Chapter 16

AEROSPACE MEDICINE

ALFRED C. EMMEL, MD, MPH*; RAYMOND R. BATZ, DO, MPH†; and JOHN J. VENEZIA, DO, MPH‡

*Colonel (Retired), US Air Force; Attending Physician, Emergency Medicine and Occupational Medicine, Presbyterian Hospital, 1100 Central Avenue, SE, Albuquerque, New Mexico 87106

†Captain, Medical Corps, US Navy; Force Surgeon, III Marine Expeditionary Force, PSC 559 Box 6853, FPO AP 96377, Okinawa, Japan

‡Major, Medical Corps, US Army; Associate Program Director, Department of Occupational Medicine, US Army School of Aviation Medicine, 340 Hulse Road, Naval Air Station, Pensacola, Florida 32508

INTRODUCTION

Aerospace medicine is a subspecialty under the American Board of Preventive Medicine that focuses on the health of crews, passengers, and support personnel of aviation and space vehicles. Segments of this population often work and live in remote, isolated, or austere environments. Not surprisingly, the aerospace working environment is replete with physical and psychological stress. Hazards are unique and, not infrequently, immediately dangerous to both life and health.

Aerospace medicine is often considered a subset of occupational medicine with some aspects of family practice and emergency medicine. Aerospace medicine's unique focus is on aviation occupational and environmental hazards, the prevention and treatment of illnesses and injuries related to these hazards, and the design of airframes and equipment to prevent injuries, foster fitness, and promote health.

This chapter will discuss the practice of aerospace medicine in terms familiar to the occupational specialist by introducing the major hazards, illnesses, and injuries, and the prevention programs that maximize the health, safety, and general well-being of the aviation and space community.

AEROSPACE HAZARDS, ILLNESS, AND INJURY

The Atmosphere and Altitude

Structure of the Atmosphere

The atmosphere provides life on earth with essential elements and protection from harmful agents. Sunlight penetration provides energy and warmth, while harmful high-energy solar and cosmic radiation are largely shielded. Life-essential oxygen and water are maintained as necessary elements, while more harmful carbon dioxide is recycled.[1]

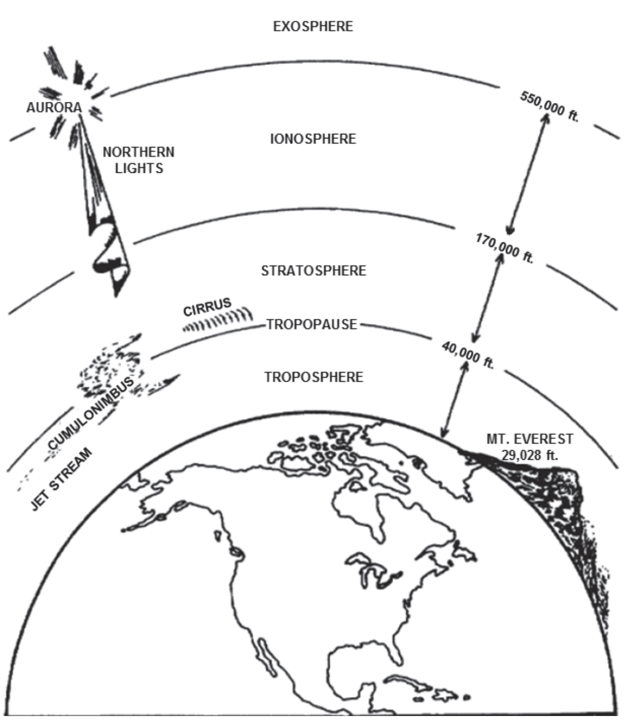

Figure 16-1. Diagram of the atmosphere showing increasing altitude.
Reproduced from: US Department of the Army. *Aeromedical Training for Flight Personnel*. Washington, DC: DA 2009. Training Circular TC3-04.93. August 31, 2009: 16.

All these events take place in a massive, four-layer gaseous blanket, with the true vacuum of space occurring at an altitude of approximately 1,000 miles. The innermost layer, the troposphere, is most familiar and the site of 99% of human activities. The other remaining layers, in order of occurrence, are the stratosphere, ionosphere (or mesosphere), thermosphere (not pictured), and exosphere.[2] Figure 16-1 provides an overview of the layers of the atmosphere along with their associated altitudes.

The troposphere is approximately 60,000 ft thick. It is not uniform in density from top to bottom: air density at the earth's surface diminishes rapidly with increasing altitude, reaching half its overall density at 18,000 ft. At this altitude, the oxygen-deficient environment is insufficient to fully saturate hemoglobin. Moreover, as altitude increases, temperatures decrease, reaching freezing temperatures at 8,000 ft and -2°C to -60°C at the higher altitudes where large and fast aircraft travel. Likewise, as temperatures drop, so does humidity, to a low of 5% or less at the upper reaches of the atmosphere. From a physiological perspective, the human body is generally able to adapt to an altitude up to 12,500 ft; above that, the human body is unable to compensate and is considered physiologically deficient.[2]

Altitude-Induced Hypoxia

High altitude exposure and the accompanying decrease in relative ambient pressure lead directly to hypoxia and decompression illness. With increased altitude, the partial pressure of oxygen is decreased unless it is augmented by a mechanical system. Many aircraft cabins are sealed and therefore can maintain a cabin pressure compatible with normal physiological function. Most pressurized aircraft maintain a cabin pressure between 6,000 and 8,000 ft above mean sea level. When flying in an unpressurized aircraft above 10,000 ft, the aviator should breathe oxygen from an aviator's mask to prevent hypoxia.[2] At higher altitudes, oxygen must be delivered under pressure to maintain sufficient partial pressure of oxygen to saturate hemoglobin.

Military aviators are specifically trained to recognize the symptoms of hypoxia so they can immediately initiate lifesaving interventions in the event of in-flight hypoxia. Progressive symptoms of hypoxia include headache, difficulty performing tasks requiring fine motor skills or higher intellectual functioning, malaise, light-headedness, sleepiness, nausea, giddiness, loss of color vision, blurred vision, tunnel vision, loss of vision, unconsciousness, and finally death, if the hypoxia is not corrected.[2] Hypoxia can also occur if an aircraft loses pressure, either slowly or rapidly, depending on the altitude. If pressure loss is undetected, the time of useful consciousness an aviator has to don an aviation mask and descend to a safe altitude or otherwise remedy the problem will be short. The time of useful consciousness is determined by the altitude to which the aviator is exposed. Table 16-1 lists the times of useful consciousness for various altitudes.[2] In aviation, a flight level is defined as a vertical profile of airspace at standard pressure, expressed as a nominal altitude in hundreds of feet. In-flight treatment for altitude-induced hypoxia involves switching the oxygen regulator to deliver 100% oxygen and descending to an altitude below 10,000 ft above sea level.[2] If symptoms persist upon landing, the aviator should be treated with 100% oxygen via a tight-fitting aviator mask.

TABLE 16-1

TIMES OF USEFUL CONSCIOUSNESS

Altitude in Flight Level	Time of Useful Consciousness	Altitude in Feet
FL 180	20–30 min	18,000
FL 220	10 min	22,000
FL 250	3–5 min	25,000
FL 280	2.5–3 min	28,000
FL 300	1–2 min	30,000
FL 350	0.5–1 min	35,000
FL 400	15–20 s	40,000
FL 430	9–12 s	43,000
FL 500 and above	9–12 s	50,000

Adapted from: US Department of Transportation. *AC 61-107A – Operations of Aircraft at Altitudes Above 25,000 Feet MSL and/or Mach Numbers (MMO) Greater Than .75*. Washington, DC: US Deptartment of Transportation, Federal Aviation Administration; 2009.

Pressure Illness

Barotrauma

Boyle's law is associated with a proportional inverse relationship between volume and ambient pressure.[2] Ambient pressure changes with altitude and translates directly to gas volume changes inside physiological tissues. Because a volume of gas is inversely proportional to the pressure surrounding it, this situation can lead to trapped gas disorders.[2] Pain can occur when the increased pressure inside a tissue cavity cannot equilibrate with the environment. Chapter 18 of this textbook, Physiology and Medical Aspects of Diving, provides more information regarding gas laws pertinent to understanding the physiological effects of pressure changes on the human body. Trapped gas disorders are either associated with ascent or descent.

Barotrauma of the sinuses and middle ear (sinus block and ear block, respectively) are usually associated with trapped gas during descent, due to the pressure gradient between the area of trapped gas and the environment. The Valsalva maneuver is typically used to equalize pressure associated with descent when the pressure of the trapped gas is lower than that of the hypopharynx.[3] In this situation, the eustachian tube, a collapsible tube that connects the middle ear to the hypopharynx, acts as a one-way valve to allow pressure equilibration with exhalation against a closed nose and glottis. Unfortunately, the Valsalva maneuver is not effective in managing ascent because the relative pressure in the middle ear is increasing. During ascent, a healthy and patent eustachian tube is required to equilibrate the pressure, often augmented with a swallow. Ear block occurs with descent if the aviator is not able to equalize pressure with Valsalva or any other maneuver via the eustachian tube. Such tube dysfunction is usually caused by inflammation or congestion of the proximal tube due to upper respiratory infection, allergic rhinitis, or other inflammatory disorders. Similarly, sinus block occurs if the ostia, which allow the cranial sinuses to drain and equalize pressure, are not sufficiently patent to allow for normal physiological equilibration during descent.[4] Eustachian tube dysfunction and sinus ostial drainage obstruction associated with allergy or upper respiratory infection are contraindications to flight duties.

Dental and gastrointestinal pain are typically associated with trapped gas during ascent (also see Chapter 18 of this textbook). Dental cavity and root abscesses are rare but severely debilitating causes of ascent-associated pain. Good dental hygiene and a high regard for dental readiness are vitally important in prevention. At higher altitudes, trapped gastrointestinal gases begin to cause discomfort, and may be controlled with eructation (burping) and flatulence. However, on occasion this pressure can only be resolved with descent. To minimize the risk of discomfort, it is important to avoid gas-producing foods and rapid food consumption (increasing swallowed air).

Decompression Sickness

Decompression sickness (DCS) is one of the most potentially dangerous effects of high altitude exposure. DCS occurs when nitrogen bubbles exit solution to enter the tissues and fluids of the body. As discussed in Chapter 18, Henry's law states the concentration of a gas in solution is directly related to the partial pressure of the gas above the solution and is the primary mechanism for DCS development.[2] Bubbles cause both mechanical and biochemical effects. Bubbles mechanically block small vessels; biochemically, they trigger an inflammatory response, leading to vasoconstriction.

DCS is classified into two types. DCS type I refers to pathology of the integument and musculoskeletal systems caused by bubble formation.[2] Due to the kinds of tissues involved, type I is not thought to be as debilitating as type II DCS. Type II DCS encompasses the more severe forms, including all DCS with neurological or cardiopulmonary symptomatology.[5] The exception to this statement is bilateral pain involving the trunk or hips and should be considered type II DCS. Though nitrogen bubbles are a common etiology in all DCS cases, it is important to realize altitude-related DCS is a unique clinical entity when compared to diving-related DCS.

Approximately 65% of altitude cases and 85% of diving cases of type I DCS involve limb pain. The onset of pain is gradual but develops into a throbbing ache in the affected limb.[2] Usually direct pressure over the painful area exerted by a blood pressure cuff is sufficient to relieve the pain. Pain from ischemia and nerve entrapment would be made worse by applying direct pressure. The pain experienced with type II symptoms is much worse. There is an acute onset of sharp shooting or encircling pain, accompanied by tingling or burning when the central nervous system is involved. These symptoms represent type II DCS disease and must be treated more aggressively.[5]

The skin is often affected, and there are two distinct skin manifestations. The most common symptom is a transient, multifocal itching or crawling sensation. This sensation is common in the hyperbaric chamber and does not require recompression. Venous obstruction and vasospasm can present as confluent rings of pallor, surrounded by areas of cyanosis that blanch to touch.[6] This condition is known as cutis marmorata, which is thought to be more serious. It responds well to recompression, but swelling of the lymphatics may persist.[2] The primary care or occupational health provider should discuss all type I DCS cases with an aerospace medicine physician to ensure type II DCS cases are prevented.

