AETC Student Guide P-V4A-J-AP-SG
P-V4A-N-3-AP-SG, C-V4P-P-AP-SG

Flying Training

Aerospace Physiology

March 2021

Air Education and Training Command

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AETC Student Guide P-V4A-J-AP-SG, P-V4A-N-3-AP-SG
C-V4P-P-AP-SG
December 2020

This student guide lists all the objectives for each lesson in T-6 Physiology. These objectives identify what students need to learn. Review questions are at the end of most lessons to aid understanding of the material with the answers on the last page of each exercise. These questions also provide an excellent review for the exam. Address questions or recommendations for course improvement to the instructor. The next planned revision is December 2023.

CONTENTS
PREVIOUS

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Course Contents

CONTENTS

PREVIOUS

Special Instructions

This SG and CBTs are also available for review outside of class via the Distributed Learning Portal (DLP) on a .mil computer or personal computer with CAC access. Follow procedures outlined in the "STINFO Handling Requirements" section of the AETC Handout, *Courseware Handling Instructions*. You can access the DLP at https://www.my.af.mil/BRIProd/DLP. Course should be accomplished via live, in-person, face-to-face instruction.

Level-of-Learning Objectives and Samples of Behavior

This document uses "level-of-learning" objectives and samples of behavior. The verb used in the objective (know, comprehend, apply, etc.) identifies the desired level of learning to be achieved and implies the highest level at which student learning may be evaluated, but only the highest level is contained in each objective. A sample of behavior is a statement that specifies one of several observable behaviors a student should be able to demonstrate at the end of instruction. A limited number (a sampling) of behaviors are listed.

Page Navigation

Students viewing the .pdf version of the student guide can access the first page of any lesson, the associated Review Questions, and the Answer Key through the Course Contents page. Blue text designates the clickable area. Navigation buttons (Previous View and Course Contents) are also available at the right margin of each page.

Bookmarks can also be used as an alternate method for accessing each lesson as well as any attachments. The bookmarks are available through the navigation pane on the left side of the .pdf document by clicking the blue ribbon or View>Show/Hide>Navigation Panes>Bookmarks.

There are a variety of devices available with distinct platforms (iOS, Android, Windows®, etc.), so users should determine the prescribed method to access their device's bookmarks. Navigate through the Student Guide's bookmarks and tap the one you need to open the specified page.

Course Hours

The Physiology course is 18.5 total hours.

AP101 — Introduction and Atmosphere

Hours and Medium

0.5 Hour (IBT)

Objectives

1. Know basic information about the science of HF and its role in aviation.

   Samples of Behavior:

   a. Recall the HF definition, its associated terminology, and scientific concepts.

   b. Throughout the entire course students will identify the HF challenges associated USAF aviation and the human performance implications.

2. Know the characteristics of the earth's atmosphere.

   Samples of Behavior:

   a. Recognize the functions of the atmosphere.

   b. Identify which gasses are present in the atmosphere and their associated percentage of the total composition.

   c. Recall the common units of measurement for atmospheric pressure.

   d. Recognize the description and common unit of measure of the U.S. Standard Atmosphere.

   e. Recognize the definition of the standard temperature lapse rate.

   f. State the standard temperature lapse rate.

   g. List the physiological divisions of the atmosphere.

3. Know the potential impact of the gas laws.

   Samples of Behavior:

   a. Recall partial pressure and identify its notation.

   b. Identify the gas laws.

   c. Recall the physiological effects of each gas law.

Assignment

Read AP101 in the SG and answer the review questions.

***Note* —** Complete each lesson's assignment before reporting to class. Answers to the review exercises are on the page following the questions. If you answer incorrectly, review the material until you understand it. Review the material to ensure comprehension and retention.

Information

Introduction to Human Factors in Aviation

Today, as never before, you face the challenge of expanding technology and a rapidly changing world. The ever increasing complexity of weapon systems and mission requirements place greater and more diverse stress on crewmembers. The Aerospace Physiology (AP) course prepares you to successfully cope with these stresses, whether they are the physical requirements of egress, physiological stresses of loss of aircraft pressurization, or performance decrements caused by self-imposed stress. We have reached a point where the major limiting factors to weapon system performance are the human limitations of the crewmember. These human limitations form the basis of a field of study, *Human Factors*, which is a part of this course.

The Human Factor

According to the Civil Aviation Authority (as cited by the AFRL Handbook of Aerospace and Operational Physiology, 2016), "Human Factors is concerned to optimize the relationship between people and their activities, by the systematic application of human sciences, integrated within the framework of systems engineering." The role of human factors in aviation has its roots in the earliest days of aviation, where aircraft began rapidly exceeding the human's capability of

CONTENTS

PREVIOUS

directly sensing & responding to the vehicle and the environment, and their ability to ensure optimum outcome & safety of flight (Wise et al., 2009).

The Royal Flying Corps (UK) was the first to harness human factor specialists in the form of flight surgeons during the First World War. The aeromedical factors identified during the early investigations have become foundational to the USAF's aim to prevent aviation mishaps and preserve combat assets.

In modern aviation, human factors have historically accounted for the majority (60-80 percent) of aircraft accidents. As a result, the USAF continues to develop and improve programs to eliminate human factors errors.

SHELL Model

According to Heinrich (1980), "the inseparable tie between individuals, their tools and machines, and their general work environment" is critical to understanding human systems integration (HSI). One of the most well-known HSI models is the SHELL Model (Figure 1-1). The SHELL model is a conceptual model of human factors that clarifies the scope of aviation human factors and assists in understanding the relationships between the aviation system (and flying subsystems) and the human component in the aviation system (and human subsystems).

The original model was actually the S-H-E-L model (with one *L*) and was first developed by Elwyn Edwards 1972. Edwards' model describes the four basic components needed for successful man-machine integration. SHEL is an acronym used to represent the four components of the model and is based on a systems perspective that the human is rarely, if ever, the sole cause of an accident (Wiegmann & Shapell, 2003).

The *S* represents *Software* which encompasses more than computer software that drives the logic and design of a system, but software also comprises the rules, regulations, policies, and guidance that govern how a system operates. The *H* represents the *Hardware* associated with a given system such as equipment, material, and other physical assets. The *E* refers to the *Environment* that humans operate in such as the cockpit, flightdeck, ground control station (GCS), the organization, and the culture in which the human (represented by *L*) operates. The *L* symbolizes the *Liveware* (human element) in the aviation system and considers human performance, human capabilities, and their limitations. Edwards' SHEL model has all but disappeared in modern HF theory; however; it is survived by its offspring, the SHELL model.

According to the website Skybrary, in 1975, Frank Hawkins modified Edwards' SHEL concept into a *building block* structure, along with an additional Liveware element as represented by a second *L*. The additional (outer) *L* represents the critical Liveware-Liveware interface between the primary human element (the inner *L*) and the secondary human element (the outer *L*). Examples of secondary human elements are other crew members, air traffic controllers, maintainers, meteorologists, commanders, etc.

All five SHELL components play an important role in human performance however, effective component interaction is critical to optimizing human performance. At some point, human operators will recognize, either consciously or subconsciously, when there is a barrier to effective component interaction. Below is a two SHELL-component interaction example:

> An automobile driver reaches down to turn the radio station, and realizes the knob is missing. It is obvious the radio knob is missing because it is absent when the driver reaches down to change the station. This is an example of an interaction barrier in a two-dimensional Liveware (driver)-Hardware (radio knob) relationship. Therefore, the solution to this barrier is to find and replace the radio knob.

In the midst of all of today's technological changes, there are two factors that have undergone little change — (1) the atmosphere in which we conduct aerospace operations, and (2) the physiologic requirements unique to our human nature. Each time you fly, you enter an environment where changes in ambient pressure (the immediate surrounding atmospheric pressure), weather, and temperature can pose significant hazards. Therefore, it's imperative for you to know the characteristics of the atmosphere. This knowledge will form a basis to understand the physiological limits to functioning in this dynamic environment.

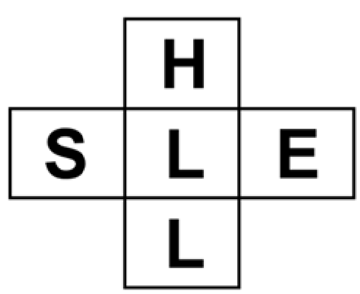

Figure 1-1 — SHELL Model

CONTENTS
PREVIOUS

The Atmosphere

For simplicity, the atmosphere is defined as the gaseous envelope surrounding the Earth. According to Central Connecticut State University, the earth's atmosphere is a reservoir of gases and air is a mixture of gases that is naturally odorless, colorless, tasteless and formless. The atmosphere is bound to the Earth by gravity and provides some unique protective functions that help sustain our existence on Earth.

The atmosphere contains oxygen which is essential for life, as you already know. In return humans and animals produce carbon dioxide, which is essential for plant life. Plants in turn produce oxygen for us to use. It also provides a shield that absorbs harmful electromagnetic radiation, streams of charged particles in the solar wind, and from natural and human made space debris. Lastly, the atmosphere contains precipitation, helping to maintain the temperature and climate.

Atmospheric Characteristics

The composition of the atmosphere is remarkably constant up to approximately 300,000 feet. The gaseous envelope surrounding the Earth is divided into layers. *Sphere* signifies the actual layer of air, whereas *pause* is the outer boundary of that layer that separates the next layer. A physicist or meteorologist would divide the atmosphere as depicted in Figure 1-2. The densest layer of the atmosphere is the one closest to the earth, the troposphere. Almost all flying takes place in the troposphere. The troposphere is the layer from the Earth's surface to approximately 30,000 feet at the north and south poles and about 60,000 feet at the equator. The difference of 30,000 feet is due to the heated air at the equator, because warm/hot air expands. This is the layer that captures the most solar energy. In this layer there is water vapor (humidity), a decrease in temperature with the increase of altitude, and weather phenomena (Reinhart, 2008). The Tropopause is the layer of temperature stability. Stratosphere is a layer that has little change in temperature and has little water vapor. There is a layer that can extend to a height of 55 miles, this is sometimes called the mesosphere. Ionosphere is where the ozone is most prevalent. This layer protections the earth from ultraviolet radiation. Exosphere is the outer boundary of the atmosphere, sometimes referred to as deep space.

These layers are composed of nitrogen, oxygen and argon with traces of carbon dioxide and other inert gases (such as helium and neon). The approximate percentages of gases in the atmosphere are 78 percent nitrogen, 21 percent oxygen and 1 percent other gases (including 0.03 percent carbon dioxide). These percentages remain relatively constant with increased altitude. So what changes? ***Pressure***!

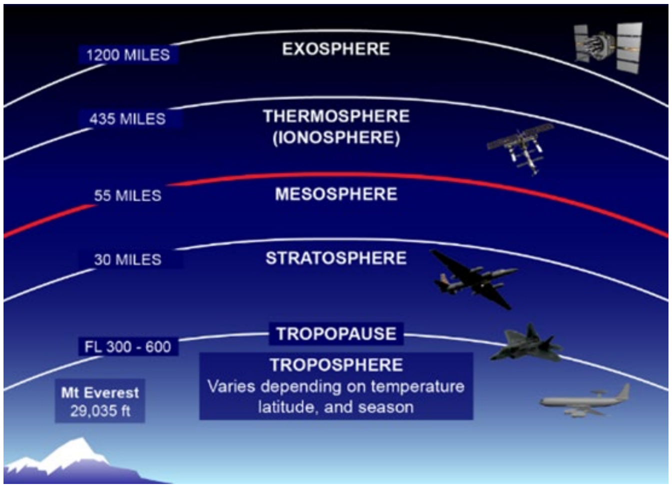

Figure 1-2 — Physical Divisions of the Atmosphere

Pressure

Pressure is defined as force that acts on a unit area. Atmospheric or barometric pressure is the combined weight of all the atmospheric gases acting to create a force upon the surface of the Earth. This force is caused by gravity pulling gas molecules earthward, as well as thermal and solar radiation expanding the gases outward toward space. A barometer is a tool used in measuring atmospheric pressure (Figure 1-3). Density and pressure decrease exponentially as one ascends from the earth's surface. Pressure can be measured at any altitude. The weight of the atmosphere can be measured in pounds per square inch (psi), millimeters of mercury (mmHg), or inches of mercury (inHg). Atmospheric pressure readings will vary daily, depending on changing surface temperatures, humidity, high and low pressure weather fronts.

CONTENTS
PREVIOUS

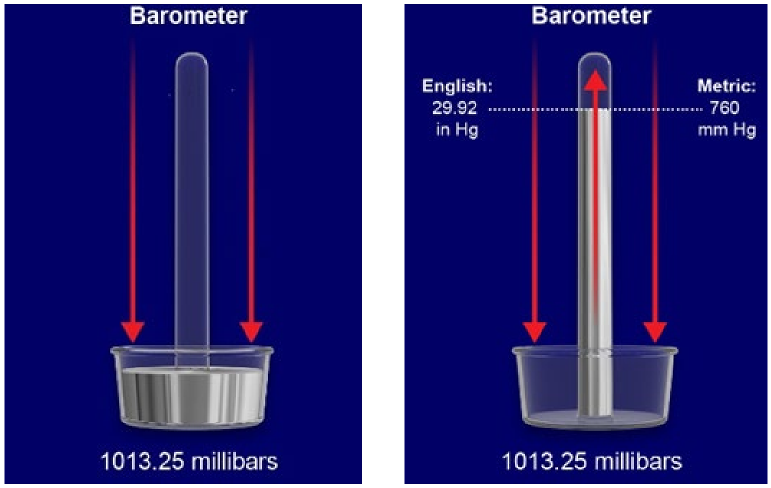

Figure 1-3 — Measuring Pressure

Pressure altimeters (Figure 1-4) sense atmospheric pressure and convert the data into feet above mean sea level. To construct an instrument of this nature, a standard pressure reading for each altitude had to be developed. This standard which is referred to as U.S. Standard Atmosphere was computed by taking the average pressure and temperature readings for a year at mid-latitude locations. At sea level, these readings were determined to be +15 °C and 760 mmHg (29.92 inHg) pressure.

Figure 1-4 — Pressure Altimeters

Figure 1-5 shows the U.S. Standard Atmosphere pressures at various altitudes. The pressure at 18,000 feet is 379.4 mmHg, or about one half of the pressure encountered at sea level. This illustrates that the greatest pressure change occurs at lower atmospheric levels between sea level and 18,000 feet.

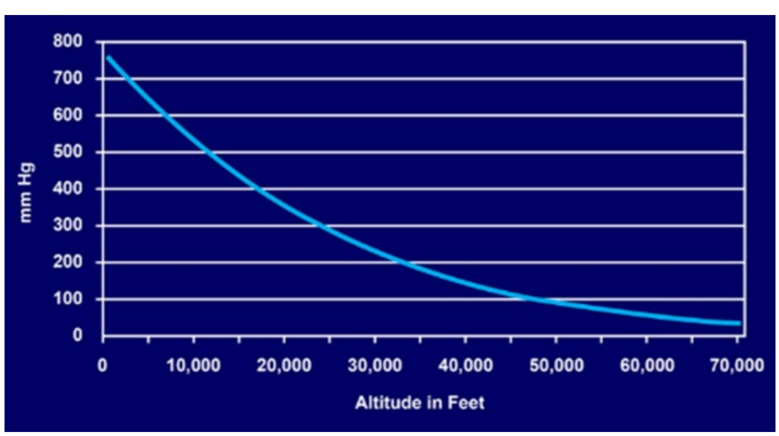

Figure 1-5 — Pressure Altitude Relationship

CONTENTS
PREVIOUS

Temperature

The earth's surface temperatures vary day to day and season to season. Altitudes up to about 35,000 feet reflect a constant decrease in temperature of about 2 °C (3.6 °F) per 1,000 feet (Figure 1-6). This constant decrease is referred to as the standard temperature lapse rate. If it is 30°C on the runway at sea level, then the temperature would be about -10 °C at 20,000 feet. By using the standard temperature lapse rate you can determine that there is a 40 degree Celsius change in temperature (-2 °C/1,000 feet).

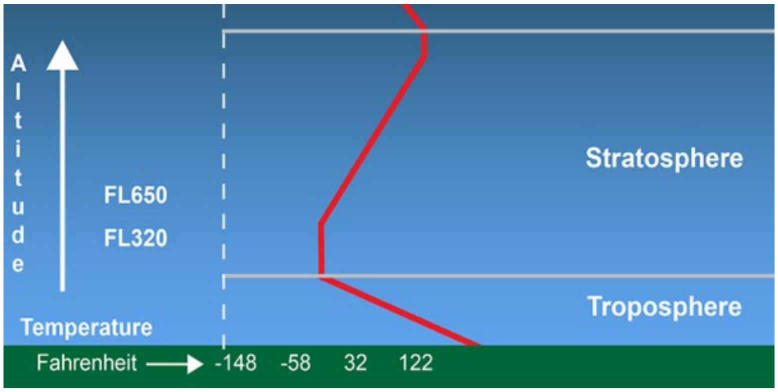

Figure 1-6 — Temperature Lapse Rate

Divisions of the Atmosphere

Physiological Zone

The physiological zone extends from sea level to approximately 10,000 feet and is the zone the human body is adapted to. Life above this zone requires considerable acclimatization. During ascent in the physiological zone, atmospheric pressure drops from 760 mmHg to 523 mmHg. Even though the oxygen partial pressure (PO_2) falls, the body's compensatory mechanisms keep oxygen delivery within normal limits. Only at the upper boundary of the physiological zone and in tissues with very high O_2 requirements, e.g., the retina, are symptoms of O_2 deficiency noted. When flying unpressurized above 10,000 feet mean sea level (MSL), the use of supplemental oxygen is required.

Physiological Deficient Zone

The Physiological Deficient zone is significant because the reduced atmospheric pressure means there is an inadequate amount of oxygen pressure to sustain normal physiologic functions. This zone extends from approximately 10,000 feet to approximately 50,000 feet. Decompression sickness (caused by evolved gas) can also occur in the body tissues and joints at in this zone. This phenomena will be covered in later chapters. Atmospheric pressure decreases from 523 mmHg at 10,000 feet to 87 mmHg at 50,000 feet. Pressure suits are required above FL500.

Space Equivalent Zone

The space equivalent zone exists above 50,000 feet. The physiological problems of flight above 50,000 feet are essentially the same as those for space. The need for protection in a sealed cabin or pressure suit, the problem of ebullism (tissue water vaporization) above 63,000 feet, and other adverse influences on the body make this area of the atmosphere extremely hazardous (Figure 1-7).

