RECENT ADVANCES IN AVIATION MEDICINE*

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Aviation medicine is that branch of medicine which is concerned with and related to the biology of flying. Research scientists of many disciplines, both in aeromedicine and related fields, are constantly striving to keep abreast of the demands made on human physiology by the performance factors inherent in modern high-performance aircraft.

Professionally, aviation medicine is classified under industrial medicine, in the sense that it is a highly developed branch of preventive medicine which, because of its military significance, is in a position to apply vastly expensive research programmes to the solution of its problems. In the United States it has in fact been elevated to the status of a distinct speciality, a lead which is certain to be followed by other countries. This recognition serves as an indication of the importance attached to its endeavours to keep human beings alive in the hostile environment of extreme altitudes into which modern high-performance jet and rocket aircraft are taking him. Man, who was designed for a terrestrial existence and is at best only a flying compromise, is confined by relatively narrow physiological limits of pressure, temperature and atmospheric composition. Modern aviation, however, requires him to remain fully functional at altitudes and speeds of a magnitude unheard of even a few years ago. Seeing him safely past these physiological and physical barriers is the abiding task of aviation medicine.

Historically, aviation medicine is the product of World War I, when a survey of the Royal Flying Corps in 1915 showed a non-effectiveness rate of 65% among flying personnel. Subsequent investigation revealed the familiar problems of altered barometric pressure, hypoxia, operational fatigue and temperature changes which even today are not completely solved, but it is significant that once these challenging problems were recognized and the appropriate action taken, the non-effectiveness rate dropped steeply to the insignificant levels of today despite the fact that the stresses and strains involved have multiplied many times. The most important factors responsible for this achievement and for the recent advances in aviation medicine are the concerted efforts of research workers in aeromedicine and the practical application of these techniques by the airforce medical officer, who by virtue of his training and experience has an appreciation of the limiting factors in the adjustment of the human body to flight. This knowledge is utilized at squadron level in an air-crew effectiveness programme, whose objective is their continued maintenance in the highest possible state of effectiveness under all conditions of flight. The scope of such a programme is very wide and involves the full application of the resources of aviation medicine to the operational requirements of all air crew.

The most critical problems in aviation medicine are naturally concerned with the protection of air crews against the hazards of exposure to flight at high altitudes and high speeds. Decreased barometric pressure involves the hazards of hypoxia, dysbarism, neurocirculatory collapse, hyperventilation, extremes of temperature, ozone toxicity and cosmic radiation. Very high speeds although not significant *per se*, produce stress mainly through the application of acceleration forces—linear, angular and radial—and by the production of excessively high temperatures creating the so-called 'heat barrier'. In addition it poses certain problems of reaction time, and also profoundly complicates escape from disabled aircraft.

With the advent of really high-performance jet and rocket aircraft capable of flying transsonically and at extreme altitudes, many of the problems of flight, and particularly of human control over these manned missiles, have become critical. It has been found that, despite the amazing range and flexibility of the physiological compensatory mechanisms, there are certain definite limits which may not be exceeded. Such a limitation is that imposed by a reaction time which, although adequate in terrestial situations, is unable to provide fast enough responses from the pilot to cope safely and adequately with control problems encountered in the speed ranges above Mach 2.

Velocity and Acceleration

Take the problem of pilots in two hypersonic aircraft flying at say 1,800 miles per hour, or approximately 1 mile every 2 seconds. They will have a closing speed on a collision course of 3,600 miles per hour. At these speeds, even with the best possible visual acuity of say 6/3 to enable them to see each other at maximum visual range, the pilots would be unable to react fast enough to avert a collision. This happens because their reflexes are transmitted at a mere 200 miles per hour and this is quite inadequate to cope with the necessary avoiding action. This again is due to the fact that the lag time in visual preception is appreciable, and at supersonic speeds it becomes critical in relation to the distance travelled. Under such circumstances, the sequence of events would be an initial latent period of perception varying from 0·03 to 0·3 seconds, during which time the aircraft has travelled nearly 1,000 feet. Then it takes 0·4 seconds from the time the other aircraft appears in the visual field until it is perceived by the pilot's central vision, and his own aircraft has gone another 1,200 feet. At this stage the pilot has only seen the approaching aircraft—it has not been recognized. Recognition time may vary between 0·65 and 1·50 seconds and another 3,000 feet will be covered. This means that from perception to recognition the aircraft has traversed more than 5,000 feet. Now add to this the time required to make a decision and to do something about it, which may take several seconds, plus the motor reaction time to transmit an impulse to move the control column, which in turn activates the control surfaces, which after another latent period will begin to overcome the flight of the aircraft in a straight line and turn it away to avert a collision.

