Current Research in Aviation Medicine in the Royal Air Force*

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There are at least as many definitions of Aviation Medicine as there are laboratories engaged in it. For some practitioners, the clinical care of flying personnel is a primary purpose; for others, the main objective is to protect aircrew against the rigours of an unnatural environment; for a few, aviation medicine is merely a narrow branch of the general physiology of work and stress.

This account of British aviation medicine must therefore begin with a simple classification of its content, and with an explanation of the terms to be used. The work of an organisation such as the RAF Institute of Aviation Medicine can be broken down into four broad categories, but it must always be remembered that none of them can exist in isolation. The four classes are :-

a. Clinical investigations.

b. Applied research and development.

c. Long term objective or supporting research.

d. Basic or fundamental research.

This scheme deliberately omits some aspects of the art; for example, the function of the medical officer at an operational flying station is not included, nor is casualty evacuation, nor yet the teaching and training of aircrew in the principles of aviation medicine. Although these are essential parts of the total structure, they do not generally involve the research which forms the subject of this Oration.

Clinical investigation forms but a small fraction of the research load. Routine cases are, of course, the responsibitity of the medical specialists elsewhere.but some conditions that are manifested during or soon after flight merit special study. They include severe or atypical vestibular disorientation, decompression sickness, and collapse apparently attributable to a low tolerance for centrifugal acceleration. The aeromedical investigation of aircraft accidents and in-flight incidents may also conveniently be placed in this category.

Applied research is directed to the solution of practical problems related to the Requirements and Targets of the Air Staff, and to the short term needs of the Royal Air Force. Its objectives are usually clearly defined and its timescale is usually limited. Its medical content is often small, although it cannot properly be carried out without a fair understanding of the physiology of flight. Although in the United Kingdom the development of items of personal equipment is not an

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** Royal Air Force Institute. of Aviation Medicine aeromedical responsibility, it is impossible to divorce development processes from applied research. The laboratory evaluation of a new prototype life-saving waistcoat, for example, may well reveal ~~defi-~~ Deficiencies that can be corrected by local action. The changes may be minor or they may be so radical as to constitute a virtual re-design of the equipment. In either event they are likely to be queried by the original manufacturer, who will then introduce further modifications and thus extend the period of development.

Long term objective research is the framework around which the whole of aviation medicine is built. It provides the information without which applied research cannot be undertaken or future questions answered, but because it has no immediately obvious application to the practical problems of exisiting aircraft its importance is commonly underrated. Work in this category was concerned, in the early days of aviation medicine, with establishing the limits of human tolerance for the individual stresses of flight–the standard graphs of times of useful consciousness at altitude or of blackout thresholds bear witness to these endeavours. Recent studies have been both more complex and less dramatic, often with the object of measuring the effects of one or more marginal stresses upon the performance of skilled tasks. For example, exposure to an effective altitude of 8.000 feet for 8 hours presents no hazard to life or limb, but it can be shown to have a deleterious influence upon the process of learning. The results of objective research will, by defiinition, eventually be directly applied to future problems; in the quoted example the findings might lead to a recommendation that the normal cabin altitude of a new navigational training aircraft should not exceed 5,000 feet.

Basic or fundamental research has no such future application, and it may be described as science for its own sake. It can be argued (notably by financiers and Air Staffs) that activities producing nothing but an increase in the understanding of physiological systems have no place in Government-funded research, but this is a short-sighted view. The most cogent reason for supporting basic investigations is that scientists of the calibre required for the proper conduct of applied and objective research must have the intellectual stimulation provided by a pure or academic topic of their own choosing. An opportunity to undertake basic research attracts and retains competent staff, and it also improves the quality of the most pragmatic programmes that form the bulk of aviation medicine. The proportion of the total research time that can be allotted to basic research is variable, for such work must take second place to the pressing problems of the Royal Air Force. A figure of 10% is often quoted as the optimum, but this level can rarely be achived in practice, and 5% would currently be a more realistic estimate.

Before some research programmes are described, a few words should be said about the organisation of the Institute of Aviation Medicine, for this affects the nature of the work and the manner of its execution. Aeromedical laboratories tend to evolve as a series of islands, each having an item of capital equipment as its nucleus. Thus, the possession of a decompression chamber leads to the formation of research team whose members have experience of respiratory physiology, cardiovascular physiology and perhaps neurophysiology. The acquisition of a human centrifuge requires the establishment of another group but the research skills that it must encompass are the same, and the establishment of a climatic facility leads to a repetition of the process. The result is a collection of self-sufficient departments which, unless a great care is takenwill tend to work as isolated units with little needs or desire for cross-fertilisation.

This situation may be contrasted with the usual pattern of a University department, in which the members of each research team are united by a common interest in respiration, or the circulation, or the central nervous system. In such an academic environment insularity is also to be found, but its undesirable features are less important than in aviation medicine, where interactions between the different stresses must be considered and evaluated.

Some degree of scientific autonomy is desirable, if not essential, for the subgroups of an aeromedical laboratory, but because the overall objective of the work is to provide a better total environment for aircrew in flight, special measures must be taken to co-ordinate the applied research and development functions. At the RAF IAM this has been achieved by the formation of an Aircrew Equipment Group which unites the research and development components of three otherwise separate divisions and which can call on other parts of the Institute for advice and investigations when necessary. The relationship of the Group to the functional organisation of the research unit is shown below. The system has some disadvantages, but it does ensure that the development of a personal equipment assembly does not proceed piecemeal, and that the information given to the Air Staffs is consistent and balanced.

After this long philosophical preamble on the nature and organisation of research, some specific programmes may now be considered. The examples have been chosen from the work of many of the Divisions shown in the diagram, but the selection does not claim to be uniform or to reflect the relative importance of the topics. Nor can it hope to be comprehensive-it should be regarded more as an anthology than as a report.