Figure 1-7 — Physiological Divisions of the Atmosphere

CONTENTS
PREVIOUS

Gas Laws

Most of the physiological complications can be explained by several elementary principles of gas behavior as individuals ascend and descend within the earth's atmosphere. These gas laws are the basis for much of the information in future lessons. To understand the gas laws you should have an understanding of Dalton's Law of Partial Pressure.

Dalton's Law of Partial Pressure

Dalton's Law of Partial Pressure states the total pressure of a mixture of gases is equal to the sum of the partial pressures of each gas in the mixture or stated slightly differently; the amount of pressure that a single gas out of a mixture of gases contributes to the sum or total pressure of that mixture. The denotation for the partial pressure of Nitrogen, Oxygen, and Carbon Dioxide is PN_2, PO_2, PCO_2, respectively. The pressure exerted by each gas in a mixture is independent of other gases in the mixture. For example, the total pressure of the atmosphere at sea level is 760 mmHg this pressure equals PN_2 (592.8) + PO_2 (160) + PCO_2 (.30) and the partial pressure of other trace gases (6.9).

Dalton's Law explains how exposure to a high ambient altitude can reduce the available oxygen (Figure 1-8). As ambient altitude increases, the total atmospheric pressure decreases causing, specifically partial pressure of oxygen (PO_2) to decrease even though the *percentage* of oxygen remains the same. For example, at sea level the PO_2 is 21 percent of 760 mmHg or 160 mmHg. At 18,000 feet, PO_2 is 21 percent of 380 mmHg or 80 mmHg.

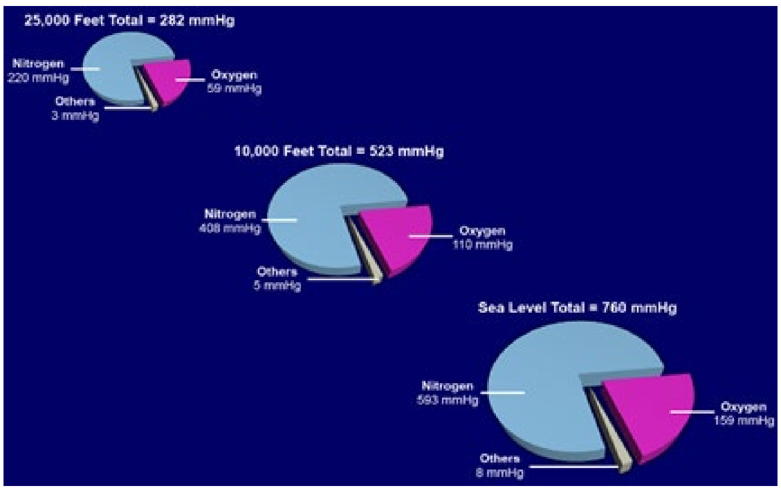

Figure 1-8 — Dalton's Law of Partial Pressure

Boyle's Law

Boyle's Law states when the temperature remains constant, as in the human body, a volume of gas is inversely proportional to the pressure surrounding it. This principle explains why a balloon expands as it ascends and also why a volume of air expands when trapped in a body cavity when the pressure is reduced around it. Boyle's Law explains for the effects of pressure changes in the ears, sinuses, teeth, and gastrointestinal tract.

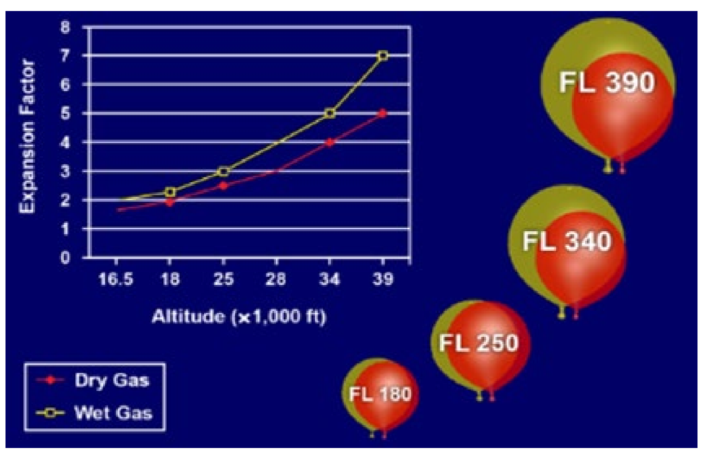

Figure 1-9 — Boyle's Law

Henry's Law

Henry's Law is when the amount of gas in a solution varies directly with the partial pressure of that gas over the solution. Therefore, if pressure is reduced above the solution, some gas will come out of solution. This principle explains why carbon dioxide bubbles are released when a carbonated beverage container is opened or why nitrogen bubbles may come out of solution in body tissues during ascent. The nitrogen bubbles can lead to altitude-induced decompression sickness.

CONTENTS
PREVIOUS

Ideal Gas Law

The ideal gas law is a common model for relating the properties of dry air. This law describes gas behavior using three interrelated variables: pressure (P), volume (V), and temperature (T). The ideal gas law can be used, for example, to illustrate how temperature is proportional to pressure in an oxygen cylinder or how pressure is inversely proportional to volume when volume is not fixed.

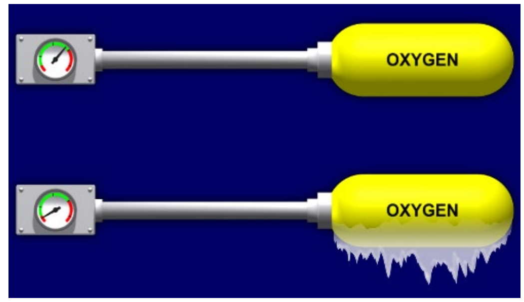

Figure 1-10 — Ideal Gas Law

Gaseous Diffusion

Gaseous diffusion is fundamental to the physiologic processes of lung and cellular respiration. It further applies to the process of denitrogenation, the removal of nitrogen from the body by breathing 100% oxygen, (HAOP, 2016). A gas will diffuse from an area of higher concentration or pressure to an area of lower concentration or pressure until equilibrium is reached. The speed of this movement depends on the relative concentrations of the gases (strength of the diffusion gradient). The physiological significance of this law relates to transfer of gases between the blood or other body fluids and the tissues they contact. For example, the gas transfer that takes place in the lungs by oxygen moving out of the lungs to the bloodstream and carbon dioxide moving from the bloodstream into the lungs based on the movement of the gases from a higher concentration or pressure area to a lower area until it has reached equilibrium. This along with Dalton's Law of Partial Pressure explains hypoxic hypoxia.

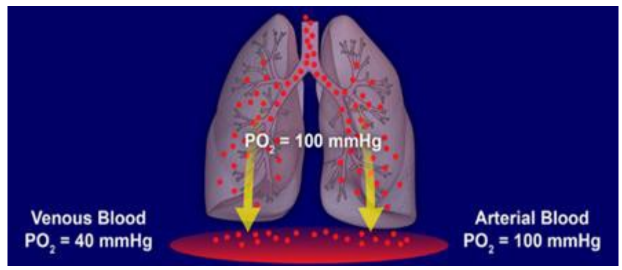

Figure 1-11 — Gaseous Diffusion

Summary

The overall goal of Aerospace Physiology is to train crewmembers to increase safety and mission effectiveness through the identification and elimination of physical, physiological, and psychological limitations of the flying environment. We began by examining the physical environment in which aircraft operate, the atmosphere, and how those gasses behave according to various gas laws. As altitude increases the ambient pressure decreases but the relative makeup of the gasses in the atmosphere remains the same. Human adaptation to these changes led to the definition of three physiological zones within the atmosphere — the physiological zone, the physiological deficient zone, and the space equivalent zone. Finally, in order to understand some of the physiological changes that occur with changes in altitude, we must first understand their cause. Most of these physiological changes are caused by elementary principles of gas behavior, the gas laws. Now that we have a better understanding of the aerospace environment, we can examine how our body is affected by this environment as we travel through it.

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CONTENTS
PREVIOUS

Review Exercise AP101

Complete the following review exercises after class by selecting the correct response or filling in the blanks. Answers follow the questions.

1. What is the approximate percentage of oxygen, nitrogen and other gases at 18,000 feet MSL?
   a. 21 percent oxygen, 78 percent nitrogen, and 1 percent other gases.
   b. 15 percent oxygen, 39 percent nitrogen, and 0.015 other gases.
   c. 78 percent oxygen, 21 percent nitrogen, and 3 percent other gases.

2. Which of the following is the best description of atmospheric pressure and its cause?
   a. The combined weight of all the atmospheric gases which is caused by thermal and solar radiation.
   b. The combined weight of all the atmospheric gases which is caused by gravity pulling the gas molecules earthward and thermal and solar radiation expanding the gases outward toward space.
   c. The weight of gas around the Earth which is caused by thermal and solar radiation.

3. What are the common units used to measure atmospheric pressure?
   a. Inches of mercury (inHg)
   b. Millimeters of mercury (mmHg)
   c. Pounds per square inch (psi)
   d. All the above are correct.

4. Which of the following represents the notation for the partial pressure of gases?
   a. PPO_2 partial pressure of oxygen, $PPCO_2$ partial pressure of carbon dioxide, PPN_2 partial pressure of nitrogen.
   b. PO_2 partial pressure of oxygen, PCO_2 partial pressure of carbon dioxide, PN_2 partial pressure of nitrogen.
   c. psi O_2 partial pressure of oxygen, psi CO_2 partial pressure of carbon dioxide, psi N_2 partial pressure of nitrogen.

5. PO_2 increases and the percentage of oxygen decreases as the altitude increases.
   a. True
   b. False

6. What is the temperature lapse rate up to approximately 35,000 feet?
   a. About 2 °C per 1,000 feet
   b. 3.25 °C per 1,000 feet
   c. About 1 °C per 2,000 feet

7. The human body is adapted to which physiological division of the atmosphere?
   a. Space equivalent zone
   b. Physiological deficient zone
   c. Physiological efficient zone
   d. Physiological zone

8. Match each gas law with its explanation.

Gas Law	Explanation
a. _____ Boyle's Law	1. Explains why the temperature increases in a cylinder that is being pressurized.
b. _____ Henry's Law	2. Explains why a balloon expands as it ascends and also why a volume of air expands when trapped in a body cavity when the pressure is reduced around it.
c. _____ Dalton's Law	3. Explains how oxygen moves out of the lungs into the bloodstream.
d. _____ Ideal Gas Law	4. Explains why a soda pop bubbles after it is opened.
e. _____ Law of Gaseous Diffusion	5. Explains how exposure to a high altitude can reduce the available oxygen

Answers to Review Exercise AP101

1. a
2. b
3. d
4. b
5. b
6. a
7. d
8. a. 2
   b. 4
   c. 5
   d. 1
   e. 3

AP102 — Respiration and Circulation

Hours and Medium

0.5 Hour (IBT)

Objectives

1. Know the structures and functions of the respiratory system.

   Samples of Behavior:

   a. Recall the phases of respiration.

   b. Recall the functions of each structure in the respiratory system.

   c. Identify structures that are important to respiration.

   d. Identify the important factors in normal respiration.

2. Know the structures and functions of the circulatory system.

   Samples of Behavior:

   a. Recall functions of the structures of the circulatory system.

   b. Recall the structures of the circulatory system.

   c. Identify factors affecting oxygen delivery to the tissues.

Assignment

Read AP102 in the SG and answer the review questions.

Introduction

The respiratory and circulatory systems work together to supply the body with oxygen and rid the body of carbon dioxide. Respiration is the process our body uses to exchange gases with our environment. The primary purpose of respiration is to provide oxygen to the body and remove excess carbon dioxide from the body. The respiratory process also helps maintain the acid-base balance (pH) of the blood.

Respiration involves ventilation of the lungs, oxygen diffusion from the lungs to the blood, circulation of the blood throughout the body delivering oxygen to body cells, and the diffusion of oxygen from the blood into each individual cell. Oxygen is then used in cellular respiration (metabolism). Metabolism is defined as the sum of all the physical and chemical processes used by cells to produce energy and building materials needed to sustain life. As we move forward we will discuss the Anatomy and Physiology of the Respiratory and Circulatory Systems.

CONTENTS
PREVIOUS

Information

Functions of the Respiratory System

Respiration is the process our body uses to exchange gases with our environment. The functions of respiration are:

Intake, filtering, and conditioning of air (warm and humidify)

Gas exchange

Temperature regulation

Metabolic function

Maintain acid-base balance (pH) of blood

Respiratory Anatomy

As the air is inhaled it will travel through mouth, nose, travels through pharynx, to trachea, and then the lungs (Figure 2-1). The Oral-Nasal Cavities (mouth, nose, and pharynx) are lined with a mucous membrane as well as, there are hair like structures (called cilia) in the nasal cavity mucous membrane filter inspired air. The oral cavity plays a lesser role in filtering the air, but regardless of the pathway, air is humidified and heated to body temperature before entering the lungs. Humidifying and warming the air protects the lungs from being cooled or dried out. Inhaling through the mouth, especially in cold, dry climates, does not allow air to be sufficiently warmed or humidified. Therefore, long term exposure of the lower lung to cool dry air can lead to infection; which can lead to a cold, or other illnesses.

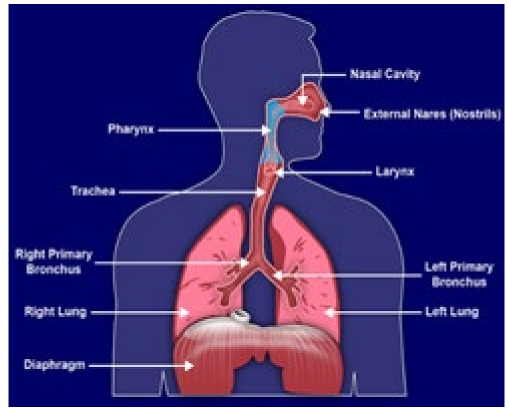

Figure 2-1 — Respiratory Anatomy

Next the air travels through the trachea (or windpipe), which divides into two branches, one to the right side and one to the left side of the lung. These branches (bronchi) form part of the root structures of the lungs' air passages. Then the air reaches the Lungs. The lungs occupy the greatest part of the chest or thoracic cavity and connect to the bronchi. The lungs' prime function is to allow oxygen to move from the air to the microscopic blood vessels (capillaries) and carbon dioxide to move from the capillaries into the lungs. The bronchi of each lung subdivide becoming narrower, shorter and more numerous as they penetrate deeper into the lung. The bronchi branch until they become bronchioles. The bronchioles continue to branch until they become the alveolar ducts, leading to the alveoli.

Alveoli are tiny air sacs in the lungs at the end of the bronchioles. Their walls have an excellent blood supply provided by capillaries. In the lung, gas exchange between the respiratory and circulatory systems occurs at the alveolar-capillary interface. Oxygen and carbon dioxide move between air and blood by simple diffusion, (Law of Gaseous Diffusion) from an area of high to low partial pressure.

Respiration Control and Integrated Responses

The rate and depth of breathing are modified in response to changes in the concentrations of carbon dioxide (CO_2), oxygen (O_2), and hydrogen ions (H^+) in arterial blood. Chemoreceptors in the medulla, the central chemoreceptors, and in the aortic arch and carotid bodies at the bifurcation of the common carotid arteries, the peripheral chemoreceptors, send both excitatory and inhibitory signals to the medulla, adjusting ventilation to the changing demands of the body.

There are three ways that the body regulates the arterial blood pH. The first line of defense is the chemical acid-base buffer system of the body fluids, which reacts within seconds. The respiratory system is the second line of defense, which regulates the removal of CO_2. The respiratory system takes a few minutes to activate if the acid-base buffer does not regulate the imbalance. Lastly, the kidneys regulate the amount of H^+ leaving the body. The kidneys are the slowest but most powerful of the regulatory systems. They can take hours and up to weeks to resolve the imbalance.

The most obvious and important for you as aircrew is the respiratory system. Therefore, it's useful to consider the overall response of the system to changes in the arterial partial pressure of carbon dioxide ($PaCO_2$), arterial partial pressure of oxygen (PaO_2), and pH.

The most important factor in the control of ventilation under normal conditions is the $PaCO_2$ of the arterial blood. The sensitivity of this control is remarkable. In the course of daily activity with periods of rest and exercise, the arterial $PaCO_2$ is normally held to within 3 mmHg of 45 mmHg. A reduction in arterial $PaCO_2$ is very effective in reducing the stimulus for ventilation. For example, if you hyperventilate voluntarily for a few seconds, you will find that you have no urge to breathe for a short period.

Arterial PaO2 can normally be reduced from the normal 95 mmHg to 50 – 60 mmHg without evoking a ventilatory response, showing that the role of this hypoxic (low oxygen) stimulus in the day by day control of ventilation is small. However, on ascent to high altitude, a large increase in ventilation can occur in response to lack of sufficient PO_2 (your tidal volume and respiratory rate both increase at higher altitudes).

This increase in ventilation can cause an increased loss of CO_2 resulting in an increased arterial blood pH. This causes a mild respiratory alkalosis (increase in pH) sometimes referred to as hypocapnia. It is difficult to separate the ventilatory response caused by a fall in pH from that caused by an accompanying increase in $PaCO_2$. However, it has been shown that ventilation is stimulated whenever $PaCO_2$ is held constant and the pH is allowed to fall.

Note — Breathing can also be controlled by involuntary means. Involuntary control occurs when certain emotional stresses such as fear, anxiety, or apprehension cause an abnormal increase in your breathing. This mechanism may take precedence over normal chemical control. Involuntary control can be overcome by consciously controlling your rate and depth of breathing. In this way, you can combat the adverse effects of certain stresses on the process of ventilation.

CONTENTS !!!
PREVIOUS

Phases of Respiration

Another way of looking at how respiration works is by looking at the five distinct phases — ventilation, diffusion, transportation, diffusion, and utilization (Figures 2-2 and 2-3). Each phase has a specific function in the overall exchange of gases.

Ventilation is the inhalation and exhalation of gas, and is mathematically defined as the volume of gas exchanged between the lungs and the ambient environment per unit time. This process is regulated to provide adequate delivery of oxygen and removal of carbon dioxide to satisfy the demands of metabolism.

Diffusion (1) is when the oxygen and carbon dioxide pass through the alveolar membrane and capillary walls into the red blood cells.

Transportation is when oxygen is carried by the blood to the cell and tissues for utilization.

Diffusion (2) here is the movement of gases between the blood, the interstitial fluid, and the cells, sometimes called internal respiration, down their respective pressure gradient.

Utilization is when the oxygen is used to produce energy which results in carbon dioxide and water as byproducts.