Service members who have type II DCS must be treated immediately, particularly when they exhibit neurological symptoms at any level. The neurological symptoms may range from mild paresthesias to numbness, or weakness limited to one limb.[7,8] More severe symptoms may affect the spinal cord in one in ten type II altitude DCS cases. The clinical presentation of DCS is discussed in greater detail in Chapter 18 of this textbook. Spinal DCS is more common in diving environments than flight decompression cases—see Chapters 17, Military Diving Operations, and 18. Cerebral decompression cases occur commonly in altitude cases of type II DCS.[9,10] The common symptoms in cerebral decompression range from mild to life threatening and include fatigue, confusion, personality changes, headache, tremor, hemiplegia, and scotomata.[9,10] Vertigo, tinnitus, and hearing loss may be symptoms of inner ear DCS, which may mimic round window rupture. Any neurological symptom after a dive or flight should raise the healthcare provider's suspicion of type II DCS or arterial gas embolism (AGE). Intravascular bubbling may cause cardiopulmonary symptoms of substernal pain, cough, and dyspnea,[9,10] present in only 5% to 10% of altitude DCS cases, and may cause circulatory collapse and death if not treated immediately.

Factors that reduce the risk of DCS include adequate cabin pressurization and prohibition from flight for at least 24 hours after diving activities, including SCUBA (self-contained underwater breathing apparatus) or compressed air dives as well as hyperbaric (high-pressure) chamber exposure.[9,10] Flight prohibition may be reduced to 12 hours for urgent operational requirements provided there are no symptoms following the dive and the subject is examined and cleared by a flight surgeon (a military medical officer who serves as the primary care physician for an aviation unit). Factors increasing the risk of DCS include a history of DCS.[2] This issue becomes especially important if one works as an inside observer of hyper- or hypo-baric chamber operations, in which exposure seems to be more associated with DCS than actual high-altitude flight. There is limited scientific evidence suggesting that being over 40, being female, exercising strenuously, and having excess body fat may increase the risk of bubble formation and DCS.[2] Hypoxia, alcohol hangover, dehydration, and fatigue have clearly been implicated in an increased incidence of DCS. Patent foramen ovale has also been implicated in stroke and type II DCS, as reported in cases of divers and astronauts, and is likely associated with venous return of bubbles formed in skin or joints moving directly into the arterial vasculature supplying the central nervous system.[11]

AGE is produced when gas emboli enter directly into the arterial circulation, with potentially life-threatening consequences. The most susceptible organs include the heart and the central nervous system. AGE symptoms usually occur within 1 to 2 minutes of surfacing after breathing compressed air. Unconsciousness occurring within 10 minutes of surfacing must be assumed to be AGE and treated immediately.[9,10,12] If AGE symptoms are present and resolve spontaneously, they may recur later with increased severity. Therefore, AGE symptoms should be treated promptly, even if they have resolved spontaneously. When deciding whether the etiology is DCS or AGE, it is safer to err on the side of treatment for AGE. In any event, the standard therapy for both conditions is recompression with oxygen.[9,10,12] Table 16-2 provides oxygen treatment parameters for recompression therapy.[12] Two basic treatment approaches exist. The first is to treat the patient with 100% oxygen for shorter duration under increased pressure, and the alternative treatment utilizes 100% oxygen for a longer time period.[9,12]

To triage and refer altitude DCS cases, type II DCS requires that all cases be recompressed urgently or evacuated promptly if recompression is not locally available.[9,12] Type I DCS patients should be treated with 100% oxygen for 2 hours and remain under observation for recurring symptoms.[9,12] If there are no recurring symptoms, the patient should be limited to light duty without flight or high altitude exposure for 1 week. Instruct the patient to return promptly for hyperbaric therapy if symptoms recur. If symptoms develop at altitude and do not resolve on descent or develop after flight, place the patient on 100% oxygen while arranging evacuation or recompression. If evacuation is delayed and symptoms resolve on 100% oxygen, the patient should remain on supplemental oxygen for 24 hours and on limited duty for 1 week, with no physical training for 72 hours. Recurring symptoms must be treated by hyperbaric therapy.

For an aero medical evacuation (MEDEVAC) of DCS cases, the medical representative must contact a provider familiar with the treatment protocol at a facility with adequate therapeutic capability prior to transport. Additionally, MEDEVAC aircraft should be pressurized to a pressure altitude of 500 ft or less. The patient should be placed on 100% oxygen via aviator mask, in a supine position with neutral head position and uncrossed extremities for transport. To monitor mental status, it is important the medical attendant not allow the patient to sleep. Intravenous therapy access should be maintained with a physiological crystallite solution. Inflatable cuffs should be filled with water rather than air.

Recommended aeromedical disposition for type I patients includes restriction from flight/diving duties for 1 week; type II patients should be restricted from such duties for 1 month. With any suspicion of air embolism, the patient should undergo further examination to rule out cardiac septal defects or pulmonary overinflation syndrome etiologies such as pulmonary bullae.[9,12] Persistent neurological sequelae of DCS or AGE should be considered a disqualifying factor for flight duties.

TABLE 16-2

OXYGEN TREATMENT TABLE FOR TYPE I DECOMPRESSION SICKNESS*

Depth (feet)	Time (minutes)	Breathing Media¶	Total Elapsed Time (h:min)
60	20	O_2	0:20
60	5	Air	0:25
60	20	O_2	0:45
60–30	30	O_2	1:15
30	5	Air	1:20
30	20	O_2	1:40
30	5	Air	1:45
30-0	30	O_2	2:15

*Treatment of type I decompression sickness when symptoms are relieved within 10 minutes at 60 feet and a complete neurological exam is normal.

† Descent rate: 20 ft/min.

Ascent rate - Not to exceed 1 ft/min. Do not compensate for slower ascent rates. Compensate for faster rates by halting the ascent.

‡ Time on oxygen begins on arrival at 60 feet.

§ If oxygen breathing must be interrupted because of CNS Oxygen Toxicity, allow 15 minutes after the reaction has entirely subsided and resume schedule at point of interruption.

¥ Treatment Table may be extended two oxygen breathing periods at the 30-foot stop. No air break required between oxygen breathing periods or prior to ascent.

¶ Caregiver breathes 100 percent O_2 during ascent from the 30-foot stop to the surface. If the tender had a previous hyperbaric exposure in the previous 18 hours, an additional 20 minutes of oxygen breathing is required prior to ascent.

Source: Navy Treatment Table 5. US Navy Diving Manual, Volume 5. Diving Medicine and Re-compression Chamber Operations. Diagnosis and Treatment of Decompression Sickness and Arterial Gas Embolism. Section 20-5: 20-13–20-17. https://www.uhms.org/images/DCS-and-AGE-Journal-Watch/recompression_therapy_usn_di.pdf. page 20-40.

Thermal Stress

Hypothermic Injury

Injuries due to cold may be local or systemic. In all cases, preventive measures including provision for adequate clothing as well as education on proper responses to emergency conditions may protect against such injury. Frostbite is the most common injury during freezing conditions. Hands, feet, face, and ears are most susceptible to injury due to rapid vasoconstriction and high surface area of the exposed skin.[13] Another form of localized damage is trench foot (or immersion foot), which is associated with poor foot hygiene and long exposure to unfavorable cold and wet conditions. Trench foot is the manifestation of neuromuscular damage, venous thrombosis, and hyperemia in a poorly protected lower extremity.

Cold and wet conditions can also lead to systemic hypothermia in otherwise healthy active adults. As the body's core temperature drops below 34°C, central nervous system depression occurs.[13] As core temperature drops below 31°C, physiological functions slow, including those measured with vital signs, and more severe hypothermia ensues, ultimately leading to apnea and death, if unchecked. In the resuscitation of a hypothermic patient, slow rewarming is the rule and the provider must watch for complications of hypothermia including electrolyte imbalance, cardiac dysrhythmias, and plasma volume decreases so the capillary area is reduced for fluid exchange. A practical reminder is that a hypothermic patient is not truly dead until vital signs confirming death are taken after the individual's core temperature has been raised through resuscitation efforts.

Another planning consideration for cold exposure is the wind chill factor. Wind speed and cooling power are proportionally related; however, no matter how uncomfortable one may feel, it is rare for frostbite to occur when the ambient air temperature is above freezing.

Heat Stress

Heat stress occurs when the body fails to adapt to high temperature extremes that result in pathology, associated with the individual's relation to environmental conditions, work load, and clothing.[14] Sweating is an individual's physiological response to increased warming. Adaptive behavior to heat stress includes moving to a cooler area, decreasing workload, or changing to lighter weight clothing; however, these mitigating actions may be impractical due to the aviator's restrictive work environment. Cockpit temperatures may exceed 50°C.[14] Many heat sources, such as radiant, convective, electrical, metabolic, and aerodynamic, may add to heat stress in the cockpit. Heat stress is heightened with protective equipment such as a helmet, gloves, anti-G suit, and chemical defense suit. Dehydration contributes to heat stress pathology as well. Without rehydration, the simple act of sweating, one of the primary means the body uses to maintain homeostasis, will eventually accelerate the pathology of heat stress. Dehydration degrades an individual's ability to handle workload. Water loss should be limited to less than 1% to 2% of body weight in all individuals, with consideration of even tighter controls for those piloting aircraft.

Risks for occupational exposure to warm environments may be mitigated through acclimatization over the course of 8 to 14 days. Exposure to warm conditions in a controlled nature with mild exercise for 1 to 2 hours results in acclimatization, manifested by more profuse sweating at a lower temperature.[15] Acclimatization allows more effective heat loss and improved thermostasis. There is a mistaken notion that acclimatization results in less sweating and water loss, which is the opposite of what actually occurs.

Three-Dimensional Motion

Acceleration, Loss of Consciousness, and Ejection Injury

Consider that ground travel is largely linear and one-dimensional and water travel is two-dimensional due to the influence of water currents and winds on intended linear travel. Air travel takes on a third dimension because travel includes altitude changes and exceeds the capacity of human sensory, postural, and locomotive systems. Additionally, human-operated aircraft start, travel, turn, and stop faster than any other moving objects, adding to motion-related flight hazards.

Motion stress can be categorized as transient or sustained acceleration. Figure 16-2 depicts the forces acting in all directions. Transient accelerations are short (1–2 second) events typical of ejections and collisions that reach the upper limits of human anatomical tolerance at 20*g* to 50*g*. Sustained accelerations encompass the centripetal/centrifugal motion of turning an aircraft at high speeds.[16] In fighter aircraft, sustained acceleration can reach the upper limit of human physiological tolerance at 8*g* to 9*g* for up to 30 seconds at a time, and repeatedly for up to 20 minutes or more in a single sortie.

Transient Acceleration

Aircraft ejections are a form of transient acceleration. Adverse effects of transient acceleration are largely anatomical, and characterized by acute physical injury. Common ejection injuries include bony and soft tissue injuries to the face, eyes, and upper and lower extremities, as well as spinal compression fractures.[16] These injuries occur at the moment of ejection and at ground upon landing. Transient acceleration prevention systems are designed to limit bodily injury to the face, head, arms, legs, and spine during ejection, parachute landing, and crash events. Injuries to these anatomical areas have decreased dramatically with improvements in safety systems.

When an aircraft crash is imminent, the aviator may decide to activate an emergency egress system, such as an ejection seat powered by a rocket, catapult, or other ballistic force. There are many types of ejection systems that work under varying altitude and velocity conditions. Some ejection seats, such as the Advanced Concept Ejection Seat II, require no minimum airspeed or altitude to safely eject the occupant from an aircraft.[17] At the other end of the spectrum, egress ejection systems have ensured aviator survival at speeds in excess of Mach 1 and altitudes greater than 50,000 ft.[17]

Ejection seats can be found in both single seat and multi-place aircraft. Upon ejection, the aviator and the seat are propelled up a rail at a high rate of acceleration out of the cockpit and into the elements. The aviator should expect injuries during this sequence. Upon ejection, explosive charges blow the top off the cockpit canopy and propel the seat upward, causing minor to major burns. Due to the positive G forces in the z-axis,

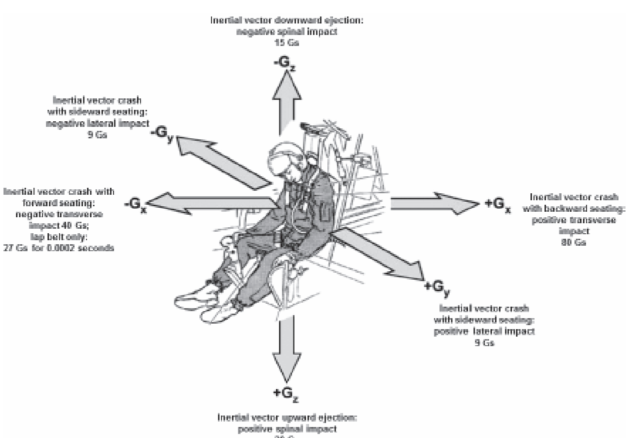

Figure 16-2. Crash forces in G_x, G_y, G_z axes.
Reproduced from: US Department of the Army. *Aeromedical Training for Flight Personnel*. Washington, DC. DA 2009. Training Circular TC3-04.93, August 31, 2009: 72.

the spine is compressed, which can result in fractured vertebrae and herniated discs.[17] These injuries can be exacerbated if the aviator does not assume the correct position before ejection, aligning the spine with the ejection seat's vector. Also, flying debris from the cockpit can cause trauma to the aviator during the ejection sequence. Once the flyer enters the wind stream, he or she may be subjected to flail injuries, hypoxia, hypothermia, frostbite, and decompression illness.[17] Although engineering designs were implemented to decrease the opening shock of the parachute, the aviator may still experience soft tissue injuries when the parachute opens.

