Chapter 25

AVIATION MEDICINE

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INTRODUCTION

Historically, military recruits were selected primarily for their strength and size and, more recently, for a lack of infectious or debilitating medical conditions because soldiers traditionally walked to war carrying their weapons and survival equipment and had to fight hand to hand. In all the services, physical strength was a sine qua non of job performance. The selection of military aviators was among the first deviations from this concept, as it was realized early that flying did not simply require strength but also excellent sensory perception, an agile mind, and quick reaction speed.

Since the early days of military aviation, it has been recognized that the aviator faces most of the same stressors as other service members, plus many more from the aerial operational environment (Exhibit 25-1). (Since at present manned space flight has little direct military utility, this chapter omits the space aspect of aerospace medicine.) Compounding these stresses is the fact that to be combat effective, the aviator must be at the highest possible level of mental and physical capability. To ensure that he or she maintains this peak capability, each US military service has devoted specially trained physicians to this duty—the flight surgeons.

EXHIBIT 25-1

STRESSES OF THE AVIATION ENVIRONMENT

- Aircraft crash protection equipment
- Aircraft escape systems (eg, parachutes, ejection seats)
- Altitude-induced dysbarisms
- Cold
- Exposure to toxic gases and chemicals
- Fatigue
- G forces (acceleration)
- Heat
- Helmet-mounted displays and sighting systems
- Hypoxia
- Motion sickness
- Noise
- Operational psychological stress
- Simulator sickness
- Vertigo
- Vibration
- Visual and sensory illusions

Many of the flight surgeon's duties (Exhibit 25-2) are the same as those of any operational military physician, so the question must be asked, "What makes aviators different from other soldiers, sailors, airmen, and Marines, and why must aviators have their own specially trained physicians?" The answer is that most medicine is concerned with the patient experiencing abnormal physiological function in his or her normal environment; aviation medicine, in contrast, focuses on normal physiological function in an abnormal environment. This short description of aviation medicine will discuss some of the medical aspects of this abnormal environment and will consider some issues in operational flight medicine. This presentation is only intended to summarize the basics of the field—the information all military physicians should know in the event that they find themselves providing care for aviation personnel. It is not intended as a "short course" in aviation medicine. Numerous references are available for more in-depth information; some are listed at the end of this chapter.

HISTORY OF AVIATION

Lighter-Than-Air Period

Excluding myths and legends, probably the first human flights took place in balloons, and physicians rapidly became involved in identifying the physiological stresses faced in this new environment. Dr. Jacques Charles made a balloon ascent on 1 December 1783, during which he served both as aeronaut and flight surgeon, suffering from and correctly diagnosing barotitis (which he was unfortunately unable to treat). Soon after the flight of the Montgolfier brothers in front of the Medical Faculty of Montpelier in 1784, physicians began to discuss the effects of flight on both sick and healthy aeronauts, with one physician recommending that the sick be offered the benefit of flight because of "the purer air encountered at altitude."[1p833] Early balloon flights reached only very low altitudes and thus rarely caused physiological distress in the aeronauts. The major health hazard of balloon flight at low altitude was death from falls. However, higher altitudes reached within a decade of those first

EXHIBIT 25-2

DUTIES OF THE FLIGHT SURGEON*

- Administrative functions (eg, flight evaluation boards, grounding and ungrounding, waiver actions)
- Aircrew physical evaluation (selection and maintenance)
- Care of acute trauma
- Crash investigation
- Diving medicine (in some services)
- Emergency care
- Evaluation of aircrew survival equipment
- Evaluation of crash protection equipment
- High-altitude parachuting support (in some services)
- Hyperbaric treatment (in some services)
- Inflight evaluation of pilots' capabilities
- Medical aspects of civic action programs (disaster relief)
- Medical intelligence production and evaluation
- Medical preparation of unit for deployment
- Occupational medicine (eg, hearing conservation, toxic exposures, repetitive stress injury)
- Operational planning support
- Participation in flight missions
- Pre-deployment planning and medical advice
- Prevention of combat stress
- Primary care (sick call)
- Provision of inflight care during medical evacuation
- Research and development
- Staff advisor to commanders
- Training and supervision of medics
- Training of aircrew in physiological factors of flight and human factors affecting flight safety
- Unit-level preventive medicine

*The US Army has trained physician assistants in aviation medicine—the aeromedical physician assistants—and for the purposes of this chapter, they are considered flight surgeons.

flights regularly caused medical problems, which are noted in the ballooning reports of Glaisher, Robertson, and Gay-Lussac, among others.

