quantities of gas. At altitude these gases tend to expand as the pressure of the atmosphere is reduced, and distension of these organs may cause discomfort or pain unless the gas can be released. Discomfort may be relieved by loosening the clothing around the abdomen. The condition may generally be prevented from occurring by avoiding gas-producing foods, particularly certain vegetables and effervescent beers or minerals. Discomfort is rare if care is taken to avoid flying with an overfull bowel.

Decompression Sickness

36. A number of symptoms occasionally experienced at altitude or in decompression chambers may be attributed to the same cause as certain conditions known as *bends*, encountered in diving and compressed-air work, namely, the liberation from the body fluids of dissolved gases, principally nitrogen. These symptoms disappear

or improve on recompression, and, fortunately for the aviator, this entails the reduction of altitude. The symptoms of decompression are very rarely encountered below 30,000 feet. The onset of symptoms depends on :—

(*a*) Altitude.

(*b*) Time spent at altitude.

(*c*) Age and obesity (uncommon in young persons of average build).

(*d*) Activity (exercise increases the likelihood of symptoms).

(*e*) Oxygen lack—predisposes to symptoms.

(*f*) Cold may increase the chances of symptoms.

(*g*) Individual susceptibility—the most important factor other than actual altitude.

37. **Symptoms.** The commonest symptoms of decompression sickness are itching (a quite harmless, if irritating, discomfort) and pain in a limb, so-called bends. The pain may be quite severe and should always be treated with respect. Very occasionally other symptoms such as headache, faintness, cough, and blurring of vision may be encountered. The treatment of all forms of decompression sickness is the same ; namely, **immediate** *descent to* 25,000 *feet, or until the symptoms completely disappear* if 25,000 feet does not afford relief. Observation of this rule is most important since adherence to this practice will always lead to relief, whereas maintenance of altitude may lead to more severe disability which will take much longer to disappear. Any limb in which bends is experienced should be kept as still as possible until descent has relieved the discomfort.

Preventive and Protective Measures against Decompression Sickness

38. Consideration of para. 36 will immediately suggest a number of approaches to the prevention of decompression sickness. Maintenance of a low altitude is the most obvious. Where high-altitude flight is necessary, pressurization of the cabin will provide a safe environment for the occupants. Full oxygenation, correct cockpit temperature control, and reduction of activity to a minimum, all aid in the reduction of the risk of bends on unavoidable exposure to high altitudes. The evaluation of susceptibility by decompression testing will help in the selection of personnel for various types of duty (more resistant persons will be required where the possibility of prolonged exposure following loss of cabin pressure is high, as in long-range bomber aircraft). Further, considerable protection may be afforded by the replacement of the nitrogen in the body fluids by oxygen (*pre-oxygenation*) before exposure to high altitude. This can only be achieved by breathing 100 per cent. oxygen for a period of several hours, and unfortunately is not often possible in service flying.

Explosive Decompression

39. As experience is accumulated, it becomes evident that man can tolerate extremely rapid (explosive) decompression, due to pressure-cabin failure, remarkably well. Two factors that govern the stress involved are the range and period of decompression. The former depends on the pressure difference between cabin and atmosphere, the latter on the magnitude of the defect and the size of the cabin. To reduce the violence of decompression, lower degrees of pressurization (combat setting) should be used, when possible, in areas where enemy action is anticipated. It should be remembered that perhaps the greatest danger from failure of a pressure-cabin wall is the forceful expulsion of the cabin contents, including unsecured crew members, in the immediate neighbourhood of the defect. It is therefore important to ensure that safety harness is worn when working in the vicinity of a large hatch or transparency.

VISION

The Eye

40. In vision there are two associated structures, the eye and the brain, the former being, in reality, an offshoot of the latter. The lens is located in the centre of the eye (Fig. 2), and a cover over the pupil expands or contracts according to the conditions of the surrounding light. This tissue, which works like the diaphragm of a camera, is called the iris. In bright light it contracts, allowing only a little light into the eye. The pupil reacts to changes of light and also to any sudden change of focus of the eye from a distant to a nearby object. The first result is known as the *light reflex*, the second the *accommodation reflex*. The pupils dilate in the dark. Broadly speaking, the wider the pupil the better the sight at night.