By the same token pilots of two aircraft flying at supersonic speeds in opposite directions and emerging suddenly from cloud, may in fact see each other only after they have passed. Known as the 'coming-past interval', this phenomenon occurs where the sum of the closing speeds exceeds the speed of transmission of the visual images of the eye to the brain. It can therefore, be defined as the present perception of an

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event that has already occurred in the past. The problems resulting from these basic reaction-time limitations of human control can, however, be overcome by the installation of electronic devices which can react much faster than man in order to control the aircraft.

Acceleration. Probably the most important manifestation of speed which affects both the pilot and the aircraft is the component of acceleration. Experimentally it has been determined that the average healthy young pilot can tolerate up to 5 positive *g* for 5 seconds, 3 negative *g* for 3 seconds and 12 transverse *g* for 3 seconds before lapsing into unconsciousness. Various methods have been devised to improve the *g* tolerance of the pilot, which is a serious limiting factor in aircraft performance. Providing the pilot with ways and means of withstanding higher *g* loads will enable the aircraft to accelerate faster and turn more steeply and make it a more manoeuverable weapon system. The latest pneumatic anti-*g* suit is the best answer to the problem and provides automatically controlled counter-pressure over certain vital body regions like the abdomen and lower limbs, to prevent the pooling of venous blood under the influence of increased gravitational pull. This garment allows the pilot to exceed his natural tolerance by approximately 30% and makes the aircraft much more manoeuverable as well as decreasing pilot fatigue after multiple applications of *g* loads.

Heat Barrier. Another important aspect of high-speed flight is the production of excessively high temperatures as a result of heating due to friction and compression of air at the boundary layer. At the present stage of development this phenomenon presents the overriding bar to progress in the hypersonic speed region, both as regards the aircraft and the pilot. The rise in temperature can be expressed by the formula $tC^{\circ} = \frac{0\cdot85\ (v)^2}{100}$, where v equals velocity in knots. Therefore at 600 miles per hour the rise in temperature is 30 C° and it increases as the square of the speed. This is no theoretical problem, because there are in fact rocket engines in existence which are capable of exerting enough thrust to overcome the drag caused by area-ruled airframes and are therefore able to keep on accelerating indefinitely through the upper hypersonic speed ranges were it not for the metallurgical problems occasioned by this so-called heat barrier. Air conditioning, ventilated suits and elaborate refrigerating systems have therefore to be installed in the aircraft to prevent the ultimate incineration of the pilot, whose heat regulating mechanisms are otherwise unable to cope with the excessive cockpit temperatures at speeds in excess of Mach 3.

Escape from Aircraft

A secondary effect of high speed is to complicate the problem of escape from disabled aircraft. Even at the very moderate speed of 350 miles per hour it becomes physically impossible for the pilot to bale out safely, because he will almost certainly be flung against the tail assembly by the slipstream. An ejection seat actuated by an explosive charge was devised to enable the pilot to leave the aircraft in an emergency. Extensive research and many experiments showed that an acceleration of at least 60 feet per second was needed to propel the seat high and fast enough to clear the oncoming tail assembly by a safe margin. This required an accelerative force of nearly 20 positive *g*. which appeared to be far above the accepted black-out tolerance of 5 positive *g* which the average fit man can withstand for 5 seconds. However it fortunately proved that if the duration of application of this force is kept down to less than 0·2 seconds and the rate of onset of *g* is kept below 200 *g* per second per second the human body, properly strapped in on an ejection seat, could safely withstand this load. Refinements to this ejection technique and equipment, by the use of an 83-feet-per-second ejection gun, used in conjunction with a duplex drogue system, have now made it possible to eject safely from both ground level and at very high speeds.