During the 19th century, other means of flight, each with its own risks and stresses, were experimented with, including man-lifting kites, gliders, and powered heavier-than-air craft. There was little interest in the physical effects of flight on humans, as the concern was more whether flight other than by balloon was possible. Particularly as balloonists reached higher altitudes, though, basic work on altitude physiology was accomplished. Soon after the manned balloon appeared, it became a military tool. The French used observation balloons in the battle of Fleurus in 1794, and they were used repeatedly by many nations for this purpose during the 19th century. There is no documented evidence of medical problems engendered by these tethered flights at low levels, but one wonders how many potential observers were eliminated due to "fear of flying."

Heavier-Than-Air Period

As with many other medical advances, operational aviation medicine grew out of war. In the first few years of heavier-than-air aviation, flights were low and slow and demanded little more than courage from the aviator. Physical considerations were of much less importance. There was little in the medical literature about altitude physiology, since only after 1910 could airplanes even approach 10,000 ft and the relevance of flight experience in balloons was nearly forgotten. In 1910, there were only about 320 aircraft in the entire world,[2] but during World War I this number climbed to tens of thousands. More important than the numbers, however, was the rapidly developing technology of aviation, as exemplified in the massive changes in aviation from 1913 to 1918. Speeds, altitudes, and military operational necessity soon added a host of stresses to those recognized before the war. No longer would an interest in flight coupled with physical courage be sufficient to qualify for pilot training. Certain physical capabilities began to be sought by the military.

In the earliest days of the war, some officers were reassigned into aviation when they became physically unfit for the infantry or cavalry. However, the necessities of war soon led all participating nations to realize that they needed to pay special attention to the selection and care of the aviator, and studies on the actual physiological and psychological requirements began to be carried out.

In these early days, accident rates were horrendous, largely due to "pilot failure." British studies[3] showed that of every 100 aviators killed, 2% were lost to enemy action, 8% to mechanical failure, and 90% to physical or mental deficiencies. In an attempt to reduce this large number of physical failures, physicians were assigned to aviation units to care for and monitor aviators. As these flight surgeons became more familiar with the flight environment, they began offering aviators and their commanders advice based on practical experience rather than theories. Although it was realized that not everyone should be an aviator, there was no recognition of any valid basis for selection. Each nation developed pilot qualification standards (which varied widely in emphasis) in accordance with its own national medical theories. Some standards were so stringent that few candidates could pass them, severely limiting the number of pilots.

After 1916, there was an outpouring of research on altitude effects, psychophysiological reactions, and cardiocirculatory response to flight stresses, including altitude. Much of this research analyzed the oft-discussed *mal du aviator*, the concept that flying was difficult, exhausting, and destined to wear out the bodies of aviators. Much additional effort was expended on determining individual pilots' tolerance to lowered oxygen tension and whether repeated exposure led to tolerance.

The immediate postwar years were nearly stagnant in technological terms, with little aircraft production or new technology, but aviators continued to push the limits of their aircraft and their bodies. Speeds and altitudes continuously increased, with maximum speeds reaching 575 km/h in 1929 and maximum altitudes reaching 13,100 m in 1930.[4] For the first time, pilots were routinely experiencing sustained gravity, or G, forces of acceleration. Aviators began intensive study of night flying and blind (instrument) flying, and the few flight surgeons left on active duty were deeply involved in evaluating the physiology involved in these new techniques. Other work led to the elucidation of the causes of decompression sickness. The work from this period proved that aviation itself is not inherently unhealthy (laying to rest the old canard of "aviator's illness") and that it causes no persistent organic or functional changes in aviators.

During World War II, the stresses of flight grew exponentially. Flights at altitudes hitherto record-setting became routine, air-to-air combat increasingly allowed the development of sustained G loads, multiple engines of increased power led to increased problems with vibration, and operational requirements led to aviators flying in the extreme cold of high altitude and the extreme heat of North Africa. As jet aircraft and helicopters entered the inventory, additional stresses were placed on pilots. The military's heavy reliance on the helicopter in Korea and Vietnam and during Operation Desert Storm raised new medical problems, especially vibration and crash survivability. In general, though, the problems were medically the same as during previous wars. Despite these changes in technology, the medical needs of the aviator and the duties of the flight surgeon have not changed.

CLINICAL AVIATION MEDICINE

Routine clinical care for aviation personnel is similar to that for other military personnel. The major distinction is in the degree of impact on mission accomplishment caused by even minor illnesses. Aviation personnel must always be as close to 100% performance as possible. While a combat service support soldier with diarrhea will be miserable and less than optimally functional, he or she usually will be able to carry out the mission; an aviator with severe diarrhea or taking most medicines that control it will be unable to carry out any aviation mission safely. Some medications exacerbate the various physiological stresses of flight and though perfectly safe in the ground environment may be hazardous in aviation. Thus, the difference in medical mission is not so much in the clinical variations of practice as it is in the knowledge and recognition of the effects of disease and of medications on the body in the abnormal environment of flight. Understanding the physiology of the aviation environment is necessary to understand the medical needs of the aviator.

