Chapter 4: Flight Physiology

Lecture

I. Introduction

Time: 3 Minutes
Slide: 1–2
Lecture/Discussion

A. CCTPs must have a thorough understanding of flight physiology and the implications for their patients and for themselves.
   1. This is equally important for both air and ground-based critical care providers.
   2. Knowledge of flight physiology involves recognition of barometric maladies and the prevention of such problems.
      a. Many conditions will be exacerbated by changes in the barometric pressure.
      b. Forces experienced during flight can have significant impact on disease pathophysiology.

B. Chapter 4 includes discussions of:
   1. Various gas laws that are pertinent to flight medicine
   2. Several common problems that can occur as the result of changes in barometric pressure
   3. Advantages and disadvantages of pressurized and nonpressurized aircraft and the impact of decompression at altitude
   4. Primary stressors of flight and the factors that can affect tolerance toward the stressors
   5. Different illusions of flight and spatial disorientation that can have disastrous impacts on flight operations

II. The Atmosphere

Time: 20 Minutes
Slides: 3–15
Lecture/Discussion

A. Flight surgeon and author Richard Reinhart defines three distinct parts to flight in his book in his book *Basic Flight Physiology*:
   1. The aircraft
   2. The flight crew
   3. The environment or atmosphere

B. Characteristics of the atmosphere include:
   1. Consists of defined layers of stratification
      a. Likened to an ocean of gases
   2. Extends from earth's surface to 348 miles (560 km), or the beginning of space
   3. Varies with time of day, season, and latitude

C. The composition of the atmosphere is constant and is defined as a percentage of gases instead of absolute amounts.
   1. Percentage of gases constitutes almost 99% of the atmosphere and remains constant, but density varies with altitude.
   2. Oxygen
      a. Constitutes 21% of atmosphere, regardless of altitude
         i. During ascent in altitude, oxygen molecules spread out and become less numerous in each breath, making breathing at high altitudes difficult.
      b. Byproduct of photosynthesis
      c. Most critical gas needed to sustain life
   3. Nitrogen
      a. Constitutes 78% of total volume of atmosphere
      b. Most abundant gas; responsible for majority atmosphere's composition
      c. Inert, odorless, colorless, tasteless
      d. While not readily used by humans is a critical element for life
         i. Present in human body in abundant quantities
         ii. Can cause evolved gas disorders at altitude or after rapid ascent while scuba diving
   4. Argon
      a. Constitutes approximately 0.93% of atmosphere
   5. Other trace gases include:
      a. Carbon dioxide
      b. Neon
      c. Helium
      d. Methane
      e. Krypton
      f. Hydrogen

D. The atmosphere has several distinct layers of stratification, with gravity holding them in place.
   1. First layer: Troposphere
      a. Extends from sea level to about 26,405 feet over the poles and nearly 52,810 feet above equator
      b. Includes virtually all weather because of presence of water vapor and strong vertical currents
         i. Clouds form, rain falls, wind blows, humidity varies depending on climate
         ii. Winds become stronger westerly with increasing west to east winds at altitudes higher than 35,000′
         iii. Strong jet stream located above 35,000′, where maximum winds average 200 mph at about 30º latitude north or south
      c. Densest portion of atmosphere
      d. Temperature varies from 62.6°F (17°C) to –68.8°F (–56°C) and decreases proportionately with increases in altitude
      e. Known as lower atmosphere (along with tropopause)
   2. Second layer: Tropopause
      a. Layer between troposphere and stratosphere
      b. Ranges in height from 30,000′ at poles to more than 60,000′ at equator
      c. Height changes in relation to expansion or contraction of rising or falling air near earth's poles
         i. Expansion of heated rising air near equator increases height
         ii. Contraction of cool air decreases height

        d. Known as lower atmosphere (along with troposphere)
    3. Other layers include:
        a. Stratosphere
        b. Stratopause
        c. Mesosphere
        d. Thermosphere
        e. Exosphere
E. The atmosphere is divided into three distinct zones that directly correlate to a human's response to hypoxia and include:
    1. Physiologic zone
        a. Contains oxygen and barometric pressure needed for a normal, healthy person to live
        b. Extends from sea level to 10,000′
        c. Includes barometric pressure that falls from 760 mm Hg at sea level to 523 mm Hg at 10,000′ and is adequate to maintenance of arterial PaO_2 without supplemental oxygen, pressurization, or protective equipment
        d. Considerations at 10,000′ include:
            i. Mild hypoxia (even in healthy people)
            ii. Hypoxia in almost all patients with comorbidities
            iii. Part 135.89 of FAR requires commercial to use supplemental oxygen when flying above 10,000′
            iv. Rapid changes in altitude at this level can produce trapped gas conditions (ear or sinus problems)
            v. Night vision impairment without supplemental oxygen (at altitudes above 5,000′)
    2. Physiologically deficient zone
        a. Defined as area from 10,000′ to 50,000′
            i. Above 10,000′, barometric pressure decreases to levels that will result in hypoxic hypoxia
        b. Barometric pressure ranges from 523 mm Hg at 10,000′ to 87 mm Hg at 50,000′
            i. Effects of trapped gases become more pronounced, necessitating protective equipment, supplemental oxygen, and pressurized aircraft
    3. Space equivalent zone
        a. Extends from 50,000′ to 120 miles
        b. 100% supplemental oxygen inadequate because of inadequate barometric pressure
            i. Requires pressure suits and sealed cabins
        c. Two additional hazards may include:
            i. Exposure to atmospheric conditions could result in boiling of body fluids
            ii. Exposure to increased levels of radiation from the sun
        d. Currently, no commercial aircraft used for air medical transport operate in this zone
F. Barometric pressure (atmospheric pressure)
    1. Direct result of the weight of air
        a. Varies with location and time because amount and weight of air above earth vary with time and location
    2. Related to density of air, which is related to air temperature and height above earth's surface
        a. Thus, is the weight per unit area of all of the molecules of the gas above the point at which the measurement was taken, with temperature and humidity as variables
    3. Related to weather; one of the most important factors that determine weather

4. Reported in different measurements:
    a. United States: inches of mercury
    b. Europe and countries using metric system: millibars
5. Two most prevalent definitions of the atmosphere:
    a. US Standard Atmosphere
        i. Recognized for longest time
    b. International Standard Atmosphere
        i. Widely recognized across the globe

