HUMAN LIMITS IN FLIGHT*

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A MODERN aircraft will climb in a few minutes to heights at which the air is so thin that it will no longer support life. It can turn and manœuvre so fast that the pilot may easily be rendered unconscious from the mechanical forces which it can impose on his body, and in an aircraft which is moving rapidly in three planes of space the pilot can be subjected to stresses beyond the limits which the human body can stand.

The adaptation of which the human body is capable to new surroundings and conditions can play a considerable part in fitting man to these new conditions; for example, airsickness which many suffer on first flying in rough air or doing aerobatics, in most people soon passes off and they become adapted to motions which at first perplex and incapacitate them; though a few never become completely adapted. But there are several stresses placed on man in aircraft that cannot be met by any unconscious adaptation, which require equipment specially designed to meet them. Some of the necessities are obvious, such as windscreens to protect the man from the enormous wind pressures at high speed and a heat supply from the engine and special clothing to keep him warm in the arctic cold of the stratosphere. His senses must be extended by a set of blind-flying instruments so that he may know his altitude and movement in space when in clouds or at night. He must learn to believe the instruments against his senses, for these are no longer a reliable guide when he may be moving at varying speeds in any direction—in fact, they will often be wrong. The human limit of visual range by day and especially by night is of paramount importance in flying.

But besides the stresses from wind pressure, cold, vibration and noise, the pilot's body must also be protected from other less obvious stresses, and here I propose dealing particularly with the two greatest stresses which an aircraft puts upon the pilot: those due to acceleration or rapid change of motion and those due to high flying in the rarefied air of the upper atmosphere.

In the last hundred years man has increased the speed at which he can travel more than tenfold, but there is no reason to suppose he is approaching any human limit in speed for, provided that he is protected from wind pressure by a closed cockpit and that the motion does not change rapidly in direction, there is no more mechanical stress on the pilot than if he were sitting on the ground.

If the human body is moving uniformly there is no force acting on it other than that due to gravity, recognized as weight. But when the motion changes in either magnitude or direction, large forces come into play; for example, while launching an aeroplane by catapult. During this linear acceleration, the pilot has the sensation of being driven backwards against his seat by forces equalling several times his own weight. This is seen in the retracting of the skin of his face, which bares the teeth like a snarling dog. In this case, the acceleration acts transversely on the body and lasts only a few seconds, and in this direction the pilot can easily withstand many times the acceleration of gravity provided his head and shoulders are well supported.

When a fast-moving aeroplane changes its direction and turns, aeroplane and pilot are both subjected to very large forces. The phenomenon known as blacking-out came into prominence in the Schneider Trophy races; pilots found that in turning at high speed their vision became blurred and that for a few seconds in the turn they frequently became blind. This is now a common event in aircraft and is well understood by fighter pilots.

When an aeroplane travels in a curved path in turning or pulling out of a dive, a large centrifugal force tends to force the aeroplane and pilot away from the centre of the circle. The magnitude of this force increases with the square of the speed and decreases as the radius increases. Subjectively, a pilot experiences a great increase in weight of all parts of his body as the centrifugal force tries to drive his body out through the bottom of the aeroplane. The magnitude of the acceleration acting on the pilot is expressed in terms of g, the force due to gravity normally acting on the body which causes it to have its normal weight. Thus in a turn producing $4g$ or four times the force of gravity, if the pilot's seat were fixed to a spring balance it would register four times his normal weight and the pilot and all parts of his body become extremely heavy. This is seen in the sagging of the soft part of the face which occurs in a tight turn (Figs. 1*a* and *b*). A turn at 300 miles per hour and 1,000 feet radius produces $6g$, and a pilot in effect weighs about half a ton and his blood virtually becomes as heavy as molten iron. The blood is normally being pumped to the pilot's head by his heart, but as its virtual weight increases, the heart has difficulty in maintaining the blood supply to the head. The brain and the eyes can only function for a few seconds without their normal blood supply, and loss of vision in blacking-out is due to failure of the circulation in the retina of the eye. If the acceleration is still greater, the whole blood supply of the brain fails and the pilot becomes unconscious.