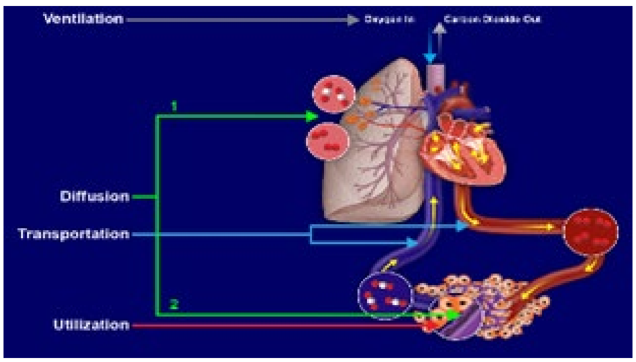

Figure 2-2 — Phases of Respiration

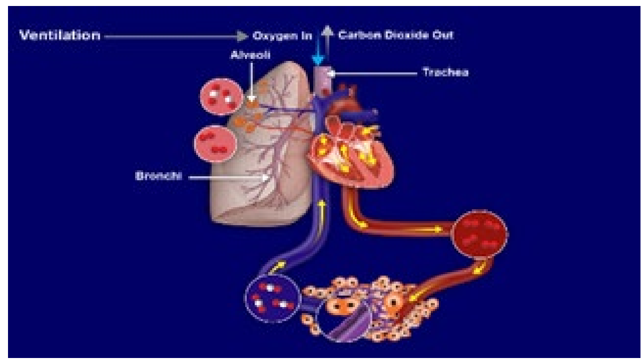

Figure 2-3 — Ventilation Phase

Mechanics of Ventilation — In adults, the tidal volume (the amount of gas inhaled or exhaled with each normal breath) is about 500 milliliters. This air is normally exchanged an average of 12 to 16 times per minute.

The *active* component of respiration is *inspiration*. It is accomplished by the contraction (downward movement) of the diaphragm and external intercostal muscles (Figure 2-4). This contraction increases the dimensions of the chest cavity, resulting in an overall increase in lung volume and a drop in lung pressure below ambient pressure. As the pressure in the lungs decreases and the volume increases, the Law of Gaseous Diffusion demands air rushes in, filling the lungs.

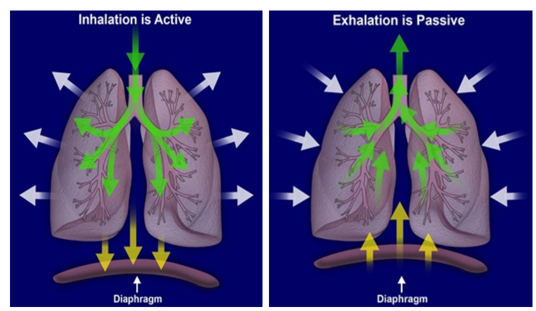

Figure 2-4 — Inhalation-Exhalation

During routine exhalation, as the diaphragm relaxes, the lungs return to their original position. Lung volume decreases and internal lung pressure increases. Once again, a momentary pressure differential exists between the lungs and ambient air. However, the greater pressure now exists within the lungs, and air moves from the lungs to the environment.

Muscular effort is not required during exhalation. Therefore, *exhalation* is referred to as the *passive* component of respiration. Continuous positive pressure breathing tends to reverse the normal breathing pattern with inspiration becoming passive and expiration becoming active.

Mechanics of Alveolar Diffusion — As the blood passes through the capillaries next to the alveoli the gases exchange through the thin layer of cellular walls. This process would continue until the partial pressures of O_2 and CO_2 came to equilibrium. In the example provided (Figure 2-5), as the blood enters the capillary the $PaCO_2$ is high at 45 mmHg and PaO_2 is low at 40 mmHg. The CO_2 moves into the alveoli and the O_2 moves into the blood as the two gases approach equilibrium. The alveolar partial pressure of oxygen ($PAO_{2)}$ will equal around 103 mmHg and the alveolar partial pressure of carbon dioxide ($PACO_{2)}$ will equal around 40 mmHg. Although this is a hypothetical figure, the principle of reaching equilibrium if diffusion were completed is shown. In the lung, equilibrium is likely not achieved due to the continuation of respiration.

CONTENTS
PREVIOUS

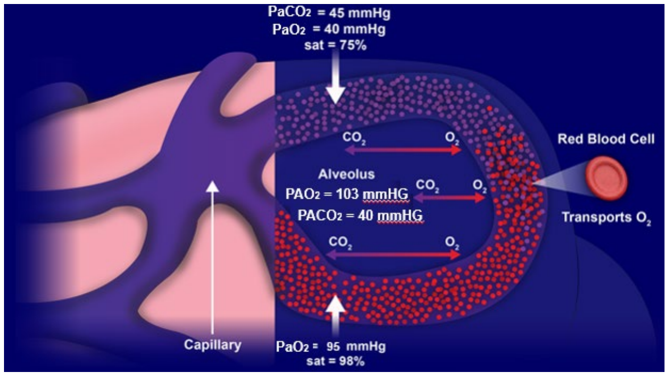

Figure 2-5 — Alveolar Diffusion

Circulation (Transportation)

Circulation (Transportation)

The circulatory system (Figure 2-6) transports and distributes nutrients and oxygen to the tissues and removes waste products of metabolism. It also shares in the regulation of body temperature, hormonal communication throughout the body, and the adjustment of oxygen and nutrient supplies during different physiological states. The cardiovascular system that accomplishes these tasks is made up of a pump (heart), a series of distributing and collecting tubes (arteries and veins), and an extensive system of thin vessels that allow the rapid exchange between the tissues and the vascular channels (the capillaries). However, before discussing the function of the part of the circulatory system, it is important to describe the system as a whole.

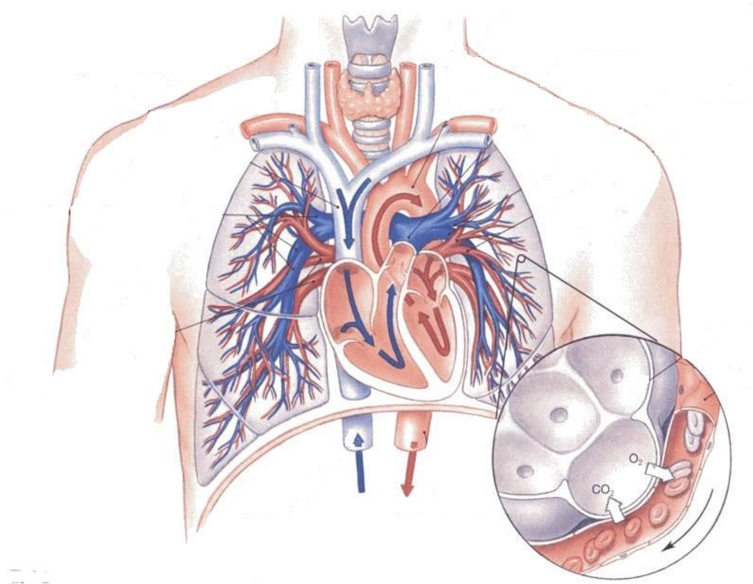

Figure 2-6 — Circulation (Transportation)

CONTENTS
PREVIOUS

Anatomy and Physiology of the Circulatory System

The heart (Figure 2-7) consists of four chambers, but functions as two pumps in series — one to propel blood through the lungs, exchanging O_2 and CO_2 (the pulmonary circulation) and one to drive blood to all other tissues of the body (systemic circulation). Unidirectional flow through the heart is achieved by an arrangement of flap-like valves. Although the blood is pumped by the heart intermittently, continuous flow to the tissues is achieved by expansion and recoil of the arteries.

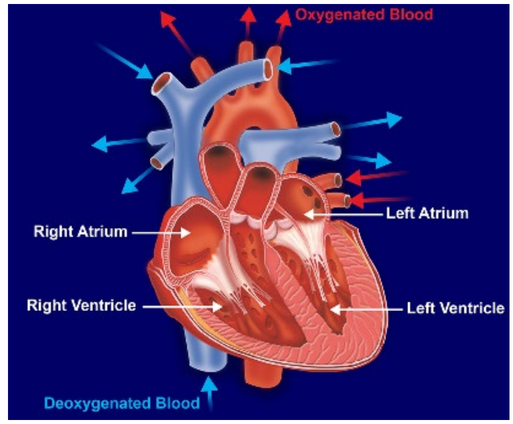

Figure 2-7 — The Heart

Vasculature

Blood flows from the larger arterial vessels into progressively smaller arteries and finally into the arterioles. Since the size of the arterioles can be altered, tissue blood flow and arterial blood pressure may be regulated. Even smaller vessels, the capillaries, branch out from a single arteriole so that the cross-sectional area of the capillary bed is very large. As a result, blood flow becomes quite slow. Since the capillaries are normally short, have walls which are only one cell thick, and a slow flow rate, conditions are ideal for diffusion of substances between blood and tissue (Figure 2-8).

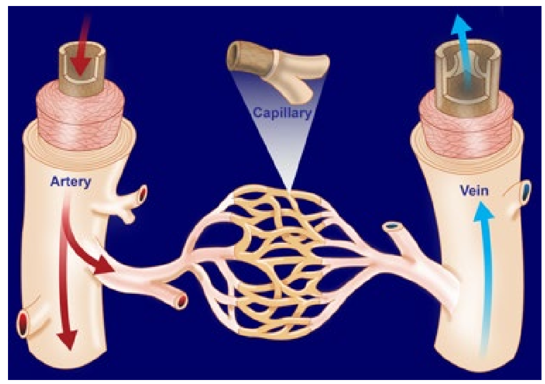

Figure 2-8 — Vasculature

On its return to the heart from the capillaries, blood passes through a series of progressively larger veins. However, as the heart is approached, the number of veins decreases, progressively reducing the cross-sectional area of the venous channels, which consequently increases the velocity of blood flow. Blood entering the right ventricle via the right atrium is then pumped through the pulmonary arterial system at a reduced pressure. The blood then passes through the pulmonary capillaries in the lungs where CO2 is released and O2 is taken up. Finally, the oxygen-rich blood returns via the pulmonary veins to the left atrium and ventricle to complete the cycle. Circulation and blood volume remain relatively (i.e. a closed loop system) constant and an increase in the volume of blood in one area must be accompanied by a decrease in another.

Blood circulates through the cardiovascular system in a mixture of cells within a liquid called plasma. The cells of the blood serve multiple functions essential for metabolism and defense of the body. However, in the brief discussion which follows, only O2 and CO2 delivery within blood will be discussed.

In the normal human adult, plasma makes up approximately 55 percent of the blood. The cellular constituents of blood include red blood cells, a variety of white blood cells, and platelets (Figure 2-9).

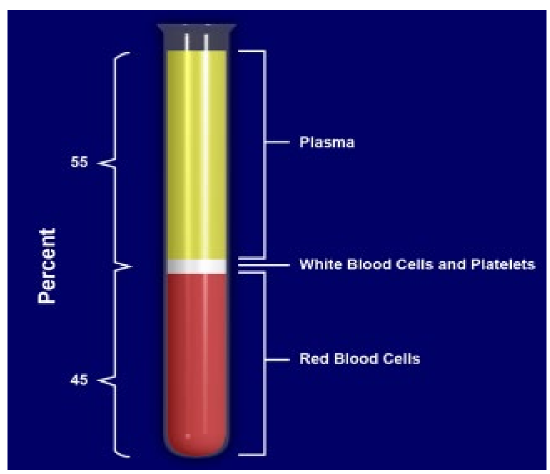

Figure 2-9 — Blood

CONTENTS !!!
PREVIOUS

Red Blood Cells (Figure 2-10) — The primary purpose of the red blood cell (RBC) is to transport O_2 and CO_2. It accomplishes this due to its unique shape. RBCs are small biconcave, circular disks. They function as a transport mechanism for gases in particular oxygen and carbon dioxide. It is the hemoglobin in the RBCs that is responsible for this activity. Each RBC contains up to 300 million hemoglobin molecules. This gives RBCs a substantial oxygen carrying capacity. Although the hemoglobin can carry CO_2, it usually does not. The main function of hemoglobin is to transport oxygen.

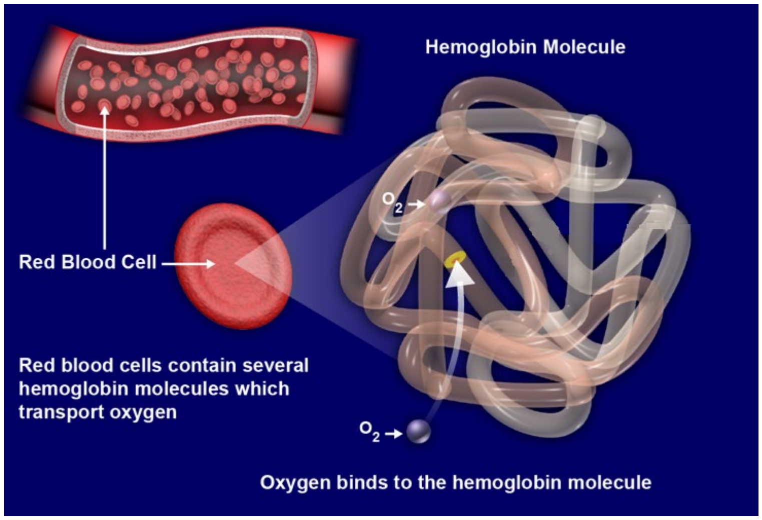

Figure 2-10 — Red Blood Cells

Utilization Phase

Metabolism is the sum of chemical and physical processes which maintain life. Essentially, the body acquires energy input from nutritional sources, and then utilizes metabolic processes to convert the chemical energy to mechanical and thermal energy (Figure 2-11).

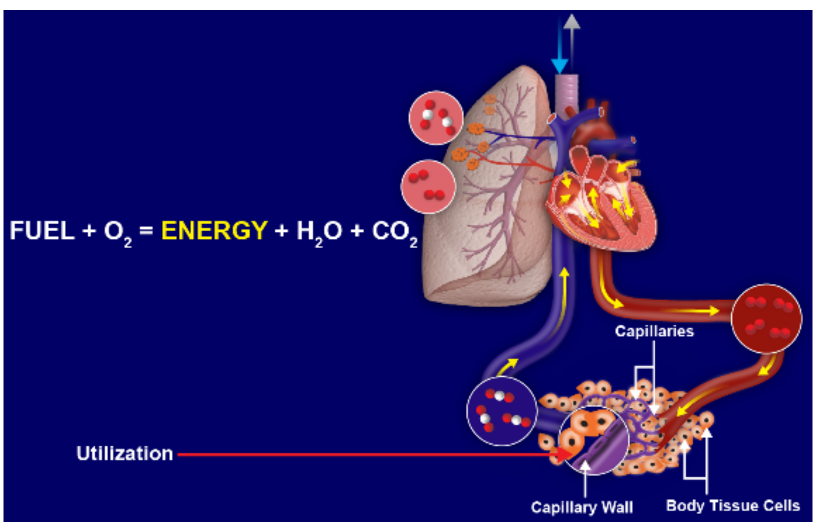

Figure 2-11 — Utilization Phase

Factors Affecting Oxygen Delivery to the Tissues

Several aviation-related factors can affect the delivery of oxygen to the tissues. A lack of oxygen in body tissues that is sufficient to cause an impairment of function is called *hypoxia.*

1. **Altitude** — An increase in altitude will reduce the PO_2 of inspired air causing *hypoxic hypoxia*.

2. **G-forces** — Blood pooling in the lower extremities during increased G maneuvering can cause *stagnant hypoxia*, another factor that can reduce oxygen delivery to tissues.

CONTENTS !!!
PREVIOUS

3. **Toxic gases or substance —** Various types of toxic gases or substances can cause the blood to carry less oxygen (*hypemic hypoxia*) or the tissues to be unable to take up or use oxygen (*histotoxic hypoxia*).

The effect of these factors is cumulative on the body and can and have resulted in aircraft mishaps.

Summary

The respiratory and circulatory systems are the primary means by which we bring oxygen and other vital nutrients to the different parts of the body and remove carbon dioxide and other waste products from the body. Respiration as a whole involves a five phase process with diffusion happening in two phases — ventilation, diffusion, transportation, diffusion, and utilization. Ventilation involves inhalation and exhalation through the oral-nasal cavity and trachea to the lungs. Gas is exchanged at the alveolar level within the lung. Normal ventilation is controlled subconsciously and adapts to changes in PCO_2, PO_2, and pH.

The next phase of respiration, transportation, is accomplished by the circulatory system. The heart serves as the pump moving the blood throughout the body and through the lungs for gas exchange. The blood is made up of plasma and three types of blood cells. Of these blood cells, it is the red blood cells that contain the oxygen-carrying chemical hemoglobin. In aviation, altitude, G forces, and toxic gasses all have the potential to affect the ability of the respiratory and circulatory systems to deliver adequate amounts of oxygen to the tissues. When this lack of oxygen reaches a level whereby it begins to impair function, this is called hypoxia. Hypoxia, as well as the other physiological threats associated with altitude, is discussed in the next lesson.

CONTENTS

PREVIOUS

Review Exercise AP102

Complete the following review exercises by selecting the correct response or filling in the blanks. Answers follow the questions.

1. The purpose of respiration is to get __________ into the body and remove excess __________.

2. What is/are the site(s) of gas exchange in the lung between the atmosphere and the blood?

   a. Trachea

   b. Bronchi

   c. Alveoli

   d. All the above

3. What is the normal breathing rate of an average adult?

   a. 8 – 10 breaths per minute

   b. 10 – 12 breaths per minute

   c. 12 – 16 breaths per minute

   d. 20 – 22 breaths per minute

4. What is the most important factor in the control of ventilation under normal conditions?

   a. PCO_2

   b. PO_2

   c. Red blood cells

   d. White blood cells

5. What is the main function of red blood cells?

   a. Fight infections

   b. Carry oxygen

   c. Transport nutrients

   d. All of the above

CONTENTS
PREVIOUS

Answers to Review Exercise AP102

1. oxygen; carbon dioxide
2. c
3. c
4. a
5. b

AP103 — Altitude Threats

Hours and Medium

2.0 Hours (IBT)

Objectives

1. Know the characteristics of hypoxia. (All Types)

   Samples of Behavior:

   a. Recall the definition of hypoxia.
   b. Recognize the potential characteristics of the onset of hypoxia.
   c. Recall the types of hypoxia and associated causes.
   d. Identify the types of hypoxia with its symptoms.
   e. Identify factors that influence hypoxia.

2. Know how to both recognize and prevent hypoxic hypoxia.

   Samples of Behavior:

   a. Recognize the importance of immediately correcting for hypoxic hypoxia after a rapid decompression.
   b. Identify the signs and symptoms of hypoxic hypoxia onset.
   c. Memorize the procedures to treat hypoxic hypoxia.