Every student of aviation medicine is taught that oxygen is not required at heights below 10,000 feet at least during day time operations. For many years the cabins of civil and military transport aircraft have been pressurised to an equivalent altitude of 8,000 feet, thus giving some safety margin and allowing passengers and crew to travel, without the encumbrance of oxygen equipment. The fact that some physiological disturbance does occur at lower altitudes is recognised by the almost universal insistence that military aircrew flying at night shall breathe oxygen from ground level up. However, there has been little attempt to question the wisdom of an 8,000 feet pressure cabin. The fact that new skills are acquired more slowly and less efficiently at 8,000 feet than at sea level has already been briefly mentioned; it has recently been shown also that the performance of a task learned at hypoxic altitudes continues to show a decrement after a return to a normal barometric pressure. There is other evidence to show

ALTITUDE	ALTITUDE RESEARCH BREATHING SYSTEMS AIRCREW EQUIPMENT ASSESSMENT	AIRCREW EQUIPMENT GROUP
BIODYNAMICS	CENTRIFUGE HELMET TESTING DECELERATION AND IMPACT	
CLIMATIC	THERMAL STRESS COLD STRESS SURVIVAL	
PSYCHOLOGY	GENERAL PSYCHOLOGY FLIGHT SKILLS BEHAVIOURAL RESEARCH	
NEUROSCIENCES	VESTIBULAR PHYSIOLOGY EXPERIMENTAL NEUROLOGY BIOCHEMISTRY	
PHYSICAL SCIENCES	CONTROL & DATA SYSTEMS STATISTICS	

A CLASSIFICATION OF RESEARCH FIELDS IN AVIATION MEDICINE that exposure to moderate altitudes may not be entirely benign. Aircrew and cabin staff frequently comment, or even complain, that they are immoderately fatigued after flights in which the cabin pressure is maintained at the equivalent of 8,000 feet, and that this state is quite different from the tiredness resulting from similar activity at a cabin altitude of, say, 5,000 feet. If significant physiological changes could be demonstrated at 8,000 feet there would be a prima facie case for action, but the engineering and cost penalties of modifying exisiting aircraft could not be contemplated unless significant benefits could be assured. A series of experiments to test this point has recently been carried out, and the opportunity to make a large number of physiological measurements was, of course, seized.

Subjects were exposed for 6 hours on each of 5 consecutive days to a fixed schedule of physical exercise and rest at a pressure equivalent to an altitude of 8,000 feet, and to similar conditions at ground level. Their estimates of fatigue, which were recorded by a line-marking technique, increased significantly more steeply during the course of a 6-hour day at altitude than at sea level. The difference was particularly marked when the periods of physical exertion were compared, and there was no evidence of useful adaptation in this respect over the 5 days of exposure. Many physiological parameters, such as blood glucose and non-esterified fatty acid levels, haemoglobin concentrations and haematocrit levels, remained unchanged at altitude, and the oxygen cost of working showed only inconstant and insignificant alterations. However, ventilation and pulse rates were higher at 8,000 feet, and the differences between these and the ground level data increased through the day. Blood levels of lactate and of 2:3 di-phospho-glycerate, and urinary outputs of catecholamines and 17-hydroxy-steroids all rose. One interesting and unexpected observation was a shift in the oxyhaemoglobin dissociation curve which could not be explained on the basis of concomitant changes in the arterial P_{CO_2} or pH. The biochemical findings are characteristic of mild stress, and taken together with the other results they support the claim that even moderate effort at 8,000 feet, is fatiguing. The extent to which the changes might be moderated by a reduction of the cabin altitude to 5,000 feet- and whether such action would have a worth while effect upon efficiency, remain to be decided.

Much of the early work on the physiological effects of rapid decompression concentrated upon the hypoxia resulting from sudden exposure to altitudes in excess of 35,000 feet while breathing air. At these heights unconciousness rapidly ensues unless oxygen is administered within a few seconds, and even if a mask is donned during the brief period of 'useful' consciousness, transient confusion or collapse may still occur when a bolus of desaturated arterial blood reaches the brain. From studies at the Institute using decompression profiles to final altitudes of between 35,000 and 50,000 feet, a relationship was developed between the probability of unconsciousness and the extent and duration of the reduction in the alveolar oxygen tension Characteristically, the latter falls abruptly with the reduction in ambient pressure, only to rise again as oxygen is excreted from venous blood returning to the lung. A critical level of alveolar oxygen tension was found to be 30mm Hg– when this figure was reached alpha-activity invariably appeared in the EEG. The onset of unconsciousness was related to the time for which the alveolar oxygen tension was maintained below this critical value, or more strictly, to the area of the tension/time curve with the 30 mm Hg line as an upper boundary. If this exceeded 140 mm Hg secs a loss of consciousness was inevitable, even if the hypoxia was corrected within the accepted time of useful consciousness.

Cabin failures resulting in exposure to altitudes greater than 35,000 feet are relatively uncommon either in military or in civil aircraft, but incidents involving decompression to around 25,000 feet occur often enough to be of more than academic interst. A more detailed study has just been completed with the object of extending the earlier data to the more commonly encountered condition. Subjects were rapidly decompressed, while breathing air, from 8,000 feet to 25,000 or to 27,000 feet and measurements of alveolar gas tensions, EEG activity, and psychomotor performance were made over the ensuing 90 to 150 seconds.

The pattern of response of the alveolar oxygen tension was similar to that seen at greater altitudes, the initial abrupt fall being succeeded by the rise. The longer time for which observations were possible allowed the expected secondary fall to be observed when, after one circulation time, venous blood that had given up its oxygen on the first circuit again passed through the pulmonary capillaries. Alpha-activity appeared in the EEG some 15 seconds after the alveolar partial pressure of oxygen had fallen to 30-35 mm Hg, and increased in rough proportion to the duration of the exposure. At the same time the performance of the psychomotor task began to show a definite impairment, and this too was progressive. Slow wave activity became manifest in the EEG shortly afterwards and in most subjects consciousness was lost within the time limit arbitrarily set for the exposure to hypoxia. As in the earlier experiments, a strong correlation was found between the changes in the alveolar oxygen tension and in the EEG, and between both of these and performance of the skilled task.

These results suggest that the 'classical' values for times of useful conciousness after decompression to intermediate altitudes are optimistic, although much hinges upon the precise connotation of the words useful. The role of the hyperventilation that always accompanies hypoxia of this degree remains to be elucidated by experiments now in progress.

A problem that has recently assumed a fresh importance concerns tolerance for prolonged radial acceleration. Many of us thought that work on this subject had been completed by the mid-1950s, for the signs and symptoms of exposure were by that time well established, limits had been set, and the development of the anti-G suit seemed to provide an adequate means of protection. It was known that black-out (or loss of central vision) would occur at about 5 G during a 15 second exposure, but that a properly designed anti-G garment could raise this level by about 1.5 G. The post-war generation of high performance aircraft appeared to be less robust than their predecessors, and the common pattern of operations seemed to involve a maximum exposure to 5 G for very short periods of time. Indeed, the main value of the anti-G suit was thought to be as a means of combating the fatigue produced by repeated exposure to comparatively low accelerations (2½-3½G). Accordingly, attention was directed to reducing the penalties associated with wearing the suit, notably discomfort and heat. Lightweight garments were developed, and in an attempt to reduce the thermal load still further, the coverage of the legs by inflated bladders was reduced. The difficulties of donning and wearing a conventional anti-G suit were mitigated by the production of an external garment that could be worn over rather than under conventional flying clothing. These various measures slightly reduced the efficacy of the anti-G protection, but this was a worthwhile trade-off for the increased comfort. With the apparently satisfactory solution of the practical problems of acceleration, human centrifuges were devoted to the study of interesting physiological questions.