The final insult to the ejected aviator is the landing. Aviators are instructed in proper parachute landing fall technique to absorb the impact with their feet, calves, thighs, buttocks, and upper body. If performed improperly or in rough terrain, significant bony and soft tissue injuries can be expected with ground contact. Following an ejection, the examining physician should consider radiographs of the crew member's entire spine and other injured areas. As with all military aviation mishaps, the physician must remember that blood and urine specimens as well as a detailed medical history are necessary, as soon as practical, as part of the safety investigation. The treating physician should follow the patient for several weeks to ensure no musculoskeletal or other injuries are inadvertently missed because some injuries may not be immediately apparent.

Sustained Acceleration

The adverse effects of sustained acceleration are largely physiological, characterized by partial or complete G-induced loss of consciousness (G-LOC). G-LOC is extremely dangerous because the unconscious pilot may not be in control of the aircraft for 30 to 60 seconds or longer, possibly leading to catastrophic or fatal results.[16] There are a variety of strategies to prevent G-LOC associated with sustained acceleration. These strategies eliminate acute loss of consciousness events, using combinations of life support equipment, muscle strength training, and breathing maneuvers. Additionally, special accelerative centrifuges are used to train and verify crew readiness for the high-G flying environment.[16] Of secondary importance is the potential for long-term degenerative effects on the spine following 10 or more years of high-G flying exposure.[18]

A loss of consciousness is one outcome of sustained acceleration occurring in the z-axis. Many military aircraft are capable of high-performance flying, including sustainment of high G-forces in multiple axes. G-forces can be exerted in any plane, but are commonly defined by the x, y, and z-axes. Aviators most commonly encounter G-force problems in the z-axis. G_z is a gravitational force that is applied to the vertical axis of the body. If it is experienced from foot to head, it is termed negative G_z and happens when an aircraft pushes into a dive or enters an outside loop. Under increasing negative G_z force, blood flow from the jugular veins to the heart decreases while arterial blood flow to the head increases. "Red out" is a visual condition that occurs when the body experiences a negative G_z force sufficient to cause increased blood pressure in the head and eyes. Red outs are potentially dangerous and can cause retinal damage and hemorrhagic stroke.[19]

Conversely, positive G_z force is experienced from head to foot and happens when an aircraft enters a high-speed turn or pulls out from a steep dive. Under increasing positive G_z force, blood tends to move from the head toward the feet and pools in the lower extremities. "Black out" is a visual condition that occurs when the body experiences a positive G_z force sufficient to lower blood pressure in the eyes to cause a complete loss of vision while conscious. Further sustainment of the positive G_z force may cause G-LOC, as discussed above. If G-LOC occurs while flying in a single seat aircraft, the outcome may be fatal. The aviator will regain consciousness once the positive G_z force load is reduced. This process generally takes seconds to a full minute and may be followed by a latent period of partial consciousness, during which the aviator is unable to make or execute sound decisions.[19]

Many factors affect tolerance to positive G forces. Aviators are trained in the anti-G straining maneuver (AGSM).[19] This maneuver involves activating the lower and upper extremity muscle groups and exhaling against a closed glottis in order to increase blood pressure in the extremities, thereby maintaining adequate venous return to the heart and effective blood pressure in the brain. AGSM allows the blood to return to the heart and remain oxygenated. Aviators are taught AGSM in the centrifuge before actually performing it in the aircraft. Aviators in high-performance aircraft are also fitted with an anti-G suit, a snug-fitting garment that covers the lower extremities and the abdomen. The anti-G suit contains bladders that are inflated with air, providing resistance around the lower extremities and abdomen. Upon onset of positive G_z force, the garment automatically inflates, augmenting the aviator's AGSM.[18]

To ensure aviators are performing a correct and adequate AGSM, a physician or physiologist reviews AGSM performance by reviewing cockpit audio recordings. These reviews are performed periodically on a preventative basis and any time an aviator experiences G-LOC. Life support equipment must also be evaluated for functionality. Physiological factors that can contribute to G-LOC include dehydration, decreased muscle tone and mass, physical illness, fatigue, and tall stature.[19] The examining physician must search for the etiology of the G-LOC event in order to make recommendations, so the aviator does not experience a similar event. A subset of G-LOC is almost G-induced loss of consciousness. Almost G-induced loss of consciousness generally occurs during and after short-duration, rapid-onset, positive G_z force and is characterized by transient incapacitation, but not loss of consciousness.

Spatial Disorientation

Spatial orientation is the ability to maintain body orientation in relation to the surrounding environment at rest and in motion. Humans sense position and motion in three-dimensional space through sight, sound, and touch (pressure). Because the human body is designed to maintain spatial orientation on the ground in a 1*g* environment, the three-dimensional flight environment creates a sensory conflict that makes spatial orientation difficult for aviators to maintain.[20] About 10% of all general aviation accidents are due to spatial disorientation, and 90% of these cases are fatal.[20]

During spatial disorientation, the pilot incorrectly perceives linear and angular position and motion relative to the earth. Sensory function limitations may lead to the loss of control. Anxiety reactions may exacerbate the situation and contribute to recurrence. Preventing the cascade of events leading to a spatial disorientation mishap begins with understanding the aircraft's orientation of flight.[20] Once in the cockpit, aviators must relearn perception skills using ambient and peripheral vision and cockpit instrument displays. Aircraft instruments allow the aviator to appropriately interpret aircraft orientation in a three-dimensional environment.

Visual cues provide for 80% to 90% of the aviator's decision-making information and are integral to spatial orientation. Ambient and peripheral vision are typically used during daylight. Ambient vision relies on movement, horizon lines, and other visual cues to provide spatial orientation.[20] Peripheral vision provides critical information to the parts of the brain that specialize in tracking movements. Visual stimuli are compared with vestibular, auditory, and somatosensory inputs to corroborate perceived movement and aircraft orientation. During flight without visual cues, for instance in bad weather, discrimination of cockpit instrument markings is critical for spatial orientation.[20] Focal vision, the central vision of the eye, is required to appreciate this fine detail on aircraft instruments.

Instrument-derived orientation may conflict with the perceived aircraft orientation provided by sensory-vestibular system or "seat of the pants" flying, but with appropriate training, the pilot interprets the instruments to correctly identify aircraft orientation.

Flight-related sensory inputs also come from the kinesthetic sensors of joints and supporting tissues. Kinesthesias receptors in the skin, capsules of joints, muscles, ligaments, and deep supporting structures are stimulated mechanically and provide sensory input associated with forces acting on the body.[20] Physicians must consider the occupational consequences of aviators who have lost a limb or experienced a significant orthopedic injury or change in weight. These anatomic changes may limit an individual's capacity to assess spatial orientation, though aviators will likely compensate and accommodate over time. Good spatial orientation relies on the effective perception, integration, and interpretation of visual, vestibular, and proprioceptive sensory information.

Alternobaric vertigo, the pathology associated with positive middle ear pressure that causes vertigo, is another cause of spatial disorientation.[21] There is a well-established association between alternobaric vertigo and eustachian tube dysfunction, typically seen while flying in high-performance aircraft. Because alternobaric vertigo is caused by a positive middle ear pressure, it arises with ascent or from overly vigorous auto inflation of the ear, which can occur during a Valsalva maneuver to clear a congested middle ear.[21] It usually presents with rotary vertigo and without hearing loss. Symptoms are self-limited and resolve when the upper airway inflammation and eustachian tube dysfunction symptoms resolve. Persistent symptoms may indicate perilymphatic fistula; patients should be referred to an otorhinolaryngologist.[21] Risk of vertigo from middle ear pressure is one of the main reasons aviators should not fly with an upper respiratory infection.

Other factors affecting spatial disorientation include weather, fatigue, alcohol or medication use, dehydration, and poor mission preparation.[2] As previously discussed, in foul weather critical visual cues and inputs to the brain are lost, potentially resulting in spatial disorientation. Fatigue, dehydration, and alcohol and medication use are preconditions that reduce the vigilance required to maintain situational awareness. Poor mission planning and preparation may lead to spatial disorientation. Impromptu missions in combat or for aero MEDEVAC may limit advance preparation for the flight due to fatigue or sleep deprivation and this may increase the risk of spatial disorientation.

Pilots who become spatially disoriented may lose situational awareness. However, pilots may lose situational awareness for other reasons besides spatial disorientation. For instance, pilots who get vertigo may lose situational awareness due to the spinning sensation, though they may maintain spatial orientation. Mishaps due to spatial disorientation claim many more lives than other mishaps.

To avoid spatial disorientation, aviators must consider their limitations, remedy correctable factors, properly use capabilities, recognize high risk situations, and stay alert. Aviators must apply operational risk management before flights, avoiding unnecessary risks and weighing operation risk in terms of benefit and cost. Aviators must be well rested, well hydrated, and well fed prior to the flight briefing. Flights during bad weather or conditions such as brownout (sandstorm or rotor wash causing poor visibility due to sand and dust disturbance) should be avoided if possible. In one study, meteorological conditions (eg, brownout, whiteout, or inadvertent entry to instrument weather conditions) accounted for more than 25% of flight mishaps due to spatial disorientation.[2] Physicians and other aeromedical consultants must educate and caution aviators against task saturation and excessive physiological or mental in-flight stress. In the long run, it is important for aviators to remain alert. Vigilance in flying includes maintaining the visual scan while aviating, navigating, and communicating. Transferring controls when the pilot is spatially disoriented in a multi-crew aircraft is another safety measure.[2]

Aviators must maintain vigilance to retain spatial orientation in-flight because the visual, vestibular, and proprioceptive stimuli all rapidly vary in magnitude, direction, and frequency. The various sensory inputs must be reconciled, or a sensory mismatch may occur that can lead to spatial disorientation. Aviators flying under instrument flight rules must get significant training to overcome the spatial illusions and successfully master flying in all conditions and prevent flight mishaps.

Motion Sickness

Motion sickness, which occurs when a person is exposed to real or apparent and unfamiliar motion stimuli, may be an additional component of spatial disorientation. The condition is characterized by dizziness, fatigue, and nausea, which may progress to vomiting, pallor, and cold sweat.[22-24] Motion sickness may initially manifest as a headache or somnolence that advances to stomach symptoms. As nausea increases in severity, the individual experiences pallor and sweating. Further worsening leads to an avalanche phenomenon associated with increased salivation, bodily warmth, lightheadedness, and subsequent vomiting. Hyperventilation and air swallowing associated with yawning and sighing may precede emesis. Excessive vomiting may be associated with electrolyte disorders, dehydration, and hoarseness.

Incidence rates vary based on stimulus, strength, and operator susceptibility. Only 1% of passengers become airsick in large, civil transport aircraft during a typical commercial flight. However, during heavy turbulence, one third to one half of airline passengers experience some degree of motion sickness. Experienced aviators, including 59% to 63% of US Navy student pilots, 10% to 75% of paratroopers, and 67% to 85% of shuttle astronauts (during or after flight), have experienced motion sickness.[22]

Motion sickness can significantly complicate operational safety. A pilot suffering from dizziness, fatigue, or nausea is more inclined to lose situational awareness and more prone to spatial disorientation. These symptoms disrupt normal physiology and preoccupy the operator, possibly eroding flight communications and duty performance. Pilots are not the only personnel who can be adversely affected by motion sickness; other crew members such as navigators and mission specialists may become incapacitated during flight and thus compromise mission effectiveness. Additionally, passengers' conditions at the time of disembarkation are important; those suffering from airsickness may be unable to function in a wide variety of operational duties following flight. Fear and anxiety can lower the threshold for symptoms; therefore, anticipatory briefings on motion sickness and situational awareness are important for passengers as well as the pilot and crew.

Treatment of motion sickness includes fresh air or oxygen, rest, fluids and electrolytes maintenance, parenteral use of antiemetics, and a light diet with adequate hydration.[22] Unfortunately, medications to prevent and treat motion sickness often have undesirable side effects such as drowsiness, altered cognition, sedation, blurred vision, dizziness, and dry mouth.[22] Side effects of prophylactic medications compromise the effectiveness of the drugs and are associated with poor performance. Waiting to use medications until crew or passengers experience symptoms does nothing to alleviate the symptoms and the affected individual may need rest before returning to full duty. Therefore, prevention may be considered the best way to manage motion sickness; early intervention is better than ignoring motion sickness symptoms.[22]

To prevent motion sickness through ergonomics, maintain a supine position as space allows (this reduces incidence by 20%), minimize unnecessary movements, and maintain a view of the horizon, if possible.[22] Adapt the aircraft to minimize low frequency movements (below 0.5 Hz), minimize foul odors such as engine exhaust, and provide cool air in warm conditions to optimize comfort. As individuals become acquainted with and adapt to these provocative stimuli, motion sickness symptoms usually become less frequent.