Leaving the aircraft safely is, however, only half the problem, because at high speeds terriffic wind-blast effects are met with, causing very abrupt decelerations. At 500 miles per hour the impact pressure of wind blast at sea level is equal to 4·4 lb. per square inch, or about 3,200 lb. on the total body surface. Winds at Mach 1, or approximately 720 miles per hour, develop pressures of 9 lb. per square inch, or about 6,500 lb. over the total body surface. At 1,000 miles per hour this will increase to about 2,500 lb. per square foot or 12,500 lb. to the body area in the seated position. In spite of these fantastic primary impact pressures live supersonic ejections have been recorded in actual flight emergencies and the pilots have survived with relatively minor injuries. This problem forms the basis for the much publicized work of Colonel John Paul Stapp of the United States Air Force on the rocket sledge at Edwards Air Force Base. His object in exposing himself to the abrupt decelerations from 632 miles per hour to a dead stop in 1·4 seconds, thereby subjecting himself to more than 40 linear *g*, was to test the ability of the human body to withstand such decelerative forces under controlled experimental conditions. His work had the important practical result of proving that the pilot could reasonably expect to survive ejections at the subsonic and mildly supersonic speeds of current high-performance operational aircraft, and that the next step of providing capsular escape for the pilot could be deferred to the next generation of fighter aircraft.

This ultimate form of escape aid will probably be ejection within a pod or capsular type of enclosure as the logical means of overcoming the effects of wind blast, as well as other hazards of cold and hypoxia. The pilot might still be subjected to high deceleration for a relatively long time but in a stabilized vehicle the force and direction of deceleration would be predictable and could be withstood by the use of the conventional safety harness. The maintenance of pressurization by emergency pressure-oxygen equipment should increase the chances of survival over ejection into the airstream. Many other advantages are offered by this form of escape which are not found with ejection seats. Capsules may have parachutes, emergency kits and oxygen equipment as integral parts, thus removing from the pilot much of the cumbersome gear that is now required. Although such capsules are very complicated they are in fact feasible and prototypes are at present being tested by the USAF at Hurricane Mesa in the United States.

Having ejected safely and survived the primary blast effects and the rapid deceleration the pilot must still be freed either manually or automatically from his seat to deploy his parachute and float down to earth. Because he might be injured or rendered unconscious by spinning and tumbling in the airstream, barostatically controlled devices have been evolved to perform these vital actions for him. If ejection occurs at altitude his oxygen supply is switched to a bale-out bottle and he is allowed to 'free fall' to an altitude of 10,000 feet, where an aneroid device will actuate the parachute-release mechanism. There are many advantages in a free fall from altitude in preference to the open parachute descent. It includes less danger of entanglement with the aircraft, less exposure to low temperatures, and smaller oxygen requirement, but its main advantage is because parachute opening shock is much greater at higher than at lower altitudes. At 40,000 feet it is 4 times greater than at sea level, or equal to approximately 33 *g*. At 10,000 feet it is no more than 5 to 8 *g*. In practice serious injuries have resulted from a parachute-opening impact at altitudes exceeding 25,000 feet.

High Altitude

Hypoxia. In considering the aero-medical aspects of high-altitude flying the central problem concerns the lack of oxygen met with at altitude. Hypoxia is a syndrome that results from inadequate oxygenation of the tissues as the result of a decrease of the partial pressure of oxygen in the inspired ambient air. The symptoms are dependent on a series of variable factors like absolute altitude, rate of ascent, duration at altitude, ambient temperature, physical activity, and individual susceptibility and tolerance, but the inevitable end-result is a progressive descending depression of the central nervous system and a disruption of the psycho-motor functions, causing serious incapacity of the pilot and invariably leading to loss of control of the aircraft. To obviate this danger it has long been standard practice to provide an oxygen system to supplement the alveolar oxygen partial pressure. However, the phenomenal rates of climb inherent in the performance of turbo-jet aircraft can expose the pilot who is not fully protected against hypoxia to these symptoms in such an alarmingly short space of time that, despite the fact that hypoxia symptoms only occur above 10,000 feet, it has now become imperative for him to use oxygen from the ground up in all flights both by night and by day. The protection afforded by the oxygen system however, is not unlimited, for high-performance aircraft can comfortably exceed altitudes where the total ambient pressure is not as high as the partial pressure of oxygen necessary for the required normal 90 to 95% oxygen saturation of the blood.

A critical height occurs at 34,000 feet, where the barometric pressure is 187 mm. of mercury. At this altitude the pilot on 100% oxygen will have an alveolar oxygen partial pressure of 160 mm. of mercury, which is equivalent to the normal conditions at sea level. However, on exceeding 34,000 feet on 100% oxygen he will exhibit symptoms of hypoxia ranging through the undetectable to the compensatory, the disturbance, and ultimately the critical stage exactly as if the pilot were ascending above 10,000 feet without oxygen. The second critical height is reached at 45,500 feet, where despite the use of 100% oxygen the pilot will be as hypoxic as he would have been at 23,000 feet without oxygen. The equivalent critical heights with and without oxygen are shown in Table I.