41. The eyeball itself has a containing structure around it which is made up of two parts : one transparent called the cornea, the other white and called the sclerotic. Behind the pupil lies the lens, which is suspended, as it were, in a kind of delicate hair-net. This is attached to a muscle

which controls the thickness of the lens, variations in the thickness being necessary for focusing. If the eye is continually focused on a nearby object, the muscle is then contracted and may become tired. This condition is called fatigue. Behind the lens is a jelly-like substance which helps to keep the eyeball round. It is transparent and is known as *vitreous humour*. A highly complicated structure known as the retina covers much of the inner surface of the eye, and contains two types of cell, one sensitive to bright light, the other to poor light. These cells are protected from the shocks produced by sudden, wide changes in luminosity by a layer of a black pigment.

42. The two forms of cells are called rods (night vision) and cones (day vision). They are connected by little nerve fibres which gather together at the extreme back of the eye and pass backwards to the brain as the optic nerve.

43. The eye transmits "messages" through the nerve fibres to the brain. If the message is badly transmitted or fleeting, there is no reaction so that the impression fades before it has a chance of becoming understood and analysed. Practice increases the ability of the brain to interpret poorly transmitted messages into something important enough to be recognized and identified. An impression received at night is more open to varied interpretations than a message received in daylight. Badly transmitted night messages are apt to cause confusion in the mind as to what is being seen. This is due to the delay in interpreting the message which, even after interpretation, may not be clear.

Rods and Cones

44. Cones are the cells situated at a point in the retina called the fixation point, the point of direct view and of maximum day vision. They are located very close together to provide a highly sensitive and receptive surface that can transmit accurate messages to the brain. The sensitivity becomes less and less as the distance from the fixation point increases. The most important facts about the cones are that they are tuned to the appreciation of detail and colour. About 3° from the fixation point the rods become effective. In thinking of the millions of retinal cells, they should be imagined as set in circular rings around a centre, and in the area between a ring about 10° from the centre and another at 15° the rods become more closely pressed together. This area is sensitive to conditions of darkness and best suited to observing objects, for example, in starlight.

45. The centre of vision (cones) is in reality blind in starlight, as compared with the light of the full moon in which the centre of fixation still plays an

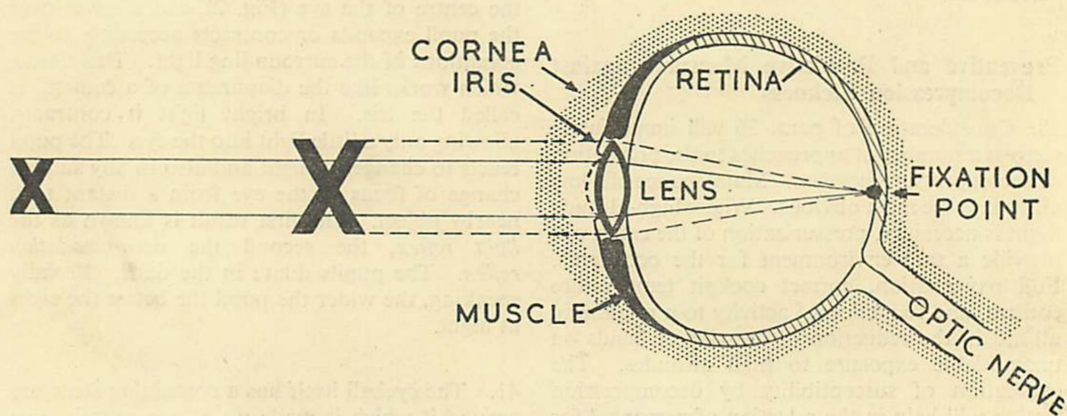


Fig. 2. Structure of the Eye

important role (Fig. 3). The loss of cone vision is, however, compensated by the fact that the observed object usually excites a big enough area of the retina to send messages down the sensitive rods. In the case of very small objects, on direct fixation, the cones will not be excited. As the rods are not called upon and the cones are blind there will be no sensation of vision. In such cases, by raising the eyes a few degrees above the object the rod area comes into action and the object can be seen.