Within the past few years the picture has markedly changed. Some aircraft in current use do not fall out of the sky if high accelerations are applied; others now being planned or developed are designed to withstand 8 G or more, and it is envisaged that such forces may be sustained for periods in excess of 30 seconds. The data on human tolerance collected with much labour during and after the war do not extend so far, nor is it possible to extrapolate from existing information to any satisfactory degree. Estimates could be made of the time for which an unprotected pilot could tolerate 8 G, and of the acceleration which could be withstood without black-out for 30 seconds, but the combination of these two parameters represented unexplored territory. There were some reports that aircrew had exposed themselves, under operational conditions, to accelerations of 8 G or more for short periods of time without apparent detriment to their flying performance, but the general applicability of these reports remained unknown. It seemed certain, however, that the anti-G suit alone would not meet the requirement for protection.

Since the earliest days of aerial combat, pilots have protected themselves against visual loss by various voluntary manoeuvres, which include crouching, muscle tensing, and screaming. The first of these effectively reduces the vertical distance between heart and brain and thus delays the impairment of the cerebral circulation which is the cause of symptoms. The other two procedures raise the arterial blood pressure at head level; the one by increasing the vascular resistance in the periphery, and the other by a direct rise in intrathoracic pressure. They were so effective that they became formalised as the M-1 manoeuvre, which consists of intermittent forcible expirations against a partially closed glottis. The proper execution of the M-1 manoeuvre requires practice and experience, and is extremely fatiguing. With the advent of satisfactory anti-G suits it became unnecessary, and its use was generally abandoned, although pilots continued to 'fight the G' by voluntary muscular action.

The exacting specifications of the new aircraft led to a re-appraisal of older methods of protection, both alone and in combination with modern anti-G garments. A study at the Institute showed that the benefits of the anti-G suit and of postural change were indeed additive, but they also confirmed that the latter conferred no worthwhile advantage unless the pilot's seat was tilted back to an unacceptably large angle from the vertical.

Respiratory manoeuvres such as the M-1 offered more promise, and in the summer of 1972 a joint study was carried out between the RAF IAM and the USAF School of Aerospace Medicine at Brooks Air Force Base. The programme was divided into two phases; the first designed to compare full length and short anti-G suits, and the second to compare the M-1 manoeuvre with continuous positive pressure breathing, which is an alternative method of raising intrathoracic (and hence arterial) pressure. In both phases the subjects were instructed to tense their muscle and thus to increase the protection further. The runs used experienced centrifuge subjects and were carried out at 3,6 and 8 G, the objective being to sustain 8 G for 60 seconds.

The results showed no significant difference in the protection given by the full length and the mini anti-G suits. At first sight this is a surprising finding, because the volume of the calves is hardly negligible, and a considerable quantity of venous blood would be expected to sequester into the capacity vessels. Further trials both on the centrifuge and in flight appear to confirm the results of the joint study, and the aircrew of current RAF aircraft have been almost unanimous in their approval of the mini-suits supplied for trials. It must be remembered that neither the centrifuge experiments nor the flight tests were carried out on relaxed subjects, and that venous pooling would have been greatly reduced by the muscle tensing which they all practised. However, there were many complaints of calf pain when using the short suit at high G levels, although superficial venous pressures were shown not to be unduly high, it is very possible that the discomfort is due to deep venous congestion associated with the exposure.

Both the M-1 manoeuvre and positive breathing significantly increased the tolerance for acceleration, and many subjects were able to withstand the full rigors of 8 G for one minute. There was no significant difference between the two procedures in this respect, but it was less tiring and less stressful. Morever, it did not require the continuous attention that had to be paid to inspiration and expiration during the M-1 manoeuvre. In operational situations, where the pilot already has much to think about, this difference would be important. From a physiological point of view also the positive pressure breathing is to be preferred, for intrathoracic pressure never falls below atmospheric, whereas with the M-1 procedure violent oscillations in the pressure within the chest occur with each breath.

If an immediate answer is required for the problem of protecting aircrew against accelerations of high magnitude and long duration, the short term advice would be to provide an efficient anti-G suit and the facility for pressure breathing at about 25 mm Hg supplied automatically when the acceleration exceeds about 3G. The development associated with the research consists of devising and manufacturing an oxygen regulator which can be activated by accelerative force in the same way as an anti-G valve, but which is still capable of fulfilling its primary role of preventing hypoxia. This short term solution is by no means ideal and certainly not the best that can be done. To answer the long term requirement for optimum protection supporting research is required. This must involve a deeper understanding of the physiological changes associated with prolonged acceleration and may well result in an entirely novel concept of protection. It would be optimistic to suggest that the final solution could be obtained in less than 3 years.

Some of the findings from the joint RAF/USAF study have repercussions into basic research. For example, measurements of the oxygen content of the arterial blood revealed a marked difference in the pattern of desaturation occurring with the M-1 manoeuvre and with pressure breathing. It has long been known that such desaturation accompanies exposure to acceleration, and a considerable amount of fundamental research has been conducted to discover the mechanism for the change. Even under conditions of normal gravity the distribution of gas and of blood within the lungs is not uniform, some areas being over perfused and underventilated, while in others the converse is true. Increased acceleration exaggerates these disturbances of the ventilation/perfusion ratio, and under certain conditions can cause sufficient distortion of the parenchyma to result in the closure of some airways. If the alveoli in these regions are under perfused, no great harm results, although by definition such volumes of lung are ineffective from the respiratory stand-point. If perfusion is maintained or increased above normal, as it is in the bases of the lungs, and if the subject is breathing 100% oxygen gas will be rapidly absorbed from the isolated segments and patchy collapse of the lungs will occur. Because perfusion continues, the blood passing through such regions receives no further uptake of oxygen and returns to the heart in a relatively desaturated condition. To a small extent such venous admixture is a normal part of everyday life, but it can be greatly exaggerated during accelerative manoeuvres. It could be that positive pressure breathing mitigates the collapse by ensuring that the susceptible parts of the lung are maintained in a distended state, and this could account for the different patterns of arterial desaturation found with the two manoeuvres. The question is partly academic, but it requires further investigation for the sake of science. In this sense the centrifuge can be used as a probe for exploring normal physiological mechanisms, rather than as a simulator of aircraft stresses. The results obtained may also have some impact in clinical medicine.

