Environmental Factors in Helicopter Operations

Maj R Thornton,
MBChB, Dip Av Med, AFOM, MRAeS, RAMC
Royal Army Medical College, Millbank

Maj P Vyrnwy-Jones,
MBBS, Dip Av Med, MSc, AFOM, RAMC
Royal Air Force Institute of Aviation Medicine, Farnborough

SUMMARY: The environmental problems affecting aircrew are partly those which all soldiers face, such as noise, heat and cold, and partly peculiar to the medium and the vehicle in which aircrew train and fight, such as disorientation and decompression. The cockpit environment of the modern helicopter is luxurious in comparison with many of its predecessors, yet most of the adverse effects of flight on the man still pertain. The result can, predictably, be acute and disastrous, resulting in an accident produced by severe disorientation, or chronic, producing insidious fatigue and performance decrement, which may also result in an accident. One particular stressor may be dominant in a given situation, but generally, many separate factors act simultaneously to produce their results.

The effects of pressure change

The normal operating ceiling for helicopters is only 10,000 feet above mean sea level (AMSL). Because of the exponential relationship between pressure and altitude, however, (Figure 1), the atmospheric pressure and the partial pressure of oxygen are both significantly reduced. Helicopter cockpits do not enjoy the luxury of pressurisation.

The first effect of reduced pressure apparent to a passenger in any aircraft is that of gas expansion, according to Boyle's Law. This affects all the gas-containing cavities of the body, principally the middle ears and sinuses.

The middle ear cavity communicates with the atmosphere by way of the Eustachian tube, the proximal two-thirds of which has soft walls which are normally collapsed. As the outside pressure reduces, the gas in the middle ear expands and vents freely into the naso-pharynx, so that pressure equalises on both sides of the tympanic membrane, the familiar popping of the ears.

On descent, gas from the naso-pharynx must enter the middle ear, but the valve-like arrangement of the Eustachian tube opening prevents this from happening passively in most individuals. If descent continues without equilibration, the tympanic membrane is pushed into the middle ear, causing initially a sensation of fullness in the ear and decreased hearing acuity, and eventually pain and the possibility of rupture. Several manoeuvres are employed to open the Eustachian tube, such as swallowing, yawning, jaw movement, or occluding the nostrils and raising nasopharyngeal pressure.

Upper respiratory tract infection (URTI) causes oedema of the mucosal lining of the Eustachian tube, exacerbating the difficulty in clearing the ears, one of several reasons why aircrew should never fly with such a condition.

The sinuses in health communicate freely with the nose during ascent, and obstruction can readily occur in the presence of an URTI, particularly during rapid descent,
causing pain and lacrimation. Auto inflation is difficult in this case, and the rate of descent may have to be controlled. The two conditions are known as otitic and sinus barotrauma, respectively.

The oxygen dissociation curve protects against the worst effects of the reduced partial pressure of oxygen at relatively low altitudes, yet even the 25% reduction at 8,000 feet produces measurable impairment of performance. Performance at well-practised psychomotor tasks is unimpaired below 10,000 feet, as are long and short-term memory, mental arithmetic and tests of reasoning. Reaction time to a complex choice-reaction test, however, has been shown to be doubled at 8,000 feet, compared with sea level, and is just detectable at 5,000 feet. It can be demonstrated that the light sensitivity of the dark-adapted eye is impaired from 5,000 feet, though the magnitude of the effect reaches significance only at 12,000 feet. If the arterial oxygen tension is already reduced by cigarette smoking, its importance increases correspondingly.

Decompression sickness is due to supersaturation of the tissues with nitrogen as the atmospheric partial pressure of nitrogen falls on ascent, because of its low solubility. This can give rise to the formation of gas bubbles in a variety of body tissues, presenting as joint pain ('bends'), respiratory disturbances ('chokes'), or neurological problems ('staggers'). The threshold for the occurrence of decompression sickness is 18,000 feet. Its significance to helicopter crews arises when flight follows a hyperbaric exposure, as in diving, whether in casualty evacuation following a diving accident, or aircrew or passengers indulging in sports diving.