46. The rods contain a substance known as *visual purple* which enables one to see in the dark. If a bright light is held before the eyes for one minute, it will be found that for some time afterwards everything becomes quite black. This is caused by the fact that bright light has bleached the visual purple and until it is replaced the night vision is seriously impaired. This visual purple takes up to 45 minutes to form and thus it takes up to that time for the eye to become night adapted.

47. Lack of ability of the body to manufacture the correct quantity of visual purple will result in a reduced night vision. This is usually caused by a vitamin A deficiency ; however, it is not a common failing and only an extreme shortage of such things in the diet as butter, milk, cheese, carrots, and certain fish oils, may bring about the defect.

Safeguarding of Vision

48. The eyes are richly supplied by the blood stream to maintain their nutrition. The condition of the blood reaching them is therefore of significance. Regular physical exercise and the correct amount of sleep assist in keeping the blood in good condition and thus in maintaining a sound standard of vision. Over-smoking is detrimental to night vision; more than twenty cigarettes a day having a noticeable effect. Alcohol in reasonable quantities has no bad effect. Games involving rapidity of perception and accurate estimation of distances have a definite value, especially for pilots.

Night Vision

49. The problem of seeing at night is the problem of the appreciation of contrast. An object is distinguished at night because it differs in some way from its background. Also, because of their poor definition, objects at night appear more distant than they really are.

50. **Ground Objects.** Objects that may be clearly defined on the ground in daylight may

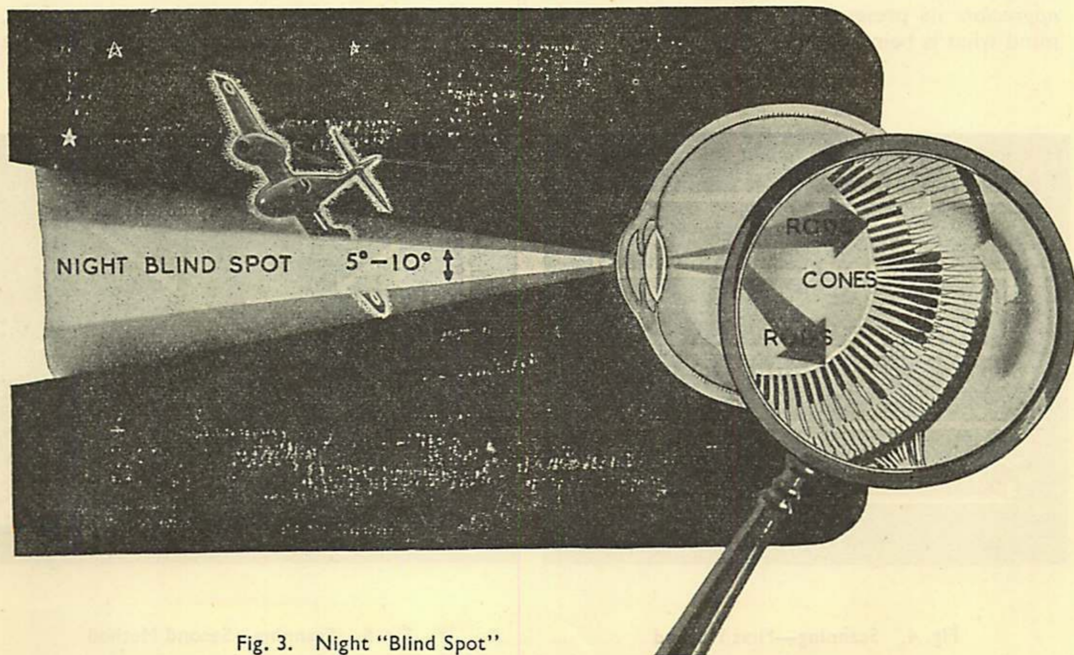


Fig. 3. Night "Blind Spot"