MAJOR PHYSIOLOGICAL CONCERNS ASSOCIATED WITH FLIGHT

Humans are adapted for life near sea level, where the normal atmospheric pressure is 760 mm Hg. Temperature and pressure decrease with increased altitude, adversely affecting physiological functions. A healthy individual readily adapts to minor variations, but if an organ or system is the site of pathological change or if the environmental change is too great, then adjustment may not occur and adverse symptoms will develop. If the aviator cannot compensate in some way, body functions will fail, and he or she will not be able to control the aircraft in an operational environment.

Alterations in barometric pressure occurring with altitude changes cause the primary adverse effects of flight on the body's physiological processes. The effects due to increasing altitude are manifested primarily in two forms: a decrease in the partial pressure of oxygen in the inspired air and an expansion of gases.

Hypoxia

Although the composition of the atmosphere remains nearly constant at all flying altitudes (78% N_2, 21% O_2), the amount of oxygen physiologically available does not. In any mixture of gases, the total pressure exerted by the mixture is equal to the sum of the pressures each gas would exert if alone in the same volume. At sea level, the total atmospheric pressure is 760 mm Hg, and the partial pressure attributable to oxygen is 159 mm Hg. This PO_2 is adequate to produce a hemoglobin saturation of 98%, which sustains life. However, the PO_2 is reduced at increased altitude, with consequent reduction in hemoglobin saturation even in normal individuals. At 10,000 ft, the total atmospheric pressure is approximately 523 mm Hg, with only 110 mm Hg provided by O_2. This leads to 60 mm PO_2 in the alveoli, which produces an arterial hemoglobin saturation of only 87% and causes symptoms of insidious hypoxia. But hypoxia simply due to altitude must be differentiated from other types of hypoxia, including pathological hypoxia, hypemic hypoxia, stagnant hypoxia, and histotoxic hypoxia (Table 25-1), because both preventive measures and corrective measures vary depending on the cause.

People differ in their reaction to hypoxia, but there are also many variables that determine the rapidity of onset and the severity of hypoxia symptoms, including:

- altitude reached (which determines the PO_2 in the lungs),
- rate of ascent to altitude (rapid rates of ascent may lead to achievement of high or hypoxic altitudes before the onset of warning symptoms),
- duration of time at altitude (in general, longer exposures lead to increased effects),
- temperature (increased metabolic rates may lead to hypoxic effects at lower altitudes),
- physical activity (increased oxygen demand may lead to the more rapid onset of clinical hypoxia), and
- individual factors, such as inherent individual tolerance, physical fitness, emotional state, acclimatization, and use of cigarettes.

A high external temperature, significant physical exertion, or fear favors the development of symptoms at lower altitudes. Physical fitness and acclimatization to high altitudes (eg, by living at elevations above 10,000 ft) raise the altitude level at which an individual will begin to experience hypoxic symptoms.

As hypoxia develops, the body experiences several stages, which are defined in terms of the degree of incapacity.

Indifferent Stage

This stage occurs at altitudes between sea level and 10,000 ft (39,000 ft if breathing 100% oxygen). The barometric pressure drops from the normal sea level pressure of 760 mm Hg to 523 mm Hg. Healthy individuals are physiologically adapted to this level, and ambient PO_2 is sufficient without the aid of protective equipment. There are no physiological effects except for some deterioration of night vision, which starts at about 5,000 ft. Hemoglobin saturation remains 90% to 100%.

TABLE 25-1

TYPES OF HYPOXIA

Type	Physiology	Common Causes
Hypoxic hypoxia	Inadequate oxygenation of blood in the lungs	Insufficient O_2 in inspired air (eg, at altitude, with contaminated breathing air)
Pathologic hypoxia	Inadequate oxygenation of blood in the lungs	Defects in oxygen diffusion from lungs to bloodstream even in the presence of adequate inspired O_2
Hypemic hypoxia	Reduction of oxygen-carrying capacity of the blood	Anemia, blood loss, carbon monoxide poisoning, drug effects (eg, nitrites, sulfa)
Stagnant hypoxia	Inadequate circulation (oxygen-carrying capacity of blood is normal)	Heart failure, arterial spasm, venous pooling during positive-G maneuvers
Histotoxic hypoxia	Interference with the use of O_2 by the tissues	Alcohol, narcotics, certain poisons (eg, cyanide)

Compensatory Stage

This stage occurs at altitudes between 10,000 and 15,000 ft (39,000 to 42,000 ft if breathing 100% oxygen). At the upper altitudes of this range, the barometric pressure falls to 429 mm Hg and the ambient PO_2 drops to 87 mm Hg. Unless supplemental oxygen and other equipment (eg, pressure regulators at the higher altitudes) are used, noticeable physiologic problems occur. This lowered PO_2 rapidly leads to oxygen deficiency, causing mild altitude hypoxia. Hemoglobin saturation ranges from 80% to 90%, and cardiac output, blood pressure, and pulse rate increase. Respiration increases in depth and sometimes in rate. Physiologic compensation provides some defense against hypoxia so that effects are reduced unless the exposure is prolonged. The healthy aviator functions normally in this stage for approximately 2 or 3 hours.