Noise and communications

Helicopters are among the noisiest of modern aircraft. The sources of noise are legion, so that frequency analysis produces a series of spikes corresponding to the low frequency 'chopping' of the rotor blades, harmonics of the main rotor frequency, the tail rotor and its harmonics, the high frequency whine of the compressor, and the transmission (Figure 2). In addition, the aircrew are assaulted by noise from their headsets, originating from perhaps four radios, the intercommunication system, and cabin noise transmitted from their microphones.

At noise levels reaching the ear of 95 dB(A) or more, reduced communication efficiency, increased workload and fatigue, and temporary and even permanent hearing loss may occur. If noise levels were considered at the design stage of a helicopter, an engineering solution to the problem could be achieved, by appropriate positioning and isolation of all major components, and selection of suitable communication equipment. As with all other human factor aspects of helicopter design, such forethought does not appear to occur. Secondary protection is therefore necessary, using noise attenuating helmets, voice operated switching, adaptive noise cancelling, re-shaping of audio signals and active noise reduction.

**Vibration**

The sources of noise in helicopters also produce vibration, in all axes, and predominantly at low frequencies (1-50 Hz). It can be exacerbated by particular flight conditions, and its effects include fatigue, discomfort and degradation of performance. A particular problem arises from the fact that the resonant frequencies of the head and eyeball lie within this range, and difficulties may occur in reading instruments, target tracking and even viewing the outside world. Vibration has also been incriminated in the aetiology of backache in aircrew, though recent work by the United States Army suggests that it is not a major factor when compared with poor seating and the posture adopted by pilots in flight.

Prevention is again largely an engineering problem, though attempts at isolating the crewman using seat dampers and suitable foam cushions have had some success.

**Thermal problems**

Helicopters are found in support of the Army in all parts of the world, including Belize, Brunei and Cyprus, the Falkland Islands and Norway. The greenhouse effect of the large area of cockpit canopy can produce temperatures much greater than those outside. Cooling is achieved by inefficient ram air systems, or by opening windows and doors, unpopular because of the increase in noise levels. In normal clothing assemblies the resulting thermal strain on aircrew is physiologically acceptable, though it may produce fatigue and impaired performance. With the increased thermal insulation of NBC equipment, the potential exists for thermoregulatory failure, particularly...
if energy expenditure is also increased, as is the case with support helicopter crewmen. Modern helicopters have reasonably efficient heaters using engine bleed air, though some are rarely used because of the accompanying noise. Cold is thus not a problem in flight, but rather in the survival situation, particularly in water when there is no time to don additional protective clothing. This, paradoxically, can lead to a situation in which aircrew flying over the sea in early summer, when sea temperatures may still be low enough to require the use of an immersion suit, suffering from the effects of thermal strain through having to wear the suit in flight.

Disorientation

15% of Army Air Corps helicopter accidents have been attributed to disorientation, accounting for one third of all fatalities. Spatial disorientation is the term used to describe a wide range of incidents where the pilot fails to sense correctly the position, motion or attitude of his aircraft, or of himself, with respect to gravitational vertical. Virtually all aircrew are repeatedly subject to minor degrees of disorientation. It is a normal phenomenon caused by the physiological limitations of the sensory mechanisms used for the perception of orientation. These mechanisms have developed to provide information on orientation in an earthbound 1G environment, with input from the eyes, inner ear and proprioceptors. When subjected to the abnormal accelerations of flight these same mechanisms can convey misleading information which may be ignored successfully in most situations, or become apparent as an illusion which the pilot is able to overcome, albeit with the development of a measure of anxiety and fatigue; or the disorientation may not be perceived, control of the aircraft is based on the erroneous perception, and an accident may result.

The eyes are the most important and most reliable sense organs providing orientation information. In conditions of good visibility, with a clear horizon, the task of determining the orientation of the aircraft is a simple extension of the perceptual skills developed on the ground. In poor visibility, or when flying in cloud, the symbology of the aircraft’s instruments must be interpreted to provide the same information. These cues lack the familiarity, and therefore the ‘strength’, of external visual cues.