Noise

Noise-Induced Hearing Loss

Hazardous noise is intense and ubiquitous to military aviation activities. Please refer to Chapter 12, Army Hearing Program, for a more in-depth discussion. Hearing loss was well recognized by the US military in the 1940s following World War II; frequent exposure to artillery, tanks, trucks, ships, and aircraft produced significant hearing disabilities. However, it was the advent of the turbojet engine that eventually forced the military to address hazardous noise and hearing loss.[25] The military aviation community first initiated hearing conservation programs in the 1950s. Not long after, the Occupational Safety and Health Administration adopted hearing conservation regulations for general industry in the early 1970s.

These early jet engines raised occupational noise levels for aircraft maintainers and operators to an extremely dangerous (and often painful) range of 120 to 140 dB. At those noise levels, even very short term exposures caused harmful effects, including permanent, high frequency hearing loss. For persons in the immediate proximity of modern US Navy and Air Force jet aircraft, such as mechanics and crew chiefs, noise levels of 120 to 150 dB remain common and continue to challenge hearing conservation.[25] Even takeoff and landing noise for bystanders, including city dwellers, can be as high as 100 dB. Alternate power units can run extensively during ground-based preflight activities and create noise in the range of 113 dB. Beginning in the 1960s, sonic booms from supersonic aircraft (eg, military, Concorde) became a major concern and eventually led to regulations that protected nearby airport residents. These environmental noise exposures are largely engine related. Of equal concern to the aviation community is cockpit noise.

Cockpit or internal noise comes from various sources, including high-pitched hydraulic systems, cabin pressurization or air-conditioning systems, internally reflected jet engine noise, and in-flight aerodynamic turbulence across the fuselage and control surfaces. All these noise sources are worse in military aircraft because designers chose to favor performance over sound-damping insulation. Modern jet fighters have cockpit noise as high as 120 dB or more.[25] Rotary aircraft, although possessing a different spectrum than fixed-wing aircraft, produce a combination of rotor, exhaust, and gearbox noise inside and immediately outside the aircraft that routinely reaches 125 dB.[25]

Furthermore, it is likely the combination of noise exposure and other ototoxic substances, such as solvents and fuels, can produce hearing loss[25] by lowering the threshold at which it occurs. Other significant hearing loss effects include chronic tinnitus, acute fatigue, and impaired communications. These latter issues directly impact human performance. Further research on hearing loss prevention in the aviation environment is needed because crews currently rely on traditional personal protection measures such as noise-dampening helmets, headsets, and earplugs.

Noise Prevention

Controls for aircraft noise, first initiated over 60 years ago, remain critical for present-day operations. Air Force programs in the 1950s were among the first industrial activities to incorporate containment measures during engine testing, mandatory use of personal protection with ear plugs and muffs, and medical surveillance with periodic pure tone audiometry. These methods remain the mainstay of modern programs even as new technologies, such as active noise reduction, are incorporated into military operations.

The US Environmental Protection Agency implemented the Noise Control Act of 1972 and Quiet Communities Act of 1978 to protect an estimated 16 million people routinely exposed to environmental aircraft noise.[26] The Environmental Protection Agency coordinated all federal noise control activities through its Office of Noise Abatement and Control. This office was phased out in 1982 as part of a shift in federal noise control policy that transferred the primary responsibility of noise regulation to state and local governments. At the same time, the Federal Aviation Administration rewrote Federal Aviation Regulation Parts 36, 91, and 150 to modify aircraft design, airport design, and the scheduling of aircraft operations. At present, the Federal Aviation Administration is developing new standards for a more stringent aircraft design standard.

Unlike the civilian aviation industry, which has reduced noise via quieter engines and aircraft interiors, military aviation has largely relied on alternative or more limited engineering controls, biological monitoring, and especially the use of improved personal protective equipment (PPE). These limited controls have been necessary to maintain engine and aircraft performance. Through its formal occupational health program, the Air Force currently monitors 42% of its active duty workforce for potential hearing loss.[25] Nonetheless, a 2006 Institute of Medicine report noted 10% to 18% of military service members continue to have significant hearing threshold shifts, a rate that is two to five times that of the civilian industry.[27] A recent Navy flight deck study demonstrated that 79% of noise-exposed flight deck personnel had only 0 to 6 dB of effective hearing protection. This inadequate protection was attributed to poorly fitting earplugs as well as the lack of hearing protection. When properly used, helmet and headset attenuation can yield protection up to 45 dB; however, this protection can be offset by bone conduction if the helmet is in contact with the skull. The Navy flight deck study also demonstrated that 75% of subjects did not have properly fitted helmets and ear cups to provide maximal protection.[27]

The optimal solution to hearing problems in the aviation community is for aircraft manufacturers to adhere to noise-reduction criteria that maintain performance and maximize protection for the crew and support team. The new FA-35 Lightning II Joint Strike fighter, for example, shows recent noise testing levels in excess of the 145 dB range. Noise levels in the crew's quarters below the flight deck are consistently above 100 dB.[27] Engineering controls in the crew's quarters and quieter engines must be part of the acquisition process. Until these engineering changes are made, the military aviation community will continue to experience higher incidents of noise-induced hearing loss than other occupations. Thus, medical surveillance must continue, and improved personal hearing protective devices must be issued to crew members.

The best PPE provides significant active noise reduction by reducing ambient exposure to loud noise as high as 140 dB to as low as 85 dB. The new hearing protection known as the Attenuating Custom Communications Earpiece System was incorporated into fighter aircraft helmets by Air Force and Navy research labs. The Attenuating Custom Communications Earpiece System provides noise reduction and improves the clarity of voice communications. The system's noise-canceling microphones and custom-fitted communication ear plugs also provide aviators and maintenance personnel sufficient, effective, and comfortable hearing protection. Figure 16-3 shows an aviator's helmet and communication ear plugs.

Sleep and Rest

Fatigue, Sleep Deprivation, and Circadian Rhythm Disturbance

The average adult requires 8 hours of sleep each 24-hour period.[28] Several factors contribute to poor sleep. Sleep loss results in a predictable pattern of symptoms, though symptoms may manifest differently among individuals. For example, for some individuals, the loss of only 2 hours of sleep a night for two consecutive nights has been shown to impair performance.

Figure 16-3. Aircrew helmet with communicating ear plugs. Photograph courtesy of Christianne N. Opresko, Major, Medical Corps, US Air Force; Eglin Air Force Base, FL.

After several days of partial or interrupted sleep, most people suffer some degree of impaired performance.[16] Long-range flight operations and multiple-day missions are operational realities in military aviation.

Fatigue results from sleep deprivation are associated with prolonged periods of work and the operational stresses of flight.[16] Flight surgeons must be familiar with flight operations and crew stresses including sleep deprivation; circadian desynchronization; prolonged sitting; heat stress; noise; vibration; motion sickness; hypoxia; dysbarism; drugs such as caffeine, alcohol, and antihistamines; bladder distension; barotrauma; G-stresses; and psychological stress.[16]

General George E. Marshall, who was chief of staff of the US Army under presidents Franklin D. Roosevelt and Harry S. Truman, noted the operational consequences of sustained operations during World War II, observing that crews were disoriented, sleepy, and unable to give and receive orders due to fatigue and sleep deprivation that led to attention lapses and poor memory.[16] Aircraft operations can be affected by poor night vision, equipment limitations, and aviator endurance. Advances in aircraft technology make sustained operations longer than 18 to 24 hours possible, so the flight duration is often limited by human endurance.

Sleep deprivation and circadian rhythm disturbances impair performance during sustained operations, so it is critical to identify signs of performance degradation to manage sleep loss and fatigue. Sleep loss and fatigue degrade performance in the following ways:[16]

- **Mood and motivational changes.** Decreased initiative and irritability may be reported in individuals who experience fatigue and insufficient sleep.
- **Attention deficit.** Tired individuals have a shortened attention span and cannot concentrate on specific tasks with the same vigilance as when they are rested.
- **Memory lapse.** The inability to remember recent events may be a sign of sleep loss. Sleep-deprived individuals, after 48 hours of continuous work, are only able to recall 40% of information.
- **Delayed responses.** During continuous work without sleep, both speed and accuracy suffer. Also, sleep loss causes unpredictable slowing of response times and nodding off, both of which can be dangerous.
- **Performance blindness.** Deficits accumulate that can go undetected until performance suffers. People can become more rigid in their approach to job tasks and problems they encounter, and flexibility may be critical.
- **Interpersonal skills and communication.** A major factor in safe flight operations is the crew's ability to maintain command, control, and communications among all members of the crew. Communication problems due to fatigue and sleep loss often result in improper task prioritization and poor coordination. Breaks seem to increase performance and mood, and built-in breaks may have sustained benefit during long-term flight operations. Even short periods of sleep, such as strategic naps, help increase alertness. Studies have shown 2 hours is the minimum amount of sleep needed to boost performance.

Operators can partially offset sleep difficulties arising from irregular work and rest patterns through physician-prescribed hypnotics. Hypnotics can aid airmen during rest periods scheduled at unusual times of the day and under circumstances that may not be conducive to sleep. A hypnotic should decrease sleep latency, preserve normal sleep architecture, and be free of residual sequelae. The Air Force studied F-16 pilots who flew an average of 149 hours over a 3-month period, and found that sleep aids zolpidem and temazepam were effective when prescribed and monitored by a flight surgeon.[16]

Stimulants are another class of drugs that improve performance during sustained operations. These medications can help an individual maintain vigilance during long duty periods without rest or sleep. Currently the military services use dextroamphetamine and modafanil for long-duration tactical and strategic missions in single-seat fighters and B-2 aircraft. Like hypnotics, direct physician oversight is critical. Caffeine is widely used by crew to maintain alertness, and is generally safe and effective.[16] However, prolonged use of caffeine over time can cause insomnia, nervousness, gastritis, nausea and vomiting, and increase both the heart and respiration rates. Higher doses of caffeine cause headache, anxiety, agitation, chest pain, and ringing in the ears, and very high doses can cause arrhythmias and death.[29]

Fatigue Management

Flight surgeons are in a key position to watch for the onset of sleep deprivation and operational fatigue and recommend corrective actions. Recommendations should include appropriate rest schedules and lodging accommodations to reduce light, attenuate noise, and maintain climate control. Whenever possible, critical mission segments (eg, aircraft recovery) should not be scheduled during the circadian trough. Additionally, flight surgeons can aid commanders and their assigned crew with environmental and life stressors that can add to operational fatigue. Some of these stressors include inadequate diet and irregular meal schedules, uncomfortable or improperly sized equipment, personal and family difficulties, and poor physical conditioning. Several monitoring tools are at the flight surgeon's disposal, including software that plots a crew member's past activities and their relationship to circadian rhythm and sleep cycles. The sleep data can be used to track operational fatigue and adjust operations to protect individual safety and mission execution. When appropriate, hypnotics and stimulants may be prescribed to mitigate acute, in-flight fatigue.

Weaponry and Injury

The extreme hazards from the intentional use of modern weaponry are self-evident. Aviators and their maintainers must be familiar with these threats and minimize their effects during air operations and on the ground. Among the broad array of chemical, biological, radiological, nuclear, and high-yield explosives weaponry, those of special interest to the aviation community are chemical, laser, and other directed energy threats. The challenge to protect the aviator with a suitable barrier from chemical exposures in and out of the cockpit has been daunting, focused currently on using specialized PPE or mission oriented protective posture gear, to minimize restrictive effects while providing adequate protection. Lasers present a threat as both a tool (targeting, alignment devices) and a weapon. Laser beams pointed at an aircraft cockpit in-flight not only create a form of intense operational flash blindness from the scattered canopy or windshield illumination, but may also create temporary retinal or permanent corneal injury.[30] Special aviator medical screening programs using Amsler grid interpretation and retinal photography provide monitoring and determine the incidence of laser eye injuries. Laser eye injury management and an assemblage of laser eye protection (LEP) devices are available for use. Additionally, microwave and particle beam forms of directed energy have been developed as weapons and present challenges for crew protection.

Ergonomics

Most aircraft restrict the pilot's in-flight mobility. Especially during long flights aviators find themselves in an ergonomically challenging workplace. Contributing factors to musculoskeletal disorders, especially neck and back pain, include long periods of stationary work, safety harness wear, exposure to whole-body mechanical vibration (especially in rotary-wing aircraft), PPE such as flight gear, survival equipment, and possibly night vision goggles (NVGs) and body armor. Aviators and their flight surgeons must closely monitor back pain because it is a long-term exposure risk and common complaint among the general population.