III. Gas Laws

Time: 21 Minutes
Slides: 16–29
Lecture/Discussion

A. Boyle's Law
1. Robert Boyle studied relationship between volume of a dry gas and its pressure by fixing the amount of gas and its temperature.
    a. When volume of gas increases, the pressure decreases; when volume of gas decreases, the pressure increases
2. Mnemonic for remembering: "Boil Very Prudently," where Boyle = Volume (Very) x Pressure (Prudently)
    a. Example: as altitude increases, atmospheric pressure decreases, or there is less outside pressure on gas molecules holding them close together.
        i. Gas molecules expand as a result
3. Numerous implications in aviation medicine include:
    a. Gas trapped in the chest will expand approximately 35% when going from sea level to 8,000′, while at 18,000′ it will expand to twice its size.
        i. To minimize effects of altitude, maintain lowest possible cabin pressure during flight.
        ii. Altitude will usually not become significant factor until 3,000′ above ground level
        iii. Most people, except those with significant respiratory disorders, tolerate altitudes of 5,000′
        iv. Below 10,000′ (low as 3,500′) unhealthy people can experience significant effects
    b. A pneumothorax can quickly progress to a tension pneumothorax as altitude increases.
    c. Patients with an open skull fracture are at risk for pneumocephalus.
    d. Patients with pneumoperitoneum or pneumomediastinum are susceptible to altitude changes and cause significant discomfort.
    e. Gases trapped elsewhere within body will also expand and cause discomfort.
        i. Examples: middle ear, sinuses, stomach, and intestines
4. Some medical equipment is also sensitive to an increase or decrease in barometric pressure, including:
    a. Cuffed balloon on endotracheal tubes
        i. Can double in size from 5,000′ to 10,000′ and cause balloon to rupture or cause tissue necrosis
    b. IV fluids

        i. Increases rate of flow of fluids in glass bottle because of inability of bottle to expand or contract
        ii. Use of pressure infusers to administer fluids is recommended
        iii. Use of "dial-a-flow" considered unreliable; use IV infusion pumps instead
    c. PASGs
        i. No longer routinely used or recommended
        ii. When used on patient, pay close attention and open relief valve as soon as Velcro begins to "pop off" or PASGs will come apart
        iii. Same concept applies to air splints
    d. Other devices
        i. Patients with nasogastric or orogastric tube inserted should be transported with tube open or frequently vented.
        ii. Patients with colostomy bags should frequently have built-up gas "burped" to prevent overpressurization and failure of colostomy bag.

B. Charles' Law
1. Discovered in 1787 by Jacques Charles
2. States that volume of a gas is directly proportional to the temperature, with the pressure remaining constant
    a. As air heats up, the volume increases, allowing molecules to spread out, making air less dense
        i. Helicopters fly better in cold weather because gas molecules more compressed, allow more lift as rotor blades spin; have fewer molecules to "push off of" in hot weather and can also carry less weight
3. Mnemonics:
    a. "Charles' cold"
    b. "Charles Celsius"
4. Significant in flight medicine because aircraft cabins get very cold at altitude without supplemental heat
    a. Patients and crew at significant risk for hypothermia

C. Dalton's Law
1. Discovered in 1800 by John Dalton
2. States that total pressure of a gas mixture is sum of the individual pressures, or all of the parts equal the whole
    a. In a gas mixture, gas molecules are unaffected by each others' motion because of space between molecules
3. Also called the law of partial pressure, with partial pressure being the pressure of a single gas in the mixture
4. Illustrates that increasing altitude results in proportional decrease of partial pressures of gases found in the atmosphere
    a. Although percentage concentration of gases remains stable with increasing altitude, partial pressure decreases in direct proportion to total barometric pressure.
    b. Even though percentage of oxygen is constant, the partial pressure will decrease proportionately as atmospheric pressure decreases, or vice versa.
5. Application to critical care
    a. Pressure is required to facilitate passing of oxygen from blood to the cells.
        i. Decrease can lead to hypoxia
    b. Although proportion of oxygen remains about 21% in atmosphere, there are fewer molecules for the body to use

c. When supplemental oxygen is given, use Dalton's law to calculate expected partial pressure of oxygen (PO_2) that should be obtained when checking arterial blood gas values.

6. Mnemonic: "Dalton's gang"
   a. Oxygen molecules that were "ganged up" at lower altitudes spread apart at higher altitudes, making less oxygen available for breathing

D. Fick's Law
1. Established in 1855 by Adolph Fick
2. States that the diffusion rate of a gas is proportional to the difference in partial pressure, proportional to the area of the membrane, and inversely proportional to the thickness of the membrane
   a. Rate of diffusion is affected by atmospheric pressures, the surface area of the membrane, and the thickness of the membrane.
3. Application to critical care:
   a. Primary gas law for diffusion of oxygen across alveolar membrane
      i. Example: Elderly patient with COPD who also has pneumonia will have decreased gas exchange at altitude.

E. Henry's Law
1. Discovered by J.W. Henry in 1800
2. States that amount of a gas in a solution varies directly with the partial pressure of a gas over the solution
   a. As the pressure of a gas over a liquid decreases, the amount of gas dissolved in the liquid will also decrease.
   b. As more pressure is applied over the liquid, more gas can be dissolved in the liquid.
   c. In practical terms, molecules of a gas can be dissolved in a liquid and remain in the liquid as long as the liquid is in a pressurized, closed container.
      i. Example: All carbonated beverages are an example of Henry's law.
3. Application to critical care
   a. Decompression sickness (discussed later in chapter)

F. Universal gas law (ideal gas law)
1. States how a hypothetical gas should act if there are no variables affecting it.
   a. A change in density is directly related to a change in temperature and pressure.
   b. Many gases have properties similar to this law at ambient temperature and pressure.