Blacking-out is a warning that the blood pressure in the cerebral arteries is getting low. If the control column is eased forward, the aeroplane straightens out, the centrifugal force ceases and within a few seconds the circulation returns to normal. While this happens in the head the deficit of blood tends to gravitate to the legs, and the phenomenon can be regarded as the head losing blood to the feet.

This draining of the blood from the head takes time. The greater the acceleration the less the time that the pilot can retain his sight.

Many measures have been taken to reduce the effect of centrifugal force on the pilot; much may be done by posture and seating. If the pilot's attitude is crouched with his legs raised, the distance through which the heart has to raise the blood to his head can be reduced, and the loss of it to his feet is again less if the feet are high. Another method of lessening the effect of this force which may be mentioned is to place the pilot in the prone position. The heart and head are then nearly at the same height and a man in this position can withstand some $10g$, but this posture is a very fatiguing and inconvenient one for the control of an aircraft, though it is reminiscent of the very earliest aeroplanes in which the pilot frequently lay prone. The effect of posture on blacking-out is shown diagrammatically in Fig. 2.

The engineer has produced machines that are so strong and manœuvrable that they can subject the

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pilot to forces beyond his tolerance, and the useful limit in design for manœuvrability at high speed changes from being an engineering limit to being a human limit. It would be useless for the aircraft designer to produce an aeroplane so strong and manœuvrable that it could turn with a centrifugal acceleration of $20g$, because the pilot would not be conscious to control it under these conditions; the ability to out-turn the enemy has an important tactical advantage in 'dog-fighting', but to achieve this it is now necessary to look to the man rather than the machine. Fig. 3 illustrates how the human limit makes it impossible for a fast aeroplane to follow a slow one in a tight turn; both pilots are subjected to $5g$.

The most important stress, however, to which man is subjected in aircraft is that resulting from the thinness of the air at great altitudes.

The air pressure at ground-level is 14·7 lb./sq. in. (Fig. 4), it has fallen to one half at 18,000 ft. and to less than one fifth, about $2\frac{3}{4}$ lb./sq. in., at 40,000 ft. The effects of altitude on man are those resulting from the lowered atmospheric pressure.

The disabilities which a man suffers at lowered pressure first came into prominence on the surface of the earth as 'mountain sickness'. Later the term 'balloon sickness' was given to the troubles experienced in high balloon ascents at the beginning of the last century; long before aeroplanes had become practical flying machines, the problems of high altitudes had been encountered, because early balloon ascents carried the balloonists to heights at which the air would scarcely support life, and at that time their knowledge of how to overcome this was lacking.

Fig. 1*a*. MAN DURING STRAIGHT AND LEVEL FLIGHT.

Fig. 1*b*. IN A TIGHT TURN PRODUCING ACCELERATION OF $4\frac{1}{2}g$ 15 SECONDS LATER.

It is necessary to emphasize the difference between rapid ascent from ground-level, as in an aeroplane, and slow ascent in climbing mountains. In the latter case, weeks are spent at 15–18,000 ft. to become acclimatized to the thin air. Great changes occur throughout the climber's bodily processes which enable him to live at altitudes which are fatal to a 'sea-level' man. Acclimatization is soon lost on return to ground-level, so it is not possible to make much use of this in flying.

Climbers have reached 28,000 ft. on Mount Everest, but in contrast to this the first serious high-altitude accident occurred in 1875 when Tissandier with two companions went up in the hydrogen balloon *Zenith*. The balloon ascended to about 26,000 ft. and the occupants became unconscious; although they carried bags of oxygen they failed to make use of them. They became conscious again when the balloon descended to 20,000 ft. but then threw out ballast and the balloon rapidly ascended to about 28,000 ft. All became unconscious, and when Tissandier regained consciousness the balloon was at about 19,000 ft., descending rapidly, but his two companions were dead. This accident focused a great deal of attention on the physiological problems of altitude, and to investigate these Paul Bert constructed a steel chamber from which the air could be removed by a pump to simulate altitude conditions at ground-level. Since then a great deal of research has been carried out in such decompression chambers, on mountains, and in aircraft, on the nature of altitude sickness and the ways of overcoming it.

The R.A.F. Medical Service uses decompression chambers in which a man can be taken to a pressure equal to that at 30,000 ft. in less than a minute, and are capable of producing pressures down to a small fraction of a pound to the square inch.