Travel Health Hazards

The need for military aviation personnel to respond to events anywhere in the world, on short notice, for prolonged periods of time, and in remote and austere living conditions makes them world travelers. These military professionals must be protected from diseases indigenous to developing countries, by immunization (for yellow fever, typhoid, tetanus, hepatitis, measles, etc); prophylactic treatments (for malaria and traveler's enteritis); and good hygienic practices in bathing, eating, drinking, clothing, and shelter. Medications and immunizations must not interfere with the aviator's job performance (some drugs require pretesting or use restrictions).

Common Industrial Hazards

Like many other industrial settings, the aviation environment is replete with general and specific hazards and respective prevention programs. In addition to noise, confined spaces and heights (platform, hoist, and crane operations) are of concern. Lead and asbestos are present in older buildings and must be mitigated according to laws and policies.

Fuels, propellants, and solvents such as jet fuel, hydrazine, and benzene are of special importance in the aviation environment. Jet fuel comes in various mixtures; Jet Propellant 8 is the most predominantly used fuel. Jet Propellant 8 poses an exposure risk for people who inspect and maintain fuel tanks. The concern for fuelers is the combination of chronic below threshold fuel exposures paired with hazardous noise potentially causing more pronounced hearing loss. In addition, Jet Propellant 8 has been found to produce immune suppression in laboratory animal studies, so use of an Air Force protective overgarment is recommended. Hydrazine, an F-16 engine starter propellant, is an acutely toxic substance. It is a mucosal irritant, readily absorbed through the skin in its normal liquid state, and capable of causing skin and eye burns, neurological and hepatic damage, nausea, vomiting, and convulsions, with potential histological damage to liver and kidneys. Among the many solvents used in the aviation environment, benzene, a known carcinogen, is a principal ingredient of concern, and is found in cleaning products and fuels. In all cases, medical surveillance programs generally follow Occupational Safety and Health Administration regulations and National Institute for Occupational Safety and Health guidelines.

Corrosion control involves the removal and replacement of paints, coatings, and platings on both mechanical and nonmechanical portions of the aircraft. Removing old protective layers by sand or bead blasting or using chemicals may result in worker exposures to these agents, heavy metals, and isocyanate paints. Silica and methylene chloride are also used for paint stripping. Exposure to these materials is controlled through the use of local exhaust ventilation, substitution, and respiratory protective equipment. Medical surveillance follows Occupational Safety and Health Administration regulations and National Institute for Occupational Safety and Health recommendations. The paints and coatings used in aviation often contain cadmium and chromates, both of which have superb anticorrosion characteristics. Cadmium is used for plating moving parts; chromium is used in paints that coat the fuselage, wing, and tail surfaces. Because aircraft parts maintenance is a constant process, tight controls and periodic medical surveillance are necessary. Isocyanates used in paints have superior bonding and abrasion resistance but are known pulmonary sensitizers, even at low doses, and even relatively short exposure times require close monitoring for isocyanate sensitization.

Composite materials are increasingly being used in place of traditional aluminum for aircraft fuselages and wing fabrication. These can consist of boron, carbon/graphite, and glass fibers imbedded in a polymer (epoxy or polyester) matrix.[31] Hazards are directly related to the components themselves. The fibers can become particulate irritants to skin, mucus membrane, and lungs; respiratory protection is critical to avoid inhalation. Polymers must be controlled for their largely irritant and sensitizing effects. Exposures occur not only during manufacture and repair, but also following aircraft mishaps during the crash investigation, when burning materials can release fibers and particulates.[31]

Ionizing radiation methods are used for nondestructive investigation of aircraft structural integrity. Workers are monitored via dosimetry, similar to methods for medical radiology. Radar systems that emit nonionizing microwave radiation may cause physical effects with short-range exposures. Workers must be aware and take protective measures to avoid short- and long-term exposures. Chapter 22 of this textbook, Ionizing Radiation, addresses precautions and protective measures.

PREVENTION, FITNESS, AND PERFORMANCE

Workplace injuries can happen to any employee regardless of the type of work. Each year hundreds of thousands of people are injured at work. These injuries cost both employees and employers billions of dollars annually in health costs and lost work time. Injury data and near-miss incident reviews must be analyzed to find ways to prevent future workplace injuries through the adoption of proper safety procedures and workplace practices.

General Environmental

Whether in garrison or on deployment, occupational medicine providers need to perform several services to ensure force protection and human performance enhancement. These safeguards include ensuring food and water quality, optimizing the unit's medical readiness to fight, and supporting the operational mission.

One of the basic functions of aerospace medicine involves safeguarding the food and water military personnel consume. Systematic surveillance ensures food safety and quality at the time of procurement or receipt, during storage, and at the time of serving. Likewise, water sources, storage, and distribution systems are routinely monitored for bacteria and chlorine residuals. In the Air Force, ensuring food and water quality and safety is the key task for deployed preventive aerospace medicine teams. In the Army, this is a joint effort of the Preventive Medicine and Veterinary Corps services. During Operations Iraqi Freedom and

Enduring Freedom, personnel who performed food receipt inspections identified food spoilage in the hot Middle East environment and guarded against tampering when convoys transported food across long distances.

Personnel ensured water quality through source analysis—bottled water was purchased only from approved vendors after source water was treated with reverse osmosis filtration and chlorination. High temperatures rapidly neutralized chlorine, which then required frequent monitoring for appropriate chlorine residuals. Also, storage in bladders and water distribution through tent cities posed a challenge to maintaining potable water. The distribution system's integrity in field conditions is paramount in preserving potability.

The population at risk must be optimally fit to effectively execute deployed operations. Optimization begins with the home station ensuring all military members manage their diet, weight, aerobic, and strength fitness. The services' fitness programs provide for unit level fitness activities, testing, and management for noncompliant members. Each member undergoes a periodic health assessment to screen for health maintenance, health changes, disease risk factors, counseling, and medical interventions. Immunizations are given as needed depending on the deployed location. Every service member has an individual medical (mobility) readiness status, which indicates deployment readiness based on system-defined health parameters. In aggregate, the command (ie, Air Force Wing) has visibility of its population, ensuring its medical readiness and ability to deploy anytime.

Air Force bioenvironmental engineers and Army environmental science officers are charged with supporting surveillance for chemical and biological attacks in concert with civil engineering readiness. Sampling, substance identification, and plume characterization are bioenvironmental engineering's key roles. Its capabilities are crucial to an airbase's ability to survive and operate following an attack of any kind. Chemical gas mask fit testing is another service provided by bioenvironmental engineers. Depending on the military threat, deployed troops may be issued chemical and biological antidotes.

Readiness and Deployment

Assessment

Military medicine is now linked with individual medical readiness. Individual medical readiness is assessed throughout the year, but is particularly focused during an annual preventative health assessment (PHA) visit. During this encounter, the primary care clinician documents readiness, consolidates evidence-based clinical preventive services, conducts occupational health and risk screening, reviews the health record, makes referrals for specialty physical examinations, conducts deployment health assessments, and performs individualized counseling, testing, and treatment. The PHA visit has replaced the annual Air Force physical; however, in the Army, the PHA is only part of the annual flight physical. All service members are required to receive an annual PHA during which the six elements of individual medical readiness are measured and documented in MHS Genesis (the new electronic health record for the Military Health System). The six elements of individual medical readiness include:

1. absence of deployment-limiting conditions;
2. dental readiness;
3. laboratory tests (human immunodeficiency virus, DNA, blood type);
4. immunizations;
5. medical equipment; and
6. completion of the PHA questionnaire.

Readiness tracking allows for real time data updates during the PHA. In the case of those on flight status, the review should encompass a hearing status update, visual acuity check, and update on occupational hazards. Readiness assessments are also done both before and after deployment. *International Classification of Diseases, Tenth Revision* coding guidance for all readiness assessments may be found in the Military Health System medical coding guidlines.[32]

New Accession Exams

New accession exams are performed on every new recruit or employee. These comprehensive physical examinations include blood tests and radiographs. The labs and physical exams are tailored to the existing occupational hazards. Air Force pilots are evaluated at the 711th Human Performance Wing Human Systems Integration Directorate with specific tests including echocardiography as well as an exam by a team of aeromedical specialists. In the Navy and Army, all aviation applicants are evaluated by the Naval Aerospace Medical Institute and the Army Aeromedical Activity, respectively, to ensure quality control and database exam records that can be used for comparison later. The entry examination ensures the member meets all physical demands of military service, screens for existing physical problems that would prevent the member from performing duties, and establishes a medical baseline to detect service-connected physical problems.

Flight exams are performed annually in conjunction with the PHA. These exams are more stringent as the risk to the pilot and aircraft increases from flying class I to flying class III. The sole pilot of a high-performance jet aircraft undergoes a class III flight physical.

Modified Duty Programs

Modified duty programs involve a brief or prolonged illness. To place someone "on quarters" is a medical recommendation given to military members who cannot perform their required duties because of a medical condition.[33,34] Quarters are a temporary administrative program lasting 24 to 72 hours. If the member has a condition that exceeds this timeframe, then medical leave can be used. If the medical condition is ongoing and requires a longer work absence, the member can obtain a temporary physical profile. With a physical profile, the active duty member can be restricted from participating in certain or in some cases all of their duties. These restrictions protect the member by ensuring prompt and appropriate medical care and preventing deployment or leave status where medical supervision may be limited or inadequate. An active duty member can stay on this program for 365 days before a medical evaluation board (MEB) is required. An MEB is a detailed summary of medical care submitted on behalf of the military member to the military treatment facility's commander or a designee. A panel of three appointed physicians reviews the individual's history and physical findings, considers other specialty care providers' medical opinions on the likelihood of recovery or resolution of a particular medical condition, and then makes one of three recommendations.[35,36] The MEB can recommend a member return to active duty without restrictions, convene a physical exam board consisting of a panel of specialists who meet with the member, or recommend to medically retire a member, bypassing the need for a physical exam board.[36]

Profiles noting a physical restriction are issued for documentation as well as protection (ensuring a member does not perform duties that could cause injury). Hearing loss is an example. As hearing worsens, a member's profile rating may change from excellent hearing (H1) to lower levels (H2 or H3). Many jobs require a minimum hearing level for worker safety. An individual who is unable to meet those requirements may need a waiver to continue working in the specialty or at a specific job site. A waiver is very much like the MEB process in that a summary of medical care is completed; however, the panel of physicians is generally smaller and the individual's physical ailment is permanent and unlikely to change.[33]

A similar profile program for aviators is the duty not involving flying (DNIF) status. All personnel on flying status need a medical disposition from a flight surgeon for flying duties. A member who cannot safely fly is placed in a DNIF status. The status of the crew member is recorded on the DD Form 2992, Medical Recommendation for Flying or Special Operational Duty, used by all services. Flight surgeons record flight status as either qualified or disqualified and the DD Form 2992 is maintained in the crew member's flight records. There is no definitive length of time a person remains in DNIF status, but a general rule is no longer than a year. After a year, an MEB or physical exam board should be considered.[33] Once the MEB is complete, an aeromedical summary, which includes waiver recommendations to the approving authorities, is submitted for review by the respective services' aeromedical review sections. The Air Force uses the grounding management information system or aeromedical services information management system, tracks all DNIF crew, and generates a weekly report for review by the flight surgeon staff. The use of information management systems ensures aviators receive proper medical follow-up. All of these programs ensure commanders have a fit and healthy force able to safely accomplish the flying mission.[37]

Fitness Testing Programs

Fitness testing programs are used to ensure military members are fit for duty. Fitness and overall good health practices are vital to any organization but especially in the military during arduous and austere operating conditions. Every active duty member is required to pass a physical fitness test that measures strength, physical conditioning, and aerobic fitness. The fitness testing program is also based on the military member's profile status. If the member is restricted from certain physical requirements, then a fitness program is tailored to meet individual needs. If the member is unable to perform and maintain a minimum level of fitness, then the MEB or physical exam board process is initiated.