appear in reverse contrast at night, the differing effects being influenced by what is known as *reflectivity*. Surface texture is of particular significance and the appearance of many areas is altered owing to the presence of contained shadows. A ploughed field, for example, may appear lighter than an adjacent grass field at high moon, but viewed in the light of a low moon the ploughed land darkens in relation to the grass because of the shadows produced by the furrows.

Scanning

51. Several methods may be used for carrying out a visual search of the sky at night, but for general purposes two simple methods are used. In one the visual sweep is made horizontally (Fig. 4). Eye movements must be slow and stops made at proper intervals. At the end of each transverse movement the gaze should be dropped about 15° and the movement repeated in the opposite direction. On a dark night the sweep should be reduced, while on a clear moonlight night the scan can be increased in all directions.

52. In the other procedure, the area is divided into four imaginary squares projected into space in any direction (Fig. 5). Starting at the top left, the scan is passed to the bottom right, from there to top right, and then down and across to the bottom left. A pause of two to three seconds should be allotted to each square, and a rather shorter pause half-way along each diagonal. As it is possible actually to *see* an object and yet not *appreciate* its presence, it is essential to bear in mind what is being searched for.

Oxygen and Night Vision

53. The efficiency of the rod cells decreases with a lack of oxygen, so that it is advisable to use oxygen from ground level upwards at night, even if the intention is to fly at only 5,000 ft. The adverse effect of oxygen lack on night vision will become more rapidly noticeable as height is gained. At 16,000 ft. the effect will appear in 15 minutes, and visual power may be seriously reduced in half an hour.

54. The visual range is decreased with lack of oxygen as shown below :—

Height in feet	*Average percentage decrease in range of night vision if oxygen is not used*
4,000	5
6,000	10
8,000	15
10,000	20
12,000	25
14,000	35
16,000	40

The figures relate to starlight conditions ; under darker conditions the decrease will be slightly greater, while by moonlight it will be rather less.

Dark Adaptation

55. While it takes fully 30 minutes to adapt the eyes for seeing to the best advantage at night, night adaptation can be seriously reduced in a