Disturbance Stage

This stage occurs at altitudes between 15,000 and 20,000 ft (42,000 to 44,000 ft if breathing 100% oxygen), and physiological responses no longer compensate for the oxygen deficiency. Hemoglobin saturation is 70% to 80%. Occasionally there are no subjective symptoms of hypoxia until unconsciousness occurs, but usually symptoms are noted. The aviator becomes drowsy and may make errors in judgment. He or she has difficulty with simple tasks requiring mental alertness or muscular coordination.

Critical Stage

This stage occurs at altitudes between 20,000 and 23,000 ft (44,000 to 46,000 ft if breathing 100% oxygen). Hemoglobin saturation is less than 70%. Within 3 to 5 minutes, judgment and coordination deteriorate and mental confusion, dizziness, and incapacitation occur.

Due to the significant risk of hypoxia during flight, it is imperative that each aviator knows about the symptoms of hypoxia (Exhibit 25-3) so that countermeasures may be taken as soon as possible. Failure to recognize the symptoms and take corrective action has caused numerous aircraft accidents.

Dysbarisms

Dysbarisms are syndromes resulting from the nonhypoxic effects of a pressure differential between the ambient barometric pressure and the pressure of gases within the body. These are of two predominant types, trapped gas and evolved gas dysbarisms.

Trapped Gas Dysbarisms

These dysbarisms are caused by the effects of Boyle's Law, which states that the volume of a gas is inversely proportional to pressure when temperature remains constant. This means that as altitude increases, gas expands. One liter of gas occupies

EXHIBIT 25-3

SIGNS AND SYMPTOMS OF HYPOXIA

Special Senses

- Extraocular muscle weakness and incoordination
- Central vision impairment
- Peripheral vision impairment
- Hearing loss (usually one of the last senses to be lost)
- Touch and pain diminished

Personality Traits

- Depression
- Euphoria
- Overconfidence
- Pugnaciousness

Psychomotor Function

- Decreased muscular coordination
- Loss of fine muscular movement
- Stammering

Mental Processes

- Calculations unreliable
- Intellectual impairment (often prevents recognition of hypoxic symptoms by the affected individual)
- Judgment and reaction time slowed
- Memory poor
- Thinking slowed

Subjective Symptoms

- Air hunger
- Apprehension or anxiety
- Dizziness
- Fatigue
- Headache
- Nausea
- Numbness

1.5 L at 10,000 ft, 2 L at 18,000 ft, and 4 L at 34,000 ft. Trapped gas dysbarisms vary, depending on which normal or pathological body cavity contains the gas. Air trapped in the gastrointestinal tract, the middle ear, the sinuses, or under a recent dental filling may cause problems. Perhaps the most common example of this syndrome is barotitis or "ear block." When the barometric pressure is reduced during ascent, the expanding air in the middle ear exits the middle ear through the eustachian[3] tube. The eustachian tube readily permits the exit of air but tends to collapse and resist reentry of air into the middle ear on descent. If the pressure differential becomes too great, it may be impossible to open the eustachian tube. This condition is painful and may lead to tympanic rupture. A similar problem is "sinus block," which occurs with similar physiology if the aeration of the sinus cavities is inadequate. Since two major causes of blockage of both the sinus ostia and the eustachian tube are the common upper respiratory infection and allergies, the significant concern among flight surgeons about aviators flying with a "simple cold" may readily be understood.

Evolved Gas Dysbarisms

Evolved gas dysbarisms are also called decompression sickness (DCS) and are caused by the effects of Henry's Law, which states that the amount of a gas dissolved in a solution is directly proportional to the pressure of the gas on the solution. This situation is exemplified by gas being held under pressure in a soda bottle—when the cap is removed, the liquid inside is exposed to a lower pressure, so gases escape in the form of bubbles. Nitrogen in the bloodstream behaves in the same manner. When an individual is exposed to such a reduction of pressure that he or she becomes supersaturated with nitrogen, nitrogen bubbles form in the blood and tissues, then cause symptoms by exerting pressure on surrounding tissues. Depending on where the bubbles form, the patient may suffer from classic bends (pain in the joints), paresthesias (tingling and itching sensations caused by bubbles formed along the nerve tracts), chokes (bubbles blocking the smaller pulmonary vessels), or central nervous system effects if the brain or spinal cord is affected.