Counter Fatigue Programs

Counter fatigue programs are available for all aviators; those on flying status undergo ground testing for counter fatigue medications prior to use during flight in operational environments.[38] Although dextroamphetamine has traditionally been used, modafanil has recently also been shown to attenuate many of the cognitive deficits associated with inadequate sleep with fewer side effects than dextroamphetamine. The sleep aids temazepam, zolpidem, and zaleplon have been used successfully in the treatment of circadian rhythm disturbances, especially when transitioning through several time zones or when the time zone changes are rapid. These medications are used in conjunction with missions that do not allow for adequate sleep/rest cycles or adequate time zone adjustment.[38]

Circadian rhythm or "jet lag" fatigue is of particular operational concern, especially with the need to rapidly deploy troops who are fully mission capable upon arrival. Researchers with the Warfighter Fatigue Countermeasures program at Wright Patterson Air Force Base, Dayton, Ohio, have developed counter-fatigue measures such as optimal crew work/rest schedules, sleep-enhancing techniques and circadian rhythm adaptation, and assessment of alertness enhancing medications. One such measure is the Fatigue Avoidance Scheduling Tool. This interactive software program allows mission planners, flight surgeons, and aerospace physiologists to assess the effects of work/rest cycles, circadian rhythms, performance declination with sleep loss, and sleep inertia.[38]

Personal Protective Equipment

PPE is used as the only measure of protection when engineering and administrative controls are not feasible. Employees and employers must be educated regarding workplace hazards and the controls necessary to protect workers. Physicians, industrial hygienists and safety professionals must assess the potential risk for workplace-associated injuries. They should review each of the basic hazards and determine the hazard type, risk level, and seriousness of potential injury. They should also consider the possibility of simultaneous exposure to several hazards. Assessment should then lead to selection of the appropriate controls to include engineering controls, administrative controls, product substitution, and/or appropriate PPE selection.

A variety of devices are available to provide a barrier between the worker and hazardous exposure. Eye protection equipment comes in such forms as safety glasses, goggles, and face shields. There are many types of skin protection such as gloves, aprons, and full body suits made of materials impervious to chemicals. For example, flight gloves and suits are made of flame-resistant Nomex (DuPont, Wilmington, DE) material.

If the air in the workplace contains fine particles, sprays, mists, or toxic gases, there is almost certainly a risk of exposure to a worker's respiratory system. Workers in these areas should wear respirators. Air-purifying respirators filter contaminants out of the air, while supplied-air respirators provide an air source free of contaminants or additional oxygen in oxygen-deficient working environments.

If any substance in the workplace can fly, splash, or drip into the eyes, the worker likely requires eye protection. This protection may be as simple as safety glasses with splash guards or more involved, such as heavier duty goggles or face shields to protect against impact or trauma risks to the eyes or face.

High noise levels can cause hearing loss.[19] Often workers and employers are unaware of the degree of noise exposure. Noise exposure can be intermittent and perceived as nonthreatening. Protecting a worker's hearing is complicated by the perceived inconvenience of wearing hearing protection. A proper assessment of noise exposure, hearing protection training, and periodic follow-up testing for hearing loss are all essential parts of the hearing program.[19]

Visual Performance and Protection

While visual cues are valuable on the ground, they are absolutely essential to flight operations. As such, vision constitutes a critical portion of entrance physical examinations, where candidates are expected to possess excellent visual acuity, color vision, depth perception, and binocular vision.

Color Vision

Color perception allows a person to quickly distinguish objects from each other, interpret important information (eg, traffic signals and sports jerseys), and process information more efficiently. Even small changes in color perception can affect interpretation and situational awareness. Technological advances and harsh environmental conditions challenge the warfighter's ability to assess color; therefore, it is critical for healthcare providers to be aware of color vision physiology, abnormal color vision, and color vision testing.

Color vision is an extraordinarily complex process involving physics, biology, and psychology. The physics of color begin with light that is either reflected off a surface or emitted from a source. A person considered to have normal color vision has three classes of cone photoreceptors within the retina, with each tuned to a range of short (blue), medium (green), or long (red) wavelengths of light. After the cones receive light stimulation, the biology of color vision begins.[39] The remaining retinal layers convert light energy into neural signals via electrochemical processes. These neural signals are then transmitted to the visual cortex for further processing. Color perception and visual processing mostly occur within the occipital lobe of the brain.

The main components in color vision are hue, brightness, and saturation. Hue is the name given to a particular wavelength interpretation, for example, red and blue. Brightness is the perception that a given hue is emanating light; for example, a red car may appear dim red when dusty and bright red when newly polished.[39] Saturation is the amount of color concentration. For example, pink, red, and scarlet are varying degrees of the same hue at the same brightness, but with different amounts of red. Color vision is subject to misinterpretation or illusions resulting from the brain's rules of interpretation.[39] For example, objects in the distance are more faded in color than near objects. On a clear day, a distant mountain that appears crisp and sharp in color will often be interpreted as being much closer to the observer than it really is. It is important to note without a psychological interpretation of wavelength, color does not exist. For individuals who do not have the same mechanisms or processes as most people, color still exists, but in a skewed form.

While most people are considered color normal, roughly 6% to 8% of males and 0.4% of females experience some form of color blindness.[39] Total color blindness (ie, monochromatism) is exceptionally rare and is due to the complete lack of retinal cone cells. Medications, genetics, disease, and ocular appliances (eg, colored spectacle lenses or LEP) may alter color perception. The severity of color deficiency can range from mild to severe. A color-deficient person may confuse stimuli in the short end of the spectrum (blue-yellow deficiency) or, more commonly, in the medium and long ends of the spectrum (red-green deficiency).[39]

Even mild color vision alteration may affect occupational safety. Color-deficient individuals require more processing time for color-based information, and they are known to make significantly more errors than color-normal individuals. In 2002, the National Transportation Safety Board made a significant discovery following a commercial airliner mishap. The safety inspectors found the main cause of the aircraft mishap was the pilot's color vision deficiency.[40] The pilot was unable to distinguish the runway lights during an approach, and as a result, the aircraft collided with trees 3,100 ft short of the runway. Such mishaps underscore the importance of color vision testing, not just upon entry into the military, but also during routine physical exams, with the diagnosis of certain health problems, or after brain or ocular injury.

Color vision testing assesses an individual's ability to name colors, distinguish between different colors, and match different objects of the same color.[41] Tests vary considerably in their ability to identify a color deficiency, determine superior color vision, or determine if a person is able to perform a particular color-dependent task. The most common and reliable color vision tests include the Ishihara pseudoisochromatic plate, Farnsworth-Munsel 100 Hue, and Farnsworth Lantern.[41] All color vision tests require specific lighting conditions, a proper test environment, and a skilled administrator to ensure accurate results. It is also important to maintain the tests in a cool, dry environment free from the sun and fingerprints; a color vision test that has been faded by the sun or exposed to fingerprints suffers pigment alteration, which may result in color-deficient individuals passing a test they would otherwise fail. The cone contrast test has replaced the pseudoisochromatic plate and Farnsworth Lantern tests as a more sensitive screening tool for general red-green color deficiencies.[41]

The growing importance of color vision in the military aviation environment (from pilots to air traffic controllers) is important for testing and safety. In the past, most color demands in the cockpit were minimal. Cockpits had a small number of red or green lights. Most color was outside of the aircraft: blue lights on the night taxiway; flashing red, green, or white lights on other aircraft; and occasionally red and green flares. Little time was spent processing color information, because these lights centered around safety and navigation. Today's multifunctional aircraft displays are not comparable to past cockpits. Pilots in military aviation environments are required to assess cockpit displays, external navigation aids, and aeronautical charts for air-to-ground and air-to-air operations. Additionally, aircraft carrier operations require the color detection of flight deck jerseys, signal wands, deck lights, and signal lights and beacons. Cockpits feature polychromatic, multifunctional displays that present flight management and control data with over 256 color shades. These colors are often superimposed on each other, requiring excellent discrimination. Color use in aviation has increased dramatically, as has the time spent examining color displays, tools, and the environment.

Though color vision requirements in aviation have become more sophisticated, color vision testing has not. Current studies have found large variabilities in color vision tests, administration, and integrity.[41] Universal tests and standards are needed to reduce the variabilities in color vision testing results. Additionally, there is debate regarding the proper assessment of perceptual color in the aviation environment. The Commission Internationale de l'Eclairage (International Commission on Illumination) has developed a metric for quantification and measurement; however, while the metric provides a standard for clinical assessment, its application to aviation remains unclear.

The Research and Technology Organization of the North Atlantic Treaty Organization recently called for a more objective color vision assessment that takes into account special flight circumstances.[42] These circumstances include ambient lighting, display size, object versus aperture color, task requirements, and the importance of color. Current tests built specifically for the aviation environment are promising. These tests range from lanterns with a wider range and stronger system for representing the spectral array found in aviation, to tests that mimic actual demands, such as map reading, head-up display stimuli, and air traffic control signal lights.

Lastly, few aviation communities utilize testing of blue-yellow color discrimination despite its importance. A number of pharmaceuticals affect color perception, especially of blue-yellow,[42] and the blue-yellow axis is the most affected by aging-related color vision changes. Additionally, demands of the flight environment subject all visual pathways to disruption; again, the blue-yellow pathway is most affected. It is important that future research examining color perception and aviation include the blue-yellow axis. If there is any doubt regarding an individual's color vision status, it is best to refer the case to a color vision specialist, who can administer and interpret more specialized and sensitive color vision tests.

Laser Eye Protection

Many eye components are prone to laser-induced damage. The retina is the most vulnerable,[19] due to the intense concentration of visible and near-infrared wavelengths of light onto the retina by the eye's optical components. Symptoms can range from no impairment to severe visual loss and pain, depending on the severity and location of the insult. It is important to note most laser-induced retinal insults are painless, because the retina has no pain receptors. Overall, lasers can affect vision by producing glare, interfering with dark adaptation, inducing flash blindness, or causing temporary or permanent vision loss.[19]

Due to the risk of enemy and friendly laser fire, all branches of the US military utilize some form of LEP, usually in spectacle or visor format. The overall goal of LEP is to block laser threat wavelengths from reaching the eye while concurrently allowing a maximum amount of nonthreat wavelengths to pass through. Because some useful wavelengths of light are blocked in this process, LEP is always a visual compromise. Users can expect slightly reduced daytime visual performance and color perception and significantly reduced nighttime visual performance (unaided). Another drawback is the fact that one pair of today's LEP cannot protect the user from *all* laser threats.[19] Therefore, LEP must be carefully selected, based on the power and wavelength of the laser threat. The latest military LEP combines older dye-based protection with newer, high-tech reflective technology.[43] The result is an expensive but highly capable LEP that protects against multiple hazardous laser systems and minimizes the impact to visual performance. Figure 16-4 provides an example of coated thin film LEP on the visor of a crew helmet.

Night Vision Goggles

NVGs are electro-optical sensors, which use an image intensifier tube to amplify visible and near infrared light energy. The image intensifier converts incident photons into electrons, which are then multiplied and converted back into viewable photons.[44] The result of this intensification process provides the user with a two-dimensional, monochromatic image of the nighttime scene. Most importantly, the scene detail is increased from a 20/200 to 20/400 scotopic (ie, nighttime) image to near-photopic (ie, daytime 20/30) visual acuity levels.[44] Just as the human eye's spatial discrimination varies with illumination and contrast, so too does the NVG image quality. Actual acuity with NVGs depends on the NVG specifications and the night environment. Military specifications for NVG acuity can vary, but most NVG systems provide 20/30 visual acuity or better under ideal environmental conditions and after proper focusing techniques.

Figure 16-4 Laser eye protective film on the visor of an aircrew helmet.
Photograph courtesy of Alfred Emmel, Colonel (Retired), Medical Corps, US Air Force; Presbyterian Hospital, Albuquerque, NM.

Two important components of NVGs are the objective lens and the diopter (or eyepiece) lens. The objective lens focuses the reflected light energy from an object onto the image intensifier.[44] Improper objective lens focus will result in poor visual acuity and suboptimal sensor performance. Once the amplified electrons are converted back into photons, the diopter lens focuses the output image onto the user's eye. Proper diopter focus is required to avoid eyestrain or eye fatigue. The diopter lens can correct for simple, mild myopia (nearsightedness) and hyperopia (farsightedness). There are three main NVG designs: monocular, biocular, and binocular. The AN/PVS-14 used by some ground forces is a monocular design. It has one image intensifier, housed between the objective and diopter lenses, and the user views objects in direct line-of-sight with one eye. The AN/PVS-7, the most common NVG used by ground forces, has a biocular design. Its single image intensifier amplifies the night scene, and, through combining optics, the intensified image is presented to both eyes simultaneously. The AN/AVS-9, used by Navy and Marine Corps flight personnel, has a binocular design; each eye has its own independent NVG monocular.[44]

The NVG design limits the user's ability to estimate distance and depth. All NVGs should be focused and aligned so the user experiences no accommodation or ocular convergence. With monocular designs, only one eye sees the image and there is no binocular information available to estimate distance or depth. With binocular design, each eye sees the same image and binocular designs provide for limited binocularity and stereopsis. Beyond 600 ft, where binocular cues cease to provide useful information, humans naturally use monocular cues for distance and depth estimations. These same cues provide the majority of the distance estimation and depth perception to NVG users.