Fig. 4. Scanning—First Method

Fig. 5. Scanning—Second Method

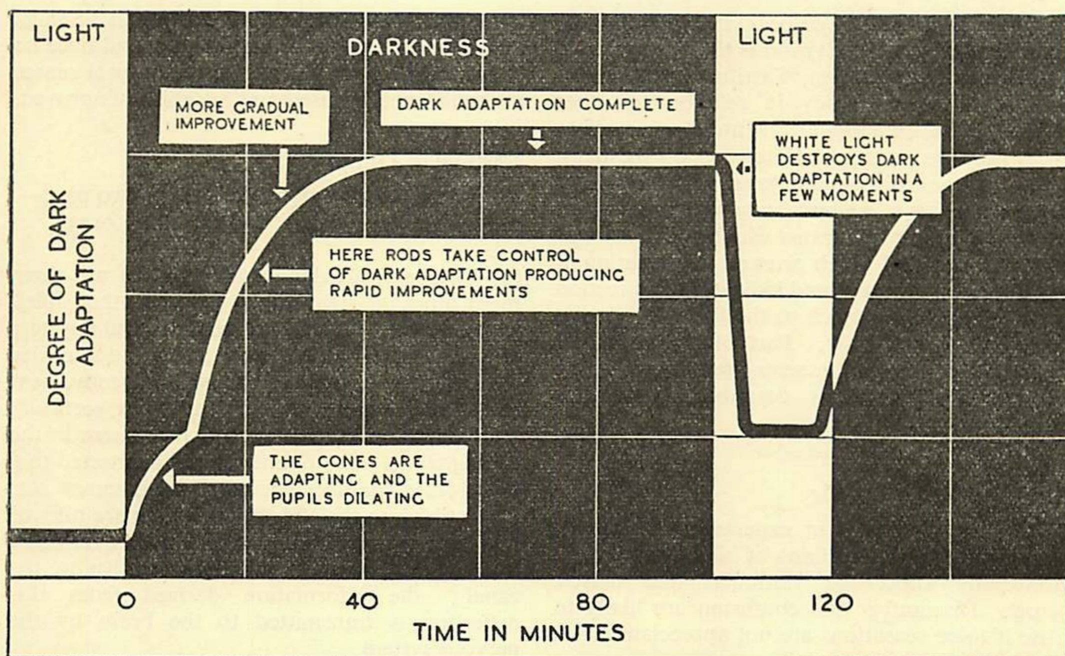


Fig. 6. Night Adaptation Graph

second. If adaptation is well established, however, it will not be entirely destroyed, but it may require up to three minutes to be restored (Fig. 6). Reduction can be brought about either by exposing the eyes to strong light or by staring at instrument panels that are lit more brightly than necessary.

56. *After images* are produced when the dark-adapted eyes become *glared* by a very bright object, with the result that after removal of the cause the image of the glaring object (the filament of an electric lamp, for example) takes shape in front of the eyes. If the source of glare is weak, a changing pattern of colour in the centre of vision may be observed, such as from red to vivid green. The patterns fade away, and then return for about two minutes if their cause has been specially concentrated. Red light does not destroy dark adaptation, hence the use of red illumination in instrument panels for night flying. A further benefit of red light is that it can be used in sufficient strength to make the marks on instruments quite clear at a level of luminosity well below the safety margin. All internal aircraft lighting, including fluorescent light, should be kept at the lowest possible level.

INSTRUMENT FLYING—HUMAN UNRELIABILITY

Equilibrium and Attitude

57. Under normal conditions the three senses responsible for man's sense of balance are vision, muscle sense, and vestibular sense, the last-named being a function of the inner ear (Fig. 7). While

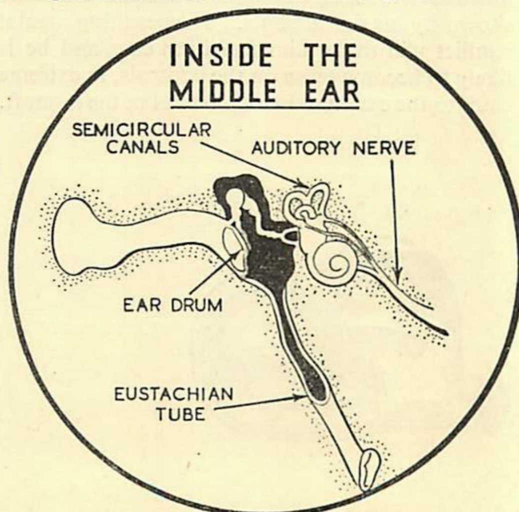


Fig. 7. The Structure of the Inner Ear

the brain continuously co-ordinates the information from each source, vision is the most reliable for correct interpretation of attitude, particularly in orientating the body in relation to other objects, fixed or moving. Muscle sense arises from pressure changes and tension on the flesh, joints, skin, and internal organs. The vestibular sense comes from a small bony structure known as the vestibular apparatus which forms part of the inner ear, and which gives an appreciation of turning about any axis and indicates the direction in which any force, such as the force of gravity, is acting on the body. Part of the vestibular apparatus consists of the semi-circular canals, the operation of which is described in a later paragraph.