Numerous variables determine whether an individual will develop DCS. The incidence increases with increased altitude. Traditionally 18,000 ft has been felt to be a threshold, but cases have occurred at significantly lower altitudes. Flying within 24 hours after SCUBA diving is extremely hazardous (see Chapter 26, Military Diving Medicine). The longer the exposure to altitude, the higher the incidence of DCS. The incidence is also increased in older personnel and those with previous injuries.

Mechanisms used to prevent DCS include pressure suits, pressurized cabins, and prebreathing of 100% oxygen for a period of time sufficient to rid the body of dissolved nitrogen before reaching altitude. If DCS occurs, the optimum treatment is pressurization in a compression chamber to reduce the bubble size, then a slow return to sea-level pressure.

Other Medical Concerns Associated With Flight

In addition to the two major potential problems noted above, numerous other stresses of flight may affect aircrew function.

Vibration

Vibration has been a problem in flight ever since heavier-than-air craft were fitted with engines. As multiple reciprocating engines became the norm, multiple nodes of vibration developed in an airframe, having lesser or greater effects depending on where the crewmember was placed. In helicopters, however, vibration is omnipresent, affecting all those inside the aircraft equally. The medical impact of vibration has been debated for years. Current belief is that there is a distinct relationship with the chronic low back pain often experienced by helicopter pilots, though posture and seat design are believed to be greater causative factors. Although vibration has an impact on medical issues (eg, it is a significant contributor to chronic and acute fatigue in operational aircrew), its major effects are operational. For example, the utility of sights and vision-enhancing devices is degraded by severe vibration. Engineering solutions have to date been unsuccessful in eliminating vibration as a stressor, so the flight surgeon must remain alert to the demonstrated effects on aviators of repeated exposure.

Noise

Ever since powered flight became a reality, "aviator's ear," or hearing loss, has been noted. Aircraft engines, weapons systems, and other sources of ambient noise (eg, auxiliary power units) are constant sources of damaging steady state or impulse noise. Noise-induced hearing loss occurs when the receptors on the cochlear hair cells become fatigued and do not return to their normal state or when the ossicular chain is acutely disrupted by overpressure. Sudden noise-induced loss is usually due to impulse noise above 140 dB (eg, explosions, weapons firing). Gradual noise-induced loss is insidious and caused by noises from equipment that abounds in aviation, such as engines, transmissions, and power units. Hearing loss from chronic noise exposure is painless, progressive, permanent, and preventable. It remains, however, a major cause of disability for aviation personnel. Much of the hearing loss induced by noise exposure can be prevented by proper hearing conservation measures, and thus a major part of an aviation medicine program is devoted to hearing protection. Protection is by means of ear plugs, earmuffs, headsets, or helmets.

Problems of Proprioception

Despite modern technological instruments, the basic instruments used by pilots to orient themselves are those that evolved for slow-moving terrestrial beings—vision, vestibular system, and proprioceptive receptors. Unfortunately, these systems were not developed to serve in the airborne environment and can readily be deluded by position or direction changes, especially when coupled with partial loss of some input (as when vision is hindered by weather conditions) or with a lack of reference data (as in the desert or arctic snow fields). In these extreme environments, altitude and distance may be very difficult to judge, and dangerous objects such as crevasses or sand dunes may visually blend with the background and not be seen. The use of modern vision-enhancing devices (eg, night-vision goggles) may actually make these problems worse, since such devices have reduced fields of view, are monochromatic, and provide less than 20/20 visual acuity.

The range of problems that fall into the category of spatial disorientation is huge: visual and vestibular illusions of flight predominate, but psychological phenomena such as "breakoff" (in which the aviator feels a strong sense of unreality and may suffer an "out of aircraft" experience) are relatively common.

Visual System. The eyes can be fooled by many sensory inputs during flight. These illusions result from the pilot's misinterpretation of visual input, often due to conflict between "what is seen" and "what should be seen." For example, runways that are not the expected length or width may make an aviator believe that an approach is perfect, when in fact it may be high or low. The slope of terrain can cause a pilot to misjudge the aircraft's height above the approach path. Multiple visual illusions occur at night, often involving fixed light sources that appear to move ("autokinesis") or ground lights that may be mistaken for stars, leading to abnormal flight positions.

Vestibular System. The otoliths and semicircular canals of the inner ear make up the vestibular system. They detect acceleration rather than speed, which explains many vestibular illusions. The otoliths detect linear acceleration, while the semicircular canals detect angular acceleration. Just as in the visual system, errors may occur due to failure to detect clues (eg, very slow turns), or active illusions may arise from falsely interpreted input (eg, after stopping a prolonged turn). Vestibular illusions experienced by the aviator include somatogravic and somatogyral illusions and the leans.