3. Know the characteristics of hypocapnia.

   Samples of Behavior:

   a. Recall the definition and causes of hypocapnia.
   b. Recall the signs and symptoms of hypocapnia.
   c. Memorize the procedures to treat hypocapnia.
   d. Recall the similarities of treatment for hypocapnia, hypoxia, and other physiological symptoms.

4. Know the characteristics of trapped gas disorders

   Samples of Behavior:

   a. Identify the basic cause of trapped gas disorders.
   b. Identify the areas of the body most likely to be affected by trapped gases and when it is most likely to occur.
   c. Identify the various trapped gas disorders.
   d. Recall symptoms of trapped gas disorders.
   e. Memorize how to treat and prevent trapped gas disorders.

5. Know the characteristics of decompression sickness.

   Samples of Behavior:

   a. Identify the common types and causes of decompression sickness.
   b. Identify the symptoms associated with each type of decompression sickness
   c. Recall the corrective actions for suspected decompression sickness.
   d. Identify the impact various factors have on DCS incidence and severity.
   e. Recall risks concerning flying and SCUBA diving.
   f. List methods used to treat decompression sickness.

Assignment

Read AP103 in the SG and answer the review questions.

Introduction

We have examined the atmosphere and how the respiratory and circulatory systems work together to support life. Now, we need to address how the changes in atmospheric pressure will affect your body during flight. The following topics will cover hypoxia, hyperventilation, trapped gas problems, and decompression sickness, which are all distresses a person can experience with increased altitude the associated pressure changes. We will also discuss how cabin pressurization will help prevent most of these hazards.

Information

Hypoxia

Hypoxia is an oxygen (O_2) deficiency sufficient to cause impairment of function. It occurs most frequently when protection against the fall in O_2 partial pressure at altitude fails. The insidious onset is hypoxia's most dangerous characteristic. Hypoxia symptoms do not normally cause discomfort. In fact, many individuals perceive their symptoms as quite pleasant. During a slow decompression (where the cabin altitude gradually increases), hypoxia has a slow onset and the symptoms may be well developed before you recognize them. In some cases, you may not recognize hypoxia and become impaired to the point of no longer being able to recover on your own. Hypoxia can occur at any altitude and at any time. There are four types of hypoxia: *hypoxic hypoxia*, *hypemic hypoxia*, *stagnant hypoxia*, and *histotoxic hypoxia*. In the following paragraphs, each form of hypoxia is defined and discussed in relation to its impact on oxygen delivery and utilization.

Hypoxic Hypoxia

Hypoxic hypoxia results when there is a reduction of the PO_2 in the lungs. Hypoxic hypoxia is usually caused by exposure to low barometric pressure and is frequently referred to as *altitude hypoxia*. This reduced oxygen partial pressure can result from oxygen equipment malfunctions, improper use of oxygen equipment, and loss of cabin pressurization at altitude.

The altitude threshold for hypoxic hypoxia is generally considered 10,000 feet MSL.

Factors Influencing Hypoxic Hypoxia

There are several factors that influence the development of hypoxic hypoxia. The altitude of the cabin is a factor. The cabin altitude of the aircraft can determine how quickly hypoxia is experienced. The time spent at altitude also has a direct correlation to the effects of hypoxia. The effects of an exposure become more detrimental as exposure time increases at a higher altitude. At lower levels (around 10,000 feet) you might not notice your symptoms for quite some time. It could take hours and your symptoms would come on slowly. Because of the low PO_2 above 10,000 feet MSL, the USAF requires supplemental oxygen for flight above a cabin altitude of 10,000 feet.

The rate of pressure change could also be a factor. Rapid decompression may reduce alveolar pressure below that of arterial blood, thereby reversing the direction of O_2 diffusion so that the blood is actually giving up O_2 through the lungs.

There are variations in a person's tolerance to hypoxia due to an individual's personal physiology. The reasons are not completely understood but an individual's metabolic rate and acclimatization to altitude are important factors. Physical activity during the flight can be a factor. Metabolic oxygen requirements are increased several times during exercise. The physical activity factor is most significant if you are required to be active while performing crew duties. For example, flying a contact mission and pulling Gz is more strenuous than flying a high altitude navigation mission. Lastly, a person's life-style affects all facets of your flying environment, including tolerance to hypoxia. Often, crewmembers impose unnecessary stresses upon themselves through tobacco use, poor sleep patterns, excessive alcohol consumption, improper diet, etc. Self-imposed stress and its overall impact on the crewmember will be discussed in detail in a subsequent lesson.

Recognition of Hypoxic Hypoxia

One of the reasons you attend Aerospace Physiology training is to witness other crewmembers' signs and to experience your own hypoxic hypoxia symptoms in a controlled environment. This experience enables you to identify signs of hypoxia in fellow crewmembers and experience your own individual symptoms. The warning signals most important to you are those you actually feel or sense. They are emphasized to help you recognize hypoxia during flight.

According to the *Handbook or Aerospace and Operational Physiology* (2016), common signs of hypoxia can often be recognized by another individual. These include cyanosis (blue lips/fingernails), degraded reaction time, euphoria (feeling/state of intense excitement and happiness), belligerence, impaired judgment, increased respiration (increased

CONTENTS
PREVIOUS

rate and depth of breathing), mental confusion, muscle incoordination, unconsciousness, or dysphoria (state of unease or generalized dissatisfaction).

Symptoms are the warning signals most important to the crewmember. These are the symptoms only *you* can actually sense and identify. Symptoms are emphasized as a means for crewmembers to recognize their own hypoxia indicators during flight. Hypoxia symptoms are very individualized and can include *air hunger* (oxygen want), *apprehension, dizziness, fatigue, headache, hot/cold flashes*, or *lightheadedness* (dizzy sensation). Other symptoms may also include *nausea, numbness, tingling in extremities, tunnel vision, visual impairment, euphoria, and dysphoria.* The altitude chamber hypoxia demonstrations allow you to experience your own personal symptoms so you may identify hypoxia should it happen to you in the aircraft.

Because hypoxic hypoxia does not usually cause physical pain or discomfort, it can be difficult to detect. Ultimately, it can creep up on you before you realize that something is wrong. This difficulty can be exacerbated when mentally focused on completing a task. Without running a consistent mental checklist of the human system, threats such as hypoxia are more likely to have greater negative repercussions.

Time of Useful Consciousness (TUC) is the period of time from the interruption of the oxygen supply or exposure to an oxygen poor environment, to the time when useful function is lost (Reinhart, 2008) (Figure 3-1). You are no longer capable of taking proper corrective and protective action, but are still conscious. It is ***not*** the time to total unconsciousness.

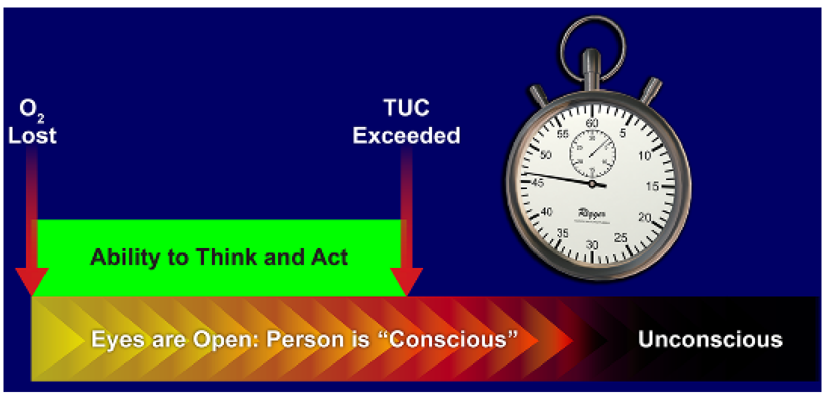

Figure 3-1 — Time of Useful Consciousness

Common factors that affect TUC are:

Acclimatization

Altitude

Rate of ascent

Duration at altitude

Exertion at altitude

Environmental temperature

Individual tolerance

Physical fitness

Self-imposed stresses (alcohol, fatigue, etc.)

Medication and drugs

At higher altitudes, the TUC becomes very short. Figure 3-2 shows mean TUC for resting individuals at various altitudes. Exercise or stress will reduce these times. Additionally, a rapid decompression can reduce TUC up to 50 percent (DeHart, 1996). For example, at FL350, the mean TUC is approximately 30 to 60 seconds. After a rapid decompression, the mean TUC would only be 15 to 30 seconds.

CONTENTS
PREVIOUS

Altitude	TUC*
FL 430 & Up	9 – 12 Seconds
FL 400	15 – 20 Seconds
FL 350	30 – 60 Seconds
FL 300	1 – 2 Minutes
FL 280	2 – 3 Minutes
FL 250	3 – 5 Minutes
FL 180	20 – 30 Minutes

***Rapid decompression can reduce TUC up to 50%**

Figure 3-2 — Times of Useful Consciousness

Precautionary Actions for Hypoxic Hypoxia

Cabin pressurization is the most common means of preventing hypoxia, which will be discussed in the next block, Cabin Pressurization. To be proactive in case you experience hypoxia, you will need to know how to use YOUR oxygen equipment, preflight your oxygen equipment, and ***know your symptoms***!

Treatment of Hypoxic Hypoxia

First step in treatment of hypoxia is verifying your oxygen equipment works prior to take off. You are responsible for your own oxygen equipment. ***You*** must ensure your equipment is working correctly prior to take off. Always preflight your helmet and oxygen mask at the life support shop to ensure correct function. If problems are detected, they can be corrected prior to reaching the aircraft. Once in the aircraft, thoroughly preflight your oxygen regulators and systems prior to takeoff. After the aircraft is airborne, additional checks are required to ensure the aircraft oxygen and pressurization systems are functioning correctly. ***Please reference your Dash 1***.

Immediate corrective actions must be taken when hypoxia symptoms are recognized or when a decompression occurs. 100 percent oxygen must be administered through an oxygen mask. The type of mask and delivery system used depends on the aircraft flown, your crew position, and your immediate location in the aircraft during the emergency. Specific corrective actions are listed in each aircraft's flight manual. The following procedures are generalized to include corrective actions for all the aircraft used in joint undergraduate flying training.

1. Maximum Oxygen Under Pressure —Your first priority when correcting for physiological symptoms is to obtain oxygen. When using narrow panel pressure demand-type regulators, like those found in the T-6 and the altitude chamber, this is accomplished by placing all three switches in the full-up position (Figure 3-3), which should resolve conditions within a few breaths. This is known as "Gangloading" the regulator. For speed, the procedure should be accomplished with a single sweep of the hand. "Gangloading" the regulator will place it in the On, 100 percent/Max oxygen, emergency pressure setting.

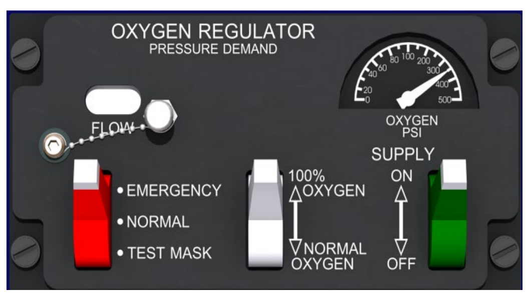

Figure 3-3 — Gangload Position in Chamber

Note — If you suspect a problem with your aircraft oxygen supply or regulator, you may need to activate an alternate oxygen system (such as an emergency oxygen cylinder located in a parachute or seat kit in a single/dual-seat aircraft and the yellow walk around bottle or protective breathing equipment located in multi-place aircraft).

2. Connections - Check Security — Equipment function, connections and oxygen system pressures must be quickly evaluated when hypoxia symptoms are recognized or suspected. Equipment preflight and frequent in-flight monitoring will reduce the occurrence of hypoxia.

Note — Immediately after completing the first two steps of your emergency procedures, communicate with fellow crewmembers.

3. Breathe at a Rate and Depth Slightly Less Than Normal Until Symptoms Disappear — Recovery from hypoxia usually occurs in a few seconds following the administration of 100 percent oxygen. However, if the cause of hypoxia is

CONTENTS
PREVIOUS

smoke, fumes, or chemicals, the recovery period may be considerably longer. For this reason it is imperative to continue breathing 100 percent oxygen. Your respiratory rate may increase because of anxiety from the incident. If your respiratory rate is not controlled, hyperventilation may result, causing hypocapnia. Respiration monitoring should be accomplished simultaneously with the initial corrective steps. Monitor and control your rate and depth of breathing to prevent hyperventilation during recovery from hypoxia. If your symptoms have been caused by hyperventilation rather than hypoxia, monitoring your rate and depth of breathing should eliminate them.

4. Descend Below 10,000 Feet and Land as Soon as Practical — If your symptoms persist after completing the initial corrective steps, descend below 10,000 feet MSL. Descending will not counteract hyperventilation and you must continue to monitor your rate and depth of breathing.

Pressure Breathing

Pressure Breathing delivers oxygen, under pressure, through the crewmember's oxygen mask. It is a method of maintaining adequate PO_2 in the lungs at cabin altitudes above 40,000 feet (Figure 3-4).

The aircraft oxygen system provides an increased fraction of oxygen as cabin altitude is increased above 1,000 feet. Breathing 100 percent oxygen at FL340 is equivalent to breathing ambient air at sea level. Above FL400 (cabin altitude), breathing 100 percent oxygen alone is not adequate to prevent hypoxia and positive pressure breathing is needed.

Altitude	Total Pressure	Lung PAO_2	% Blood Saturation	
FL 500	87	60	87	Pressure Breathing 100% O_2
FL 430	122	60	87	
FL 400	141	60	87	Breathing 100% O_2
FL 340	187	103	98	
10,000 ft	523	60	87	Breathing Air
Sea Level	760	103	98	

Figure 3-4 — Maintaining PO2 with pressure breathing

Pressure breathing has limitations. It reverses the normal breathing cycles; inspiration becomes passive and expiration now requires active effort. Over-inflation of the lungs from pressure breathing inhibits exhalation and reduces venous return to the heart. This reduction in venous return may result in stagnant hypoxia and is the most limiting factor of pressure breathing.

Note — Hyperventilation/hypocapnia may occur during pressure breathing if you do not control your rate and depth of breathing. Pausing between breathing phases will help prevent hyperventilation and can be learned with practice in the altitude chamber. Familiarize yourself with the process to minimize or eliminate problems when treating for hypoxia symptoms or following a loss of cabin pressurization.

Oxygen Paradox

In addition to pressure breathing, another potential result of gangloading is the human body's response to the sudden influx of 100% oxygen. The result of this is a condition known as oxygen paradox. Although providing oxygen to an extremely hypoxic individual is essential for recovery, symptoms may, at first, seem to get worse, with the individual feeling dizzy and nauseated, and even trying to remove an oxygen mask. In severe cases, breathing may cease entirely for many seconds after a deep breath of oxygen.

These are symptoms of oxygen paradox and usually pass quickly. The cause of oxygen paradox is believed to be hypocapnia resulting from hyperventilation during hypoxia. As a result, plasma carbon dioxide is insufficient to drive the respiratory reflex. During hypoxia, oxygen drives respiration. The first breath of oxygen eliminates this drive, and many seconds pass before carbon dioxide builds up enough to again drive respiration. Oxygen administration also affects capillary flow control and causes transient reductions in blood pressure, leading to dizziness and nausea. Once again, these symptoms last until cardiovascular effects have passed and CO_2 returns to normal

Hypemic Hypoxia

Hypemic Hypoxia is when the O_2 carrying capacity of the blood is reduced. This type of hypoxia affects O_2 delivery by reducing the functional hemoglobin available for transporting O_2. Certain drugs and chemicals can combine with or alter

CONTENTS !!!
PREVIOUS

the characteristics of hemoglobin and reduce its O_2 carrying capacity. For example, hemoglobin has an affinity for carbon monoxide (CO) about 200 – 250 times greater than O_2.

The threat of inhaling carbon monoxide from smoke or fumes in the cockpit can be mitigated by using 100 percent oxygen. Smoking cigarettes prior to flight increases the amount of CO in the bloodstream and raises your physiological altitude. Then you become more susceptible to hypoxic hypoxia because of the preexisting hypemic hypoxia. Blood donation and bleeding injuries also deplete the RBC/hemoglobin supply and cause hypemic hypoxia.

Stagnant Hypoxia

Stagnant hypoxia occurs when reduction in cardiac output, pooling of the blood, or restriction of blood flow reduces O_2 delivery (Figure 3-5). Several conditions cause stagnant hypoxia. Two of these will be discussed in detail during subsequent instruction — hyperventilation and acceleration (G forces). Stagnant hypoxia can also be caused by shock (blood pooling in dilated blood vessels) or cold temperatures (constricting the blood vessels of the extremities, causing pooling of blood in the body core). Even sitting very still for long periods of time can result in stagnant hypoxia. An individual passing out while standing in formation is an example of stagnant hypoxia.

Figure 3-5 — Reduced Blood Flow

Histotoxic Hypoxia

Histotoxic hypoxia results when the O_2 delivered to the cells cannot be used for energy production. Adequate O_2 is available to the lungs and the blood is capable of carrying it to the tissues. However, the tissues and cells are unable to use the available O_2.

The primary cause of histotoxic hypoxia in a crewmember is cyanide. Cyanide, in the form of hydrogen cyanide gas (HCN), is a byproduct of the combustion of plastics, insulation, seat covers, and other synthetic substances found on aircraft. HCN is highly toxic and extremely small concentrations (300 parts per million) cause incapacitation within seconds; death occurs within minutes. Therefore, you must not hesitate in donning oxygen equipment and breathing 100 percent oxygen. If you suspect contamination of the primary O_2 system, activate the emergency O_2 system. Remember: Symptoms may be slow to go away. Follow procedures outlined in flight manuals / checklists.

There are components of hydraulic fluids, oils, and jet fuels which can be distributed within the cockpit in mist form. These fumes can impose inhalation and eye irritation problems. Additionally, excessive temperatures in electrical equipment may cause thermal breakdown of the equipment which could cause hazardous fumes.

Secondary causes of histotoxic hypoxia are alcohol and some medications. To reduce the possibility of mishaps, AFMAN 11-202, Volume 3, *Flight Operations*, restricts alcohol consumption 12 hours prior to flight. USAF instructions restrict medication unless prescribed by a flight surgeon.

Hypocapnia

Hyperventilation is a condition in which the rate and depth of breathing is abnormally increased. This increase causes an excessive loss of carbon dioxide (CO_2) from the blood which is called hypocapnia.