The organ of equilibrium of the inner ear is the vestibular apparatus. The semicircular canals function as 3 matched pairs detecting angular acceleration in the 3 orthogonal axes of pitch, roll and yaw. The canals have a threshold of 3° per second, above which change in angular velocity is detected by the pair of canals in the plane of movement. Movement continues to be detected only so long as there is a suprathreshold acceleration or deceleration. Once constant velocity is reached, the signal will decay, even though movement is continuing. The otoileths act as linear accelerometers, detecting acceleration in horizontal (utricles) and vertical planes (saccules). The otoileths are sensitive to accelerations greater than 0.1 ms⁻², with the signal again decaying as constant velocity is reached.

The principal function of the vestibular apparatus is the reflex maintenance of equilibrium through muscle groups. The particular significance of this in aviation lies in the vestibulo-ocular reflex, which stabilises the position of the eyes relative to a viewed object, whenever the head is moved.

The proprioceptors of skin, joint capsules and ligaments are responsible for the perceptual bond between the pilot and his aircraft, so that cues from other organs are perceived not simply as movements of the head, but of the whole aircraft.

The illusions which aircrew suffer can be divided into those due to input error, when erroneous or inadequate information is transmitted to the brain, and those due to central error, where there is an erroneous or inadequate perception of correct sensory information by the brain. The input errors can be further classified by the organ in which they originate, and in each case they may be inadequate or erroneous.

Visual illusions

Disorientation rarely occurs when a pilot flies in good visibility with a clear horizon. If he attempts to fly in fog, cloud, rain, snow or total darkness, disorientation rapidly ensues, unless attention is transferred immediately and completely to the flight instruments. It is when an aircraft is flown inadvertently into cloud, and the pilot is slow to transfer his attention, or when trying to mix instrument and visual flight in conditions of gradually deteriorating visibility, that he is particularly vulnerable.

Even in good visibility the external cues provided by ground texture or calm water may be inadequate for the perception of height. Difficulties arise particularly when attempting to hover or land, and flying at very low level. The small area illuminated by the landing light at night exacerbates the problem.

An example of erroneous visual information is when a pilot estimates height above a forest of conifers, only to discover on closer inspection that it is a plantation of saplings, and the pilot is much nearer the ground than he first thought.

Illusory perceptions of motion can be generated by movement of external visual cues. The rearward moving wave pattern created by the rotor downwash when hovering over long grass or water, may produce a sensation of forward movement. Water droplets or snow moving downward in the air flow can produce a similar illusion of climbing. Flicker vertigo is a sensation of angular motion in the opposite direction to the moving shadow of the rotor blades.

Epileptic Phenomena

Flicker is one of the stimuli, like hunger or fatigue, which can induce paroxysmal brain activity. On rare occasions myoclonic jerks or perceptual distortions may result.
Vestibular illusions

Inadequate vestibular cues pertain when a change in linear or angular velocity takes place which is below the threshold of the otoliths or semicircular canals. The figures already quoted are derived from laboratory work. In practice they may be much higher, as the pilot's attention is likely to be distracted. Subthreshold angular rotation is responsible for the most commonly reported form of disorientation, the 'leans'. The aircraft is inadvertently allowed to adopt a slight 'one wing low' attitude at a subthreshold rate (Figure 3), and the vestibular apparatus is not stimulated. On noticing his abnormal attitude, normally by reference to his flight instruments, the pilot recovers to level flight, but relatively quickly, at a supra-threshold rate of angular acceleration. The ensuing perception is one of bank in the opposite direction, even though the aircraft is 'wings-level'. He may even attempt to counteract this strong conflict by leaning his body, to align it with his perceived vertical.

Environmental Factors in Helicopter Operations

Erroneous vestibular information is also common. The somatogyrical illusion is produced by executing a prolonged steady turn. As the pilot rolls into the turn, the cupulae of his semicircular canals in that plane are deflected by the angular acceleration, generating an appropriate signal (Figure 4). Once the rate of turn becomes constant, the cupulae start to return to their resting position, as, although there is still angular velocity, there is no angular acceleration. All vestibular sensation of roll ceases. When the pilot then recovers back to straight and level flight, there is angular acceleration in the opposite direction, which is sensed by the semicircular canals as a roll in the opposite direction of equal intensity, despite the aircraft flying level. This sensation in turn decays.