Aircrew may be exposed to inhospitable thermal environments, at both ends of the temperature scale. In general, a cold cockpit poses less of a problem than a hot one, for it is relatively simple to supply extra insulation in the form of more (or thicker) garments. The provision of cooling is a much more difficult and expensive exercise, and measures designed to lower the temperature in the cabin space will be defeated if, for other reasons, the occupants must wear impermeable garments such as immersion suits, or many layers of protective clothing. The need for adequate cabin conditioning is recognised in the time-honoured phrase 'flying in a shirt-sleeve environment', but to put this principle into effect involves far more than the assurance of thermal comfort. It requires that the integrity of the cabin shall be absolute, that its internal pressure shall be high enough to make the use of oxygen unnecessary, and that emergency escape in the air will never be called for or possible. These conditions can almost be met in airliners and some military transport aircraft but even in these cases some compromises must be accepted.

In high-performance aircraft the shirt-sleeve environment is a pipe dream. The provision of protection against hypoxia, against acceleration and deceleration, and against the sequelae of emergency egress entails thermal penalties that lead to still greater complexities of aircraft equipment or of personal equipment or, more usually, of both. Air from the engines is used to pressurise the cockpit and to ensure that it enters at a low temperature would present no insuperable engineering difficulties, but the need to save space, weight and electrical power may override physiological considerations and conditions are therefore usually less than ideal. Moreover, the supply of cooling air is only available when the engines are running, and no self-contained cabin conditioning system, however efficient, can solve the thermal problems of aircrew who must enter an aircraft that has been exposed for many hours to full sunlight in a hot climate. It is not even possible always to ensure that their unhappy situation is relieved by a speedy departure, for in some states of alert the aircraft must be occupied for comparatively long periods, ready for take-off at short notice but with the engines silent. Ground-based cooling trolleys can alleviate the distress to some extent, but they can rarely remove it completely.

The stock solution to these problems is to equip the aircrew with personal conditioning garments, of which air-ventilated suits (AVS) are the best known. A properly designed AVS distributes gas differentially over the surface of body so that cooling balances the heat production in different areas. Its action is two-fold; a direct effect resulting from the temperature difference between the incoming air and the layer bounding the body, and indirect cooling from the evaporation of sweat. The latter can be exploited to overcome one disadvantage that the air-ventilated suit shares with the cabin conditioning system; namely, the need for an external source of cold air on the ground. Provided that the ventilating gas is not staturated with water vapour and that its temperature is lower than that of the surface over which it flows, it will remove heat in proportion to the sweat that is evaporated. This means that a degree of cooling can be achieved by 'reverse-flow-ventilation' in which ambient air is drawn through the garment by suction. The output from a pump, whether it be a compressor or a suction device, is at a higher temperature than the input. In conventional systems this increases the need for refrigeration, but in the reverse-flow system the air leaving the pump is discharged to waste, and the heating action of the machinery is immaterial. Recent evaluations of a reverse-flow air-ventilated suit have shown that worthwhile cooling can thus be obtained by very simple means although the efficiency is, of course, less than that of a good forward flow system. The reverse-flow device could have another significant advantage in combat conditions. If the atmosphere is contaminated by chemical agents the ventilating air must be filtered before it passes through the suit. Suction ensures that the ambient air is drawn through the outer layers of clothing before it reaches the skin, and because those layers will necessarily incorporate chemical filters no further treatment is required. By contrast, a blown system must first pass the air through a relatively bulky filter, which will also impair the efficiency of the compressor by introducing resistance to flow.

An attractive alternative to the air-ventilated suit is the liquid conditioned suit (LCS) which was devised at Farnborough and has progressively developed. In its simplest form, the suit consists of a geometric arrangement of pipes, sewn to a suitable undergarment, and filled with water or with some other fluid having a high heat capacity. The system is closed, the liquid being circulated by a small pump. A heat exchanger or refrigeration unit constantly removes accumulated heat from the fluid. The LCS has some outstanding and obvious advantages over its rival. The volume of the working liquid is small and flow rates can be low; a small pump is therefore adequate and large power supplies are not required. Within reason, the temperature of the fluid can be kept very low so that the cooling efficiency is high. The system can easily be operated in an aircraft on the ground, and it is readily adaptable for use during the long walk from the crewroom to the flight line. It needs no modification in a chemical environment.

Against these good features must be set some disadvantages. The LCS exchanges heat with the body, but it cannot evaporate sweat. Indeed, it may suffer from what has been called the 'bathroom effect' that is, the condensation of water from warm saturated air in contact with a cold surface. If the circulation is through pipes, 'striping' also occurs, with narrow bands of very cold skin separated by zones in which the cooling is less effective or absent. Apart from the local discomfort of this situation, it produces a false subjective impression of cold even when the deep body temperature may in fact be rising. These difficulties have been largely obviated from current models of the LCS, notably by re-design of the distribution system to replace the original pipes by interconnected compartments. An experimental trial in Cyprus last year fully demonstrated the effectiveness of the new garment, but more spectacular evidence of success was provided by the Apollo space flights, in which liquid conditioned suits were used both in the cosmos and on the moon.

Cooling garments do not remove heat from the hands and feet or from the head. The extremeties are not a serious problem in this regard, but the benefits of keeping a cool head and the dangers of hot-headedness are so well recognised that the phrases have become part of everyday speech. Even automobile manufacturers now accept that face-level ventilation should be a standard fitment to their products and not a luxury item. Various attempts have been made in the past to extend the value of the AVS by the addition of an air ventilated skull cap, but they have been thwarted by mechanical difficulties and by discomfort. The lack of objective evidence that a hot head impairs the performance of a man with a normal core temperature or that there is merit in cooling the head when the rest of the body is hot led to some recent experiments in the climatic chamber at IAM.