For life, man needs food, water and air. He can live without food for weeks, without water for days,

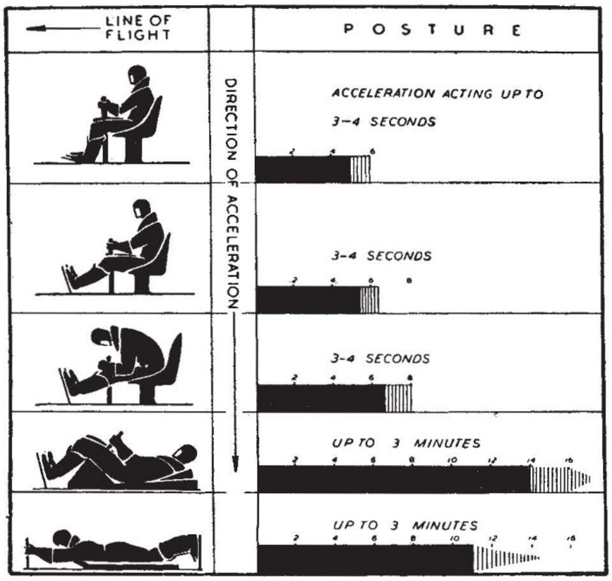

Fig. 2. EFFECT OF POSTURE ON THE TOLERANCE OF ACCELERATION. (DATA FROM RUFF.)

but without air he can survive only a few minutes.

At increasing altitudes, although the proportion of oxygen in the air remains one fifth, the density of the mixture becomes less, and a certain pressure of oxygen is essential for living cells to function normally. At an altitude of 42,000 ft., if the lungs are filled with air they contain less than one sixth of the normal quantity of oxygen, and this is insufficient to support life. Much of the Battle of Britain was carried out in an atmosphere in which a pilot unassisted with breathing apparatus would be dead in a few minutes. However, long before this height is reached, oxygen-lack makes its presence felt in the impaired intelligence and mental performance of the pilot. As oxygen-want comes on, judgment is lost, gross errors are made, intelligence fails, muscular control is lost and this may be followed by unconsciousness and death if the anoxia is severe. Moreover, oxygen-want is very insidious because the sufferer is often almost unaware of it. At 20,000 ft. a man without oxygen may do irrational things; oxygen-want resembles drunkenness both in its symptoms and in that the sufferer is confident that he is normal and much resents any suggestion to the contrary.

It would clearly be dangerous to send an aircraft up to 25,000 ft. unless it was ensured that the crew were protected from oxygen-want. Much research on the practical protection of flying personnel from the effects of altitude has been carried out by the R.A.F., particularly by the Medical Branch, which directs research in this very important side of the pilot's welfare. The importance of this is emphasized by the following true story of an incident which occurred over Germany. A pilot's breathing apparatus became disconnected, and the pilot thereupon told the crew that he was going to land. He put down his wheels and tried to land on a cloudbank at about 18,000 ft. He then told the crew over his intercommunication system that they were below ground-level and he was going to get out, whereupon the navigator, realizing what had happened, was in time to stop him climbing out of the machine, take over the controls and re-connect the pilot's breathing apparatus. It is easy to see that such an incident might not always have a happy ending. The effects of oxygen-want may often be extremely amusing, but clearly there is no place for such events in the dangerous and difficult work of high-altitude flying.

There are two ways in which altitude effects can be overcome. The first is to increase the amount of oxygen in the air which the pilot breathes by mixing oxygen from gas cylinders with it, thus giving the pilot a mixture rich in oxygen or even pure oxygen to breathe. In this way when the pressure is one quarter of an atmosphere at 33,000 ft., if his lungs are filled with pure oxygen he will not suffer from any symptoms of oxygen-lack. To this end the pilot always wears an oxygen mask, which also carries a microphone for his communication with the crew or ground.