A somatogravic illusion is due to failure to correctly interpret otolith movements. Since the greatest continuous linear acceleration humans normally experience is gravity, otolith changes are normally interpreted as a change in the earth's gravitational vector rather than as some alternative acceleration. An example of this illusion is the sense of pitching up during forward acceleration (especially with catapult takeoffs).

Somatogyral illusion, in contrast, is a response to rotation. The vestibular system is unable to recognize prolonged rotation; it detects changes in angular acceleration, not persistent acceleration. Thus, if rotational acceleration turns to constant angular velocity, the sensation of rotation experienced by aviators becomes less and less, until they feel they are no longer rotating. If they then slow the turn and return to straight and level flight, their vestibular systems may interpret the angular deceleration as being acceleration in the direction opposite to the original turn. In simpler terms, a constant slow turn to the right may eventually be perceived as straight and level flight, and stopping that turn may be perceived as a turn to the left.

The illusion known as the leans occurs when a pilot allows the aircraft to make a very slow, subthreshold roll. When the pilot subsequently notices the abnormal attitude and rapidly corrects it, the labyrinthine system senses this second roll, and the pilot believes that he or she is banked in the opposite direction, even if flying straight and level.

Aviation Toxicology

Military aviation operations expose aviation personnel to a wide range of potentially toxic chemicals. Jet fuel, carbon monoxide, and weapons exhaust may be encountered during normal operations of the aircraft. Other exposures may occur only under unusual circumstances, such as an aircraft fire, which may expose the crew to hydrocyanic acid, hydrochloric acid, hydroflouric acid, Halon, or hydrazine. The recent increased use of composite materials in aircraft construction has increased the range of potential exposures. Typical occupational medical surveillance and protection programs have direct applicability in the aviation environment.

G Forces

Flight imposes major effects on the body when acceleration forces are applied during aerial maneuvering. Acceleration is the rate of change in velocity and is measured in G units. As an aircraft accelerates, the occupants experience acceleration forces in the opposite direction. A pilot exposed to 2G is being acted upon with force equal to two times the normal force of gravity in a direction opposite to that of the accelerative force. In many aircraft maneuvers, G forces are applied along the spinal cord toward the feet, causing movement of body components toward the feet. Since blood is the most mobile part of the body, it tends to move the most under the impact of G forces. As G forces are applied, the ability of the automatic regulatory system to ensure a continuous flow of blood to the heart and brain is affected. At some point less than 2.5G, the blood pressure at the level of the eye and brain stem starts to decrease. As a result, most individuals begin to experience fuzziness of the visual fields (ie, grey-out) at about 3G to 4G. At around 4G to 4.5G, further increase in forces leads to total loss of vision (ie, blackout). At approximately 5G, unconsciousness (G force–induced loss of consciousness or GLOC) occurs. GLOC has caused the loss of many high-performance aircraft and pilots. Unfortunately, the preceding progression of symptoms may not occur in cases of rapid onset G forces; the pilot may progress directly to GLOC without any intervening visual or other symptoms.

The brain and retina are very sensitive to hypoxia; function is lost seconds after the blood supply ceases. Although this theoretically would allow up to 5 seconds of consciousness even after high G exposures, centrifuge studies[5,6] have demonstrated that up to 30 seconds are required before the pilot can function adequately to regain control of the aircraft. Normal G tolerance can be reduced by many factors, including many common to aviators in a field environment: lack of sleep, dehydration, inadequate diet, illness, and medication, among others. Pilots are protected from G forces by training in protective maneuvers (eg, L-1 straining maneuver), development of mission profiles limiting rate of onset of high G forces, pressure suits, seat positioning, weight training, and positive-pressure breathing systems.

SELECTED TOPICS IN OPERATIONAL AVIATION MEDICINE

Medications

Since all medications have an effect on the body, the flight surgeon must be knowledgeable about these effects and their potential interaction with the flight environment to ensure that pilots do not fly when impaired. Normally if a pilot is ill enough to take therapeutic medications, he or she should probably not be flying because of the medical condition rather than the medication. Prophylactic medications pose a risk-benefit question, but when the risk demands them, efforts must be made to minimize the effects. For example, the US Army does not permit pilots to take mefloquine for malaria prophylaxis because of its acknowledged side effects on the central nervous system in some patients; doxycycline is substituted. All services have strict regulations against aviation personnel self-medicating, even for minor illnesses; all care must be under the supervision of a flight surgeon who knows how the medication may affect the aviator in the flight environment.