TABLE I: EQUIVALENT CRITICAL HEIGHTS WITH AND WITHOUT OXYGEN

Stage	*Altitude in feet*		*Arterial oxygen-saturation %*
	Breathing air	*Breathing 100% oxygen*	
Indifferent	0′-10,000′	34,000′-39,000′	95-90
Compensatory	10,000′-15,000′	39,000′-42,500′	90-80
Disturbance	15,000′-20,000′	42,500′-44,800′	80-70
Critical	20,000′-23,000′	44,800′-45,500′	70-60

To overcome this difficulty, the latest pressure-demand oxygen regulator was introduced whereby oxygen is delivered to the lungs under positive pressure to a maximum equivalent to 8 inches of water. With this amount of positive pressure an increase in ceiling of roughly 5,000 to approximately 50,000 feet is possible, but its application is limited owing to the fact that it reverses the respiratory cycle with a passive inspiration and an active expiration against pressure, which is very difficult and fatiguing over long periods. In addition there is in any case a limited amount of positive pressure that the alveoli can safely withstand. Pressure breathing is therefore an expedient of limited value and it does not greatly increase the absolute ceiling, but it is a very useful and life-saving emergency procedure up to altitudes of 52,000 feet.

The reversal of the breathing pattern and respiratory cycle with pressure breathing tends to an increased respiratory turnover and hence to the development of the symptom complex of hyperventilation. These symptoms closely resemble those of hypoxia and it is virtually impossible for the pilot to differentiate between these two conditions, which may be described as cause and effect tending towards the same end-result—loss of control. It will be appreciated that the pilots of modern high-performance aircraft must have a fairly high level of physiological training and indoctrination to be able to avert disaster by taking the vital corrective action when they are overwhelmed by the symptoms of a respiratory emergency.

Decompression Sickness. At altitudes exceeding 30,000 feet the bizarre symptoms of dysbarism, or decompression sickness, are liable to effect an air crew, particularly if they stay above this altitude for several hours. The symptoms are due to the escape of gases normally held in solution in the body fluids. As the body is decompressed bubbles collect in the tissues and joint spaces, giving rise to severe and sometimes intolerable pain. Large joints become painful and may cause apparent paralysis, paraesthesias and pruritus develop, and uncontrollable spasms of coughing with visual and vestibular disturbances sometimes follow. Dysbarism, however, does not disturb consciousness or the higher mental functions, except if it is allowed to become very severe, when a profound neuro-circulatory collapse may follow. This is one of the most dangerous complications of flight at altitude, for spontaneous recovery is not possible and even with hospital care the outcome is usually fatal.

Pressurization. As modern aircraft have a service ceiling far in excess of 50,000 feet the only possible way for the pilot to achieve a high altitude is to make use of a counter-pressure suit or a pressurized cabin, i.e. by artificially surrounding the pilot with a pressurized environment which is equivalent to a lower altitude than the height at which the aircraft is actually flying. Cabin pressurization has the advantage that an adequate pressure differential will, within certain limits, maintain the cabin at a functional altitude where pressure breathing is not necessary. In South African Air Force Sabre 6 aircraft, for instance, a pressure differential of 2·75 lb. per square inch is employed, which is approximately equal to 160 mm. of mercury. In other words, at 38,000 feet indicated altitude the 'cabin' altitude is roughly 18,000 feet, where the pilot is still quite comfortable on a normal oxygen-demand regulator system. In fact even when flying at 50,000 feet the cabin altitude will still be at a pressure which will not necessitate pressure breathing.

Ozone. Even cabin pressurization, however, is not the complete answer, because in the rarified air above 50,000 feet very large and heavy compressors are needed to maintain cabin pressurization. Between 60,000 and 70,000 feet the aircraft will encounter the ozone layer between the stratosphere and the ionosphere, and ozone in the cabin in concentrations of more than 6 parts per million under a pressure of 2·7 lb. per square inch has a fatal toxicity.

Explosive Decompression. Whilst cabin pressurization up to a certain altitude is a satisfactory solution, the attainment of higher altitudes requires an additional method of ensuring the survival of the pilot should cabin pressure be lost for any reason thereby causing explosive decompression. The result of such an explosion is to transport the pilot instantaneously from his artificial atmosphere inside the pressurized cabin to the actual altitude he happens to be flying at; for instance from, say, 32,000 feet to 55,000 feet in a split second. Now above 50,000 feet a given volume of gas will expand to 14 times its volume at mean sea level. Seeing that all the gases trapped inside the body in the lungs, gastro-intestinal and other cavities are subject to this expansion the pilot may be in danger of rupture of his alveoli, with subsequent air embolism, should the expanded gases not be able to escape freely.

