always been mindful of her obligations and has fulfilled her responsibilities and duties as a prefect admirably well. Amiable and industrious she appears to have a spirit incapable of boredom and her constructive loyalty to the school, along with her unflinching good nature, has won her the high esteem and admiration of staff and contemporaries alike.

We recommend her warmly as a top-drawer student.
A "top drawer" student indeed—and a top drawer headmaster.

When to apply

When is it best to apply: in September at the first opportunity, in October–November, or at the last possible moment? To apply late is not good strategy because applications reach schools from September to January and applicants are selected for interview or offer sequentially, as applications are received. The early applications are often the strongest, and by Christmas most of the offers a school can give have been given. All schools doubtless have a formula based on experience which determines how many offers can be given to allow for A level failures and successful higher preferences at other schools.

While there seems no advantage in being among the very first—indeed an average candidate may appear relatively unattractive against the Oxford and Cambridge applicants—applications should preferably be submitted to UCCA by early October.

The final consideration is whether to apply for admission a year before planned entry so as to be able to take a year off between school and university. Few schools commit themselves firmly on their attitude to delayed entry but most are prepared to consider individuals on their merits. Schools may be reluctant to offer a place a year ahead to any but outstanding applicants because of the possibility that competition will be even keener the next year. Applicants who have decided to take a year off but have not obtained deferred entry are wise to submit their applications at the first possible opportunity in the application period of the year of intended entry; if they are planning to travel they should send a note to the deans of the schools to which they have applied requesting early consideration.

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Aviation Medicine

Special forms of flight

IV: Manned spacecraft

F JOHN MILLS, RICHARD M HARDING

"We set sail on this new sea because there is new knowledge to be gained and new rights to be won, and they must be won and used for the progress of all people. For space science, like nuclear science and all technology, has no conscience of its own." (President J F Kennedy)

Since Gagarin first orbited the earth on 12 April 1961 over 100 human beings have been into space. It has become clear that weightlessness is the major physiological challenge to man in space. Before experiencing microgravity, however, man must first tolerate the increased accelerations imposed by the launch of his spacecraft and be provided with a life supporting environment.

Acceleration

A velocity of 8 km/s (21 600 kph, 17 900 mph) must be attained to enter earth orbit, while a velocity of 11.6 km/s (41 760 kph, 25 950 mph) is needed to leave the earth's gravitational field. Such velocities may be reached by an infinite number of combinations of acceleration and time provided that their product is 828 G-seconds for orbit or 1152 G-seconds for escape. In practice the acceleration profile is limited by the design of rocket motors, which produce high thrust for only a relatively short period. The two stage Gemini launch, for example, produced peak accelerations of 5.5 G and 7.2 G.¹ During Apollo launches accelerations were not much greater than 4 G, but re-entry from lunar missions has produced levels of 6.7 G.²

Because of hydrostatic circulatory effects, such levels of acceleration are poorly tolerated unless the body is exposed to them transversely ($\pm G_x$) (see previous article, 14 May, p 1557). Thus the astronauts adopt a reclined position during high G exposure. Human tolerance to $\pm G_x$ is limited by chest pain and an inability to breathe as a result of the increased effective weight of the chest wall. The latter is reflected by a reduced vital capacity: at $\pm 6 G_x$, for example, the vital capacity is halved.³ Ventilation-perfusion inequalities are created and lung collapse may develop by the same mechanisms that produce

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such changes under $-G_z$ acceleration—except, of course, that the dependent lung is posterior rather than basal. Atelectasis does not, however, cause problems in space flights, but the right to left shunt will produce arterial oxygen desaturation, similar falls occurring whether air or an enriched oxygen supply is breathed.⁴ Although these accelerations have proved to be tolerable, any reduction in their magnitude is preferable, and the Space Shuttle's acceleration profile does not exceed 3 G.