Hypocapnia at Altitude

Lung and blood O_2 partial pressure is reduced below minimum acceptable levels with hypoxia onset above 10,000 feet. Decreased O_2 levels stimulate the respiratory center via chemoreceptors in the aorta and carotid arteries. This stimulation causes increased breathing in an attempt to make up for O_2 deficiency. Hypocapnia, or the state of reduced carbon dioxide in the blood, occurs if the resulting hyperventilation is permitted to continue, creating a constriction of blood vessels

CONTENTS !!!
PREVIOUS

leading to the brain. This vasoconstriction reduces circulation within the brain and decreased O_2 causes stagnant hypoxia in brain tissues. Unconsciousness may result from the cumulative effects of hypoxic and stagnant hypoxia of brain tissues.

Pausing between breathing phases will help prevent hyperventilation and can be learned with practice in the altitude chamber. Familiarize yourself with the process to minimize or eliminate problems when treating for hypoxia symptoms or following a loss of cabin pressurization.

Pressure Breathing and Hypocapnia

Active inhalations and passive exhalations characterize normal breathing cycles. As previously mentioned, pressure breathing from an O_2 regulator actually reverses the breathing cycle; inspiration becomes passive and expiration now requires active effort. Over-inflation of the lungs from pressure breathing inhibits exhalation and reduces venous return to the heart. This reduction in venous return may result in stagnant hypoxia and is the most limiting factor of pressure breathing.

Additionally, this reversed breathing cycle can cause hyperventilation. You can prevent hyperventilation by controlling the rate and depth of breathing while pressure breathing. It is important to be prepared for the possibility of being uncomfortable and the unfamiliar sensation of breathing under positive pressure. To counteract the positive pressure from the regulator, you should allow the air to fill your lungs, pause, and then forcefully exhale against the pressure.

Emotional Causes

Fear, anxiety, stress, or tension, resulting from emotional or physical discomfort sometimes causes the normal control of breathing to be overridden. These factors are the most frequent causes of hyperventilation. Pay particular attention to possible increased rates of breathing during initial flying sorties or whenever new flying techniques are encountered or stressful situations are experienced. Changes in breathing can occur very insidiously.

While hypocapnia occurs more frequently with inexperienced crewmembers, it will remain a potential hazard throughout your flying career. Always be aware of the possibility of hypocapnia.

Recognition and Prevention of Hypocapnia

Signs most often observed in hypocapnia are increased rate of breathing, muscle tightness and twitching, paleness, cold clammy skin, muscle spasms, rigidity and unconsciousness. Symptoms most often noted are dizziness, faintness, slight nausea, numbness, tingling or coolness and muscle tremors. The most effective way to prevent hypocapnia is to control your rate and depth of breathing. Continually monitor your rate and depth of breathing, especially during stressful situations.

Treatment of Hypocapnia

Many symptoms we experience are so similar that it is hard to determine the cause. As seen in Figure 3-6, hypoxia, toxic exposure, hypoglycemia, dehydration, hypocapnia, and hypercapnia, all have very similar symptoms. The most dangerous of the conditions is hypoxia whose conditions can be so similar to hypocapnia and the other conditions that they may be hard to distinguish.

Causes of Symptoms

Symptoms:	Hypoxia	Toxic Exposure	Hypoglycemia	Dehydration	Hypocapnia	Hypercapnia
Dizziness	X	X	X	X	X	X
Cognitive Impairment	X	X	X	X	X	X
Tingling/Cold Extremities	X	X	X	X	X	X
Fatigue	X	X	X	X	X	X
Headache	X	X	X	X	X	X
Light Headedness	X	X	X	X	X	
Nausea	X	X	X	X		X
Vision Hazy/Blurry/Fuzzy, Visual Disturbance	X	X	X		X	X
Rolling/Tumbling Sensation	X					

Figure 3-6 — Causes of Physiological Symptoms

Not only are hypoxia and hypocapnia hard to distinguish, there are many other physiologic symptoms that make it hard to determine their causes as well. This can confuse diagnosis and potentially delay treatment. In an emergency or

CONTENTS
PREVIOUS

uncertain environment (e.g. in flight), time should not be wasted attempting to distinguish causes of symptoms. Therefore, all physiological symptoms are treated the same.

Treat All Physiological Symptoms the Same

Since physiological symptoms (e.g., hypocapnia, hypoxia) may be confused or occur at the same time, immediate corrective actions are required and will resolve any of them. As corrective procedures are being implemented, remember **symptoms may be slow to resolve**.

At the most elementary level, the treatment of hypoxia involves providing oxygen. Following the appropriate MDS BOLDFACE procedures *should* provide oxygen and restore normal breathing rate and depth, thus treating all physiological symptoms simultaneously and without delay.

T-6 Recovery Procedures for Physiological Symptoms (Boldface)

1. **Green Ring – Pull (AS REQUIRED)** (Figure 3-7)

Note — 100 percent/max oxygen does not compensate for decreased blood-carbon dioxide saturation caused by hypocapnia but serves to ensure that hypoxic hypoxia is not mistaken for hypocapnia.

2. **Descent below 10,000 feet MSL – INITIATE**
3. **OBOGS SUPPLY LEVER - OFF**
4. Emergency O_2 hose – Check (Both)
5. Rate and depth of breathing – Normalize (Both)

Breathe at a Rate and Depth Slightly Less Than Normal Until Symptoms Disappear — Respiratory monitoring should be accomplished simultaneously with the initial three corrective steps. If the symptoms you have recognized have been stimulated by hypocapnia, respiratory monitoring should eliminate them.

6. OBOGS – Off (Both)
7. Pressurization switch – RAM/DUMP
8. Bleed Air Inflow switch – Off
9. Oxygen mask – Remove

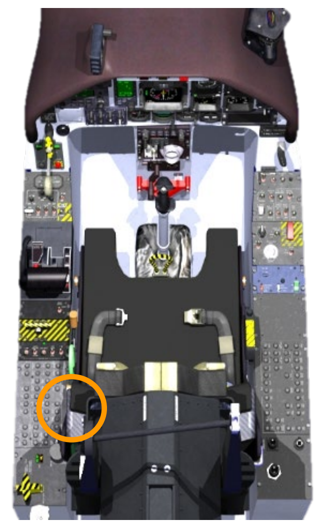

Figure 3-7 — Emergency O_2 Handle "Green Ring"

WARNING

Oxygen mask must be on and secure before actuating CFS or initiating ejection

10. **Land as soon as practical**

WARNING

If symptoms persist and the pilot(s) feel unsafe to land, maintain below 10,000 feet MSL as long as practical before considering ejection.

Trapped Gas Disorders

Boyle's Law states the volume of a gas is *inversely* proportional to the ambient pressure. Therefore, changes in ambient pressure during flight will result in changes in the volume of body gases, in other words, expansion of gases during ascent and contraction of gases during descent.

The human body can withstand these changes, including expanding gas pressure buildup, when the pressure can be relieved. However, when the pressure cannot be relieved or the expanding gas cannot escape; then the gas is considered "trapped." With further decrease of ambient pressure (ascent), a greater increase in volume or pressure within the cavity

CONTENTS !!!

PREVIOUS

occurs. These increases sometimes result in pain. Figure 3-8 shows the areas most often affected by the change in pressure: *middle ear*, *sinuses*, *GI tract*, and *teeth*.

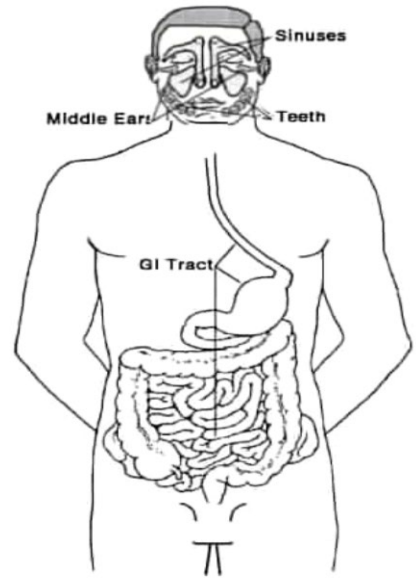

Figure 3-8 — Areas of Trapped Gas

Middle Ear Trapped Gas

To understand why the pressure builds in the middle ear and how to resolve it appropriately, we need to discuss the anatomy of the middle ear. The middle ear cavity is connected to the throat by the Eustachian tube (Figure 3-9). The Eustachian tube has a slit-like opening at the throat end, allowing middle ear air pressures to vent outwardly more easily than inwardly. During ascent, excess pressure in the middle ear caused by gas expansion will escape through the unobstructed Eustachian tube with little or no effort. The released pressure is often accompanied by a physical "click" in the ears. During descent, however, the opening of the Eustachian tube acts as a one-way flapper valve and resists equalization of ambient and middle ear air pressures. The increased ambient pressure forces the eardrum inward and you must assist the equalization process.

Equalizing air pressure in the ear during descent may be accomplished by swallowing, yawning, tensing the muscles in the throat, moving the head from side to side, extending the jaw forward, or rocking the jaw from side to side. However, the most effective way to equalize the pressure in the middle ear is the use of the *Valsalva maneuver*. The Valsalva maneuver will force air into the middle ear by closing the mouth tight enough to not let air pass into the mouth, pinching the nose closed and forcefully exhaling. This method forces air through the previously closed Eustachian tube and equalizes the pressure differential between the middle ear and the atmosphere. Practice in clearing the ears can improve and sustain the rate of descent without discomfort. Some crewmembers find they must use the Valsalva maneuver frequently during descent without waiting for a sensation of discomfort. Others use the Valsalva maneuver as soon as they recognize fullness, ringing of the ears, decreased ability to hear or pain. With experience you will develop your own technique, but it is best to not wait until you feel pain before you accomplish the Valsalva maneuver.

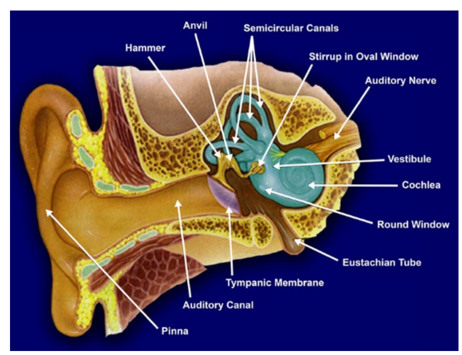

Figure 3-9 — Anatomy of the Ear

Problems with the ears occur more often at altitudes closer to the earth's surface where there are greater pressure changes. If the pressure differential of the atmosphere over the middle ear exceeds 80 mmHg, it may be impossible to open the Eustachian tube with equalization pressure methods. This condition is known as an *ear block* (barotitis media). An ear block may be defined as an acute or chronic traumatic inflammation of the middle ear produced by a pressure differential (either positive or negative) between the air in the tympanic cavity and contiguous air spaces and that of the surrounding atmosphere. If descent is continued, increasing pain and eardrum rupture will result. Prior to eardrum rupture, relief from pain can best be obtained by ascending to an altitude where pressure equalization methods can be used; a slow descent is then recommended. If an eardrum is ruptured, most pain will cease and healing normally occurs in 3 to 5 weeks. This condition should always be reported to your flight surgeon.

An ear block is characterized by congestion, inflammation, discomfort, pain, and is usually followed by a temporary impairment of hearing. The Eustachian tube opening is restricted by inflammation or infection from a head cold, allergy, sore throat, infection of the middle ear, sinusitis, or tonsillitis. Forceful opening of the tube under these conditions may introduce infection into the middle ear and cause severe ear problems. In addition, infection can cause difficulty in clearing the ears resulting in sudden pressure changes. These pressure changes in the middle ear can affect the vestibular system of the inner ear, causing dizziness or disruption of equilibrium referred to as pressure vertigo. If you are suffering from upper respiratory infections, apparent allergic reactions or any congestion, **you should not fly or participate in an altitude chamber flight**. Consult a flight surgeon.

A *delayed ear block* (post-flight ear block) can occur up to 2 to 6 hours after landing. It results from breathing high percent oxygen for an extended period of time. As oxygen diffuses out of the middle ear into the surrounding tissues, a relative low pressure area results. The low pressure area allows the now greater ambient pressure on the exterior surface of the ear drum to deflect the ear drum inward, dulling the hearing and producing pain. Performing the Valsalva maneuver several times after flight can prevent a delayed ear block.

CONTENTS !!!
PREVIOUS

Sinuses

Sinuses are another area where pressure can get "trapped." The sinuses are cavities housed within the bones of the skull and are lined with moist mucous membranes (Figure 3-10). Sinuses vent to the atmosphere through tiny slit-like openings into the nasal cavity. Under normal circumstances, the pressure is equal to the outside barometric pressure. The sinuses most frequently affected by pressure changes are the frontal sinuses, located above and behind each eye, and the maxillary sinuses, located in the bones of the cheeks beneath the eyes.

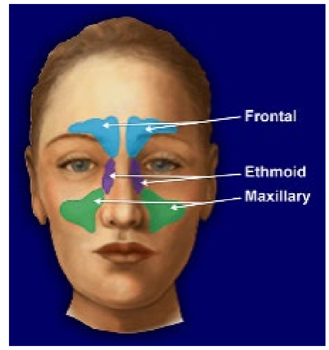

Figure 3-10 — Common Sinus Cavities Vulnerable to Trapped Gas

When pressure changes occur during ascent or descent, the gases in the sinuses increase or decrease in volume. Normally, sinuses vent with no discomfort. However, if the sinus ducts are swollen because of an upper respiratory infection, there may be a blockage of the ducts. This condition is called a *sinus block*. On ascent, blockage at the opening of the duct may prevent the expanding gas from venting to the outside, and localized pain will occur. However, blockage occurs more often on descent when the pressure difference across the duct is increased without relief. To prevent pain during descent, pressure must be equalized as rapidly as possible to relieve the differential and discomfort. The degree of pain will naturally depend on the pressure across the duct. The onset of sinus pain due to barometric pressure change is rapid. The Valsalva maneuver will usually alleviate the problem. If necessary, relief from pain can be obtained by ascending to an altitude where pressure equalization can be accomplished.

Blockage of the ducts leading to the maxillary sinuses may be mistaken for upper tooth pain because of their proximity to the upper teeth. All of the upper teeth will be affected as opposed to one isolated tooth and may be treated like any other sinus block. If isolated tooth problems continue on ascent, discomfort can be resolved by descent and landing. The flight surgeon and dentist should be consulted after the flight.

Gastrointestinal (GI) Tract

A problem that may be experienced with a decrease in atmospheric pressure is discomfort from expansion of gases in the GI tract. This problem is not usually serious at low altitudes. However, at the higher altitudes, enough expansion may occur to produce pain. Extreme discomfort may result unless the pressure is relieved by belching and or passing flatus. Sometimes relief is only gained by descent.

Crewmembers participating regularly in unpressurized high altitude flights should learn to avoid foods they know disagree with them. These foods may include onions, cabbage, raw apples, radishes, dried beans, cucumbers, melons, and carbonated beverages. Eating irregularly or hastily also makes a crewmember more susceptible to gas pains. To reduce your chances of GI tract problems before flights, avoid hasty, irregular, and heavy meals, especially foods and beverages you know produce excess gas.

Teeth

Tooth pain, or barodontalgia, is also a case of a trapped gas exerting positive or negative pressure on surrounding tissue. Rarely, a bubble can be seen on x-ray in the vicinity of an affected tooth, but more often there is no obvious source of pressure. It is believed that microbubbles trapped in small fractures or under a recent filling may be enough to exert pressure on the nerve in the tooth pulp. Tooth pain can also be caused by maxillary polyps that block sinus equalization, resulting in sinus block that can exert pressure on a nerve leading to a tooth.

The altitude at which the onset of tooth pain usually occurs varies. Pain in a given tooth often may show remarkable constancy in the altitude at which it first becomes manifest. The pain may or may not become more severe as altitude increases. Descent invariably brings relief, the pain often disappearing at the same altitude at which it was first observed. The incidence of barodontalgia is low, but when it occurs, it is usually quite severe and causes excruciating pain. If problems occur, descend and see a flight surgeon/dentist.

Gas Movement in the Lungs

Lung overinflation due to breath-holding or inadequate equalization of pressure during decompression, can result in serious problems, such as pulmonary embolism (air in arterial circulation), pneumothorax (air in pleural cavity), or pneumomediastinum (air in the mediastinum). In animal studies, intrapulmonary pressure differentials of 80 – 100 mmHg (1.5 – 1.9 psi) occurring in 0.1 – 0.2 seconds has led to alveolar rupture (Barratt & Pool, 2008). Pulmonary overpressure may occur if a rapid decompression happens during breath-holding, swallowing, or yawning. Fortunately, the chances of the glottis being closed, and maintained in such a state, during a rapid decompression is extremely rare (Luft & Bancroft, 1956).

CONTENTS
PREVIOUS

Decompression Sickness

One of the most potentially dangerous effects of exposure to high cabin altitudes is *decompression sickness* (DCS). DCS is the disorder produced by the evolution of gas from tissues and fluids of the body (nitrogen bubble formation).

Henry's Law states the amount of gas in a solution varies directly with the partial pressure of that gas over the solution. When the atmospheric pressure is decreased, the pressure difference between gases dissolved in body fluids and the ambient air may cause dissolved gases to come out of solution in the form of bubbles. This process can occur in the blood, other body fluids, and or body tissues.

Types of DCS and Their Symptoms

The evolution of nitrogen bubbles can manifest many places in the body. The most common places are the body's joints, central nervous system, lungs, and the skin. The joints are the most common place and has the nickname of "*The Bends.*" The evolution of nitrogen bubbles into the joints of the body causes pain. The pain is generally localized in and around the joints of the body. The smaller joints, of the fingers for example, can be involved; however, the larger joints like the shoulders, elbows, knees, and ankles are the usual sites. The pain is variable in nature and may occur suddenly. It is usually a deep, dull, and boring pain. Factors such as exercise, time at altitude, and increased altitude influence the degree of pain. With time, the pain may spread and seem to involve the muscles. Movement of the affected joint tends to increase the discomfort.

Treatment for *joint pain* or "*The Bends*" is to descend below the altitude of occurrence will usually decrease or resolve the pain. Continued descent is required even if the pain completely resolves on initial descent. Ascent to the same altitude will cause the pain to return in the same location. Increasing the total barometric pressure on the body is the only effective means of eliminating bends. Any painful condition at high altitude is potentially dangerous and should be avoided.. *Once bends have developed, breathing 100 percent oxygen while at altitude will not normally resolve the pain. Descent is the only cure and is mandatory for any DCS.*

In rare incidents of high altitude exposure, *the brain and or spinal cord (the central nervous system)* may be affected by nitrogen bubbles. Although rare, it is potentially very dangerous. The most common symptoms are very similar to those of a stroke: disturbances in vision, varying from blind spots in the visual field to flashing and or flickering lights. Other symptoms include severe persistent headache, partial paralysis, loss of speech or hearing, vertigo, distinct sudden personality changes, or loss of orientation. Numbness and tingling of one arm, leg, or side of the body may occur. One explanation for these symptoms theorizes the bubbles of evolved nitrogen circulate through the brain, reducing blood flow and causing localized, small regions of the brain to become hypoxic. These symptoms are attributed to abnormal brain function in the areas of localized hypoxia.