G. Gay-Lussac's Law
1. Discovered in 1809 by French chemist Joseph Louis Gay-Lussac
2. States that there is a correlation between the pressure and the temperature when volume is constant
   a. Expressed as a ratio
      i. Example, if pressure increases, temperature increases, and vice versa

H. Graham's law (Graham's law of effusion)
1. Formulated by Scottish physical chemist Thomas Graham
2. States that rate at which a gas moves through a small hole, avoiding interaction with other particles along the way, is related inversely to the square root of the mass of one mole of its molecules
   a. Example: If molecular weight of one gas is four times that of another, it would diffuse through a porous plug or escape through a small pinhole in a vessel at a rate half that of the smaller molecule.
3. Application to critical care

a. Ongoing process of diffusion of oxygen and carbon dioxide in the blood and transfer of oxygen from blood into the cells is an example
    i. Carbon dioxide molecules much more massive than oxygen molecules, and carbon dioxide also has 22 times solubility of oxygen, making diffusion rate much quicker than that of oxygen

I. Formulas based on the seven gas laws
1. Please refer to equations on page 75 of the textbook.

IV. Types of Hypoxia

Time: 15 Minutes
Slides: 30–39
Lecture/Discussion

A. Hypoxia is the main hazard in aviation and can have catastrophic results.
1. May occur in otherwise healthy people at altitudes less than 10,000′
2. Can greatly affect patients with impaired pulmonary function at much lower altitudes
3. Statistics on hypoxia include:
    a. US military reports 8 to 10 incidents of hypoxia during flight every year.
    b. Most cases attributed to failure in cabin pressure with concurrent failure in oxygen delivery system.
        i. Usually resolved by corrective action by pilot
4. Early signs of hypoxia are not easily recognized and include:
    a. Impaired judgment one of earliest effects, limiting aviator’s ability to recognize condition and ability to take immediate corrective actions
    b. Mimics fatigue and hypoglycemia, making it difficult to recognize
    c. Fatigue and hunger contribute to hypoxia

B. Effective performance time and time of useful consciousness are consequences of hypoxia.
1. Effective performance time is a limited timeframe during which a person can function with inadequate level of oxygen.
2. Time of useful consciousness is the period between a person’s sudden deprivation of oxygen at a given altitude and the onset of physical or mental impairment to the point at which deliberate function is lost.
3. Both states vary by individual and depend on:
    a. Individual tolerances
    b. Method of hypoxia induction
    c. Environment before hypoxia
    d. Amount of exercise undertaken by person
        i. Example: Exposure to hypoxia at 25,000′ gives average person 3 to 5 minutes of useful consciousness vs 1 to 1.5 minutes after performing 10 deep knee bends
    e. Percentage of oxygen prior to hypoxia onset
        i. Aircrew member who was breathing 100% oxygen before onset has longer period of compensation than an aircrew member who was breathing ambient air
    f. Rapid cabin depressurization
        i. Aircraft cabin decompression that occurs above 33,000′ causes immediate reversal in oxygen flow in the alveoli causing higher PaO_2 in

pulmonary capillaries to occur, depleting oxygen reserves in blood and cutting effective performance time by up to half

ii. Useful consciousness normally varies, but could be a matter of seconds under rapid depressurization

g. Living at higher altitudes causes body to produce red blood cells at a faster rate, facilitating oxygen transport, but does not mean such individuals will not require supplemental oxygen

i. Slight physiologic advantage exists: Aircrew members who live at 5,000′ may be able to fly 1,000′ to 2,000′ above 10,000′ recommended ceiling without ill effects, for example, but tolerance is not extended an additional 5,000′.

C. Hypoxic hypoxia (altitude hypoxia)

1. Results from inadequate ventilation or reduction in the PO_2 and is characterized by lack of oxygen entering the blood.
2. Various causes include:
   a. Lung disease
   b. Right-to-left shunt in heart
   c. Airway obstruction
   d. Reduction in gas exchange area in alveoli
   e. Low PO_2
   f. Increased altitude
3. Cases within air medical environment usually are a result of reduced atmospheric pressure that causes reduced alveolar PaO_2.
   a. Remember Dalton's law: Oxygen molecules are further apart, so less oxygen is available.
      i. Oxygen diffusion dependent on PO_2, which decreases as oxygenated blood flows through capillaries
      ii. Part of capillaries farthest from lungs requires at least 1 mm Hg of pressure for diffusion of oxygen to cells.
      iii. As altitude increases, pressure decreases below 1 mm Hg, and aerobic metabolism inhibited and cellular death begins
   b. Clinical hypoxia starts to develop within few hundred feet from ground
      i. Symptoms do not begin to manifest until heights above 5,000′

D. Histotoxic hypoxia

1. Cell's inability to adequately use oxygen
   a. Plenty of oxygen may be available, but tissues cannot accept it, or
   b. Oxygen cannot offload from hemoglobin
2. Venous hemoglobin oxygen saturation higher than normal
   a. Result of oxygen not being unloaded to tissues because the tissues are unable to metabolize delivered oxygen
3. Result of poisoning
   a. Such as by cyanide, a major toxin generated by house fires
4. Exacerbated by use of narcotics, chewing tobacco, alcohol

E. Stagnant hypoxia

1. Occurs when there is failure to transport oxygenated blood
   a. Result of reduction in blood flow, but not necessarily complete stoppage
   b. Frequently seen in heart failure and major myocardial infarctions
2. As related to flight medicine, can result from:
   a. Venous pooling in patient during accelerated maneuvers or those that increase gravitational load on aircraft

   b. Blood pooling in lower extremities of patients and crew who sit in aircraft for extended periods

F. Hypemic hypoxia (anemic hypoxia)
   1. Occurs when a lack of one of the following causes a reduction in ability of blood to carry oxygen to tissues, despite oxygen's abundance:
      a. Lack of hemoglobin molecules present (exposure to chemicals like carbon monoxide)
      b. Lack of red blood cells (hemorrhage or anemia)
   2. Causes of include:
      a. Blood loss
      b. Anemia
      c. Excessive smoking
         i. Occurs at lower altitudes than in nonsmokers
      d. Carbon monoxide poisoning
      e. Use of nitrite and sulfa drugs
      f. Sickle cell disease
   3. Reduction of hemoglobin by half reduces body's transport ability by half
      a. In healthy adult, hemoglobin can transport 20 mL of oxygen in 100 mL of blood