Orientation in the Air

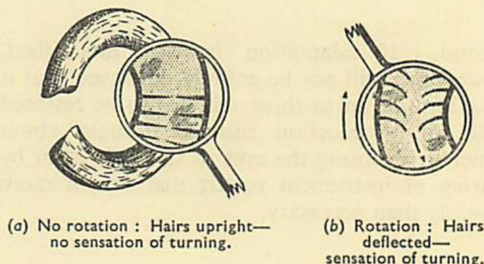
58. In the air the pilot experiences sensations caused by the accelerations of his aircraft which principally affect the vestibular and muscle senses. Discomfort and confusion are likely to arise if these sensations are not appreciated.

59. In contact flight the pilot controls the attitude of his aircraft largely by what he sees outside the cockpit, and these visual impressions are so strong that he is only vaguely conscious of the reactions of the other senses. However, once his external visual aids are lost he immediately becomes fully aware of the impressions of the vestibular and muscle senses. As these are only designed to supply supplementary information to the brain, and then only when on the ground, their indications may well persuade him that his attitude is entirely different from the true one shown by his instruments. The resulting mental conflict will make him feel ill at ease and he is likely to become tense on the controls, in extreme cases to the extent of losing control of the aircraft. If the pilot is to ignore these sensations he must understand why they are unreliable, and once he is aware of the limitations of the natural senses his confidence is raised and his ability improved.

Vestibular Organ

60. The vestibular organ consists of two parts—the semi-circular canals and the static organ.

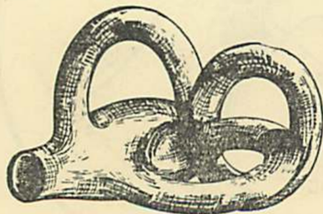
61. The semi-circular canals (Fig. 8) are three small tubes, at right angles to each other, filled with a liquid ; one lies horizontally and registers any movement in the yawing plane ; another lies vertically fore-and-aft and registers any movement in the pitching plane ; the third lies vertically and laterally and registers any movement in the rolling plane. These tubes are all connected to a liquid-filled chamber known as the common sac. Projecting into the ends of each tube are tufts of fine sensory hairs (Fig. 9), which will be deflected by any movement of the fluid relative to the canal ; the information derived from this deflection is transmitted to the brain by the nervous system.



(a) No rotation : Hairs upright—no sensation of turning.

(b) Rotation : Hairs deflected—sensation of turning.

Fig. 9. Semi-Circular Canal—Cross Section



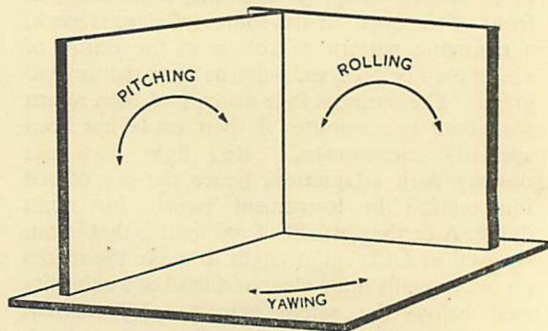


Fig. 8. The Vestibular Apparatus

62. If the head is turned laterally the inertia of the fluid causes it to flow through the horizontal canal, deflecting the hairs (Fig. 10) and transmitting a sense of turning to the brain. However, once the inertia of the liquid is overcome there is no relative motion ; therefore in a sustained turn there is no sense of turning. Further, if the turning motion is stopped quickly, the momentum of the fluid causes it to have a relative flow in the opposite direction, producing a sensation of turning in a reverse direction to the original turn.

(*a*) Constant rotation :
No acceleration and no sensation of turning.

(*b*) Checked rotation or

(*c*) Rotation in the opposite direction :
Sensation of opposite turn.

Fig. 10. Effect of Accelerations on Sensory Hairs of Semi-Circular Canal

63. Although this sensation is normally suppressed by visual references it is strong during instrument flight, particularly in the case of spin recovery, when on checking the spin the pilot will have a marked sensation of falling into a turn in the opposite direction so that he may tend to re-enter a spin or spiral in the same direction as before. The canals in the pitching and rolling planes can give equally misleading information. If the pilot changes the position of his head suddenly during a turn, possibly to look quickly upwards, he may experience the sensation of a flick roll or snap turn, as the movement of his head into a new plane in space will place a new semi-circular canal in the plane of rotation of the aircraft. Angular accelerations of less than about 2° per second have no effect on the vestibular apparatus, so that the pilot experiences no sensation if the entry into a turn is made sufficiently slowly and smoothly.