Since these problems affect the brain or spinal cord, they are considered the most dangerous and are known as central nervous system (CNS) manifestations. Circulatory shock, or failure of circulatory control, is a possible effect of neurological involvement. Typical symptoms of circulatory shock or circulatory failure are pale clammy skin, feeble rapid pulse, decreased breathing, and unconsciousness. Blood pressure may fall with severe blood pooling and resultant stagnant hypoxia. *Immediate descent is necessary after any evidence of CNS involvement.*

Rare but potentially very dangerous, the nitrogen can manifest in the lungs often referred to as "*The Chokes*." The symptoms are very similar to those of a heart attack, and may be misdiagnosed if they are presented to a civilian physician. The causes of chokes symptoms are not fully understood. One hypothesis is that bubbles evolve in the smaller blood vessels in the lungs and in the tissue of the trachea (windpipe). The symptoms are deep sharp pain centrally located under the sternum (breast bone), a dry nonproductive cough, and difficulty with inspiration. Increased expansion of the lungs causes the pain to increase and there is a sense of suffocation and apprehension. Symptoms of shock may appear — sweating, pallor, faintness, and cyanosis may be observed. *Immediate descent is necessary* and post flight shock is a possibility. The chokes symptoms may disappear with the descent but there can be some residual soreness in the chest and the crewmember should receive immediate post flight medical attention.

Note — *False chokes* may be experienced by crewmembers who are exposed to prolonged breathing of dry, aviator's oxygen. False chokes are nonhazardous and represent a drying of the mucous membrane linings. Symptoms are a dry nonproductive cough and minor tissue irritation. They are quickly resolved by breathing moist air or by drinking water.

One type of DCS involves peculiar sensations of the skin sometimes called "*Creeps*." In some instances, a mottled, reddish, or purplish rash develops on the skin. The rash may be localized in a small area or may be diffused over the body. A slight swelling of the skin may be noted and a slight increase of temperature may exist. The rash may not disappear with descent and may last for hours. Skin manifestations of DCS may indicate bubbles in and around the skin or possibly bubbles affecting the peripheral nerves of the spinal column. Skin manifestations should be considered a serious type of DCS because of the possibility of CNS involvement.

CONTENTS
PREVIOUS

It is important for you to realize there is no predictable progression of symptoms. It is possible to have several of the symptoms at the same time.

Occasionally, the onset of DCS symptoms may appear after the flight. This condition is known as a *delayed DCS* and may occur within 24 hours. As always, treatment must be initiated and the affected individual referred to the flight surgeon.

Factors Affecting DCS Incidence and Severity

Decompression is not the only controlling factor in the evolution of nitrogen. There are other important factors which help to explain the unpredictably of bubble formation and DCS.

Increasing the altitude contributes to an increased incidence of DCS. Considerable debate surrounds the minimum, or threshold altitude for DCS. Although no precise boundary exists, studies have shown an abrupt increase in altitude DCS (without pre-oxygenation exposure) at about 21,200 feet (MSL).

A faster *rate of ascent* to altitude contributes to a greater incidence of DCS. For example, you are more susceptible to DCS after a rapid decompression than you would be from a slow decompression to the same altitude.

***Note* —** Cabin pressurization systems protect against DCS by keeping the body below 25,000 feet cabin altitude. However, mechanical failure of the system is a common cause of cabin decompression and possible nitrogen evolution. In high altitude flights above FL500, crewmembers are protected against DCS by prior denitrogenation and a pressure suit. If loss of cabin pressurization occurs and symptoms of DCS are not present, a descent must still be made immediately to a pressure altitude per technical guidance (unless a functioning pressure suit is worn).

Recent research suggests that an increase in *physical activity* at altitude (as well as after descent) tends to dislodge nitrogen bubbles from joints, increasing the risk that bubbles will travel to potentially dangerous locations within the body. Furthermore, if DCS does develop, any additional movement of the limb (in the case of the bends) may worsen the condition.

The effect of exercise on bubble formation after return to ground level following an altitude exposure remains unproven. Numerous anecdotal accounts, however, suggest that postflight exercise increases the probability of delayed DCS. Also, postflight exercise-induced injury may be confused with or mask DCS pain.

Finally, if during physical activity, asymptomatic bubbles caught in the lungs pass through to the arteries as cardiac output increases blood flow to the lungs, then very serious DCS symptoms may arise. For these reasons, persons exposed to high altitude should *not* perform strenuous exercise for 12 hours after exposure.

Age can be a factor. Before the age of about 40 years, no correlation between age and DCS incidence is clearly demonstrated. However, after age 40 DCS incidence increases with increased age. Factors contributing to this effect might be an increased deposition of fat within connective tissues, and changes in capillary density and permeability. There are some indications that *body composition* plays a part in an increased risk for DCS. An increase in body fat may increase the risk for DCS.

There is controversy concerning the effects of *repeated exposure*, i.e., two or more altitude exposures in succession. It appears that exposures occurring in rapid succession within minutes or a few hours of a previous exposure increase the incidence of DCS during the subsequent exposure. This increase is presumably because some bubbles may remain from the previous exposure. Bubble growth is more likely under this condition. If the exposures occur on successive days, there may be no increase in the incidence of DCS, but the time to first appearance of symptoms is often decreased in the subsequent exposure.

There is substantial evidence that dehydration increases the likelihood of DCS. When a person is dehydrated, this decreases the amount of water not only for the body, but the amount of water in the blood. The blood then is slightly thicker and it will take more work for the blood to flow through the body. This causes issues with moving the gases through the body to be effectively removed.

Diving prior to flying with a self-contained underwater breathing apparatus (SCUBA) vastly increases the incidence of DCS. Furthermore, the procedure decreases the minimum altitude at which DCS manifestations begin. This decrease allows the occurrence of DCS even during flight on aircraft equipped with excellent pressurization systems such as commercial airlines, whose cabin altitudes are 5,000 to 8,000 feet. Even helicopter flight or driving to altitudes only a few thousand feet above sea level have contributed to DCS after a SCUBA exposure.

USAF regulations forbid flight within 24 hours of a compressed air exposure (SCUBA diving) for all normal flying operations.

CONTENTS

PREVIOUS

Prevention of DCS

Adequate protection against DCS can be established by aircraft pressurization and or denitrogenation.

Most military aircraft are pressurized and maintain a cabin altitude below 10,000 feet. In addition, the operational ceiling of unpressurized aircraft is FL250. Maintaining aircraft pressurization and a FL250 ceiling significantly reduce the incidence of DCS. But remember, DCS can occur at lower altitudes.

Denitrogenation (preoxygenation) is very effective in decreasing your susceptibility to DCS. This method involves breathing 100 percent oxygen to eliminate nitrogen from the body. When 100 percent oxygen is breathed through a tightly fitted oxygen mask, no ambient nitrogen enters the lungs. This procedure eliminates the lung nitrogen partial pressure; nitrogen rapidly diffuses from the tissues to the blood then to the lungs and is exhaled. The amount of nitrogen eliminated during denitrogenation is dependent upon time. Assuming that the body contains 1200cc of dissolved nitrogen at sea level, Figure 3-11 shows the amount of nitrogen washed out by denitrogenation.

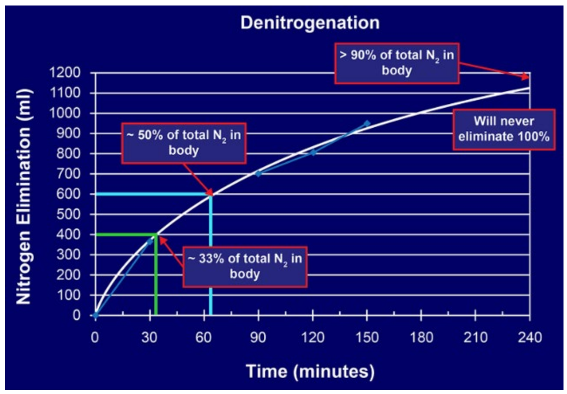

Figure 3-11 — Nitrogen Elimination Table

Treatment of DCS

Anytime an occupant of an aircraft appears to be experiencing the symptoms of DCS, 100 percent/max oxygen should be administered and the affected area immobilized as much as possible.

1. A crewmember should administer 100 percent/max oxygen to that individual.
2. The pilot must descend as soon as practical and land at the nearest suitable installation where medical assistance can be obtained.
3. Before the affected person may continue the flight, consult a flight surgeon or civilian aeromedical examiner. (DCS may occur up to 12 hours after mission completion.)

Several considerations should be remembered. If symptoms of DCS are recognized, landing is mandatory and treatment should be initiated. If all symptoms disappear prior to landing, or immediately thereafter, 100 percent oxygen therapy should be continued as a precaution. A flight surgeon must be notified. If symptoms still persist after landing, compression therapy may be administered at the nearest hyperbaric facility. Compression therapy results in reduction of the nitrogen bubble size and resolves the DCS.

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CONTENTS !!!
PREVIOUS

Review Exercise AP103

Complete the following review exercise by choosing the correct answer(s) or filling in the blanks. Answers follow the questions.

1. During ascent (as ambient pressure decreases), gases trapped within body cavities will __________.

2. The four areas of the body influenced by the mechanical effects of trapped gases are:

   a.

   b.

   c.

   d.

3. What is the ***best*** method of *preventing* problems with the ears and sinuses in-flight?

   a. Breathe 100 percent oxygen under positive pressure.

   b. Do not fly with a cold.

   c. Perform the Valsalva maneuver frequently on descent.

4. Match each symptom with the appropriate DCS type.

		Symptoms	DCS Types
a.	_____	Deep, dull boring pain in a joint	1. Bends
b.	_____	Deep, sharp pain centrally located under the sternum	2. Chokes
c.	_____	Difficulty with inspiration	3. Skin manifestations
d.	_____	Visual disturbance	4. Central nervous system (neurological manifestations)
e.	_____	Mottled and diffuse rash	
f.	_____	Pain may involve the muscles	
g.	_____	Itching sensation	
h.	_____	Partial paralysis, loss of speech or hearing	
i.	_____	Severe, persistent headache	
j.	_____	Vertigo, loss of orientation	
k.	_____	Tingling of one arm, leg, or side of the body	
l.	_____	Usually occurs in shoulders, knees, elbows, and ankles	

5. DCS is caused by __________ coming out of solution in the tissues and blood.

6. List, in order, the corrective actions for any suspected or observed DCS.

   a. __________ oxygen.

   b. __________ the affected area.

   c. __________ as soon as practical.

   d. Obtain __________ (flight surgeon).

   e. __________ therapy (if required).

7. Adequate protection against DCS can be established by __________ and or __________.

8. The USAF forbids flight within __________ hours of a compressed air exposure for all normal flying operations.

CONTENTS

PREVIOUS

9. __________ is a state of oxygen deficiency in the blood, cells or tissues sufficient to cause an impairment of function.

10. __________ __________ is usually caused by exposure to low barometric pressure.

11. Match each type of hypoxia with the appropriate cause.

Causes			Types of Hypoxia
a.	____	Loss of cabin pressurization	1. Hypoxic hypoxia
b.	____	Cold temperatures	2. Stagnant hypoxia
c.	____	Shock	3. Hypemic hypoxia
d.	____	Alcohol	4. Histotoxic hypoxic
e.	____	Drugs	
f.	____	Carbon monoxide	
g.	____	Cyanide	
h.	____	Hyperventilation	
i.	____	Oxygen equipment malfunctions	
j.	____	Improper use of oxygen equipment	
k.	____	"G" forces	
l.	____	Blood donation	

12. The most dangerous characteristic of hypoxia is its __________ __________.

13. Place a checkmark beside the signs/symptoms normally associated with hypoxia. **(Select all that apply)**

    a. ____ Bluing (cyanosis)
    b. ____ Impaired vision
    c. ____ Muscle ache
    d. ____ Hot or cold flashes
    e. ____ Dizziness
    f. ____ Light headedness
    g. ____ Loss of muscle coordination
    h. ____ Apprehension
    i. ____ Feeling of well being
    j. ____ Pain on inhalation
    k. ____ Tingling
    l. ____ Impaired judgment/confusion

14. The time of onset of hypoxia and the severity of symptoms are identical with all crewmembers from one day to the next.

    a. True
    b. False

15. __________ of __________ is the period of time from the interruption of the oxygen supply or exposure to an oxygen poor environment, to the time when useful function is lost.

16. Which of the following factors decrease TUC? **(Select all that apply)**

    a. Increased physical activity

    b. Stress

    c. Sufficient oxygen supplies

    d Hypoxia (histotoxic, hypemic, stagnant)

    e. Rapid decompression

    f. Anxiety

    g. Increased altitude

17. A __________ can reduce your TUC by as much as __________ percent.

18. Hyperventilation is a condition in which the __________ and or __________ of breathing is abnormally increased.

19. Hypocapnia causes an excessive loss of __________ from the lungs and blood.

20. List five signs and five symptoms of hypocapnia.

    Signs

    a.

    b.

    c.

    d.

    e.

    Symptoms

    a.

    b.

    c.

    d.

    e.

21. The most frequent cause of hypocapnia in flying training is stress.

    a. True

    b. False

22. Complete the crewmember's emergency procedures for the treatment of hypocapnia and or hypoxia.

    a. __________ oxygen under __________

    b. Connections —

    c. Breathe at a __________ and depth slightly less than normal until symptoms __________.

    d. Descend below __________ feet MSL and land as soon as __________.

CONTENTS

PREVIOUS

Answers to Review Exercise AP103

1. expand

2. a. Ears
   b. Sinuses
   c. G.I. tract
   d. Teeth

3. b

4. a. 1
   b. 2
   c. 2
   d. 4
   e. 3
   f. 1
   g. 3
   h. 4
   i. 4
   j. 4
   k. 4
   l. 1

5. nitrogen

6. a. 100% or maximum
   b. Immobilize
   c. Land
   d. medical assistance
   e. hyperbaric

7. cabin pressure; denitrogenation

8. 24

9. Hypoxia

10. Hypoxic hypoxia

11. a. 1
    b. 2
    c. 2
    d. 4
    e. 3
    f. 3
    g. 4
    h. 2
    i. 1
    j. 1
    k. 2
    l. 3

12. insidious onset

13. a, b, d, e, f, g, h, i, k, l

14. b

15. Time; useful consciousness

16. a, b, d, e, f, g

17. rapid decompression; 50%

18. rate; depth

19. carbon dioxide

20. **Signs**
    a. muscle tightness/spasms
    b. increased rate/depth of breathing
    c. paleness
    d. cold, clammy skin
    e. unconsciousness

    Symptoms
    a. dizziness
    b. faintness
    c. slight nausea
    d. numbness
    e. tingling
    f. coolness
    g. muscle tremors

21. a

22. a. Maximum; pressure
    b. Check security
    c. rate; disappear
    d. 10,000; practical

AP104 — Cabin Pressurization

Hours and Medium

0.5 Hour (IBT)

Objective

1. Know how aircraft pressurization affects aircrew members.

   Samples of Behavior:

   a. Identify the different pressurization systems.

   b. Recall the advantages and disadvantages of pressurization systems.

   c. Recall the types of decompression and characteristics of each.

   d. Identify the physical indications of rapid decompression.

   e. Identify the procedures for dealing with rapid decompression.

Assignment

Read AP104 in the SG and answer the review questions.

Introduction

Increased pressure in an aircraft cabin or cockpit is maintained by pumping pressurized, conditioned air into the cabin from the jet engine compressor or an aircraft-powered electronic compressor. Pressurization systems provide the most effective method of protection from hostile high altitude environments by minimizing the hazards of decompression sickness (DCS), hypoxia and fatigue.

Information

Cabin Pressurization

Pressurization Schedules

Conventional cabin pressurization systems (Figure 4-1) use engine bleed air. Cabin pressure and ventilation can be controlled by varying the amount of air forced into the cabin and adjusting the overflow.

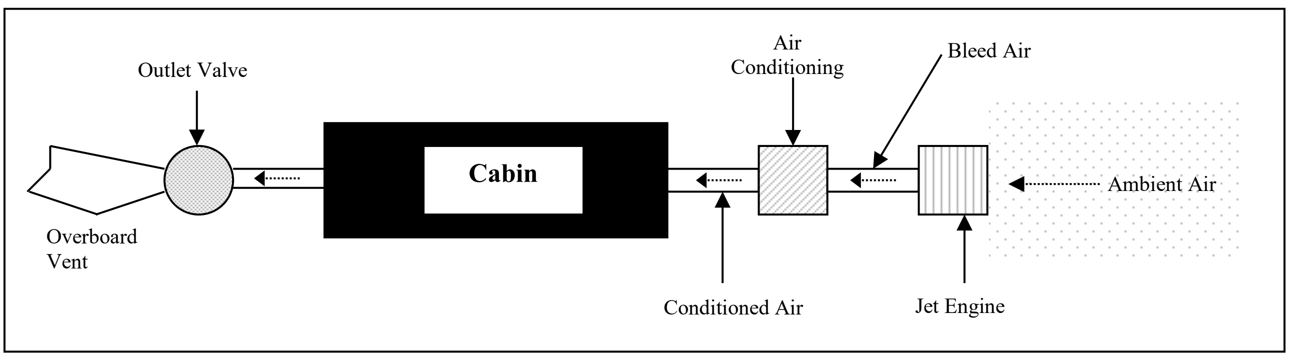

Figure 4-1 — Typical Aircraft Pressurization System

Aircraft Pressurization System Types

Isobaric System

Aircraft pressurization may be regulated by maintaining a *constant* cabin pressure (isobaric system) as aircraft altitude increases. With this type system, the pressure difference between cabin pressure and ambient pressure increases with altitude. An example is the C-17 aircraft which maintains a pressure schedule slightly greater than ambient to 8,000 feet MSL and then maintains 8,000 feet MSL through its certified ceiling.