V. Four Stages of Hypoxia as They Relate to Altitude

Time: 9 Minutes

Slides: 40–45

Lecture/Discussion

A. Indifferent stage
   1. Experienced between sea level and 10,000′
      a. May manifest at altitudes as low as 5,000′
   2. Effects include:
      a. Causing night vision to deteriorate at altitudes above 5,000′
      b. Causing electrocardiographic changes at altitudes as low as 5,000′
      c. Tachycardia
      d. Slight increase in alveolar ventilation
   3. Oxygen saturation varies from 98% to 87%
   4. Name refers to minor physiologic effects on body

B. Compensatory stage
   1. Name refers to body's ability to provide short-term physiologic compensation against effects of hypoxia
      a. Compensation dependent on:
         i. Physical shape of flight crew member
         ii. Physical activity level
         iii. Duration of exposure
   2. Respiratory rate and depth may increase and cardiac output increases
   3 Experienced between 10,000′ and 15,000′
      a. Between 39,000′ and 42,000′ if breathing 100% oxygen
   4. Hemoglobin saturation varies from 87% to 80%

C. Disturbance stage

1. Tissue can no longer depend upon physiologic compensatory mechanisms for sufficient oxygen supply.
2. Experienced between 15,000′ and 20,000′
3. Characterized by subjective and objective symptoms of hypoxia
    a. During altitude testing, some subjects did not experience subjective symptoms before becoming unconscious.
4. Senses are affected during disturbance stage
    a. Affects vision, hearing, sense of touch
        i. Visual ability decreases as eye muscles become weak, uncoordinated
        ii. Sensations of touch and pain diminished, eventually lost
        iii. Weakness and loss of muscular coordination experienced, become worse with degree of hypoxia
        iv. Loss of hearing further confounds safety, success of mission (one of the last senses impaired)
        v. Consider hypoxia if medical crew member is having difficulty following simple commands or performing simple tasks
5. Cognition impairment is one of the most dangerous hallmarks of hypoxia.
    a. Impossible for people to comprehend their own disability due to:
        i. Inability to make coherent judgments and calculations
        ii. Slower reaction times
        iii. Impaired short-term memory
    b. Common misconception is that flight crew can they can learn early signs and take immediate corrective action
        i. Impaired judgment makes this impossible
        ii. Flight crew may recognize hypoxia, but then take inappropriate corrective actions
6. Personality manifestations are similar to those of a person under influence of alcohol and include:
    a. Aggressiveness
    b. Euphoria
    c. Irritability
    d. Overconfidence
    e. Depression
7. Psychomotor functions
    a. Muscular coordination decreases
    b. Occurs when partial pressure of alveolar carbon dioxide falls below 25 mm Hg
    c. Deteriorates to levels incompatible with coordinated activity as pressure continues to fall
    d. First signs include speech difficulty, illegible handwriting, and poor coordination in flying
        i. Stammering and illegible handwriting are two hallmark signs of impairment
    e. As severity increases, delicate and fine muscular movements become impossible, gross motor movements become significantly impaired

D. Critical stage
1. Last stage of hypoxia that occurs at 20,000′ and above (44,800′ and above with 100% oxygen)
    a. Within 3 to 5 minutes, judgment and coordination deteriorate to the point of inadequate or inappropriate function.
    b. Mental confusion is quickly followed by incapacitation, unconsciousness, and death, if uncorrected.

    c. Hemoglobin saturation drops to less than 65%
2. Hyperventilation
    a. Symptoms mimic hypoxia, so crew must first address possibility of hypoxia before assuming the problem is caused by hyperventilation.
        i. Both result in confusion, poor judgment, inappropriate corrective maneuvers
    b. Caused by subconscious reaction to a stressful situation; manifested by abnormal increase in volume of inspiratory and expiratory air and tachypnea, which causes respiratory alkalosis
    c. Serious consequences include:
        i. Rapid decline in sodium bicarbonate in blood, causing elevation in blood pH and interruption of homeostasis
        ii. Following this, cellular activity quickly declines or stops
    d. Leads to several important physiologic changes that begin cascade of events, including:
        i. Decrease in partial pressure of carbon dioxide, resulting in increase in blood pH
        ii. This causes vasodilation of cerebral blood vessels, which causes blood to shunt to various parts of the body while starving other areas.
        iii. Cellular hypoxia and anoxia occur in areas with decreased circulation
        iv. Unconsciousness quickly follows induction of prolonged or significant hypoxia into cerebral tissue
    e. Symptoms include:
        i. Light-headedness
        ii. Feelings of suffocation
        iii. Drowsiness
        iv. Tingling in the extremities
        v. Painful muscle spasms
        vi. Ataxia
        vii. Disorientation
        viii. Unconsciousness
    f. Most disastrous effect is promulgation of panic, remedied by maintaining control

E. The key to recognition and treatment of altitude-induced hypoxia is a thorough knowledge and understanding of basic flight physiology.
1. Recovery is rapid when sufficient oxygen supplied.
    a. Oxygen paradox: Hypoxic person who rapidly breathes 100% oxygen may experience sudden dizziness, which is quickly resolved, followed by complete restoration of function.
2. Avoidance of hypoxia is the key to safety
    a. Immediately use supplemental oxygen and descend to below 10,000′ if hypoxia is detected.
    b. Hypoxic crewmembers is a valid reason to declare an emergency with air traffic control.

F. FAR has outlined supplemental oxygen requirements to prevent hypoxia.
1. FAR Part 135.89 governs use of supplemental oxygen by pilots and provides rules for pressurized and nonpressurized aircraft.
2. Nonpressurized aircraft (helicopters included):
    a. Must use oxygen continuously if duration of flight at altitude from 10,000′ through 12,000′ is longer than 30 minutes
    b. Must use oxygen at all times above 12,000′
3. Pressurized aircraft:

a. Must follow same rules when cabin altitude exceeds 10,000´
b. Must use continuous oxygen unless aircraft is equipped with approved quick-donning-type mask at altitudes from 25,000´ through 35,000´
c. Pilots must wear an oxygen mask continuously above 35,000´
    i. Pilots have mere seconds to respond to sudden loss of cabin pressure at this altitude.