The deep body temperature of each of a group of subjects was raised to, and maintained at 38.5°C, and the head was placed in an environment of 15°C. or of 50°C. Subjective assessments of comfort were made and performance was measured by tests of psychomotor ability, attention, calculation and reasoning power. The first of these showed a small decrement in performance when either the body, or the head, or both were hot. There was no significant difference in the scores recorded in the other three tests, but the number of 'false alarms' in the attention task and the time taken to complete the reasoning test rose when the head and body temperatures were increased. Cooling the head improved the former but was without effect upon the latter. These findings were in contrast with the subjective assessments. A cool head tended to improve the comfort rating of the body, and the converse was also true. The head was judged to be significantly cooler when the core temperature was normal than when it was high, even although the environment around the head was the same in each case. These experiments demonstrate that head comfort has little or no effect upon the performance of hot subjects, but that it does improve the sense of well-being. There is no doubt that aircrew, like many motorists, feel that a draught of cool air on the face is beneficial and the introduction of small fans mounted at head level at some crew stations in certain bomber aircraft is reckoned by the users to be major triumph for aviation medicine and for common sense.

One other development in the field of thermal stress is worthy of mention. The sole purpose of a cockpit conditioning system is to provide a suitable environment for the aircrew, but in order to do this entire volume of the cabin must be maintained at the desired temperature. Large quantities of air must be supplied through complex distribution channels, and the whole process is expensive, inefficient and often noisy. Preliminary studies of an alternative solution are now in progress at the Institute. They are based upon the idea of a personal micro-environment, which is maintained by control only of the immediate surroundings of the man. Spray-bars mounted on the seat or designed into its structure supply air at a temperature regulated by the occupant to form a 'curtain around him. The effectiveness of the cooling decreases as a function of distance, but this is unimportant, for in this concept the remainder of the cockpit is regarded as unconditioned space requiring no special treatment. If it is successful this conditioning system will have the advantages of simplicity, economy, efficiency and quietness.

A major topic of research is covered by the omnibus heading of 'aircrew workload'. It is generally accepted that the increasing complexity of modern aircraft, whether they be military or civil, imposes greater demands upon the crew, and that the missions and schedules that they are required to fly have become more exacting. If the resulting workload becomes excessive, precision will suffer, performance will decline, and flight safety may be in hazard.

This argument applies not only to the acute overload that may occur during a single difficult sortie but also to the cumulative effects of a longer series of less intensive flights. It is therefore necessary to distinguish between 'mission workload' and 'operational workload'.

All this is so intuitively obvious as to need no formal proof, but intuition cannot be expressed in the quantitative terms required by planners and designers. Unfortunately, the definition of such words as workload, performance, efficiency and fatigue poses severe problems and undisputed methods for measuring them have still to be devised. The simplest approach is that of subjective assessment by the aircrew themselves of the work stress to which they are exposed, but although it has been shown that such judgements are remarkably consistent for any given individual, it is clearly less easy to equate the impressions of one pilot with those of another. Moreover, subjective assessments can only be of value if they are correlated with objective measurements, however crude, and with the external factors contributing to the workload.

An attempt to establish such relationships has recently been made in a large series of scheduled flights with a civil airline. The study concentrated on the let-down and landing, for these are said by most pilots to constitute the most difficult and critical phases of flight. Using the technique of placing a mark on an unscaled 10 centimetre line, the pilot gave an assessment of the overall difficulty of the let-down and landing, and also reported by the same method on five associated factors. These comprised meteorological conditions, adequacy of navigation aids, runway length, aircraft characteristics and serviceability, and crew efficiency.

Physiological measurements had necessarily to be simple, and they consisted of the heart rate (derived from the electrocardiogram) and the tremor of the outstretched hand. The former was determined at defined points during the approach, let-down and landing, and the latter as soon as possible after the aircraft had come to rest.

A very high correlation was established between the subjective appraisal of overall difficulty and certain of the external parameters, of which the adequacy of aids was by far the most important. More than two thirds of the approaches involving a high subjective workload had limited navigation aids and in more than one quarter of the total the air traffic control was imperfect, this proportion being higher when the meteorological conditions made assistance from the ground more critical.

As expected, the heart rate always rose during the approach and reached a peak just before landing. In straightforward conditions the rise was relatively small, and the maximum heart rate rarely exceeded 140 beats/minute. Less favourable circumstances were accompanied by greater degrees of tachycardia, and in very difficult landings heart rates of 180 beats/minute or more were sometimes recorded. Uncomplicated approaches did not result in a gross exaggeration of the normal finger tremor after touch down, even when the situation was adjudged to be difficult and the heart rate was in excess of 150 beats/minute, but untoward events such as the sudden appearance of an obstruction on the runway or an unexpected down draft in the final stages led to a considerable increase in the 10Hz component of the tremor. These physiological changes reflect varying degrees of 'arousal' of the central nervous system. It is obvious that heightened activity is a necessary accompaniment of a demanding task; but it is not easy to decide whether the extent of the response is appropriate to the situation. Studies of shared approaches, in which the co-pilot hands over control to the captain at a pre-determined distance from touch down, and of coupled approaches in which the pilot monitors an automatic system until very late in the sequence, have shown that the pattern of physiological response can be modified so that the heart rate is lower than it would otherwise be. The ultimate step in this process of shedding workload is, presumably, the routine use of fully automatic approach and landing. A system of proven reliability in which the crew has complete confidence should obviate the need for any increase in central nervous arousal, but if a malfunction or emergency does develop it will be necessary for the human reaction to be both prompt and adequate. Whether the recruitment of arousal can suffer from disuse atrophy is not yet known, but it seems probable that some impairment in the speed of response may occur.

In civil airline practice the period before touch down may well be the most stressful part of flight, but the same cannot be said of military operations. The technique of subjective assessment has been used to analyse the temporal distribution of workload in a wide variety of missions ranging from low level ground attacks to troop transport and also to indicate the relative involvement of individual crew members. Not surprisingly, a phase difference exists between the periods of most intense activity of pilots and navigators, but a more unexpected finding was the high workload rating given by all crew members to the preflight briefing and post-flight de briefing. This demonstrates yet again the fallacy of assuming that the only flying time is working time. From the results of the surveys so far accomplished it is clear that workload is not a single entity but a complex of physical, mental and perceptual tasks, each with a different influence upon the total load. Experiments using tasks specifically designed to study the effects of these components in the context of strike operations are now being carried out using a flight simulator.

There has recently been much discussion, on an international front regarding permissible flight times and duty periods for the crews of commercial airlines. Concern that current schedules might, by causing fatigue, compromise the safety of aircraft led in 1972 to the appointment of a Committee on Flight Time Limitations under the chairmanship of Group Captain Douglas Bader. The Committee found itself enmeshed in conflicting opinions and inadequate data, but it distinguished between tiredness, which is the normal result of labour and from which arousal to a high level of performance is possible and fatigue which was defined as a markedly reduced ability to carry out a task. Fatigue was judged to be the result of two prime factors; sleep deficit, and high levels of workload on the flight deck. After hearing a large number of medical and lay witnesses on these matters the Committee concluded 'although there has been much aeromedical research into the problem of flight deck workload and fatigue, it is fragmentary and not comprehensive........... Therefore we recommend that a properly co-ordinated programme of research, suitably supported by field work, be undertaken...........'