![Fig. 4 Response of the cupula and sensations of turning during prolonged rotation (After Benson)](image)

Particularly bizarre sensations of movement are produced by the semicircular canals if the head is rotated while the aircraft is turning. This cross-coupled (Coriolis) effect is produced by the stimulated canals being removed from the plane of rotation at the same time as a previously unstimulated pair enter the plane of head movement. The induced sensation is normally one of movement in the plane of the third pair of semicircular canals which received no stimulation.

Central illusions

Coning of attention, or fascination, occurs at times of high workload or undue anxiety. The regular scan of attention round the instruments and the outside world breaks down, and one instrument, or an external feature, absorb all the pilot's attention, so that the development of changes in other parameters is missed. Errors of expectancy have already been discussed under visual illusions, and occur because the brain 'expects' trees to be a particular height.

Because disorientation is a normal physiological response to an abnormal environment, prevention is
difficult. Aircrew are educated about disorientation, and are taught to recognise the environments and manoeuvres which are likely to produce it, and what to do when it occurs.

Motion Sickness

The symptoms and signs of motion sickness are too familiar to most people to need description. Air sickness is no different. It is a normal response of the healthy individual to unfamiliar motion of sufficient severity. Its significance in aviation lies in three different areas. Aircrew themselves are by no means immune, particularly during training, before they have a chance to adapt to the unusual motion stimuli. Passengers including paratroops are obviously prone to air sickness because of their unfamiliarity with the environment. In the survival situation, sea sickness can be potentially fatal when drinking water is already restricted.

The ‘neural mismatch theory’ of Reason is the most favoured aetiology for motion sickness. The sensory information received by the brain from the eyes and vestibular apparatus in particular, is at variance with the information the individual expects to receive, based in his past experience, due to ‘mismatch’ between the two pairs of organs. An example would be when the vestibular apparatus is stimulated by turbulent flight, but the individual is unable to see the outside world through the eyes. This partly explains the increased incidence in observers and navigators who habitually spend much of their time studying maps. It is also due in part to the pilot knowing how the aircraft is about to respond to his control inputs, whereas the observer may be taken by surprise by changes in the aircraft attitude.

Individual susceptibility to motion sickness depends on three factors, receptivity, adaptability and retentivity. Receptivity refers to the way in which the individual processes the stimulus. High receptivity denotes a powerful subjective response to the stimulus, because of a more intense neural mismatch. Adaptability describes the rate at which an individual adapts to a new motion environment. Slow adaptors are more susceptible to motion sickness (though they need not be more receptive). Retentivity denotes how well adaptation is retained between exposures to the provocative motion environment. The aviator with poor retentivity develops motion sickness unless he can fly regularly. Returning after leave or illness may be accompanied by a resumption of symptoms.

The treatment of motion sickness in the student pilot or observer begins with the sympathetic instructor who gently introduces the new environment, encourages his pupil to report early symptoms, and moderates or curtails the flying accordingly. Medical intervention, having as far as possible excluded other causes, including the use of symptoms to explain poor flying performance or motivation, usually begins with a short period of a drug such as hyoscine. Solo flight during treatment is banned completely. The drug is effective by allowing flying to continue, and therefore adaptation to be achieved. It has the added advantage of not interrupting flying training.

If drug therapy fails, and the student is well motivated and has proven potential, desensitization therapy may be carried out. This involves a ground phase of repeated cross-coupled stimulation, increasing the duration over several days until adaptation is achieved. The stimulus is produced by rotating the pupil about a vertical axis, while he is instructed to move his head in pitch and roll. At the successful completion of the spin table phase, he progresses to a flying phase which is divorced from his normal training, and concentrates on gradually increasing the student’s adaptation.

REFERENCES

Environmental Factors in Helicopter Operations

R Thornton and P Vyrnwy-Jones

J R Army Med Corps 1984 130: 157-161
doi: 10.1136/jramc-130-03-03

Updated information and services can be found at:
http://jramc.bmj.com/content/130/3/157.citation

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/