4. FAR Part 91.211 requires passengers be provided with supplemental oxygen.
    a. Cabin altitudes above 15,000´ require provision of all occupants with supplemental oxygen.
    b. In pressurized aircraft, 10-minute supply of oxygen for each occupant must be available above 25,000´
    c. Sick or injured patient will likely need supplemental oxygen at all altitudes to prevent hypoxia

VI. Pressurized and Nonpressurized Aircraft

Time: 3 Minutes

Slides: 46–47

Lecture/Discussion

A. Pressurizing the aircraft is the most effective method to protect people from the physiologic effects of reduced barometric pressure.
    1. Accomplished by increasing barometric pressure in aircraft above ambient pressure
        a. Stronger and heavier fuselage constructions are required for higher differential pressures required between aircraft cabin and ambient pressure
        b. Pressurization system requires greater capacity for higher differential pressure
        c. Both requirements increase engineering and maintenance costs, require more power

B. Isobaric control system is the most frequently used method for pressurizing aircraft
    1. Designed to:
        a. Maintain aircraft cabin at constant pressure despite falling barometric pressure outside aircraft, usually between 5,000 and 8,000´
        b. Maximize comfort of crew and passengers
        c. Not require supplemental oxygen as long as system working properly
        d. Minimize effects of fatigue on crew and passengers
        e. Allow for maximum mobility of crew and passengers
    2. Disadvantages include:
        a. Requires heavier fuselage and airframe to keep higher pressure inside aircraft cabin
        b. Adds more weight to aircraft because of necessary equipment
        c. Has explosive rate of decompression that can occur when pressure inside aircraft cabin much greater than ambient outside pressure

C. Differential control method
    1. Used primarily by tactical military aircraft that fly above designed and engineered limits of the isobaric system
    2. Design includes:
        a. Ensuring cabin pressure does not exceed outside pressure by predetermined amount, but may change based on altitude variations

            i. Versus constant cabin altitude
            ii. Slowly adjusts pressures within predetermined ratio
        b. Lightweight aircraft fuselage
        c. Less of a risk of explosive decompression
    3. Disadvantages include:
        a. Supplemental oxygen and pressure suits must be available and used at certain altitudes
D. Aircraft depressurization when at altitude is categorized as "slow" or "rapid."
    1. Rapid cabin depressurizations
        a. Dramatic events accompanied by loud explosion and numerous master caution warning horns
        b. Events that expose occupants to dangers of:
            i. Hypoxia
            ii. Decompression sickness
            iii. Gastrointestinal expansion
            iv. Hypothermia
            v. Cyclonic winds
            vi. Dense fog and icy temperatures within cabin
    2. Slow cabin decompressions
        a. Can occur when small leak develops in pressurized aircraft
        b. Dangerous because of insidious onset and undetectable loss of oxygen leading to hypoxia and death if uncorrected
            i. Example: Payne Stewart
    3. National Aeronautics and Space Administration date shows:
        a. 40 to 50 decompressions annually classified as rapid decompression
            i. Of these, approximately 70% occur above 30,000´
            ii. If loss of cabin pressure occurs, descent must be made immediately to level at which cabin altitude can be maintained at or below 10,000´ and oxygen used by all occupants

VII. Primary Forces That Act on an Aircraft

Time: 2 Minutes
Slide: 48
Lecture/Discussion

A. There are four primary forces that constantly act on an aircraft in flight: lift, thrust, weight (gravity), and drag.
    1. Lift counteracts weight, and thrust opposes drag.
        a. Greater amounts of thrust and lift allow aircraft to take off.
        b. Conversely, greater amounts of drag and weight must exist for aircraft to land.
    2. In straight and level flight, thrust equals drag and lift equals weight.

VIII. Primary Stressors of Flight

Time: 14 Minutes

Slides: 49–57

Lecture/Discussion

A. Decreased levels of PO_2
   1. Can quickly cause hypoxia in flight crew and passengers
      a. At 15,000′, barometric pressure is 429 mm Hg
         i. Average values for healthy patient includes oxygen saturation of 80%, PaO_2 of 44 mm Hg
         ii. These values not representative of critical care patients
B. Barometric pressure changes
   1. Greatest pressure change takes place from sea level to 5,000′
      a. Problems associated with pressure must be considered even in nonpressurized aircraft not flying at altitudes requiring supplemental oxygen or cabin pressurization
   2. Supplemental oxygen guidelines
      a. During daylight hours for nonpressurized aircraft: Use at 10,000′
      b. During nighttime, use at 8,000′
      c. Certain military operations allowed at 13,000′ as long as flight duration is less than 3 hours
   3. May also cause discomfort in air-trapped organs and sinuses
C. Thermal changes
   1. Flight crew members subjected to variety of thermal extremes ranging from very cold to very hot, affecting metabolic rate and demands on body
      a. Temperature changes increase oxygen demands and make body less tolerant of effects of hypoxia.
         i. Can also result in effects of hypoxia at lower altitudes than normally expected
   2. Temperature declines with increases in altitude
      a. By 3°F to 5ºF (1ºC to 2ºC) per 1,000′ gain in altitude, depending on humidity
         i. At altitudes from 35,000′ to 99,000′, temperature remains relatively constant at –32°F (–50ºC)
         ii. Helicopters may ascend in summer to take advantage of cooler temperatures at higher altitudes
   3. Hot temperatures may be experienced by flight crews when operating outside at emergency scenes for extended durations during summer months.
      a. Fire-retardant flight suits trap heat
      b. Helmets can lead to increases in the core body temperature
   4. Ambient temperatures fluctuate widely because of aircraft range of their aircraft.
      a. Changes in terrain from ground to mountains or northern zone to southern zone cause vast temperature changes.
      b. Greenhouse effect can result in an increase in temperature by 50°F (10°C) to 59°F (15ºC) in the cockpit or cabin of a small aircraft from radiant solar heat.
   5. Effects of heat stress include:
      a. Decreased short-term memory
      b. Degradation of motor skills
      c. General decrease in performance
      d. Increased irritability and poor judgment
      e. Motion sickness
      f. Hypoxia
      g. Potentiates effects of gravitational forces
D. Vibration