Crew Rest

Both acute and chronic fatigue are severe threats to aviation safety. The military aviator is constantly stressed in this regard, particularly with military doctrine requiring continuous or sustained operations. Even in combat, crew rest schedules and flight schedules must be carefully monitored to ensure safe operations (see Chapter 15, Jet Lag and Sleep Deprivation). Fatigue, whether due to physical or mental stress, degrades the ability to make rapid decisions. Acute fatigue is relatively common and is caused by excessive mental or physical exertion. It is usually relieved by rest, relaxation, or sleep. Acute fatigue cannot be avoided but can be controlled. Chronic fatigue is both more insidious and more dangerous. It is secondary to unresolved acute stress over a variable period of time and may be unrecognized by the aviator or the chain of command, but it can be prevented. Each service has developed crew rest guidelines based on aircraft and mission types designed to ensure that aircrew have the opportunity to recover from their acute fatigue, thus preventing it from becoming chronic. Signs and symptoms of fatigue may include boredom, headache, chest pain, dyspnea, inability to concentrate, increased rate of errors, acceptance of unnecessary risks, carelessness, irritability, physical exhaustion, and sleep disturbances.

Contact Lenses

The development of new vision-enhancing systems, chemical protective equipment, and instrument display mechanisms has made the use of spectacles in the aviation environment less satisfactory than previously. The use of contact lenses is therefore desirable operationally. All services currently have ongoing projects to evaluate the safety and efficacy of contact lenses in this environment. While the benefits are in many cases obvious, the potential detriments are less so. In addition to the problem of aviators who cannot wear contact lenses, problems of ophthalmologic support and resupply, the incidence of ocular trauma caused by the lenses, and the actual utility of lenses in an operational environment must be considered. Much concern has been raised about the possibility that lenses (especially soft or gas-permeable lenses) may trap toxic fumes or chemicals, thus increasing corneal exposure. Most research to date, however, has shown this to be more of a theoretical than a practical problem. Currently, many aviators have been granted waivers to fly using contact lenses by their services on a case-by-case basis, and blanket approval in at least some services appears imminent.

Surgical Correction of Refractive Problems

Since perfect vision is such a desideratum for pilots, particularly with regard to use of new generation sighting and vision-enhancement equipment, there has been a great deal of interest in ways to achieve 20/20 vision without the use of lenses. Radial keratotomy, laser corneal reshaping, and laser in-situ keratomileusis (LASIK) are the three most commonly discussed modalities. Because of unresolved issues with glare and flare in patients after these procedures and the absence of long-term outcome data, none is currently accepted for flight personnel in any US service. As these techniques become more a part of the mainstream of ophthalmologic care and the incidence of side effects is reduced, it is likely that some version of them will be considered acceptable for flight personnel, but that time is not yet here.

Flight Physicals and Standards

To many aviators and medical personnel, the primary function of the flight surgeon is to perform the routine Flying Duty Medical Examination (FDME), better known as the flight physical. The routine FDME gives the flight surgeon an opportunity to detect future medical problems in their early stages, when they may be prevented or ameliorated, and to emphasize preventive medicine recommendations to their aviators. But the FDME is a more complex issue than it would appear at first glance. Closely intertwined with the actual clinical examination are the issues of what standards should be applied for both selection and retention. Standards and the components of the FDME have changed over the years, based on the results of public health epidemiology, aeromedical experience, and a review of medical factors involved in aviation mishaps. Frequency and content of FDMEs vary between services, and requirements may vary depending on the type of aircraft being flown. Today, major attention is paid to vision, hearing, cardiovascular condition, and psychological status. One of the greatest contributions of the flight surgeon has been in the evaluation of the actual impact of various health conditions on flight safety, which has frequently led to modification of the standards or to the granting of restrictive flight waivers for aviation personnel with various conditions. If an aviator can be safely allowed to fly under restrictions such as "no ejection seat aircraft" or "must fly with another qualified pilot," the aviation community may be able to make continued use of his or her experience and training, which otherwise would be lost to the military.

Aeromedical Evacuation

Providing medical care in flight is in many ways different from providing the same care in a hospital or a ground ambulance. Although aircraft have been used for the movement of critically ill patients since World War I, this modality still poses risks as well as benefits to the patients. Most of the physiological changes noted to affect aviation personnel apply with equal force to patients who already have a deranged physiology. In addition, the stresses of flight have special impact on some types of medical equipment and materiel. Gas, which expands on ascent to altitude, poses a significant threat when it is enclosed in an air cast, the inflated cuff of an endotracheal tube, or MAST (military anti-shock trousers). The vibration of flight makes many pieces of medical equipment fail. Many pieces of medical materiel commonly used on the ground produce electromagnetic radiation, which can interfere with aircraft navigation or flight controls. Capabilities for providing care in flight are constantly expanding, and we now routinely transport patients who would have been considered nontransportable only a few years ago. The knowledge to merge medical care successfully with the in-flight environment is a major contribution of experienced aviation medical personnel.