Both before and since the report of the Bader Committee, the RAF IAM has undertaken studies of the sleep patterns and duty hours experienced by civilian and military aircrew in world-wide operations. Such flights provide more valuable material than can be obtained from domestic or short haul schedules, because they involve changes of time zone and hence discrepancies between subjective 'physiological' time and local custom. Rest and sleep must in these circumstances be a compromise between arrival and departure times which are set by the convenience of passengers, and the ability of the pilot to adjust his internal clock.

Records of normal sleep and activity patterns were obtained from diaries kept for the purpose by the aircrew, and an acceptable quantum of sleep was defined as the average amount obtained per 24 hour over a 3 day off-duty period. A graph of cumulative duty hours during route flying against days on the route was plotted, and the above criterion was used to construct a zone beyond which an acceptable sleep pattern could not be maintained. The precise position of the line of demarcation will, of course, vary with the normal habits of the individual, but the general shape of the curve is similar for all subjects. The most critical parameter in prolonged schedules seems to be not the duration of any one duty period but the total number of duty hours in relation to the progress of the operation.

The implications of these findings for military aviation are apparent. Thirty two hours of duty time can be amassed in the first 3 days of an engagement, but some 38 hours of rest will then be required before a further stint of 10 hours can be recommended. The penalty of a high initial workload is thus the need to reduce the frequency of duty periods as the operation proceeds. This is a fine precept, which can probably be honoured in peacetime but which cannot be allowed to override other considerations. The definition of an acceptable sleep pattern is generous, and that of workload is not clear cut. It is more than probable that small encroachments beyond the line can be permitted without great detriment to efficiency, and the risks of such trespass might readily be justifiable in time of war.

Part of the problem stems from the ineffective use of off-duty time, for many people find great difficulty in falling asleep and remaining asleep at unusual hours, despite the fatigue induced by previous hard work. When faced with this situation the temptation to woo sleep with hypnotics is great, and the over-prescription of these drugs is by no means confined to civilian medical practice. One of the most useful soporifics known to civilised man is alcohol, but this is denied to flying personnel because of its undesirable aftereffects, even at moderate dosages. The hang-over effect of some barbiturates is also well-recognised, but the so-called 'short-acting' hypnotics have acquired a reputation for safety. Opinion in the RAF is divided, but most medical authorities agree that circumstances can be envisaged in which the use of hypnotics by pilots may be necessary. A programme of research now in progress at the Institute is attempting to give guidance to clinicians on the least harmful prescription to aid sleep.

The absorption and excretion rates of a number of barbiturate and other hypnotics said to have a short biological effect have been measured after a single therapeutic dose given by mouth. The half-lives of the drugs varied widely; for quinalbarbitone (which is not claimed to be short-acting) a value of 29 hours was obtained, and for heptabarbitone (which is) the figure was 10 hours. Ethinamate levels in blood decayed to one half in about 2½ hours, while methaqualone, which is commonly regarded as a safe effective hypnotic, was cleared in a bi-phasic manner, the half-life of the faster component being slightly less than one hour and that of the slower fraction being 16 hours. With the exception of ethinamate all the drugs could be detected in the blood 24 hours after a single dose. Nitrazepam (Mogadon) is another fashionable hypnotic with a high margin of safety but the work at IAM has shown that its half-life is more than 24 hours and that its presence can still be demonstrated 72 hours after ingestion.

Blood or plasma concentrations per se do not provide evidence of a persistent effect, and some previous studies have demonstrated that the short acting hypnotics cause no residual impairment of skilled activity, although a delayed rebound has occasionally been seen. However, the tests used to assess performance have generally been unrelated to the flying task, and the responses of the subjects have not usually been followed over a period of more than a few hours. The experiments at RAF IAM use an adaptive tracking task, which increases in difficulty as performance improves, and which has a high face validity to aircraft control. Significant decrements of performance have been found up to 19 hours after the administration of heptabarbitone, and both the impairment and its persistence have been shown to be dose-related. Although the work on other drugs is as yet incomplete, it is already clear that similar conclusions will be reached. Thus, even hypnotics widely approved for clinical use are suspect in the context of aviation. The question posed by the originator of the RAF study is 'Would you rather fly with a pilot whose sleep last night was induced by Mogadon, or with one who calmed his troubled mind with a stiff shot of gin?'

Although the search for an entirely safe drug to combat sleep disturbance must continue, the demonstration that serotonin and other biogenic amines play a part in the maintenance of central nervous arousal raises the possibility of precise control of sleep and wakefulness by purely biochemical means. The concept of a military unit that could be switched on and off between states of restful sleep and sustained alertness according to the needs of the situation must be close to the heart of every Commander, and although work along this line is still at a tentative and exploratory stage, preliminary results from monkeys show some promise

The Institute's work on the biological effects of laser radiation provides an example of speculative research that has been transformed into an applied programme by technical progress. The studies began at a time when the coherent light emitted by a laser was little more than a scientific curiosity. It was clear, as James Bond was soon to discover, that the destructive effect of this form of radiation was far higher than that of 'conventional' light sources of similar wavelength and energy, and that even a relatively low power laser beam could damage the eye. The original investigations at the RAF IAM were academic in the sense that they were concerned with the mechanism of action of a device having little obvious practical application. In the past 7 years a very large number of different types of laser has been developed, with wavelengths extending throughout the visible spectrum and beyond. The power output of the sources has increased many times, and the uses to which they have been put are legion. Laser rangefinders and target markers based on ruby, neodymium and other substances are already in use in military vehicles such as tanks and aircraft, and new systems will undoubtedly be designed and introduced in the future. The risk that aircrew may be endangered by the light from their own laser devices or those of their allies is small, and the use of lasers as 'death rays' is at present unlikely. Nevertheless, the servicing and alignment of military systems entails a potential hazard of accidental exposure, and the possibility that members of the population inadvertently encounter direct or reflected laser radiation cannot be entirely discounted.