The second alternative is to increase the amount of oxygen in the pilot's lungs by compressing the air in them. In an engine the loss of power from oxygen-lack is overcome by compressing the thin air with a supercharger; but it is not possible to supercharge the lungs so easily, as the pressures required would burst them. The pilot must therefore be completely surrounded by air at increased pressure. This can be done either with a pressure-suit something like a diving dress, or by sealing the cabin and making it strong enough to withstand a raised air pressure produced by a pump attached to the engine. The air around the pilot can then be kept at 14 lb./sq. in. and the atmosphere he breathes can be exactly like that at ground-level. However, it is clear that for military use such a pressure-cabin is very vulnerable, though for civil use it is the ideal method in high flying because the passenger is not inconvenienced by a mask on his face and need not be aware, by any change in the air pressure, that he has left the ground. Both alternatives are in use in civil airlines. The pressure-cabin has other advantages over the oxygen mask besides preventing lack of oxygen. At heights up to 36,000 ft. a man can avoid oxygen-lack by breathing pure oxygen, but above 44,000 ft., even breathing pure oxygen, he would become unconscious. Moreover, the vapour pressure of blood equals the atmospheric pressure at 63,000 ft., so if a man could reach this pressure his blood would boil and his lungs be filled with steam. At heights above 40,000 ft. it becomes necessary not only to breathe pure oxygen but also to increase the

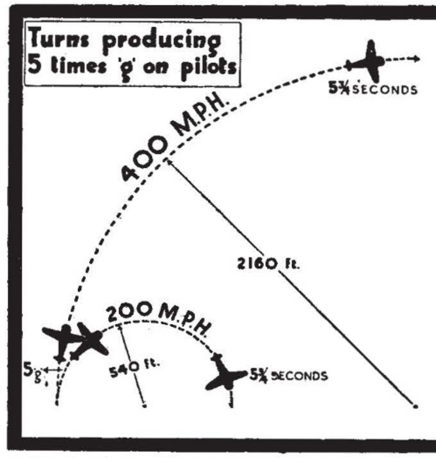

Fig. 3. HOW HUMAN TOLERANCE OF ACCELERATION MAKES IT IMPOSSIBLE FOR A FAST AEROPLANE TO FOLLOW A SLOW ONE IN A TIGHT TURN.

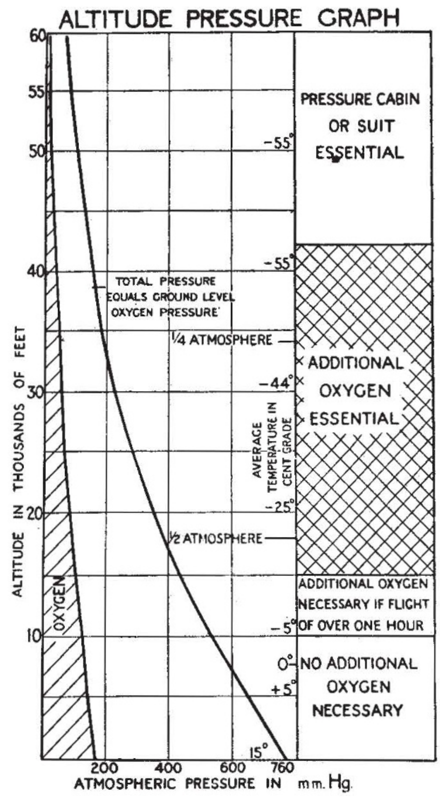

Fig. 4. RELATIONSHIP BETWEEN ALTITUDE AND ATMOSPHERIC PRESSURE (I.C.A.N. SCALE).

pressure acting on man. When Flight-Lieut. Adam broke the world's altitude record by reaching 54,000 ft. in 1937, he wore a pressure-suit which was blown up to some 2½ lb./sq. in. pressure and filled with pure oxygen. In it man could survive even in a vacuum. Thus the effects of oxygen-want can be completely overcome up to altitudes of some eight miles by breathing pure oxygen, and this is done in military aircraft of all nations. Above this height, pressure must be applied in addition. In the altitude record balloon ascents by Prof Piccard and by the U.S. Army, closed gondolas at raised pressure were used.

Fig. 5 illustrates the time elapsing between cutting off the oxygen supply to a man and his becoming unconscious at various heights. From this it will be realized how quickly a pilot must act should his oxygen supply fail at high altitudes.

The physiological abnormalities at altitude are not entirely solved by breathing oxygen, as there are effects on the body at low pressure in addition to oxygen-lack. At ground-level the air pressure drives nitrogen into the blood which dissolves in appreciable quantity. If now the pressure on the man is rapidly reduced before this nitrogen can escape, it will form bubbles in his blood vessels and stop the circulation.