Spacecraft environment

CABIN ATMOSPHERE

At 100 000 ft (30 480 m) the atmospheric pressure is a mere 8.2 mm Hg (1.09 kPa), while at 186 miles (300 km) the value is about 1×10^{-11} times that at sea level. Air compression is, therefore, no longer a practical method of providing a cabin atmosphere. Instead, spacecraft use a system which is sealed before launch and which requires only the addition of oxygen—to compensate for outboard leakage and respiratory consumption—and the removal of carbon dioxide.

The composition of the sealed atmosphere differed considerably between the American and Soviet space programmes. For the Gemini and Mercury projects an atmosphere of 100% oxygen at a pressure of 259 mm Hg (34.4 kPa) was selected. This single gas system had the advantage of simple engineering control, and since the gas was oxygen the risk of decompression sickness was minimised. The Russians, on the other hand, selected an atmosphere similar in composition and pressure to that of air at sea level.⁵ Although physiologically ideal this imposes weight penalties on the spacecraft, and because of the risk of decompression sickness cosmonauts are required to breathe 100% oxygen for long periods before undertaking extravehicular activity.

The 100% oxygen system was not, however, without hazard. The fire risks of such an atmosphere had been suggested by work at the RAF Institute of Aviation Medicine⁶ and were tragically confirmed by the fatal launch pad fire of Test Apollo 204 in 1967. The cabin atmosphere for the remaining Apollo launches was changed to 64% oxygen and 36% nitrogen at a pressure of just over 259 mm Hg (34.4 kPa), and to compensate for the loss of protection from decompression sickness pure oxygen was breathed for three hours before launch. After entry into orbit oxygen was used to purge nitrogen from the atmosphere through the valve used for discarding urine into space, so that the oxygen content was gradually raised to over 90% by the third day of flight. Throughout Apollo flights the Po_2 was never less than its sea level equivalent.² Similar atmospheric conditions were provided for Skylab.

This atmospheric change was expected also to have the benefit of preventing the falls in red cell mass—of up to 20%—which occurred in astronauts during the flights before the Apollo missions² and were possibly due to oxygen toxicity—a mechanism suggested by the haemolysis observed in mice exposed to hyperbaric oxygen.⁷ No reduction in red cell mass occurred in Apollo 7 or 8 crewmen, but it did recur in later Apollo flights and in all Skylab missions.⁸ The loss of erythrocytes in Skylab crewmen was associated with a lowered reticulocyte count, and isotopic measurements of red cell life span produced no evidence of haemolysis.⁸ The cause of what appears to be bone marrow suppression remains unknown. Since it has also been reported by the Russians,⁹ it may occur in Shuttle crewmen, who are also provided with an atmosphere equivalent to sea level.

this pressure is the minimum that is physiologically acceptable, it allows more mobility than higher pressures, which reduce suit flexibility. A ventilating circuit in the system ensures regular circulation of fresh oxygen after carbon dioxide and excess water have been removed. Although the oxygen is also cooled, this does not adequately control body temperature during some phases of extravehicular activity when large heat loads are produced. For these occasions liquid refrigerant is cooled in the system and circulated through a network of plastic tubing in a "liquid conditioned garment" worn next to the astronaut's skin. The portable life support system also includes an oxygen purge system used in case of loss of suit pressure and a sophisticated biotelemetry system which permits ground based assessments of the astronaut's requirements for oxygen and cooling.

HUMAN WASTE COLLECTION

On flights before Skylab a plastic bag and finger cot were used for defecation but proved unpopular with the astronauts, not least because to preserve specimens an antibacterial agent had to be added to the bag which then had to be kneaded to ensure thorough mixing. Urine was collected through rubber tubing. The Skylab astronauts had greater privacy in a purpose built toilet area which used electric air blowers to carry waste away from the user into collection bags. Faecal material was subsequently dried in a special processor and stowed for later analysis on earth. A similar system has been adopted for the Shuttle, but the urine collecting device has been designed for use by both men and women.