These considerations, together with the spreading use of lasers in industry, have led to an urgent call for the establishment of more realistic safety codes than those currently in force. The latter, which were produced from various medical and non-medical sources, are based upon very limited experimental data from animals, and upon deductions made from physical principles. Of necessity, they include very large and arbitrary margins intended to cater for unkown or undetermined factors, and their rigid application would virtually prohibit the use of military laser devices. The Institute's work provided ample evidence that this caution was excessive, but information relating to specific airborne systems was essential.The methods already developed and the expertise acquired in the preceding years at last came into their own, and the academic research programme became intensely practical and applied. The crude criterion of ophthalmoscopically visible damage to retina has been refined by the technique of fluorescein angiography and latterly by electron microscopy. Safe retinal energy densities have been established for Q-switched ruby and neodymium lasers operating in single and multimode configurations, and using single and repetitive exposures. Perhaps the most important result of the work has been the derivation of a relationship between the energy required to produce a lesion and the size of the retinal image. Other workers have made false assumptions in this regard, and the error is reflected in their recommendations. The net result of the IAM experiments has been a considerable relaxation of the present stringent codes for safe exposure. This has led to a reduction by a factor of 5 or more in the range at which a chance encounter with laser radiation is considered to constitute a significant hazard; a concession that is of the greater importance for military operations in peacetime.

It is probable that the revised energy levels are still unduly pessimistic, for generous safety margins are included in the recommendations. One point of uncertainty is the extrapolation from animals to man. The experimental data have been obtained from rabbits and monkeys, and although the retinal structure of these species is similar to that of the human, the characteristics of the pigment layers are not. Physical principles suggest that for this reason the eye of the monkey is more sensitive to laser light than that of man, but the scale factor between the two is unknown. To resolve this question work with human eyes is now contemplated. Graded exposures spanning the range producing lesions in the monkey will be delivered to the retinae of patients awaiting enucleation for malignancy or other reasons. Histological examination of the excised eyes should then allow a correlation to be established between human and animal tissues, and hence permit the criteria for safety to be further defined.

Most of the tools of aviation medicine-centrifuges, decompression chambers, climatic laboratories and the like simulate one or more of the stresses of flight. The term 'flight simulator' has the special meaning of an implement that reproduces more or less faithfully the instrument displays and controls of an aircraft. In the training role, flight simulators range from simple familiarisation devices intended only to acquaint the student with the layout of the cockpit, through procedures trainers in which the required responses to a variety of in-flight events (notably emergencies) can be taught and practised, to full mission simulators. These latter are complex and sophisticated machines with control characteristics, in terms of 'feel' and instrument response, closely similar to those of the real aircraft. They invariably incorporate motion in more than one axis and usually include a representation of the external visual world appropriately coupled to the controls.

Despite the widespread acceptance and use of flight simulators as training and familiarisation aids, and of economic alternatives to practice in the air, the specification of the required properties is difficult. At one end of the scale is the intuitive argument that the device should be as representative as possible, and that good reasons must be advanced for omitting any characteristic of the real aircraft. The synthetic approach agrees that a certain minimum standard should be achieved, but holds that refinements should be added only if they can be shown to be essential for the validity of the simulation. Proponents of the first thesis insist, for example, that six degrees of freedom of motion are essential and that a full-colour three dimensional external view should be included. Advocates of the second school, who tend to be either scientists or financiers, accept that motion cues are essential and an outside world desirable, but claim that evidence is lacking of the need for full fidelity of either. Small degrees of roll and pitch may suffice to give the necessary realism, and a stylised representation of cloud formations or of the approach to an airfield may provide adequate visual information.

Research into flight simulation must attempt to resolve such issues, but it also has other objectives. One of the more important is to obtain quantitative correlations between experience on simulators and performance in flight, both for student pilots and for aircrew undergoing refresher training or conversion to a new type of aircraft. A technique known to psychologists as the Specific Behavioural Objectives Approach is being used to assess the long term implications of flight simulators for such purposes. The programme includes a survey of the characteristics and utilisation of current training devices and parallel analysis of the components of the training task. It is possible that the results will indicate that increasing use should be made of simpler types of synthetic device. The feasibility of providing computer-controlled training in procedural and manual skills is also being investigated-this is the aviation medical equivalent of the self-paced programmed learning now widely used in other branches of education.

A flight simulator is, in many respects, an ideal vehicle for the study of aircrew workload, because the many variables can be closely controlled. Mention has already been made of the differentiation between physical, mental and perceptual tasks that the simulator permits. The effects of changes in central nervous arousal upon the performance of these activities are now being investigated, and the research programme will shortly be extended to determine the influence of the disturbed sleep patterns and abnormal hours of duty that may be encountered under operational conditions. The general philosophy of research on flight simulators is, or should be, that the decrements in performance resulting from a wide range of environmental and psychological stresses can be measured under conditions as representative as possible of actual flight, but with complete safety and objectivity.

Nausea is a not uncommon complaint from the users of flight simulators, and a research programme at the RAF IAM is examining this problem. Similar symptoms occur frequently in devices in which motion and vision are dissociated; a classical example is the simple automobile training simulator where a moving display of a road and the surrounding country side is projected in front of a static driver. Malaise is rapidly induced, and it is more common in experienced drivers who are accustomed to dynamic cues when negotiating bends, or accelerating, or braking, than in novices who have not yet developed a strong association between vision and motion. It is also common knowledge that the development of motion sickness has a negative correlation with workload. Drivers with nerves of steel may become nauseated when they ride as passengers, and student pilots who feel sick may often be restored to health when they are given control of the aircraft.

In flight simulators these factors may be complicated by others. Although both the external environment and the cockpit may move, there may be a mis-match of amplitude or phase or both. Indeed, some imbalance is inevitable, for although the external view can respond appropriately to control movements that would cause a real aircraft to perform a barrel roll or a loop, the simulator cabin cannot. Moreover, the centres of rotation of the cockpit and the outside world will rarely be the same, and for mechanical reasons the lead/lag relationships between movements of the controls and the responses of either the cabin or the instruments may be distorted or even reversed. To experienced pilots and instructors the unavoidable discrepancy between the 'handling' characteristics of the simulator and those of the actual aircraft may prove both disappointing and physically disturbing, while for their students the transition in the other direction may have similar consequences. It is easy to say that if a simulator produces nausea it is a bad device, but if symptoms also occur during a comparable phase of aircraft flight it can be agreed that the simulator is a faithful instrument !

The Institute's programme aims to investigate the influence of individual difference in sensitivity to motion upon the acceptability and value of motion cues in simulators. As a first step the range of variation in sensitivity within the aircrew population is being explored and correlated with the incidence of nausea in simulators. The effects of different degrees of sensory interaction and task activity upon the perception of motion cues are also being studied, and when the basic data have been established the influence of changes in phase relationships between the components of simulator system will be investigated.