The possibility that bubbles might occur in animals at low pressures was envisaged in 1670 by Robert Boyle, who placed a viper under a bell-jar and pumped out the air; when the pressure was reduced he saw a bubble within the eye of the viper. Bubbles forming in the body fluids have long been a difficulty in deep diving where men have been subjected to much increased pressures of air. The body fluids then dissolve a large quantity of nitrogen, and if the diver comes to the surface too rapidly it cannot escape from his lungs in time to prevent bubbles forming, and he gets decompression sickness or 'bends' (caisson disease, compressed air illness), with severe pain, cramps, occasionally unconsciousness and even death. A diver can get severe bends coming up from a depth where the pressure is 4 atmospheres, to the surface where it is only 1 atmosphere, but fortunately an airman does not get into such serious difficulties if he goes from ground-level to one quarter ground-level pressure at 33,000 ft. Bends as they occur in the air are rarely experienced at altitudes below 25,000 ft. They come on slowly and are rarely of a serious nature. Unconsciousness can result if the warning symptoms of pain in the joints are neglected. The pains are cured almost instantly if descent is made to about 25,000 ft., where the air pressure compresses the bubbles sufficiently to drive them back into solution in the blood.

Much research has been carried out on men in decompression chambers to find ways of alleviating these effects. One method is to breathe pure oxygen before ascent so as to replace the nitrogen in the blood with oxygen. The oxygen is then used up in the tissues before it can form bubbles. This method has long been used to displace nitrogen from the blood while ascending from deep dives.

There are other disturbances to man with rapid changes of altitude resulting from the change in air pressure. The middle ear communicates through the eustachian canal with the throat and it is necessary for air to leave and enter it with ascent and descent lest the ear-drum be collapsed. The canal to the throat will normally open on swallowing, and in a dive a pilot clears his ears almost unconsciously; but should he fail to do so or have severe catarrh, he may damage his ear-drums. Enclosed gas elsewhere in the body, as in the sinuses surrounding the nose, has to equalize its pressure as the altitude changes or severe pain may result. Again, the gas normally present in the intestines expands to a larger and larger volume as the outside pressure falls when climbing, but this is rarely a serious practical problem.

Thus the human safety limit in height is some 10–16,000 ft. breathing air and 40–42,000 ft. breathing oxygen; heights much in excess of the latter are only achieved by enclosing the pilot in an artificial atmosphere.

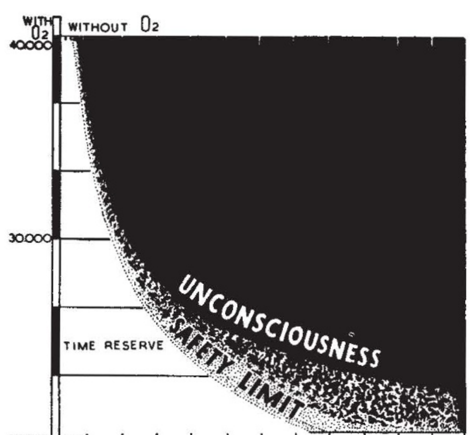

Fig. 5. TIME BETWEEN CHANGING FROM BREATHING OXYGEN TO BREATHING AIR AND THE OCCURRENCE OF UNCONSCIOUSNESS. (AFTER RUFF.)

It is clear that, starting with fit pilots on the ground, much must be done to keep them efficient in the air, and the efficiency of the man may often be of even greater importance than that of the machine.

In the Battle of Britain quality in men and machines overcame weight of numbers, and although always greatly outnumbered, the R.A.F. by efficiency and courage were able to rout the Luftwaffe. To maintain that efficiency in the air and at high altitudes is no mean problem. That it is done is the result of scientific research during the last seventy years into life at great altitudes, and the successful application of what has been discovered to the particular problems of the pilot. I should like this lecture to be considered a tribute to all those scientific men, from Paul Bert onwards, and to many officers of the R.A.F. who have contributed so much to the solution of high-altitude flying, and in particular to those medical officers who have lost their lives in this War in flying experiments.