1. Vibrations between 1 and 12 Hz can cause significant effects on body.
2. Low-frequency vibrations can cause:
    a. Body discomfort
    b. Chest or abdominal pain
    c. Decreased vision
    d. Fatigue
3. Excess vibration must be addressed with aircraft mechanics and manufacturers.
    a. Modifications to reduce effects include:
        i. Seat cushioning
        ii. Proper use of shoulder and lap belts
4. Prolonged effects of vibration can cause:
    a. Restrictions regarding amount of time a crew is allowed to fly on any given shift before resting exist to fight fatigue caused by vibration
    b. Preventive measures, which include:
        i. Prohibiting medical crew members from leaning against the airframe
        ii. Providing extra padding for patients

E. Decreased humidity
1. Humidity is the degree of water vapor in air, expressed as a percentage
2. Relative to temperature:
    a. Increases with temperature increases
    b. Decreases with temperature
3. Humidity levels in rotor-wing and propeller aircraft are higher than those of jet aircraft.
4. Jet aircraft fly at high altitudes where there is low humidity.
    a. Causes dryness, dehydration, feeling of jet-lag
    b. Effects compounded in injured or ill patients
        i. Ensure proper hydration
        ii. Provide humidified oxygen to those patients receiving supplemental oxygen
        iii. Protect patient's corneas from drying with taping or artificial tears
        iv. Increase rate of IV fluids or provide additional oral hydration, if possible

F. Noise
1. Long exposure to noise can damage, or completely destroy, soft tissue of the inner ear, impairing hearing.
2. Consider three factors of loudness, pitch, and duration of exposure to consider damage potential.
    a. Results of loudness and duration are inversely proportional.
        i. Louder the sound, the less time before damage occurs
3. Subtle symptoms of hearing loss include the following and may go away or remain permanently:
    a. Feelings of pressure or fullness in ears
    b. Muffled speech
    c. Ringing in ears
4. Proven negative consequences to exposure to noise include:
    a. Increase in blood pressure, especially in people who are susceptible to hypertension
    b. Headaches
    c. Stomach ulcers
    d. Feelings of apathy
    e. Feelings of a "headrush"
    f. Low-birth-weight neonates and fetal birth defects

            i. Per findings by US Environmental Protection Agency upon exposure to high levels of noise for extended period
      g. Sleep disturbance
      h. Increase in aggressive behavior
      i. Overall increases in chronic stress levels
      j. Intensification of adverse effects of carbon monoxide and hypoxia
      k. Fatigue
   5. Cabin noise can cause following problems:
      a. Poor communication between patients and care providers
      b. Increased patient anxiety
      c. Inability of caregiver to assess heart and lung sounds, monitoring errors
   6. Strategies to reduce or prevent noise:
      a. Modify equipment to reduce noise exposure
      b. Wear hearing protection anytime around or inside aircraft that is running
            i. May not apply to jets
G. Fatigue
   1. Most physiologic problems encountered in the flight environment can cause significant fatigue.
   2. Fatigue is caused by:
      a. Lack of restful sleep common to most personnel
            i. Crew rest essential when feeling fatigued
      b. Jet-lag in the fixed-wing environment
      c. Constant vibration of aircraft also causes fatigue
      d. 24-hour operational nature of air medical transport
            i. Prevents establishment of natural circadian rhythm
            ii. New emphasis on 12 hour shifts
   3. Consequences of fatigue include:
      a. Delayed reaction time when caring for patients
      b. Increased vulnerability to error
H. Gravitational forces
   1. The body's response to gravitational forces is affected by:
      a. Intensity of impact of acceleration
      b. Its direction
      c. Length of time body is subjected to stress
      d. Time it takes for gravity's effects to appear
      e. Individual's unique physical makeup
   2. Body is affected by the rapid acceleration or deceleration, not gravity
      a. One unit of gravitational force (g force) is equal to weight of object
      b. Multiply gravitational force experienced by weight to determine actual force on body
            i. For example: 100-lb person who experiences 10g will have 1,000 lb of force on his or her body
   3. Negative gravitational forces result from a steep dive in an aircraft.
      a. Pushes blood toward brain
   4. Positive gravitational forces result from high-speed acceleration, climbs, or high-speed turns.
      a. Push blood away from the brain
      b. Most humans can survive positive gravitational force of 9g, but only tolerate negative gravitational force of 2g or 3g; become unconscious around forces of 6g to 8g

5. Physiologic response to gravitational forces is influenced by the length of time a person feels the effects of acceleration.
    a. Acceleration "pushes" lasting fewer than 0.2 seconds can be tolerated at a relatively high gravitational force under short duration is brief
    b. Exposure to a gravitational force that lasts longer than 0.2 seconds considered sustained or prolonged
        i. May cause organs to shift and third spacing
6. Gravitational forces can have significant impacts on the human body.
    a. First physiologic sensation is a feeling of being pushed down or weightless, depending on whether the aircraft is accelerating or decelerating.
    b. Breathing next becomes labored as acceleration compresses rib cage, and can cause:
        i. Exhaustion and air hunger
    c. Hypoxia as blood leaves brain and transfers to lower extremities
        i. Can result in loss of peripheral vision, tunnel vision, or blackout
    d. Organ displacement downward, significantly affecting blood flow
    e. Loss of consciousness
        i. Gravitational force loss of consciousness or gravitational force–induced loss of consciousness
    f. Other signs and symptoms include:
        i. Petechiae
        ii. Rashes
        iii. Bruising
        iv. Loss of consciousness with accompanying seizures
        v. Amnesia
        vi. Confusion
        vii. Cardiac arrhythmias (tachycardia and bradycardia)
        viii. Heart blocks
        ix. Stress cardiomyopathy
7. Several factors affect tolerance to sustained exposure to gravitational force, including:
    a. Person's conditioning
    b. Psychological stress level
    c. Amount of muscular straining while experiencing gravitational force
8. Several other factors are known to decrease tolerance to positive gravitational force during acceleration, including:
    a. Age
    b. Infection and illness
        i. Resulting in fever and dehydration
    c. Hypoglycemia
        i. Causes loss of consciousness sooner under acceleration stress
    d. Alcohol consumption
    e. Hypoxia and heat stress

I. Spatial disorientation and illusions of flight
1. Spatial disorientation is a condition in which a person has an incorrect understanding of the body's position with respect to earth.
2. Three key components to maintain spatial orientation on ground are:
    a. Effective perception
    b. Integration
    c. Interpretation of visual, vestibular, and proprioceptive sensory information
3. Learning not to rely on visual reference is an important factor for pilots who are flying by instruments.