Radiation

It had been predicted that radiation might be a serious medical hazard to astronauts, particularly on lunar missions which necessitated passing through the two van Allen radiation belts.¹¹ The crews of Apollo 11, 12, and 13 reported seeing flashes of light which were later attributed to the penetration of the spacecraft by high energy, high charge HZE particles which produced visual sensations after interaction with the retina. Despite these observations the average radiation exposure on Apollo flights was only 4 mGy (0.4 rads), with Apollo 14 receiving the highest dose of 11.4 mGy (1.14 rads) due to solar flare activity.¹² The highest doses recorded on American missions have been during Skylab 4, but the exposure levels were well below permitted limits.¹³

Weightlessness

Astronauts are not actually exposed to zero gravity but to microgravity of 1×10^{-4} to 1×10^{-5} G (during spacecraft manoeuvres this may increase to 1×10^{-3} G).¹⁴ Weightlessness has its principal effects on the vestibular, musculoskeletal, and cardiovascular systems. Because observations have been possible on only a few subjects additional data have been derived from ground simulations of prolonged weightlessness, notably bed rest and water immersion. Clearly such simulations cannot duplicate weightless conditions since gravity is never completely eliminated.

VESTIBULAR SYSTEM

The most important vestibular disturbance encountered in weightlessness is motion sickness. By itself microgravity does not induce space sickness; indeed, space sickness did not occur in American astronauts until the early Apollo missions. The 22 Mercury and Gemini astronauts were free of symptoms because their head movements were restricted by body restraint

PORTABLE LIFE SUPPORT SYSTEM

During extravehicular activity astronauts wear gas impermeable space suits, which for the Apollo/Skylab missions were pressurised to a nominal 194 mm Hg (25.8 kPa) with pure oxygen supplied by a portable life support system.¹⁰ Although

and lack of room.¹⁵ The larger size of the Apollo spacecraft allowed more movement, and before the Apollo 10 mission head movements were actually encouraged.² As a result, five of the six crewmen of Apollos 8 and 9 reported symptoms. Similar problems were also experienced by the Soviet cosmonauts: the association between rapid head movements and malaise was first reported by Cosmonaut Titov, the second Russian in space.¹⁶

Space sickness produces similar symptoms to terrestrial motion sickness. It usually occurs early in flight, but after three days most astronauts are able to move their heads without any discomfort; all except the scientist astronaut on Apollo 9 were free of symptoms after six to seven days. This adaptation does not, however, afford protection against sea sickness on return to normal gravity. Furthermore, return is often associated with tumbling sensations and vertigo similar to those experienced during weightlessness. Physiologically, space sickness is probably due to absent or incorrect otolithic information which is at variance with normal semicircular canal cues.¹⁶ This is the opposite mechanism to the normogravic sensory mismatch between erroneous canal and correct otolithic cues (see previous article, 28 May, p 1728). The possibility that the redistribution of body fluid during weightlessness has a direct effect on the central nervous system is unlikely.¹⁷

Unfortunately, no laboratory test has yet been devised which accurately predicts an individual's susceptibility to space sickness, but Skylab experiments have shown that drugs against motion sickness—for example, hyoscine—are effective in its treatment and prevention.¹⁵

MUSCULOSKELETAL SYSTEM

Weightlessness reduces the muscular effort required to perform physical tasks and to control posture. Because of the relatively short duration of the Apollo missions (maximum 302 hours) muscle atrophy was not an important problem, although when investigated in Apollo 16 leg size was found to be decreased.¹² Changes in gait, due to reduced muscle tone, were also noted after flight in the crew of Soyuz 9, a Russian mission lasting 425 hours.¹⁸

Changes in body composition were studied in the nine astronauts who took part in the three extended Skylab missions (28, 59, and 84 days). Biostereometric analysis, using stereophotogrammetry, was used to measure the total and regional body volumes of the astronauts. All but one of the astronauts had lost muscle from the legs and probably also from other parts of the body, such as the trunk.¹⁹ Muscle atrophy was accompanied by increased urinary excretion of nitrogen (an average rise of 4.0 g a day over preflight values) and phosphorus (a negative shift of between 222 and 400 mg a day).²⁰ Muscle strength was also compared before and after flight using an isokinetic dynamometer. The different exercise regimens used on each mission showed that muscle exercising devices could reduce atrophy. Nevertheless, loss of strength from the arms was less than that from the legs, probably because everyday tasks required greater use of the arms.²¹ Overall, it was estimated that exercise during flight of 80-100 watt-minute per day per kilogram body mass would be needed to prevent leg muscle atrophy.¹⁹