Isobaric-Differential System

A more common type of pressurization system is the isobaric-differential system, used on single or dual aircraft. With this system, the aircraft is unpressurized until a preset cabin pressure is reached. Once reached, the isobaric function of the system maintains a constant pressure within the cabin until a selected pressure differential (cabin pressure versus ambient pressure) is attained. Thereafter, as the aircraft climbs, the system maintains the designated pressure differential between cabin pressure and ambient pressure. With an isobaric-differential system, the cabin altitude varies with flight altitude; although at a reduced rate (it is not linear).

The T-6 is equipped with an isobaric differential pressurization system (Figure 4-2). As the aircraft approaches 8,000 feet pressure altitude, the control valve regulator will open and close the control valve to maintain cockpit pressure. An 8,000 foot cockpit altitude is maintained until a pressure differential pressure of 3.6 ±0.2 psi is reached at 18,069 feet. This differential is maintained from 18,069 feet to 31,000 feet, where maximum cockpit pressure altitude is 16,600 feet.

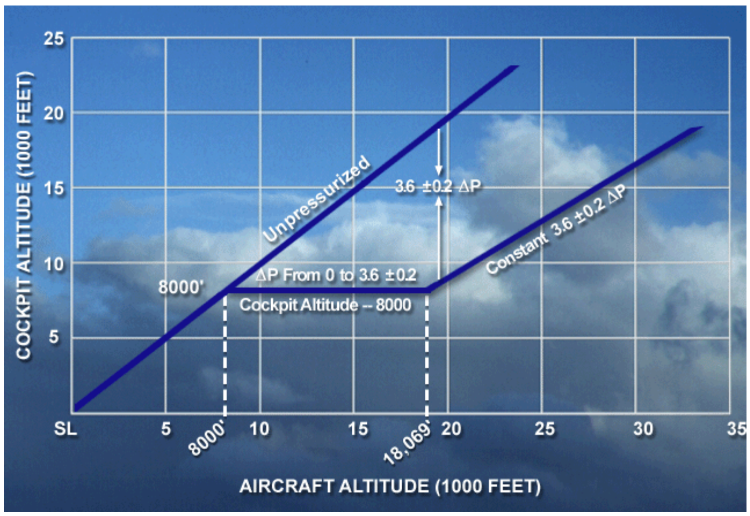

Figure 4-2 — T-6A Pressurization Schedule

For fighter/attack aircraft, pressurization systems are set at a lower pressure differential, typically 5.0 psi. This safeguard is provided because of the smaller cabin volume and the increased danger of decompression during combat operations. Most of these aircraft do not employ pressurization until 8,000 feet MSL. Above this level, the cockpit remains at 8,000 feet pressure altitude until FL230. Thereafter, the system maintains a pressure differential of 5.0 psi. If this aircraft is flying at an altitude of FL400 (and assuming normal pressurization system operation), the cabin pressure will be 7.72 psi (5.0 psi plus 2.72 psi). On an atmospheric pressure table, 7.72 psi will indicate an approximate cabin altitude of 17,000 feet.

Advantages and Disadvantages of Pressurization Systems

There are advantages and disadvantages to having a pressurization system. Listed below are the advantages and the disadvantages.

Aircraft pressurization provides the following ***advantages***:

1. Reduced probability of DCS
2. Reduced possibility of hypoxia

Note — The *primary* purpose for aircraft pressurization is to reduce the possibility of DCS and hypoxia.

3. Reduced need for supplemental oxygen equipment below 10,000 feet cabin altitude. However, crewmembers are required to wear oxygen equipment during certain situations. For example, all crewmembers must wear oxygen equipment during emergencies involving loss of pressurization or emergencies involving the presence of fire, smoke, or fumes.
4. Reduced expansion of gastrointestinal trapped gas
5. Controls cabin temperature, humidity, and ventilation within a desired comfort range
6. Allows the crew and passengers to move freely within large cabins unencumbered by oxygen equipment

CONTENTS
PREVIOUS

7. Minimizes fatigue and discomfort of crew and passengers during long flights (air evacuation, troop transport, etc.).

8. Protects the sinuses and middle ears from sudden pressure increases during descents by slowly scheduling the cabin descent

Aircraft pressurization has the following ***disadvantages***:

1. Decompression. The *primary,* and most critical, disadvantage of aircraft pressurization is the potential for decompression. If decompression should occur, the aircraft occupants are immediately exposed to the inherent hazards of high altitude — hypoxia, DCS, trapped gas problems and hypothermia. Decompression will be discussed in greater detail later in this lesson.

2. Increased aircraft weight because of the additional fuselage strength required

3. Requires additional design engineering, mechanical systems, and engine power

4. Decreased performance and payload

5. Increased maintenance requirements and costs

6. Requires control of cabin air contamination from smoke, fumes, carbon monoxide, carbon dioxide, water vapor and odors

Types of Decompression

There are three different types of decompressions. There are explosive, rapid, and slow. The effects of a decompression are primarily due to the rate of pressure change and the pressure differential.

Explosive decompression is the quickest with a occurring in less than a half of a second (0.5). This could occur as quickly as two-tenths of a second (0.2). Even though there is very little difference between rapid and explosive decompression, explosive decompression is important to cover because it decompresses the lungs, which could damage them. This usually occurs in smaller high flying aircraft, although not very common, and very little you can do except immediately get on oxygen.

Rapid decompression is slower than explosive (0.5 – 15 seconds) and easily recognized therefore, you must consider its physiological effects. Air expanding in the lungs may cause physical injury and unrestrained crewmembers may be forced through an opening in the cabin. Because time of useful consciousness (TUC) is reduced after an RD, oxygen is the most immediate requirement.

A slow decompression is potentially the most dangerous type of decompression because it can be so slow that you may not even notice. If unaware of the decompression, hypoxia may occur and you could be incapacitated (check cabin altitude periodically to detect a slow decompression). Slow decompression can occur when a leak develops from a failing pressure seal. Other physiological consequences that can result after decompression include DCS. A pressurization loss requires descent to or below 10,000 feet.

Factors Affecting Decompressions

Several factors affect the *speed* at which cabin pressure will drop to ambient pressure. The larger the cabin volume, the slower the decompression, assuming other factors remain the same. The larger the opening in the cabin, the faster the decompression.

The *initial* difference between the cabin pressure and the ambient pressure determines the *rate* and *severity* of the decompression. The larger the *pressure differential*, the more severe the decompression.

The *pressure ratio*, defined as the ratio between cabin pressure and ambient pressure, determines the *time* required for decompression. The larger the ratio, the longer it takes for the two pressures to equalize.

The physiological consequences after a rapid decompression are influenced by the ambient altitude at which the decompression occurs, particularly the effects and onset of acute hypoxia. The most severe effects are produced by a decompression involving a large pressure change over a short period of time (moving from a relatively low cabin altitude to an extremely high ambient altitude in the shortest amount of time). There is little effect if a large pressure change occurs over a long period of time, or if a small pressure change occurs quickly.

Physical Indications of a Rapid Decompression

The altitude chamber RD profile is intended to train you to recognize the physical characteristics of an actual rapid decompression. RDs in the chamber prepare you for recognition and action if an RD occurs in the aircraft.

Explosive Noise — When two different air masses collide, they cause a noise ranging from a *swoosh* to an explosive sound.

Windblast/Flying Debris — The rapid evacuation of air during an RD is strong enough to blow unsecured items out of the aircraft. These could include maps, charts, flight logs, etc. Dust and dirt will also kick up and interfere with vision for a short period of time. Even unrestrained passengers and crewmembers have been forced from aircraft by this tremendous movement of air. Therefore, you should always have your lap belts fastened during pressurized flight.

Fogging — During an RD, cockpit temperature, and pressure are reduced. As a result, there is a reduction in water saturation capacity and the water vapor not held in suspension appears in the compartment as fog. The dissipation of the fog is fairly rapid in fighter aircraft, but considerably slower in multi-place aircraft. The dissipation rate is affected by the volume of the aircraft cabin.

Temperature — Cabin temperature during flight is generally maintained at a comfortable level; however, the ambient temperature decreases with altitude. If a decompression occurs, cabin temperature drops rapidly, possibly as low as -55 °C. Chilling and frostbite may occur if protective clothing is not worn.

Pressure — A rapid drop in pressure occurs during an RD. The earlier you recognize the physical characteristics of a decompression, the sooner you can combat the physiological hazards.

CONTENTS
PREVIOUS

Review Exercise AP104

Complete the following review exercise by choosing the correct answer(s) or filling in the blanks. Answers follow the questions.

1. The primary purpose for aircraft pressurization is to
   a. reduce/prevent and control trapped gas expansion.
   b. eliminate pressure breathing and 100 percent oxygen.
   c. reduce/prevent decompression sickness and hypoxia.

2. List additional advantages of aircraft pressurization.
   a.
   b.
   c.
   d.
   e.
   f.

3. The primary, and most critical, disadvantage of aircraft pressurization is the potential for a __________.

CONTENTS

PREVIOUS

Answers to Review Exercise AP104

1. c
2. a. Reduced need for supplemental oxygen
   b. Reduced expansion of G.I. gas
   c. Control temperature and humidity
   d. Move without encumbrance of oxygen equipment
   e. Minimize fatigue
   f. Protect ears/sinuses from rapid pressure change
3. decompression

CONTENTS

PREVIOUS

AP105 — Vision

Hours and Medium

1.0 Hour (IBT)

Objective

1. Know the anatomy and function of the eyes.

   Samples of Behavior:

   a. Recognize parts of the eye.

   b. Memorize the function of each part of the eye discussed.

   c. Recognize the physiological blind zones associated with parts of the eye.

2. Know the characteristics of visual field.

   Samples of Behavior:

   a. Identify the characteristics of both focal and peripheral vision.

   b. Identify the limitations of focal and peripheral vision.

3. Know the limitations and visual illusions associated with daytime flight.

   Samples of Behavior:

   a. Recognize the how visual contrast, target shape, target movement, environmental conditions, and empty-field myopia limit the ability to perceive objects in the visual field.

   b. Identify the effect that perception/reaction time, visual acquisition, and scanning have on midair collision avoidance.

   c. Identify the correct scanning technique used to avoid midair collisions.

   d. Recall daytime visual illusions.

   e. Recall factors involved in daytime visual illusions.

4. Select measures you can take to ensure maximum visual acuity in both day and night flying conditions.

   Samples of Behavior:

   a. Recall techniques to maximize visual acuity.

   b. Identify methods to prevent visual illusions.

5. Know the characteristics of lasers and associated actions upon exposure.

   Samples of Behavior:

   a. Recall the hazards associated with laser exposures.

   b. Identify the correct procedures to take upon exposure to lasers in-flight.

   c. Identify the correct reporting procedures after exposure to lasers.

Assignment

Read AP105 in the SG and answer the review questions.

Introduction

Sight is your most valuable sensory system in the flying environment. Depth perception, visual acuity, night vision, and color vision are used to gather data from inside and outside the aircraft. However, possessing these attributes does not mean the eyes will be used effectively. A crewmember with average visual capabilities, using a proper scanning technique has an advantage over the crewmember with superior vision who doesn't know how to "see."

CONTENTS ⁝⁝⁝

PREVIOUS

There are also distinct physiological and perceptual limitations on the sense of vision in this environment. The human body is designed to move at roughly three miles per hour. Therefore, your sense of vision is designed to acquire, process, and react to information at that speed. However, aircraft can travel faster than the speed of sound, so you're at a disadvantage because of your limited visual and perceptual processes.

As part of this lesson, you will receive a demonstration using a night vision trainer.

Information

Anatomy and Function of the Eye

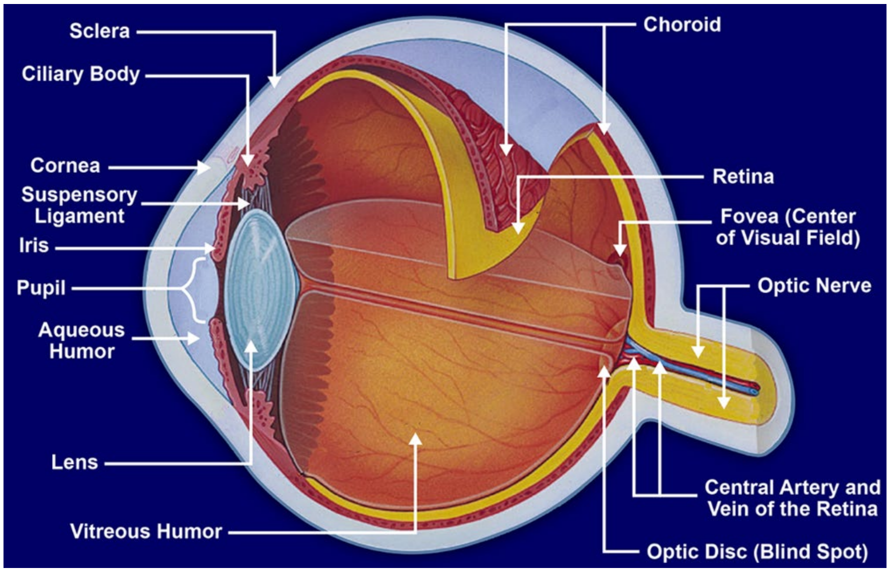

Figure 5-1 — Anatomy of the Eye

Figure 5-1 shows a cross section of the eyes as viewed from above, with the major structures labeled. The cornea and lens refract (bend) light and focus it on the retina in a manner similar to the lens of a camera. Photoreceptors in the retina are stimulated and messages are sent to the brain, via the optic nerve, where the process of perception takes place.

The Retina

The retina is the innermost layer of tissue of the eye, containing millions of photoreceptors (rods and cones) allowing you to "see" an image. The rods and cones are distributed over the entire retina, except where the optic nerve and blood vessels exit the eyeball. This sight is the optic disk or *anatomical* blind spot.

Optic Disk

The optic disk is considered an anatomical blind spot since there are no photoreceptors located here. However, the optic disks are located in different locations in each eye (Figure 5-1). Therefore, when the eyes are being used simultaneously, called binocular vision, the nerve impulses from the retinas provide the brain with an image negating the effects of the blind spots. The blind spot will only be noticed when an object is being viewed with one eye, monocular vision. This situation can occur when one eye is obstructed by a canopy rail or bow, oxygen mask, or even your nose.

Does this phenomena mean you notice a blank area in your field of vision? Unfortunately, the answer is "no." The brain does an interesting thing when one of the blind spots is "active." It "fills in" the *missing* visual information caused by the blind spot with *surrounding* visual information. This process is hazardous if you are scanning for other aircraft and there is an obstruction in your field of view exposing one of the blind spots. Figure 5-2 illustrates how the optic disk/anatomical blind spot works.

We're all a little blind. That's right, you may pass eye tests without a blink, have 20-20 vision, even see in the dark, but you could still miss seeing a jumbo jet at a mile and a half if the conditions are right. There's a blind spot in your eye about 30 degrees right of center when you're looking straight ahead. Your peripheral vision from the eye compensates for this "defect" because your brain normally combines the pictures from both eyes.

When the peripheral vision from one eye is obstructed, the brain can't fill in the missing part of the picture. That's really not a problem when you're walking around on the ground. But when you get inside of a machine — British racing machine, American flying machine, etc. — and look outside, things start getting in the way, like passengers, copilots, or windshield posts.

"Big deal," you say, "All I have to do is move my head." Maybe so, but try this test. Hold the picture below at arm's length and focus both eyes on the cross on the left windshield. Now, move the picture toward your face, you should be able to see the C-5 all the way in. Okay? Try it again with your left eye closed. The Galaxy will disappear and then reappear as you draw the picture closer. Ask yourself: How much airspace will my aircraft cover during

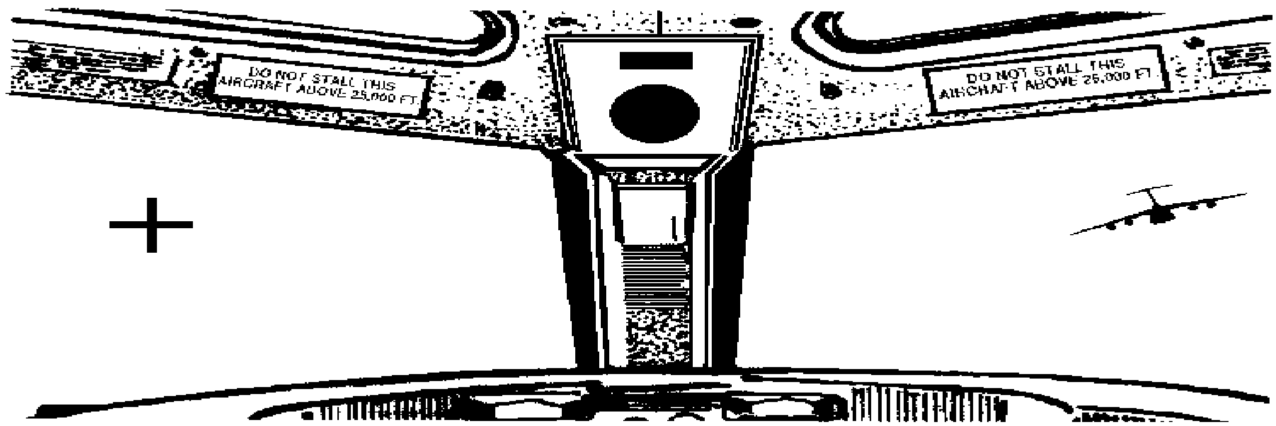

Figure 5-2 — Anatomical Blind Spot

The Fovea

Next to each optic disk is the fovea, another area of the retina with a specialized function. It is a tiny pit containing only cones and the natural point on the retina where the lens focuses an image. Your best color vision and maximum visual acuity are in the fovea. Also, the fovea of each eye (like the optic disk) is offset to help a person have stereoscopic depth perception to roughly 600 feet.

Because of the lack of rods at this site, the fovea is responsible for a second type of blind spot occurring during night vision.

Photoreceptors

The retina consists of two classes of photosensitive cells: rods and cones and various interconnecting nerves.

Cones are the photoreceptors allowing you to see the details of the world in color under bright light conditions. They are densest in the center of the retina and decrease in number toward the periphery.

There are three cones types: 1) those sensitive to short (blue), 2) medium (green), and 3) long (red) wavelengths. However, the "mixing" or interpretation of colors occurs in the brain, not the retina.

Cones require high light levels to function. Low light and night vision characteristics are discussed later in the lesson.

Rods are the photoreceptors densest at the periphery of the retina and decreasing in number as the center of the retina is approached. They allow you to see in gray tones under conditions of dim light and provide for our peripheral vision. Anything interfering with rod function interferes with your ability to see at night.

Rods are 10,000 times more sensitive to light than cones. Their sensitivity is due to a highly photoreactive protein called rhodopsin (visual purple). There is only one rod type, which is sensitive to a range of wavelengths in the middle of the cone sensitivities.