CONTROL OF OVULATION IN FARM ANIMALS

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WHEN Cole and Miller[1] obtained ovulation in anœstrous sheep there was initiated a series of studies upon the application of gonadotrophins to the improvement of animal husbandry. It is the purpose of this article to sketch out the practical problems and the progress which has been made in overcoming them. It is not practicable to quote extensively, but many of the references to experimental work, upon which this account is based, are to be found in three papers in the *Journal of Agricultural Science*[2,3,4].

The nature of the control over ovulation which it may be desirable to exercise varies with the species and the economic circumstances. The problem may be to obtain matings outside the normal breeding season, or to improve fertility by increasing the number of ova shed at a normal heat, to regulate the interval between mating and ovulation, or to treat sterility due to cystic ovarian follicles. If a method of control is to be widely applied, it is necessary that the treatment be based upon materials which are available in large amounts and which are inexpensive to produce. Such preparations are at present limited to mare serum gonadotrophin, stilbœstrol and other synthetic œstrogens, and (available to a lesser extent) chorionic gonadotrophin and some pituitary extracts.

In the sheep, the natural breeding season falls in the autumn and winter months, but the length of the season varies considerably with different breeds, and in some, notably the merino and Dorset horn, it may extend over the whole or greater part of the year. The breed kept is determined by its suitability to local conditions, the relative value of the meat and wool crops, and, where rainfall is such that feeding conditions are good only in autumn or winter, mating has to be done in spring or summer, so that a breed with a long season is essential.

The incidence of twinning varies considerably from breed to breed; more especially it is low in the wool breeds. Specialized wool breeds are kept mainly in the more remote areas of the globe, and the lamb crop may be relatively unimportant; however, as meat storage and transport facilities are improved, it becomes of increasing value. When, as in Great Britain before the War, there is a price stimulus to the production of early lambs, or when seasonal conditions require it, the ram may be put with the ewes at the start of the breeding season. As some ewes come on heat earlier than others, the lambing season may then be prolonged and labour costs consequently increased. When the sheep are kept primarily for meat, the production costs include, besides the feeding of the lambs, the maintenance for a year of the ewes. The more lambs a ewe can rear the lower is the cost of production; it is certainly desirable that she should produce twins and, if the feeding stuffs are available, it may be of advantage to breed twice a year, which is not normally possible when the breeding season is restricted.

Thus in certain circumstances it may be of advantage to induce pregnancy in the normal anœstrous period, to advance the onset of the breeding season or to increase the ovulation rate within the normal season. It is certain that by a policy of selection, twinning percentages could be much improved, and probable that, though with much more difficulty, the breeding seasons could be extended. Such methods, however, take a long time; meanwhile, hormone treatments offer a prospect of a rapid improvement in practice, pending the improvement in livestock which must be the ultimate aim.

In cattle the breeding season extends throughout the year, though there is a tendency for calving to shift to the spring. Heat periods tend to be shorter and less well marked in the winter, and there are two types of anœstrus. In the first, ovulatory cycles continue, but heat is not manifested; in the second, a true anœstrus, ovulation ceases and only small follicles are present in the ovaries; the latter state is almost entirely restricted to young animals in the winter months and under hard feeding conditions. The incidence of twinning is low, on the average well under 2 per cent, and is much lower in beef than in dairy breeds.

For milk production, calvings have to be spread over the year, and to maintain the winter supply a larger proportion must calve in the autumn months. This implies service in winter, when the anœstrous condition is liable to develop. Sterility also causes large losses to the dairy industry, and a proportion of this is due to the formation of follicular cysts. Because in cattle the female twin to a male is usually a freemartin (imperfectly developed and sterile) twinning does not increase the number of animals which can be kept for breeding. In dairy cattle twins are not wanted, but in beef breeds they would be valuable for the same reason that applies to the mutton breeds of sheep. In areas where both beef and dairy cattle are kept, it is common for an extra calf to be bought for the cow to rear; however, the dairy-bred calf is a less efficient converter of feeding stuffs. In exclusively beef-producing areas there are, of course, no extra calves to buy.

The breeding season of the mare falls in spring and summer; persistence of anœstrus causes some difficulty, and some sterility is due to development of cystic follicles, which may be associated with spiteful behaviour. The most important feature is, however, the low proportion of services which are fertile; this is attributable to the length of œstrus relative to the survival time of sperm. Ovulation occurs about a