Undoubtedly, the single most important effect of microgravity is the inexorable demineralisation of bone, which is as yet unpreventable. During the Gemini flights x ray densitometry showed reductions of 2% to 25% in the density of the astronauts' bones,²² but the methods used were later found to be inaccurate. In later Apollo, and all Skylab, flights the more sensitive technique of photon absorptiometry was used with a monoenergetic photon source.²³ Area scans conducted on the Skylab crews indicated that no bone mineral was lost from the radius and the ulna on any of the three missions. Loss from the os calcis was not seen on the first (28 day) mission but a reduction of 7.4% was recorded in one astronaut on the second (59 day) flight. It was also found in two (-4.5% and -7.9%)

of the three crewmen of the final (84 day) excursion.²³ Bone loss seems, therefore, to be regional, with greater losses from trabecular than from cortical bone. In studies of rats exposed to prolonged weightlessness trabecular bone volume was decreased and periosteal bone formation inhibited.²⁴

The amount of bone lost by individual Skylab astronauts correlated with the severity of each man's negative calcium balance. This negative balance, which was seen in all crewmen, was characterised by an increase in urinary calcium excretion, beginning soon after entry into orbit and persisting throughout flight, and a progressive decrease in net intestinal absorption as shown by increased faecal calcium.²⁰ The urinary losses averaged about 4 g of calcium (or 0.3-0.4% of total body calcium) a month and continued until return to normal gravity.²⁰ By extrapolation, clinical osteoporosis may be predicted to occur after four to eight months in space, with the consequent risk of fracture on return to normal gravity. Furthermore, although thin trabeculae can return to normal thickness, trabeculae that have been lost completely cannot be restored. An understanding of the aetiology of bone loss and the development of prophylaxis or treatment may, therefore, be vital to future extended space missions.

Bed rest and immobilisation produce a similar hypercalciuria to that seen in weightlessness,²⁵ so that disuse is a likely aetiological factor, but the actual mechanisms are not yet known. Plasma samples obtained in flight showed increased parathyroid hormone concentrations in some but not all of the Skylab astronauts compared with preflight values.²⁶ Such increases were paradoxical in view of concomitant increases in plasma calcium concentrations. Because of the problems of measuring small changes in the concentrations of parathyroid hormone, its function in bone resorption in space must remain uncertain, although increased parathyroid hormone concentrations have been reported during immobility,²⁷ and in animals immobilisation osteoporosis is prevented by parathyroidectomy.²⁸

Prevention of demineralisation by diet has not been investigated during flight, but diet has been found to be ineffective in patients treated with bed rest. Furthermore, hormonal intervention—for example, with calcitonin—has had no protective effect in such patients, although carefully controlled doses of diphosphonates, which inhibit bone resorption, may provide a remedy in the future.²⁹ The Skylab results also showed that demineralisation continued despite extensive exercise regimens, so that artificial gravity may have to be provided either continuously by rotating the spacecraft or intermittently by small centrifuges within the spacecraft. The latter approach was successful in preventing decalcification in rats after 19.5 days aboard Cosmos 936 when compared with an uncentrifuged control group.³⁰

CARDIOVASCULAR SYSTEM

Weightlessness neutralises the hydrostatic pressure gradients in the circulation so that in particular venous pressures become uniform throughout the body. Immersion in water produces a central shift of about 700 ml of blood from the legs,³¹ but under weightless conditions the volume of blood and interstitial fluid displaced from the lower extremities is considerably greater—about 2 litres.³² This discrepancy cannot be completely explained by the total abolition of hydrostatic gradients and suggests that active as well as passive factors control the compliance of the interstitial space³⁴ and determine the distribution of fluid between the intravascular and extravascular compartments. Measurement of interstitial fluid pressure in space is clearly desirable, but at present this could only be achieved by invasive techniques.