To obviate this danger of sudden exposure to the hazards of extreme altitude the pneumatic counter-pressure suit was introduced. This garment is in effect a personalized pressure environment which is barostatically controlled and is instantaneously inflated to maintain adequate pressurization around the pilot's body, when explosive decompression takes place. This application of counter-pressure to the body in conjunction with emergency pressure breathing will give the pilot a reasonable chance of survival provided he is able to descend quickly to lower altitudes.

Space Flight

At an altitude of 63,000 feet, however, the total barometric pressure has dropped to a mere 47 mm. of mercury, which is equal to the water vapour pressure of the saturated gases in the blood-stream at the normal body temperature of 37° C. Exposure to this altitude would lead to boiling of blood in the vessels and filling up of the lungs with steam. This altitude is known as the 'space equivalent' because survival times at any altitude above 63,000 feet would be identical. From here onwards only 12% of the total blanket of the atmosphere remains and for all practical purposes space flight commences.

For this purpose all the aids to high flying previously mentioned become inadequate and a self-contained pressurised capsule is called for. This capsule is the essential basis for the space ships of the near future and, like the rocket motors which must be used for propulsion at altitudes of 80,000 feet and above, it is atmospherically independent and will carry its own oxygen supply. For short flights a number of oxygen cylinders is carried sufficient for the duration of the flight, but for long flights out into space, ingenious use can be made of photochemical processes whereby used oxygen is repurified for repeated use by the crew inside the capsule. The Department of Space Medicine at the USAF School of Aviation Medicine at Randolph Air Force Base in Texas have in fact built a capsule incorporating some space-ship features and have test flown it satisfactorily in a large decompression chamber at altitudes in excess of 100,000 feet. Flights in space present a series of physical and physiopsychological barriers which have still to be overcome before it can become a reality. In the ionosphere, for instance, there is the danger of a higher level of cosmic radiation which over long periods may have deleterious radiation effects on the body. Small meteorites moving at fantastic velocities above an altitude of 460,000 feet may penetrate the skin of the space ship and cause loss of cabin pressure with dire results, but mathematically the chances of such a collision is deemed to be remote.

Pilots flying above altitudes of 60,000 feet have recently reported a disturbing subjective sensation of being completely free of all earthly associations and this has been termed 'the breakoff phenomenon'. This overwhelming sense of detachment from the earth may adversely affect air-crew performance, but prior knowledge of this and other hazards will enable man to adapt himself even to the strange environment of space flight.

Zero Gravity. Yet another phenomenon to be encountered on these flights outside the earth's gravitational field is that of the 'zero-gravity state'. Experimental studies at the USAF School of Aviation Medicine have indicated that adequate indoctrination of pilots can overcome this hazard to some extent. Indoctrination can be achieved by flying zerogravity parabolas in turbo-jet aircraft at low levels to induce zero-gravity for periods up to 60 seconds. It has been found that spatial disorientation which threatens in the zero-gravity state can be successfully overcome by visual reorientation, or by providing a small acceleration component in flight to simulate 1 *g*.

It is evident from this brief review of some of the problems and the recent advances in the field of aviation medicine, that the amazing powers of adaptation of man aided by the devices provided by the researches of aviation medicine will in the near future finally enable him to break his bonds with the earth and to penetrate beyond the threshold of space.

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Strughold, H. in Benson, O. O. Jr. and White, S. eds. (1952): *Physics and Medical Problems in the Upper Atmosphere*. Albuquerque: University Press of New Mexico.

Southern African Cardiac Society. The programme of a Meeting of the Cape Province section of this Society held at Groote Schuur Hospital, Cape Town, on the evening of 20 March 1958, Dr. Maurice Nellen in the chair, was as follows: (1) A presentation of a case of Taussig-Bing Malformation, by Drs. G. Sutin and V. Schrire; (2) (*a*) A case of Patent Ductus Arteriosus with Pulmonary Hypertension in a patient with gross Kyphoscoliosis, by Dr. Louis Vogelpoel, and (*b*) Studies on the Pulmonary Function in the same case, by Dr. B. Kaplan; (3) A study of the Racial Incidence and Seasonal Incidence of Coronary Thrombosis at Groote Schuur Hospital, by Dr. V. Schrire.