Spatial orientation requires more conscious mental processing with NVGs than with normal photopic vision due to the reduced field of view. During the daytime, peripheral or ambient visual cues provide humans with location information through subconscious or preconscious perception of a horizon. NVGs intensify only a 40-degree horizontal field of view at a time. To compensate for this reduced field of view while using NVGs, crew members and other operators must scan the scene to see the horizon, read flight instruments, and more consciously process orientation cues.

In short, while NVGs provide enhanced visual acuity at night, visual drawbacks compared to daytime can easily introduce orientation challenges. Proper NVG training, hands-on experience, and proper preflight adjustments are critical to maximizing NVG performance and reducing the propensity toward user spatial disorientation.

Refractive Surgery

For centuries, prescription lenses have been used by ametropic warfighters to maximize visual performance and mission effectiveness. With no other available options, the benefits of wearing spectacles—or more recently, contact lenses—have outweighed the disadvantages. However, glasses often become fogged, get displaced, restrict peripheral vision, induce painful hotspots under head gear, and significantly reduce the hearing protection afforded by earcup seals in aviation and flight line helmets. It is difficult to incorporate spectacles under helmet-mounted displays, chemical/biological masks, visors, LEP, and NVGs. Contact lenses can be dislodged or dislocated, and quickly become uncomfortable in extreme environments (eg, high altitudes, dry climates). Most importantly, contact lenses demand frequent care under sanitary conditions. Because this is rarely possible during wartime, contact lens use is typically discouraged or prohibited in the field. The multiple drawbacks of traditional prescription lenses, in combination with recent advancements in medical and laser technology, have permitted refractive surgery to quickly become a viable alternative for many thousands of military personnel.

In its most common forms, refractive surgery permanently reshapes the eye's anterior surface (ie, the cornea) to reduce or eliminate a patient's reliance on prescription lenses. Civilian surgeons in the United States have been performing corneal refractive surgery since the late 1970s. The earliest form of surgical correction, radial keratotomy, relied on a surgeon's steady hand to create multiple (typically eight), deep radial incisions into the periphery of the anterior corneal surface. The natural healing process that followed flattened the central cornea and thereby reduced the patient's myopia or astigmatism.[19] Because radial keratotomy incisions never fully recede, long-term complications include fluctuating refractive error, complaints of halos at night, and structural weakness of the cornea in response to trauma.[19] The advent of laser-based refractive surgery, associated with significantly better visual outcomes and lower complication rates, all but eliminated radial keratotomy as a reasonable option.

Photorefractive keratectomy (PRK) utilizes an excimer laser to remove precise amounts of corneal tissue to reshape the anterior ocular surface.[19] Another popular procedure, laser in situ keratomileusis (LASIK), uses the excimer laser in a similar manner. However unlike PRK, a corneal flap is created and folded away prior to ablation. The surgeon then exposes the corneal bed to laser treatment, and returns the flap to its original position.[19] Visual outcomes and surgical complications are approximately equal in PRK and LASIK. PRK is associated with higher initial discomfort and a longer healing time, and often with complaints of halos at night during the first year of recovery. The primary disadvantage to LASIK is its corneal flap; sharp objects (eg, fingernails, tree branches) on exceedingly rare occasions have dislodged flaps, even years postoperative. With this in mind, warfighters who have undergone LASIK treatment should exercise extra diligence in wearing eye protection.[19]

The Navy began performing corneal refractive surgery in the early 1990s. Since then, PRK in the military environment has become widely accepted. Refractive surgery for the warfighter has been shown to increase readiness, enhance operational performance and safety, and improve retention rates. Most importantly, wavefront guided (custom) treatments continue to improve postoperative visual performance for both PRK and LASIK by reducing higher-order optical aberrations.

MILITARY AVIATION ADMINISTRATION

Aerospace medicine paralleled the development of aviation. The military requirement to have a combat edge over its enemies often fueled aviation development. As aircraft technology evolved from balloons to reusable space vehicles, the challenge to keep pilots and crew functioning normally in complex airframes and extreme, unforgiving environments was daunting. Aerospace medicine requires knowledge in several areas: human factors in the cockpit and workplace design, physiological tolerance criteria, environmental cooling systems, performance psychology, selection and training, PPE, and escape and survival are among the subjects specialist flight surgeons must understand to fulfill their primary aim of preventing disease, injury, and disability in flying personnel.

Safety and Health

A good aviation safety and health program should begin with staff consisting of a safety specialist and consulting occupational health professional at a minimum. In the aerospace community, the team typically includes an aviation safety officer and flight surgeon. A successful safety program contains several basic elements, including management commitment, good facility and equipment design, safety and health training and education, safety and health inspections, accident investigation, and health hazard evaluations.

Management Commitment

The three military services have dedicated aviation safety centers: the Combat Readiness Center at Fort Rucker, Alabama; the Naval Safety Center at Norfolk, Virginia; and the US Air Force Safety Center at Kirtland Air Force Base, Albuquerque, New Mexico. These safety centers develop flight safety programs based on best practices as well as Occupational Safety and Health Administration and Environmental Protection Agency standards applied to the aviation industry. From these headquarters, the aviation safety programs are delegated to the major commands and their subordinate units to implement. By regulation, the local aviation unit commanders must comply.

Facility and Equipment Design

All three services have human systems research, development, and acquisition organizations. The US Army Aeromedical Research Laboratory at Ft Rucker, Alabama, conducts research on crew health, performance, and protection.[45] The Naval Medical Research Unit at Wright-Patterson Air Force Base near Dayton, Ohio, conducts research on biomedical sciences and spatial orientation systems.[46] The US Air Force Research Laboratory, also located at Wright-Patterson Air Force Base, conducts research on directed energy biological effects, biosciences and protection, warfighter interface, and warfighter readiness.[47]

Using applied science, the various aeromedical research labs develop state-of-the-art technology designed to give military aviation its combat edge while simultaneously protecting personnel in the weapon system. Examples include the Gentex HGU-56/P Rotary Wing Aircrew Ballistic Helmet System designed to protect the head in a helicopter crash, the tactile vest designed to give pilots situational awareness, and active noise reduction in headsets, which improve communications and reduce hearing loss.

Safety and Health Training and Education

Education on flight safety and health hazards usually occurs during a unit commander's monthly safety briefing. Normally, the briefings are conducted by or under the supervision of the flight surgeon. Some topics include altitude physiology, spatial disorientation, aviation protective equipment, exogenous factors, noise, vibration, G-forces, aviation toxicology, and visual systems. There are periodic safety stand-downs during which flying operations cease. During such events, the unit dedicates time to perform safety checks on the work environment and attend to medical or health issues.

On a larger scale and from a programmatic perspective, there are aviation safety officer courses as well as aviation safety modules in the three services' basic flight surgeon course. These courses address the theory of errors and instruct methods to mitigate human factors that are often the root cause of aircraft accidents. One such method is crew resource management, which emphasizes open and unbiased communication among all crew members. Open communication broadens the sphere of situational awareness, which helps minimize the likelihood of an accident. Another method is operational risk management, in which the crew evaluates the various risks associated with a planned sortie, and then thoughtfully plans how to mitigate them. If the risks cannot be sufficiently reduced, the crew can cancel that sortie or determine an alternative course of action.

Safety and Health Inspections

Safety and health inspections are control measures used to evaluate the effectiveness of established programs. At the local level, flight line visits and the flight medicine program (annual physicals that include screening for hearing, vision, and occupational exposures) are among the conducted inspections.

From a major command or higher headquarters perspective, units undergo periodic inspections to ensure compliance with health and safety policy and regulations. These inspections are usually conducted by personnel outside the inspected unit. In this way, findings and recommendations have less bias or undue influence. In the Army, the aviation readiness management survey is a high-level tool to ensure aviation line commanders are in compliance with the service's aviation safety program.

Mishap Investigation

Mishaps create the motivation for all safety and health actions. A mishap is an undesirable event that must be investigated to help prevent recurrences. It serves no purpose to investigate mishaps without initiating some type of corrective action to prevent future occurrences. All mishap investigations should attempt to answer who and what was involved and where, when, how, and why the mishap occurred.

The three services' safety centers conduct accident investigations using full time staff members assigned to an accident investigation team consisting of an engineer, pilot, aviation safety officer, flight surgeon, and senior officer as board president. Using oral reports, maintenance records, health records, and forensics, the team determines whether the mishap was due to material failure or human factors. The aviation safety officer and flight surgeon are responsible for analyzing human factors. The Department of Defense Human Factors and Classification System tracks causal factors throughout four distinct layers: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences.[48] The process acknowledges deficits at each layer. This model, developed for naval aviation mishap analysis by Shappell and Weigmann, has been adopted throughout Department of Defense for use in developing the final official report at the conclusion of the investigation.

Health Hazard Evaluations

A health hazard evaluation can be used to determine the risk level associated with exposures as well as measure the effectiveness of any hazard control mechanism. At the program level, evaluations are conducted during the research and development phases of the systems lifecycle management process. At the unit level, evaluations should be conducted by the flight surgeon.

Flight Medicine

The flight surgeon is integral in conserving fighting strength. In addition to clinically treating the crew member's medical condition, the flight surgeon must determine whether that medical condition will affect the individual's ability to safely perform aviation duties. In good faith, the flight surgeon will abide by the guidelines set forth by HIPAA (the Health Information Portability and Accountability Act). Operational risk and a commander's need-to-know may dictate the flight surgeon report directly to the commander about the nature and ramifications of a crew member's medical condition.[49]

Aviation Fitness Evaluation

The US military's need for a resolute and deployable fighting force means it must be able to select the best qualified and most fit individuals. This is especially true for aviators. Recruits and candidates must meet the military's stringent medical fitness standards and undergo an initial flight physical (ie, the accession physical). If the individual does not meet the medical fitness standards, then that individual will not be employed as a crew member.

Annual physical evaluations are conducted throughout the crew member's career to ensure medical fitness for flight duties. These evaluations are based on respective military services' aeromedical waiver guide and the US Preventive Services Task Force guidelines as they pertain to the aerospace mission of the three military services.

Determining Flight Status

Military medicine, by design, exists primarily to support the military community service members who are fit and able to engage in the business of war. The military' aviation community is particularly sensitive to medical conditions that affect the aviator's ability to perform safely. Regulations, instructions, and policies address conditions that adversely affect flight safety.

Determining Work Relatedness

Because military service members are subject to duty at any time, most incidents (injury or disease) are considered work related. The military provides training programs, through the various services' safety centers, to foster a culture of safety. Determining work relatedness following crew injury is no different from investigating injuries in any other military occupation. The flight surgeon should get an initial impression from the patient and validate the mechanism of injury or disease development, then document the medical findings in the crew member's electronic health record. If the service member was command referred, the commander may get medical information from the flight surgeon, but it is best if the physician asks the patient to sign a release of medical information under HIPAA.

Air Evacuation

Due to the nature of military operations, wounded combatants must be rapidly cleared from the battlefield because rapid treatment in the golden hour is paramount. The military has an echelon-based medical system starting with an individual service member providing self-aid or buddy aid, to combat medics, forward surgical teams and field hospitals, and eventually extending back to major medical centers in the continental United States, which provide definitive and rehabilitative care. The concept is to medically evacuate the wounded to a level of care where they can be treated and returned to the fight. If a return to duty is not possible, then the service member will be medically evacuated to a level where providers can treat the injury and determine the service member's fitness for duty.

Air evacuation is a means to accomplish rapid evacuation of personnel who have serious and life-threatening wounds. Although air evacuation is relatively seamless, the services have distinct roles. The Army has the primary mission to provide tactical MEDEVAC, and the Air Force provides fixed-wing, strategic aero MEDEVAC.

Army rotary-wing aircraft are generally used to evacuate wounded from a hot landing zone to a forward surgical unit or a combat support hospital. The number of patients transported range from one to four, due to the helicopter's tight configuration. A "9-line" MEDEVAC request via radio or other messaging system will mobilize the helicopter, with its flight medic, to the evacuation point. Short distance intra-theater medical treatment facility transfers go through the chain of medical command and usually follow the civilian standard of care regarding interhospital transfers. Because the Army MEDEVAC helicopter is a dedicated asset, response time is fairly rapid.

The Air Force evacuates from forward surgical units and combat surgical hospitals to rearward theater hospitals and hospitals based in the continental United States. The number of patients transported depends on the number of attendants on the wide body airframe and the stability and criticality of the patient. C-17 and C-130 aircraft can transport 50 or more litter and ambulatory patients. Because of the strategic nature of large cargo jets, it takes time to assemble a designated aeromedical evacuation wide-bodied fixed-wing aircraft for evacuations. The Air Force further supports aero MEDEVAC with ground-based en route patient staging facilities per AFTTP 3-42.51 dated 7 Apr 2015 (formerly aeromedical staging facilities). US Transportation Command (TRANSCOM) supports patient movement by tracking theater bed availability, reviewing and validating patient movement requests, and tracking patient location via the TRANSCOM Command and Control Evacuation System.[50] To initiate a patient movement request, the requesting medical treatment facility coordinates with one of TRANSCOM's patient movement requirements centers (Ramstein Air Base, Germany; Osan Air Base, Republic of Korea; Hickam Air Force Base, Hawaii; and Scott Air Force Base, Illinois).