The fluid shifts in Skylab astronauts were complete by the time measurements were first made on the third and fourth day of the missions. The shift is, however, probably accomplished within 24 to 48 hours, since the astronauts noted sensations of

fullness in the head and nasal stuffiness early in the missions.³³ No direct measurement of central venous pressure has yet been made in astronauts, but inflight photographs (both conventional and infra red) showed that all Skylab crewmen had full, distended jugular and forehead veins.³² The venous distension and its associated symptoms remained through flight.

The central volume expansion might be expected to stimulate a diuresis via the Gauer-Henry reflex: suppression of arginine vasopressin secretion in response to distension of the left atrium.³⁴ This mechanism may have accounted partly for the weight losses induced by spaceflight in all astronauts before the Skylab missions. The increased space available in Skylab (1097 m³)¹² permitted measurement of mass during flight (by definition weight cannot be measured in the absence of gravity) using a spring mass oscillator.³⁵ This machine measures the period of oscillation of a mass set in linear oscillation between two springs; this period is related to mass and allows measurement to an accuracy of 0.01%. Daily measurements showed that the astronauts rapidly lost between 1 and 2 kg within three to four days, which was probably due to fluid loss. This was followed by a slow but steady decline in mass during the rest of the flight attributable to loss of muscle and fat.³⁵

In all Skylab crewmen the net loss of fluid was caused by suppression of thirst rather than by diuresis. On average each astronaut excreted 400 ml less urine over the first six days during flight than over an equivalent period before flight, and water intake was decreased by an average of 900 ml.²⁶ Over the same period the urine osmolality also increased and was associated with increased urinary arginine vasopressin values early in flight. Twenty four hour urinary excretion of sodium and potassium was increased throughout flight in most of the Skylab crewmen, and during this period all nine crewmen had increased urinary aldosterone values, which could account for the urinary losses of potassium but not of sodium.²⁶ Increases in aldosterone also occurred in crewmen in the second half of the Apollo 17 mission, but a negative sodium balance persisted.³⁶

The mechanism of increased sodium excretion remains unknown. In studies of human subjects immersed in water natriuresis begins within the first hour and is accompanied by kaliuresis and diuresis.³⁷ These changes are associated with depressed arginine vasopressin secretion³⁸ and suppression of the renin-aldosterone system.³⁹ Injection of arginine vasopressin, although suppressing the diuresis, does not, however, prevent the natriuresis.⁴⁰ A natriuretic factor may be present in the urine of subjects immersed in water,⁴¹ and a natriuretic hormone has recently been isolated,⁴² so that the sodium loss during weightlessness may depend on the increased secretion of such a substance.

Whether central volumes and pressures are returned to normal preflight values by these homeostatic mechanisms is not known. The persistent facial puffiness suggests they are not and raises the question of whether long term weightlessness will induce changes in cardiac function comparable with those in patients with cardiac failure.

All astronauts have undergone electrocardiographic monitoring during flight, but not until Apollo 15 were any abnormalities recorded. The bigeminal beats and premature contractions (atrial and ventricular) that occurred during activity on the lunar surface and the return flight to earth were attributed to potassium deficit.¹²⁻¹³ Potassium supplements did not, however, prevent similar potassium losses during the Apollo 17 mission,³⁶ a flight in which no arrhythmias were noted. During Skylab missions prolonged PR intervals were recorded in all astronauts and attributed to increased vagal tone.⁴⁴ Sporadic ventricular ectopics also occurred but there was never any evidence to suggest myocardial ischaemia.⁴⁴ Extensive studies carried out on the Skylab astronauts after flight indicated that despite reductions in left ventricular end diastolic volume, stroke volume, and left ventricular mass no appreciable alteration in cardiac function had occurred.⁴⁵

The most important effect of the cephalad shift of fluid in

weightlessness is the temporary orthostatic intolerance that occurs when blood is pooled in the legs as a result of returning to normal gravity. This was shown—for example, after the Apollo missions—by a fall in systolic pressure, a narrowing of pulse pressure, and an increased heart rate in response to lower body negative pressure.⁴⁶ These responses were exaggerated when compared with preflight findings and were also associated with an increased incidence of presyncopal symptoms. Exercise tolerance was also reduced for up to 36 hours after flight.⁴⁷