Crash and Incident Investigation

Although the incidence of military aircraft accidents that involve medical factors reached an all-time low in the late 1990s, the flight surgeon today still plays an important role in accident investigation. Not only does the flight surgeon on an accident board evaluate possible medical causes of the incident, but also he or she plays a major role in analyzing other factors surrounding the situation. Through examination of the injured or dead aircrewmen, the flight surgeon can often identify causes and mechanisms of injury or fatality. Analysis of these factors are frequently used in human factors or safety redesign of aircraft or survival equipment. Analysis of life support equipment, which either worked as designed or failed, allows continuous improvements in protection of aviators against crash stress. Closely associated with this role is the role that flight surgeons play in the human engineering of new airframes and flight equipment. Their knowledge of human factors in the flight environment continuously helps make this inherently dangerous environment safer.

SUMMARY

Aviation has inherent hazards, but these threats can be reduced by appropriate selection of pilots and adequate training. While aviation has changed significantly in the past two centuries, the human part of the equation has not. Aviation medicine for the most part has not been able to change the body's reactions to stress and has had to concentrate on selecting people able to compensate for the stresses of flight and on developing mechanisms to ameliorate those stresses. Each new generation of aircraft stresses aviators in new ways. While the stresses of flight against which the aviator must be protected have changed as aircraft performance has increased (especially in the space operational environment), the basic mission of ensuring optimum performance in an abnormal environment has not changed. Today, flight surgeons in all military services carry out duties little different in concept from those performed by the first flight surgeons in World War I. The mission of aviation medicine—to select, train, and maintain those pilots most capable of dealing with the stresses of flying these aircraft—has not changed and is unlikely to do so.

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5. DeHart R, ed. *Fundamentals of Aerospace Medicine*. 2nd ed. Baltimore: Williams & Wilkins; 1996.

6. Dhenin G, ed. *Aviation Medicine*. London: Tri-Med Books; 1978.

RECOMMENDED READING

1. Conference or Meeting Proceedings

   These are published by the Human Factors and Medicine Panel of the NATO Research and Technology Organisation (previously the Advisory Group for Aerospace Research and Development), 7 Rue Ancelle, 92200 Neuilly-Sur-Seine, France. Full Bibliographic details are available in the "Government Reports Announcements and Index" of the National Technical Information Service, Springfield, VA 22161. Not only are these proceedings quite detailed and topically organized, but they tend to be much more current than any textbook can hope to be. Some specific ones of interest include:

   - CP-492 Ocular Hazards in Flight and Remedial Measures. May 1991.
   - CP-540 The Support of Air Operations Under Extreme Hot and Cold Weather Conditions. Oct 1993.
   - CP-554 Recent Issues and Advances in Aeromedical Evacuation. Feb 1995.
   - CP-588 Selection and Training Advances in Aviation. Nov 1996.
   - CP-599 Aeromedical Support Issues in Contingency Operations. Sep 1998.
   - MP-19 Current Aeromedical Issues in Rotary Wing Operations. Aug 1999.

2. Military Regulations

   - Department of the Army. *Temporary Flying Restrictions Due to Exogenous Factors*. Washington, DC: DA: 1976. Army Regulation 40-8.
   - Department of the Army. *Standards of Medical Fitness*. Washington, DC: DA: 1995. AR 40-501.
   - Department of the Air Force. *Medical Examination and Standards*. Washington, DC: DAF; 1994. Air Force Instruction 48-123.
   - Department of the Navy. *Aeromedical Reference and Waiver Guide*. Pensacola, Fla: Naval Aerospace and Operational Medical Institute; 1998.

3. Other Publications

   - Department of the Air Force. *USAF Flight Surgeon's Manual*. Washington, DC: DAF; 1997. AFP 161-1.
   - US Air Force School of Aviation Medicine. *US Air Force Flight Surgeon's Guide*. Brooks Air Force Base, San Antonio, Tex: USAFSAM; 1999.
   - Naval Aerospace Medical Institute. *US Naval Flight Surgeon's Manual*. Pensacola, Fla: NAMI; 1989.
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   - Lam D. *Aeromedical Evacuation: A Handbook For Physicians*. Fort Rucker, Ala: Army Aeromedical Center; 1980.
   - *Aviation, Space, and Environmental Medicine.* (The journal of the Aerospace Medical Association)
   - Societies of US Naval, US Air Force, and US Army Flight Surgeons. *The Ultimate Flight Surgeon Reference*. 2nd ed. Fort Rucker, Ala: Societies of US Naval, US Air Force, and US Army Flight Surgeons; 1999.

4. Textbooks

   - Gilles JA. *A Textbook of Aviation Physiology.* London: Pergamon Press; 1965.
   - Rayman R. *Clinical Aviation Medicine.* 3rd ed. New York: Castle Connolly Graduate Medical Publishing; 2000.