Whether transported via tactical or strategic air evacuation, the patient is exposed to environmental stressors, but unlike the crew, the patient's physiology is abnormal. The flight surgeon must consider this altered physiological state when preparing a patient for air evacuation. For example, a patient with an open wound and significant bleeding experiences hypemic hypoxia and the oxygen saturation falls to 87%. When the aircraft files over a mountain pass at 2,000 ft, the patient's oxygen saturation falls even further to between 70% and 72% oxygen saturation. If the air evacuation is longer than 30 minutes, the patient's status will require

100% supplemental oxygen. The patient is monitored by pulse oximeter to measure oxygen saturation. To provide responsive and effective support to the operational mission, air evacuation routes and availability must be preplanned and patient movement must be executed efficiently. Flight surgeon involvement is absolutely paramount in all aspects of preparation, response, and after action.

SUMMARY

The aerospace medicine specialty was created to address unique health and medical aspects of the aviation work environment. It focuses on individual health and how it interacts with altitude, pressure, thermal stress, acceleration, noise, vibration, fatigue, flight deck ergonomics, and various other hazards crews are exposed to when performing their flight duties. These factors, along with other physiological conditions, may contribute to spatial disorientation and threaten the aviator's ability to safely operate aircraft. As with many industries, the aviation community is exposed to toxicological hazards such as solvents, fuels, propellants, and materials that form the aircraft itself.

To ensure flight safety, aviation crew members must meet medical standards for accession and retention. If current health precludes them from meeting these standards, there are several administration actions, from being placed on temporary quarters to permanent suspension of flight duties, which are at the professional discretion of the flight surgeon. The flight surgeon is the medical staff officer to the commander, imbedded in the aviation unit safety program. The flight surgeon consults or participates in MEDEVAC and is involved in aviation mishap investigations as the medical expert focused on the human factors component.

While the flight surgeon is responsible for assessment, treatment, and safety, overall safety responsibility lies with commanders. Prevention programs, improvements in systems safety and design, PPE, and support in the form of equipment, maintenance, facilities, and services are components of a safety-oriented environment. A successful unit safety program includes self-disciplined crew members, leaders who enforce standards, training skills to performance standards, procedures that are clear and practical, and collaboration between leaders and military personnel.

REFERENCES

1. Columbia University. The carbon cycle and earth's climate. http://www.columbia.edu/~vjd1/carbon.htm. Accessed September 25, 2016.

2. Federal Aviation Administration. Introduction to aviation physiology. https://www.faa.gov/pilots/training/airman_education/media/IntroAviationPhys.pdf. Accessed September 25, 2016.

3. Porth CJ, Bamrah VS, Tristani FE, Smith JJ. The Valsalva maneuver: mechanisms and clinical implications. *Heart Lung*. 1984;13(5):507–518.

4. Federal Aviation Administration. *2017 Guide for Aviation Medical Examiners*. Washington, DC: FAA; 2017. http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/ame/guide/media/guide.pdf. Updated March 29, 2017. Accessed October 1, 2016.

5. American Society of Aerospace Medicine Specialists. Clinical Practice Guideline for Decompression Sickness and Arterial Gas Embolism. The American Society of Aerospace Medicine Specialists. http://www.asams.org/guidelines/Completed/NEW%20DCS_update.htm. Published November 14, 2011. Accessed September 20, 2017.

6. Ngan V. Cutis marmorata. DermNet New Zealand. http://www.dermnetnz.org/topics/cutis-marmorata. Published 2003. Accessed October 2, 2016.

7. Wirjosemito SA, Touhey JE, Workman WT. Type II altitude decompression sickness (DCS): US Air Force experience with 133 cases. *Aviat Space Environ Med*. 1989;60(3):256–62.

8. Balldin UI, Pilmanis AA, Webb JT. Central nervous system decompression sickness and venous gas emboli in hypobaric conditions. *Aviat Space Environ Med*. 2004;75: 969–972.

9. McGuire S, Michaelson R, Van Syoc D. Clinical practice guideline for decompression sickness and arterial gas embolism. Aerospace Medical Association. http://www.asams.org/guidelines/Completed/NEW%20DCS_update.htm. Published November 14, 2011. Accessed October 2, 2016.

10. Stepanek J. Decompression sickness. In: DeHart RL, Davis JR, eds. *Fundamentals of Aerospace Medicine*, 3rd ed. Philadelphia, PA: Lippincott Williams and Wilkins, 2002; 67–98.

11. Kerut EK, Norfleet WT, Plotnick GD, Giles TD. Patent foramen ovale: a review of associated conditions and the impact of physiological size. *J AM Coll Cardiol*. 2001;38(3):613–623.

12. US Navy. *U.S. Navy Diving Manual*. Washington, DC: USN; 2008. US Navy Diving Manual SS521-AG-PRO-010, Volume 5, Chap 20.

13. Curtis R. Outdoor action guide to hypothermia and cold weather injuries. Outdoor Action Program, Princeton University, Princeton, NJ. https://www.princeton.edu/~oa/safety/hypocold.shtml. Accessed October 2, 2016.

14. Goswami P, Sharma S. Evaluation of pre take-off heat stress in a modern fighter cockpit: A field study. *Ind J Aerospace Med*. 2007;51(2):54–64.

15. Armstrong LE. Heat acclimatization. Encyclopedia of Sports Medicine and Science. Internet Society for Sport Science. http://www.sportsci.org/encyc/heataccl/heataccl.html. Accessed October 2, 2016.

16. Department of the Navy. *U.S. Naval Flight Surgeon's Manual. 3rd ed.* Washington, DC: DON; 1991. http://www.med.navy.mil/sites/nmotc/nami/academics/documents/flightsurgeonsmanual.pdf. Accessed September 20, 2017.

17. Marks P. The rocket-powered rise of the ejector seat. BBC. http://www.bbc.com/future/story/20150521-the-rocket-powered-life-saving-seat. Published May 21, 2015. Accessed October 3, 2016.

18. Newman DG. *High G Flight: Physiological Effects and Countermeasures*. Burlington, VT: Ashgate Publishing Company; 2016: 89–96.

19. US Department of the Army. *Aeromedical Training for Flight Personnel*. Washington, DC: DA 2009. Training Circular TC 3-04.93.

20. Federal Aviation Administration. *Spatial Disorientation*. Oklahoma City, OK: FAA. AM-400-03/1.

21. Wicks RE. Alternobaric vertigo: an aeromedical review. *Aviat Space Environ Med*. 1989;60(1):67–72.

22. Rodgers D, Van Syoc D. Clinical practice guideline for motion sickness. Aerospace Medical Association. http://www.asams.org/guidelines/Completed/NEW%20Motion%20Sickness.htm. Published November 14, 2011. Accessed October 3, 2016.

23. Parmet AJ and Ercoline WR. *Fundamentals of Aerospace Medicine*, 4th ed. Ed. Davis JR, Johnson R, Stepanek J, Fogarty JA. Philadelphia, PA: Williams and Wilkins; 2008: 195–203.

24. Warwick-Evans LA, Symons N, Fitch T, Burrows L. Evaluating sensory conflict and postural instability. Theories of motion sickness. *Brain Res Bull*. 1998;47(5):465–469.

25. Humes LE, Joellenbeck LM, Durch JS. Editors *Noise and Noise-Induced Hearing Loss in Military, Noise and Military Service: Implications for Hearing Loss and Tinnitus*. Washington, DC: Institute of Medicine of the National Academies, National Academies Press. 2006: Chap 5.

26. EPA history: noise and the Noise Control Act. US Environmental Protection Agency. https://www.epa.gov/aboutepa/epa-history-noise-and-noise-control-act. Accessed October 3, 2016.

27. US Naval Research Advisory Committee, Panel on Jet Engine Noise Reduction. *Report on Jet Engine Noise Reduction*. Arlington, VA: NRAC; 2009.

28. National Sleep Foundation recommends new sleep times. National Sleep Foundation. https://sleepfoundation.org/media-center/press-release/national-sleep-foundation-recommends-new-sleep-times. Accessed October 3, 2016.

29. Find a vitamin or supplement-caffeine. WebMD. http://www.webmd.com/vitamins-supplements/ingredientmono-979-caffeine.aspx?activeingredientid=979. Accessed September 19, 2017.

30. Nakagawara VB, Wood K, Montgomery RW. *Laser Hazards in Navigable Airspace*. Federal Aviation Administration Oklahoma City, OK: FAA. AM-400-10/3. https://www.faa.gov/pilots/safety/pilotsafetybrochures/media/laser_hazards_web.pdf. Accessed October 3, 2016.

31. Mellema G. Safety issues with advanced composite materials Aircraft Maintenance Technology. Aviation Pros. http://www.aviationpros.com/article/10387483/safety-issues-with-advanced-composite-materials. Accessed October 3, 2016.

32. Military Health System professional services and specialty medical coding guidelines version 5.0. Military Health System. Health.mil website. https://health.mil/. Accessed November 8, 2017. Accessed September 20, 2017.

33. US Department of the Army. *Standards of Medical Fitness*. Washington, DC: DA; 2007. Army Regulation 40-501.

34. US Department of Defense. *Individual Medical Readiness (IMR)*. Washington, DC: DoD; 2014. DoD Instruction 6025.19.

35. US Department of Defense. *Disability Evaluation System (DES).* Washington, DC: DoD; 2014. DoD Instruction 1332.18.

36. US Department of the Army. *Standards of Medical Fitness*. Washington, DC: DA; 2014. Army Regulation 40-400.

37. US Air Force. *Flight and Operational Medicine Program*. Washington, DC: USAF; 2014. AF Instruction 48-149.

38. Caldwell JA, Mallis MM, Caldwell JL, Paul MA, Miller JC, Neri DF. Fatigue countermeasures in aviation. *Aviat Space Environ Med.* 2009;80:29–59.

39. Purves D, Augustine GJ, Fitzpatrick D, et al, eds. Cones and color vision. In: *Neuroscience.* 2nd ed. Sunderland, MA: Sinauer Associates; 2001. Chap 11.

40. National Transportation Safety Board. *Collision With Trees on Final Approach Federal Express Flight 1478 Boeing 727-232, N497FE Tallahassee, Florida*. Washington, DC: NTSB; 2002. Aircraft Accident Report NTSB/AAR-04/02.

41. Zhao J, Davé SB, Wang J, Subramanian PS. Clinical color vision testing and correlation with visual function. *Am J Ophthalmol*. 2015;160(3): 547–552.

42. North Atlantic Treaty Organization, Research and Technology Organization. *Operational Colour Vision in the Modern Aviation Environment.* Cedex, France: RTO/NATO; 2001. Technical Report-016 AC/323(HFM-012)TP/6.

43. Laservision. Thin-film-coated laser safety eyewear. Lasersafety. http://www.lasersafety.com/laser-safety-filter-technology. Accessed October 5, 2016.

44. Miller RE, Tredici TJ. *Night Vision Manual for the Flight Surgeon*. Brooks Air Force Base, TX: US Air Force School of Aerospace Medicine; 1992. http://www.dtic.mil/get-tr-doc/pdf?AD=ADA257059. Published August 1992. Accessed September 20, 2017.

45. US Army Aeromedical Research Laboratory. http://www.usaarl.army.mil/. Accessed October 5, 2016.

46. Naval Aerospace Medical Research Unit Dayton. http://www.med.navy.mil/sites/nmrc/Pages/namrud.htm. Accessed October 6, 2016.

47. AFRL: Transforming technology, education and the economy. Wright Patterson Air Force Base. http://www.wpafb.af.mil/News/Article/818478/afrl-transforming-technology-education-and-the-economy. Accessed October 6, 2016.

48. Memorandum of Agreement Between the Army Combat Readiness Center, Naval Safety Center, Headquarters, United States Marine Corps (Safety Division), United States Coast Guard Health and Safety Directorate, and the Air Force Safety Center. *Policy on the Collection and Analysis on Mishap Human Factors Data*. http://www.public.navy.mil/navsafecen/Documents/aviation/aeromedical/DoD_HF_MOA.pdf. Accessed September 20, 2017.

49. US Department of Defense. *DoD Health Record Life Cycle Management*. Washington, DC: DoD; 2015.DoD Instruction 6040.45.

50. US Transportation Command. Organizational Structure Information Sheet: TRANSCOM Regulating And Command & Control Evacuation System (TRAC2ES). http://www.ustranscom.mil/cmd/organization/tcsg.cfm. Accessed October 6, 2016.