During the Skylab missions determination of lower body negative pressure during flight suggested that orthostatic intolerance improved slightly after 30 to 50 days of weightlessness but the tests still remained more stressful than before flight.⁴⁸ More recent Russian studies of missions of up to 185 days have suggested that cardiovascular changes do not progress after two to three months in space.⁴⁹ Both American and Soviet astronauts have used anti-G suits, inflated before re-entry, to reduce peripheral pooling of blood and consequent cardiovascular stress. Since this and other countermeasures, such as saline ingestion by cosmonauts, have not proved entirely effective the creation of artificial gravity may again be the only complete solution to the problems of cardiovascular deconditioning in weightlessness.

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Are there any medical conditions, such as epilepsy, which should preclude employees using visual display units. Are there any tests or questionnaires that might identify susceptible individuals?

Computers present textual or graphic material on a wide variety of terminals, the most common of which use cathode ray tube displays. These displays are almost always intermittently illuminated, although the frequency and depth of modulation vary considerably and the flicker is not usually visible. Some terminals use adapted televisions on which the display is created from interlaced lines that "vibrate" 25 times a second. On others the interlace is suppressed and the display is refreshed at frequencies of 50 per second or more.¹ There have been several cases of seizures associated with the operation of visual display units. Such seizures are rare. By far the most common complaints are those of tired eyes and headaches. It is preferable to prevent these disorders than to prevent the people who suffer them from using displays. In photosensitive people (about 5% of patients with epilepsy) seizures may be induced by visual stimulation with specific spatial and temporal characteristics. These include static patterns of stripes (particularly when the stripes subtend about 15 minutes of arc at the eye) and diffuse flickering light (particularly when the flicker frequency is close to 20 per second). Television induces seizures partly because of the interlaced "vibrating" lines and partly because of the 50 per second scan. At viewing distances greater than about three times the width of the screen the interlace cannot be adequately resolved and the chances of a seizure are greatly reduced. Diffuse intermittent light is more likely to induce seizures when the frequency is 50 per second than at higher frequencies such as 60 per second.² Displays with high refresh rates may therefore be preferable.

The spatial characteristics of the displays are critical. It is now

known that the pattern formed by successive lines of text can be epileptogenic, particularly when the lines are closely spaced in a large continuous block of text. The effects of this pattern are minimised by reducing the number of lines displayed and by increasing the separation between them.³ People liable to visually induced seizures may be identified with the help of electroencephalography and suitable visual stimulation, preferably including the particular display in use. There is increasing evidence that epileptogenic pattern stimulation provokes visual disturbances and complaints of tired eyes in people without epilepsy. Migraine sufferers commonly report visual precipitants of headaches broadly similar to those that induce seizures. People susceptible to eye strain and headaches cannot easily be identified with objective tests. A statistical relation exists between the number and nature of the headaches people suffer and the visual illusions they report when they look at epileptogenic patterns. Unfortunately this relation is not good enough to screen for people at risk. It may be impossible for an individual sufferer to select a visual display unit with a high refresh rate and one without interlace. He may also be unable to adapt commercial software so as to improve the textual or graphic layout. In these circumstances the options are limited to covering sections of the display that are unnecessary—for example, text that has been read. When the text scrolls upwards from the bottom of the screen this can be achieved by hinging dark matt plastic from the screen surround so as to cover all but the bottom three lines.—A WILKINS, applied psychologist, Cambridge.

¹ Brown BS, Dismukes K, Rinalducci EJ. Visual display terminals and vision of workers. *Behaviour and Information Technology* 1982;**1**:121-40.

² Jeavons PM, Harding GFA. *Photosensitive epilepsy*. London: Heinemann, 1975.

³ Wilkins AJ, Binnie CD, Darby CE. Visually-induced seizures. *Progress in Neurobiology* 1980;**15**:85-117.