a. Senses provide invalid information because brain is convinced that "down" is bottom of the aircraft, no matter actual position or angle of the aircraft
4. Type I spatial disorientation
   a. Occurs when pilot does not notice that spatial disorientation exists because senses confirm pilot's experience is real.
      i. Without sensing danger, will not respond to disorientation and could cause crash
5. Type II spatial disorientation
   a. Occurs when pilot does not realize spatial disorientation, but senses problem
      i. Usually misinterprets problem as malfunction of controls and trusts own senses instead of relying on the instruments
      ii. Graveyard spiral
6. Type III spatial disorientation
   a. Occurs when pilot is affected by illusion of intense movement and unable to reorient
      i. Copilot can usually correct
   b. FAA has revised several rules regarding recognition of and training for spatial disorientation
7. Visual illusions
   a. Deceptive signals sent to brain by visual system
   b. More likely during instrument meteorological conditions
   c. Can lead to the misperceptions about:
      i. Location
      ii. Altitude
      iii. Distance away from other aircrafts or objects
      iv. Rate of speed as aircraft closes in on other objects, and attitude

J. Third spacing
1. The loss of fluids from the intravascular space into the tissues.
2. Centrifugal force and acceleration or deceleration of aircraft push fluids from intravascular into extravascular space
   a. Hypovolemia
   b. Potentiating hypoxia
3. Led to development of the "g-suit" or military antishock trousers (MAST pants)

K. Flicker vertigo
1. Defined by Flight Safety Foundation as "an imbalance in brain cell activity caused by exposure to low-frequency flickering or flashing of a relative bright light."
2. Effects may include:
   a. Nausea
   b. Vomiting
   c. Seizures
   d. Fainting
3. May be caused by any bright light flickering at a frequency of 4 to 20 cycles per second (Hz).
   a. Helicopter personnel affected when natural light or reflections of anticollision strobe lights distorted by rotor blades
   b. Fixed-wing propeller aircrafts
   c. Rotating beacon
4. Can also manifest in patients who are susceptible to external noxious stimuli

L. Fuel vapors
1. Exposure to may cause:
   a. Headaches

b. Precipitate feelings of nausea, if prolonged

M. Weather
1. Rapidly worsening weather conditions or inadvertent flight into conditions that require use of IFRs can be an additional stressor.

N. Anxiety
1. While it has a pivotal role in flight operations, it is rarely addressed or discussed.
2. Caused by several factors, including:
   a. Release of catecholamine in flight crew members in rotor-wing operations
      i. Initially, new flight crew members will have high level of anxiety until they have gained experience transporting patients with a range of conditions during different types of flights.
   b. Confines of the aircraft cabin may cause:
      i. Claustrophobia
      ii. Frustration at not being able to move freely and use all skills
3. Patients may also experience and may pretreated with antianxiolitics if protocols and patient presentation permit

O. Night flying
1. Crew members must be vigilant in assisting the pilot's scan for other aircraft when able, at night and during the day.
   a. Lighting makes aircraft often easier to spot at night
   b. A crew member who identifies aircraft traffic on a potential converging course should notify pilot at once
2. Crew members should reduce use of white light that may affect the pilot's night vision.
   a. Red lighting inside aircraft preferred
3. Pilot has the following disadvantages:
   a. Limited field of vision (reduced 40% due to night-vision goggles, if used)
   b. Added weight stress from helmet
   c. Loss of depth perception
   d. Monochromatic vision
   e. Reduced sense of speed

IX. Factors Affecting Tolerance of the Physiologic Stressors of Flight

Time: 6 Minutes
Slides: 58–61
Lecture/Discussion

A. In flight medicine, human factors affect a person's tolerance of flight stressors.
1. The mnemonic, IM SAFE, identifies each one:
   a. Illness
   b. Medication
   c. Stress
   d. Alcohol
   e. Fatigue
   f. Emotion
2. There are two "types" of altitude:

        a. Physical altitude, or feet above ground
        b. Physiologic altitude, or the altitude perceived by the body
            i. For example, the body may perceive the altitude at 14,000′ based on human factors even if it is less than 10,000′

B. Many illnesses, even a common cold, can significantly impair a crew member's performance.
    1. During pressure changes, nasal congestion can lead to:
        a. Severe headaches
        b. Vertigo
        c. Nausea
    2. Crew members should be cleared by a physician during any period of illness.

C. The use of medications affects the tolerance of hypoxia.
    1. Over-the counter (OTC) medications:
        a. Can result in incapacitation when effects combined with effects of hypoxia
        b. Can mask underlying problems that then go untreated
        c. May be safe for use; crew members should:
            i. Follow approved lists for OTC medications before they fly
            ii. Or consult with flight surgeon or physician knowledgeable in flight medicine
    2. FAA has list of approved prescription and OTC medications that flight crew members are permitted to use.
        a. Stated in FAR Part 61 that pilots:
            i. Assume responsibility for all medications
            ii. Must check with flight surgeon before flying if they have any doubts
            iii. Should not take new medication for the first time while working
    3. Stimulants, like caffeine, also have a high potential for abuse and may cause problems.
        a. Caffeine can cause the following problems:
            i. Tachycardia
            ii. Hypertension
            iii. Increased urine production
            iv. Increased excretion
            v. Dehydration
        b. Other stimulants may cause:
            i. Insomnia
            ii. Tremors
            iii. Indigestion
            iv. Nervousness

D. Stress can affect performance negatively and can lead to distraction and poor judgment.
    1. Most pilots and flight crew cannot simply "leave stress on the ground."
    2. Everyday stresses may include:
        a. Work
        b. Financial situations
        c. Family issues
    3. Negative consequences caused by high levels of stress may cause inattentiveness and lead to catastrophic effects in the aviation environment.
        a. Crew members should take actions to ensure safety if they recognize high levels of stress in their coworkers.