The research programme uses nausea as a yardstick or end point, but it is not concerned with the mechanisms or treatment of motion sickness per se. The Royal Air Force has, of course, an active interest in such matters, and procedures for desensitising aircrew, who may develop a susceptibility to motion sickness quite late in their careers, have been developed and successfully used. Therapy is a clinical responsibility, and although the Institute may give advice and carry out special investigations in particular cases its activities in this field are small. However, the twin problems of disorientation in flight and illusions of motion receive considerable attention, and form the supporting research programme of a Vestibular Physiology section. The effects of vestibular stimulation upon visual performance are of great practical importance. Stimulation of the receptors in the semicircular canals by flight manoeuvres such as spinning induces nystagmus which may seriously degrade the ability to read instruments–a difficulty which compounds the problems of the concomitant spatial disorientation. There are large individual differences both in sensitivity to the stimuli and in the ability to suppress the vestibular nystagmus, and the physiological correlates of this variation, are being studied.

Vestibular mechanisms normally help to preserve, rather than to impair, visual acuity. This is demonstrated by some recent experiments in which subjects were exposed to oscillations at various frequencies in the yaw axis while performing a symbol detection task on a fixed target. Despite the imposed motion of the head, acuity was preserved up to 8–10 Hz and visual performance was unexpectedly enhanced at 6-8 Hz. At frequencies above about 10 Hz rapid deterioration occurred. When the subject was stationary and the target was oscillated through the same angular subtense task performance was also degraded, even at the lowest frequencies, and a very low success rate was achieved at 2 Hz and above. The very reasonable hypothesis that vestibular mechanisms are responsible for maintaining visual acuity during oscillatory motion was elegantly confirmed by repeating the experiment on a subject whose vestibular function had been inadvertently destroyed by streptomycin. This man, who is in great demand as an experimental preparation, gave the same responses irrespective of whether he or the target was oscillated. In both cases the curve of performance corresponded to that of a stationary subject and a moving task.

This paper has described a few programmes of research currently being undertaken in various fields of aviation medicine, but it has concentrated on the long-term supporting function to the virtual exclusion of the applied work. About 60% of the total effort of the Institute is devoted to research and development connected with items and assemblies of personal equipment for aircrew, the majority of the load falling upon the Altitude, Biodynamics and Climatic Divisions. The need for co-ordination of these activities appears at two levels; the functional evaluation of all aspects of a piece of equipment, and the proper integration of separate items must both be assured. A protective helmet, for example, is not simply a device to minimise the risk of head injury in the event of a crash. It is also usually a means of reducing the external noise reaching the ear, a mounting for telephones and a platform for an oxygen mask and a visor. Thus, although the measurement of impact attenuation is a primary part of the assessment of a new helmet, all these other properties must be evaluated before a considered aeromedical judgement can be given. Similar complications afflict many of the individual components of a complete assembly, but the investigation of them in isolation is only a first step. At the second level, interactions or incompatibilities between items must be avoided (or at least minimised). This requires more than the simple check of donning the equipment and making a subjective appraisal of its comfort. It must involve tests of the entire system over the range of temperatures, altitudes and accelerations in which it will be used by aircrew; it must also include an evaluation in a representative workspace and in conditions simulating emergencies and escape. As an extreme example, perfect protection against environment stress is of no avail if its bulk makes it impossible for the pilot to fit into his seat, or for the seat to be ejected safely from the aircraft. Moreover, the assessment must be repeated for each aircraft type and each time a major change is introduced, because it is usually impossible to read across directly from one situation to another.

For each type of aircraft in service or under development the Institute nominates an Aeromedical Project Officer, whose job it is to acquaint himself as fully as possible with all aspects of the progress of the aircraft from the drawing board to the squadron, so that he can detect potential problems in the field of human factors that might otherwise escape attention. The Aeromedical Project Officer also acts as a spokesman for the Institute at policy meetings and cockpit conferences, and is responsible for transmitting the co-ordinated advice of the Institute to the Air Staffs, the manufacturers and, eventually, to the operators. This advice does not, of course, stem solely from the short-term applied projects, but relies heavily upon the supporting research programmes.

Finally, what is to be the future of research in aviation medicine? It is sometimes said that smaller numbers and fewer types of aircraft, all equipped with advanced electronic aids and the products of mechanical technology, will eliminate the need for science of 'human factors'. The past achievements of aviation medicine have determined limits of tolerance for stress and in many instances have defined the optimum parameters of the working environment; all that is now required is that the requisite conditions shall be ensured at the design stage. It has also been said, with a greater respect for reality, that 'where you've got men you've got problems: where you've got aircrew you've got *big* problems' It is certainly true that the effects of individual physical stresses have been studied to the point where firm recommendations can be made and fiats issued. In many areas the consequences of less extreme exposures have also been investigated, albeit incompletely. The action of minor degrees of different stresses acting in combination is now beginning to be explored more comprehensively, but a great deal of effort will be expended before the matrix of interactions can be completed.

The criteria by which the effects of stress are measured have also changed in a direction that ensures an ample source of future research. It is the ability of aircrew to control, monitor and process information that must be preserved, and physiological indices must therefore be supplemented by measures of performance. Ideally, such determinations should be expressed in numerical terms and be directly related to the operational mission that the man is expected to perform. Planners and commanders deal in options based upon facts and figures, and they sometimes think that human performance is amenable to the same rigorous analysis that can be applied to aircraft. The addition of X pounds to a payload reduces the useful range by Y per cent; the aeromedical analogy should be that an increase of cabin temperature by A degrees reduces efficiency by B per cent. The fact that the relationship between A and B is unknown and that B cannot even be measured in the right units may be more an indictment of aviation medicine than an indication that the demands of the Staffs are unreasonable.

The more accurate measurement of performance will enable better advice to be given, but it cannot of itself ease the lot of the aircrew. The objectives of aviation medicine are to improve the comfort, efficiency and safety of flying personnel, and these aims must be sought not only by attempting to define and correct deficiencies in current systems but also by the exploration of new ones. Improved methods of presenting complex information in a pre-processed and readily assimilable form are urgently required; novel forms of restraint systems and seats should be developed; less cumbersome methods of protection against thermal stress, hypoxia and acceleration are highly desirable. Progress in these directions requires both ideas and effort, and although the latter may be hard to find there is as yet no shortage of the former.

The history of all branches of science shows that the solution of one problem generates other questions that can only be answered by applied, objective and basic research programmes. There is no reason to believe that science of aviation medicine will ever defy this general rule, and its future seems assured for as long as mankind insists on venturing into the air.

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