64. The static organ (Fig. 11) at the bottom of the common sac is a small liquid-filled chamber in which minute sensory hairs project vertically upwards ; small crystals of a lime salt rest on these hairs. Loads imposed on the body affect the crystals, causing the sensory hairs to be deflected, and transmitting a sensation of tilt to the brain.

65. In an accurate turn the force acting on the static organ will be still at right angles to the wings ; the pilot will receive no impression of bank or tilt. On the other hand, slip or skid while the aircraft is held level will cause a lateral displacement of the hairs, which will lead the pilot to feel he is banked, unless he has a visual reference to overrule this impression.

Muscle Sense

66. Muscle sense, or *deep sensibility*, is merely an attempt by the brain to interpret the loadings placed on the muscles, joints, and internal organs to the body generally, in terms of attitude. In contact flight this sense does produce sensations that give some guide as to attitude, but only when cross referred to a more reliable sense, *i.e.* vision.

Fig. 11. Static Organ—Sensory Hairs

(*a*) Hairs erect : Sense indications upright.

(*b*) Hairs bent by offset force : Sense indication of tilt.

Muscle sense by itself, however, cannot be relied on to give any indication of aircraft attitude, since accelerations can be imposed in a variety of ways. For example, when flying in turbulent air, vertical currents produce illusions of pitching that will lead to over-controlling on the elevator. Similarly, slip or skid can produce erroneous sensations of bank, while the common fault of allowing the nose to rise after recovery from an instrument turn can be largely traced to the apparent decrease in weight which occurs when rolling out of the turn, giving an impression of the nose dropping.

Vision

67. As previously stated, vision is the most reliable of the three senses but it is by no means infallible in the air. At night, for example, completely erroneous impressions of attitude may be obtained from single rows of funnel lights seen in conditions of restricted visibility, while in daylight the impressions gained from glimpses of the ground on approaches under low ceiling can be dangerous unless carefully checked against or completely discarded in favour of the instruments.

Hearing and Imagination

68. Under certain circumstances the sense of hearing can confuse the pilot, a change of noise level being interpreted as a change in pitch, attitude, or speed. All these factors, being somewhat indeterminate, can lead the pilot to imagine the aircraft in all sorts of attitudes other than the correct one.

Hypnosis

69. Hypnosis may be described as a condition of *super-attention*—for the development of which flight conditions are often excellent. This condition is usually brought about by over-concentration of attention on a single instrument such as the artificial horizon. The technique of cross reference does much to prevent any possible onset of hypnosis, but the best method of preventing hypnosis while on instruments is relaxation, and a familiarity with all phases of instrument flying.

Concentration and Fatigue

70. Experience and understanding will considerably reduce the tendency to take notice of misleading sensations regarding an aircraft's behaviour and attitude, for in time the brain subconsciously accepts the visual indications of attitude provided by the instruments in place of the external references on which it originally relied. With the onset of fatigue or nervous tension, however, or when unusual circumstances distract the pilot's attention from the instrument panel, the false sensations come to the fore, so that instinct rather than reason may influence his actions at a vital moment.

Conclusions

71. Apart from frequent practice—which leads to confidence—a thorough understanding of the causes of misleading impressions will greatly assist in repressing them. Over-concentration is the prime cause of fatigue and tenseness. *It can be relieved by making a conscious effort to relax physically and mentally*, maintaining instrument cross reference, keeping a light grip on the controls, and moving in the seat. Finally, it must be remembered that man has relied on his senses for years and cannot be expected, automatically, to accept instrument indications as a substitute ; this can only come with training, experience, and continual practice.

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