E. Alcohol can be a toxin in the body and can result in histotoxic hypoxia, which inhibits the use of available oxygen by hemoglobin and delays metabolism at the cellular level.
    1. Research indicates the following:
        a. Intake of 1 oz of alcohol is equivalent to 2,000′of physiologic altitude.

        i. Two beers can add between 4,000′ and 8,000′ of physiologic altitude.
    b. Alcohol depresses the central nervous system and inhibits judgment and coordination, further amplifying the effects of altitude.
    c. Alcohol acts as a potent diuretic and can lead to dehydration in early stages of drinking
        i. Causes fluid retention when blood alcohol level increases nearing intoxication
    d. Review FAR Part 91 which clearly addresses the topic of alcohol
2. Most aviation companies have a 12-hour "bottle to throttle" policy
    a. However, all policies underscored by caveat that people who feel under the influence of alcohol, regardless of the time from the last drink, should not fly.
    b. FAR Parts 91 and 135 state that all flight crewmembers are subject to random drug and alcohol tests at any time while on duty.
3. Hangover symptoms also pose significant hazards, including:
    a. Tremors
    b. Thirst
    c. Nausea and vomiting
    d. Diarrhea
    e. Sweating
    f. Heartburn
    g. Dizziness
    h. Headaches
    i. Reduced physical and mental performance (14 to 24 hours after blood alcohol level has returned to zero)
    j. Propensity for hypoglycemia and significant fatigue

F. Exhaustion and fatigue have an important role in one's ability to tolerate the effects of hypoxia.
1. Shift work hinders the ability to obtain regular sleep.
    a. Flight crew members who provide air medical transport must work all hours.
    b. Shift work disrupts the circadian rhythm, making it difficult to regulate sleep at work and at home.
    c. Crew members may begin shifts exhausted, predisposing them to the effects of hypoxia.
        i. Some also work second jobs
2. Negative consequences of exhaustion include:
    a. Judgment errors
    b. Narrowed attention
    c. Uncharacteristic behavior
    d. Falling asleep at work
3. Crew members who use pharmacologic sleeping aids need to first have the medication approved by a flight surgeon.
    a. Use of such medications should be considered flight safety issue
4. The constant vibration that aircrew members experience during flight also leads to fatigue.

G. Certain emotionally upsetting events can significantly impair pilot and crew performance.
1. May include: major arguments, death in family, divorce
2. Pilots or crew members experiencing an intense emotional event should not fly until satisfactory resolution occurs.

H. An aviator who smokes risks the effects of hypemic hypoxia because carbon monoxide is 50 to 300 times more attracted to hemoglobin than oxygen.
1. Research studies have found:

        a. Smoking three cigarettes in rapid succession or smoking 20 to 30 cigarettes in a 24-hour period can saturate 10% of the hemoglobin in the body.
            i. At sea level, a regular smoker has a starting physiologic altitude of 3,000′ to 8,000′.
        b. Smoking affects night vision.
            i. Regular smoker has already lost 20% of night vision, even at sea level

I. Poor diet and low blood glucose levels can cause many negative effects.
    1. These may include:
        a. Nausea
        b. Headache
        c. Dizziness
        d. Shakiness
        e. Nervousness
        f. Judgment errors
    2. Poor diet or lack of eating may also precipitate effects of motion sickness.
        a. Prevent by eating several small meals or regularly snack on healthy foods during the shift
    3. Flight team members should also maintain a healthy weight because obesity can:
        a. Cause problems in flight environment
        b. Affect overall safety and performance of overweight flight crewmember
        c. Impact rotor-wing flight program weight limit for crewmembers

J. In addition to the aforementioned stressors, there are several others, including:
    1. Age reduces body's ability to compensate to stress
    2. Physical exertion during flight significantly lowers altitude at which evolved gas disorders occur.
        a. Increases oxygen demand, increasing risk for hypoxia
            i. Maintaining good physical conditioning will help to increase this threshold

X. Dysbarism and Evolved Gas Disorders

Time: 5 Minutes
Slides: 62–64
Lecture/Discussion

A. Various disorders are directly related to altitude.
    1. Barotrauma can result from gases expanding and contracting in the body, causing pain in the:
        a. Digestive tract
        b. Sinuses
        c. Teeth
        d. Middle ear
        e. Lungs
    2. Dysbarism is directly related to the effects of altitude as described by the various gas laws.
        a. Defined as a syndrome resulting from a difference between the barometric pressure and pressure of gases within body
            i. As gases expand at altitude, they can cause pain in closed cavities.

B. Barotitis media affects the middle ear and is one of the most common trapped-gas problems.
   1. Results from failure of the middle ear space to equalize pressures when going from low to high atmospheric pressure
      a. Pressure in middle ear becomes increasingly negative partial vacuum
      b. As pressure increases, tympanic membrane is depressed inward and becomes inflamed
      c. Petechial hemorrhage develops
      d. Blood and tissue fluids drawn into middle ear cavity
      e. Eardrum may rupture if pressure does not equalize
      f. As barometric pressure in aircraft cabin decreases during ascent, air trapped in middle ear begins to expand, pushing eustachian tube open
      g. Air escapes through nasal passages, and pressure is equalized.
   2. Normal ways to prevent include:
      a. Swallowing
      b. Yawning
      c. Tensing throat muscles
      d. Pinching the nose and attempting to blow through the nostrils.
   3. Any type of respiratory infection can make equalization in the eustachian tube difficult or impossible.
      a. Inability to relieve causes profound pain, possible occurrence of hemorrhage, indicating eardrum is about to burst or has already ruptured
      b. To relieve, pilot should ascend until pain is relieved and equalized, then slowly descend so ears can slowly equalize

C. Although decompression sickness is not the most frequent dysbarism, it is the most commonly known.
   1. Explained by Henry's law and occurs by formation of inert nitrogen gas bubbles at one or more locations in body
      a. Manifestation of symptoms depends on location in body where bubbles form
   2. If a human body is subjected to a rapid decrease in atmospheric pressure, capillaries become supersaturated and nitrogen begins to leave as a gas instead of in a solution.
      a. Nitrogen bubbles begin forming in tissue and blood.
      b. Fat can dissolve nitrogen five to six times more readily than blood, so tissues with highest fat content are more likely to become saturated with nitrogen.
   3. Negative consequences may include:
      a. Circulation problems
      b. Death
         i. Due to potential for nitrogen bubbles in arterial circulation causing an arterial gas embolism