CONTENTS

PREVIOUS

The two classes combine to give the human visual system a tremendous operating illumination range from very bright (photopic) to very dim (scotopic) conditions.

Types of Vision (Photopic, Scotopic, and Mesopic)

Photopic (day time) vision is used in daylight or artificial illumination with sufficient light to activate the cones. Colors are easily discerned and images are sharp.

Cone/color (daytime) vision

Best acuity and reaction times

Scotopic (night time) vision is used during low-light conditions. Cone cells are ineffective, resulting in poor resolution of detail. Color vision is lost and visual acuity decreases as much as 20/200.

Rod (night) vision

Blind spot

Poor acuity, no color vision

Mesopic (dawn and dusk) vision is used when light availability is between adequate and inadequate. The transition zone between scotopic and photopic vision is called mesopic vision. Here both rods and cones are active, although not at peak efficiency. Mesopic vision may be of great importance to aviators, because a low level of light is present at dawn and dusk, as well as during night operations. Under dark conditions (moonlight intensity), cones cease to function and rods alone are responsible for vision (scotopic vision).

Scotopic vision is characterized by poor visual acuity and a lack of color discrimination, but it greatly enhances sensitivity to light. Rods can function in dim light equivalent to an overcast night with no moonlight. The dimmest light cones can function is roughly equivalent to a night with 50% of a full moonlight. Another way to think of this: a white light barely seen by the rod system under scotopic conditions must increase in brightness 1,000 times to be visible to the cone system.

Light conditions during dawn, dusk, or full moon levels create these scenarios. Visual acuity and color discrimination diminish as light levels decrease and cone cells become less effective. One may incorrectly assume he or she is seeing clearly because of the gradual change in light level.

Rod and cone vision

Transition from day to night vision

Dawn and dusk

Blue and green objects appear brighter and yellows appear duller (Purkinje Shift)

Characteristics of Vision

The Visual Field

Vision can be divided into anatomical and functional systems. The total visual field is approximately 150°, depending on the individual. The center 30° is considered central vision. Of this central vision, the very center 3° is used for focal vision or high acuity. The remaining visual field is used for peripheral vision.

CONTENTS
PREVIOUS

Figure 5-3 — The Total Visual Field

Focal vision is processed at a higher level of consciousness and peripheral vision is processed at a more subconscious level. Additionally, each type of vision can be categorized by the primary functions they perform. Figure 5-3 illustrates the visual field and the regions of overlap.

Focal vision is concentrated on the fovea, constituting 3° of the total visual field. Its primary function is to recognize and identify objects, generally to answer the "what is it" question. Therefore, perceiving information with focal vision is a conscious process requiring active attention by the observer.

Focal vision orients a perceived object in space relative to the observer. It also provides maximum visual acuity and depth perception. Visual acuity decreases markedly as the image is focused away from the fovea (Figure 5-4). For example, if you have 20/20 vision and observe an object ten degrees off the fovea, your visual acuity drops to 20/100. Focal vision also requires high illumination levels because the fovea consists solely of cone cells. As a result, you don't have the same visual acuity during night or low-light operations as during the day.

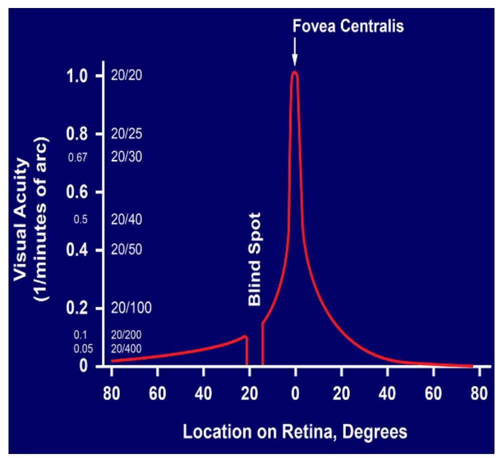

Figure 5-4 — Visual Acuity

Peripheral vision is used primarily to orient oneself relative to the environment and constitutes the remainder of the visual field. Unlike focal vision, it does not require active attention on your part to process information and serves to orient you to your environment. The majority of the photoreceptors used in peripheral vision are rods. As a result, one of the main characteristics of peripheral vision is very poor visual acuity.

There is also little color vision with peripheral vision because of the decreased number of cone cells in the periphery of the retina. However, the rods used in peripheral vision allow you to see at night.

Sensing and identifying objects with peripheral vision is difficult. Peripheral vision is largely used to detect motion (real or illusory) and positional information. Orientation cues provided by the peripheral visual field are extremely powerful. These cues are processed subconsciously and are extremely difficult to overcome. An example of the power of the visual system to orient the body is the reaction people have in wide screen movie theaters where the scene on the screen is of an aircraft flying through a canyon, with its twists and turns. The audience tends to lean in the same direction the aircraft banks in order to keep themselves perpendicular to the visual horizon.

It is important to add that a combination of these two types of vision is used at light intensities equivalent to dusk or dawn. Under these conditions the level of light is slightly below that needed for efficient cone vision and too intense for efficient rod vision. Thus, both types of sensors are operating simultaneously. Beware, since at these levels central (fovea)

CONTENTS !!!
PREVIOUS

acuity, although functional, is only about one-half as good as in average daylight conditions and rod vision is also deficient.

You will fly any time of the day. Understanding the different ways your eyes work in differing light conditions helps you understand your abilities and limitations in both daylight and night flying environments.

Day vision uses cones as photoreceptors due to the high light intensity. These cells adapt quickly to increases in light and give the crewmember the ability to use focal vision for detail and still maintain peripheral cues for orientation. Rods are used to some degree in the periphery but tend to become desensitized or "washed-out" in high intensity light environments.

Distance and Depth Perception

Binocular Vision

Due to the physical separation of the eyes, each views the environment from a slightly different perspective. Due to retinal disparity, each eye sees a slightly different picture of the world and as a result, the brain compares images from both eyes to integrate into a single picture of a 3D world though stereopsis.

Stereopsis is the mechanism for judging distances of objects within about 200 meters (Davis et al., p. 150). The effectiveness of stereo vision falls off rapidly as the viewing distance increases; the specific upper limit of distance for binocular cues is not well established (Gibb, p. 80). But, it is important to note these distance limits are for stationary objects. When an object is moving (or the observer is moving), the distance between the two eyes' images changes and it has been shown in numerous studies that the rate of this change can be used to estimate time to collision and direction of travel (Gibb, p. 81).

Oher binocular functions are:

Convergence: Inward movement of eyes to focus on a near object

Accommodation: Ability to adjust the strength (shape) of lens (required to focus both near & far objects on retina)

As a result, the overall process is termed binocular vision, as it requires the use of both eyes, and binocular cues refer to the mechanisms by which aircrew assess depth and distance. Binocular cues are assessed subconsciously and allow for very precise distance estimation, but only at relatively short distances.

Monocular Vision

Monocular vision is when input from only one eye sent to brain for interpretation. Monocular depth perception is learned over time, we become familiar with the sizes and shapes of objects in our environment. Humans have also learned to use monocular depth cues to determine an approximate depth such as:

- Motion parallax
  - Objects at varying distances "move" in different directions & at different speeds
  - Near objects move faster
- Linear perspective
  - Parallel lines "converge"
- Illumination perspective
  - Shadows, lighting, etc. affect perception of objects
- Aerial perspective
  - Blue or hazy objects appear more distant

We are then able to take these learned lessons and apply them to our activities. For example, there are plenty of people who live with very poor depth perception, but the cues they learn throughout life allow them to successfully drive vehicles. Among other things, they have learned that when driving along a road, nearer objects appear to be moving faster than distant objects. The same such information is used to help us determine how far away objects are when they are beyond the useful range of binocular depth perception (approximately 600 feet).

CONTENTS
PREVIOUS

Common Physiological Limitations and Threats

Physiological limitations involve *visual contrast* of objects against their backgrounds, shapes of targets, movement of targets and environmental conditions.

Visual Contrast helps the eye acquire the target. Objects are sensed by the differences between light and dark. Therefore, the greater the contrast of a target against its background, the easier it is to detect. For example, an aircraft painted a dark color silhouetted against a hazy sky is much easier to see than an aircraft painted gray flying against the same hazy background. This example shows why camouflage can be so effective. Camouflage attempts to blend a target into its background while breaking up the visual outline. To illustrate this concept, look at the paint schemes of some F-18 and F-16 fighters. There are two shades of gray on the aircraft with lighter shades towards the outer edges of the aircraft. The effect is to make the aircraft appear smaller and, therefore, more distant by confusing the contrast of the aircraft against the sky.

Shapes of Targets also affect the eyes' ability to acquire them. The larger, more angular the shape of the target, the easier it is to see and is sometimes referred to as its "visual cross section." A good example is viewing an F-16 head-on versus viewing it from the side or top. It is much more difficult to see the aircraft in the head-on view.

Movement of a Target against a background aids acquisition by the eye. A moving target is easier to detect than a stationary target. The degree of movement required also depends upon the background. An aircraft flying against a broken, irregular background, like a partly cloudy sky, requires less apparent movement to be detected than when it is flying against a featureless background, like a clear sky. As a result, a target's motion must be ten times faster in a clear sky than in a broken, cloudy sky to be perceived.

Environmental Influences on Vision vary based on type. An example of this is the effect of hypoxia on vision. This effect is based on altitude and duration of exposure to that altitude. With increased oxygen starvation, the extremities become less responsive and flying becomes less coordinated. As hypoxia worsens, the field of vision begins to narrow, and instrument interpretation can become difficult.

Obviously, cloudy conditions restrict visibility but clear conditions can also cause problems such as glare. **Glare** is a significant problem, especially at high altitudes. With regard to glare, the human eye only performs optimally over a very narrow range of illumination, the light source can scatter within the eye onto the retina.

For example, if you're flying at FL350 with a solid cloud deck below, you'll experience significant reflected glare (similar to being on a snow field on a sunny day). To help decrease the effects of glare, crewmembers are issued sunglasses and have visors on their helmets.

Sunglasses reduce the amount of light entering the eye, decreasing your visual acuity. The more light sunglasses eliminate, the worse the visual acuity. Military issued aircrew sunglasses eliminate 85 percent of the light entering the eye and reduce visual acuity to an average of 20/30. Commercially available sunglasses may reduce visual acuity to 20/60 or 20/65 because of the amount of light filtered out. The lenses of the sunglasses should be made of glass or polycarbonate to filter ultraviolet radiation. Additionally, the lenses should not distort color (use green or gray lenses, or lenses *certified* not to distort color) and should not be polarized, distort shapes or blur distant objects. Use issued sunglasses or buy a quality pair of sunglasses meeting or exceeding USAF requirements.

External light sources that can produce glare:

Sunlight, fires, flares, explosions, camera flash

Reflected light off snow or water

Daylight (setting sun), night (city lights)

Optics: High Contrast Visors, Glasses, Visor, Windscreen, etc.

Nighttime Conditions

In terms of human biology, night work is a crime against nature. We cannot see well in the dark. The battlefields of prior generations saw action most often during periods of daylight when visual acuity was best. Indeed, vision was a limiting factor concerning the most effective time to launch an assault. Only the most important covert missions would be carried out at night, when the element of surprise was best facilitated by darkness and suboptimal enemy performance could be anticipated in response. However, while enemy performance was degraded as a result of poor vision, the offensive force could expect a comparable reduction in its own performance due to this same limitation. Today, technology has advanced to such a degree that human visual limitations have been significantly mitigated. Nighttime battlefield operations are now carried out regularly and with much greater success (HAOP, 6.1.1.1., 2016).

Empty-Field Myopia is caused by the tendency of the eyes to focus at approximately 3 meters in front of the face. This phenomena occurs if the eyes have nothing to focus on at infinity. You face this problem during high to medium altitude flight where there may be a featureless background or indistinct horizon. The hazards of empty-space myopia are caused by an inability to see targets outside the 3 meter focal range. Therefore, be aware of empty-space myopia and focus on a distant object (like the horizon or an object on the ground) to bring the eyes' focus out to infinity before looking for traffic.

Visual Illusions

The visual perception of something existing objectively but misinterpreted is a visual illusion. In a study by Bell and Chunn (1964), spatial disorientation and visual restrictions were the psychological factors responsible for approximately 23% of the aircraft accidents they investigated. Visual illusions and reduced vision may cause judgment errors that cannot be compensated for by corrective actions. Visual illusions are a form of spatial disorientation; you mentally *perceive* an image different than the image *seen* by the eye. Visual illusions can be caused by a variety of physical and physiological/perceptual factors.

Physical Factors

Physical factors affecting daytime visual illusions include weather, terrain, lighting, and sun angles. These factors can lead to multitude of perceptual problems. For example, the horizon is used by the peripheral visual field as a cue for orientation and balance. However, when a *perceived* horizon is not parallel to the earth's surface, you may still believe it is the *correct* horizon. Therefore, you can become disoriented and experience a false sense of orientation if you do not have a reliable visual horizon. This illusion is extremely important in conditions of marginal visibility, where the true horizon is obscured or not visible. In these cases, the eyes tend to use any straight line as a horizon.

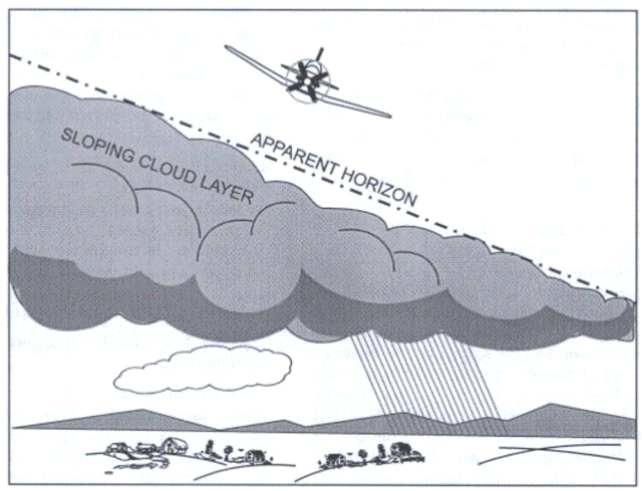

Figure 5-5 — Sloping Cloud Deck

Peripheral vision can compound the problems encountered in daytime visual illusions because it does not require conscious attention. So, in order to compensate for illusions caused by false horizons, you must use conscious thought to override the subconscious input. Doing so is difficult since it requires you to use your focal vision for orientation information, forcing you to further divide your attention between monitoring the aircraft and keeping it in the correct attitude. If you are unable to concentrate on your instruments, the subconscious input from your peripheral vision causes you to orient yourself to the false horizon. For example, flying over a sloping cloud layer where the earth's surface is not visible, you will tend to orient the aircraft so it is parallel to the cloud deck. To regain orientation, you must focus on the aircraft's artificial horizon (provided you were aware of the unusual aircraft attitude). However, if you look outside again, the horizon provided by the sloping cloud deck can cause you to reorient the aircraft parallel to the perceived horizon created by the cloud deck. Figure 5-5 illustrates this problem.

In hazy or foggy weather, indistinct horizons can also be confusing. Critical visual cues required to safely fly approaches and landings may be missing. The decreased visibility of the runway changes your linear perspective. As a result, you may descend too early (duck-under) in order to keep more of the runway in sight, or you may shift your aim point to a visible part of the runway and land short. You may fly an approach and have adequate visual cues during the approach. But, after entering a shallow ground fog during landing, you may suddenly find these cues significantly reduced or unavailable. The fog or haze eliminates the peripheral horizon and confuses the cues you use to judge distance and depth perception. Additionally, fog or haze diffuses lights, making them appear dim and causing you to think you are farther away from an object than you really are.

Sun angle and shadows also create problems. Shadows caused by low sun angles or from the time of day can mask hazardous terrain features, particularly in the low altitude environment. This illusion is important because more and more

CONTENTS !!!
PREVIOUS

aircraft fly low altitude missions. For example, during a low-level mission, with the sun low on the horizon, you may see a mountain in front of you but fail to see a hill in front of the mountain because of shadows.

Sun angle and lighting of terrain can also confuse your perception of *altitude* during low-level flight. For example, flying a low-level mission over hilly terrain may cause a misperception of altitudes. The misperception can be caused by shadows and differing contrasts due to different sun angles. This situation is particularly dangerous if you are used to flying over terrain during a specific time of day and then fly the same route at a different time, with different sun angles.

Different types of terrain can also cause visual miscues and illusions. Flat, featureless terrain like valley floors, deserts or the ocean lack distinct features allowing you to visually determine your altitude above the ground. If these factors are combined with a hazy horizon, you have the larger problem of visually determining altitude ***and*** attitude. In these situations, a slight descent is visually imperceptible; the aircraft can impact the ground before you realize the danger.

Terrain around airfields can contribute to miscues and false perceptions of altitude during approach to landing. An airfield situated at an end of a valley with slowly rising terrain at the approach end of the runway can cause you to land your aircraft long. As you approach the airfield, you fly over the terrain and visually perceive you are lower than you should be. As a result, you may climb above the correct glideslope to compensate for your perceived low altitude. Conversely, flying an approach over terrain sloping away from the approach end of the runway may cause you to descend below the ideal flightpath to compensate for the illusion of being too high. The desired and compensated flightpaths for both rising terrain and terrain sloping away from the runway are shown in Figure 5-6.

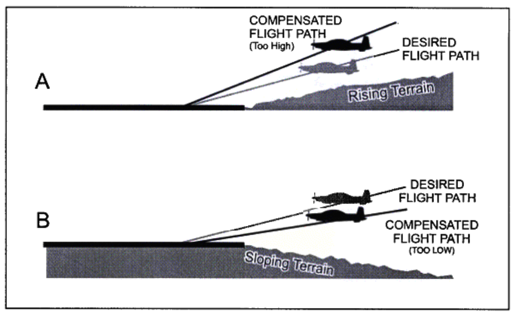

Figure 5-6 — Runway Approach Terrain

Perceptual Factors

The processing and perception of visual cues (factors) by the brain is affected by a variety of variables. These variables may include experience and expectancy, fatigue and other self-imposed stresses.

Experience and expectancy are major factors in visual illusions especially if you are fatigued or there are insufficient physical visual cues. Common examples of experience and expectancy problems are landing illusions caused by different runway widths and lengths. For example, if you are used to landing at your home field with a runway 300 feet wide and 13,000 feet long, you will develop a series of mental pictures of the runway at different stages of the approach. However, should you fly to another base and encounter a runway with a different width and length than your home base, you run the risk of landing short or long.

See Figure 5-7 for the following example. Your home base runway is 300 feet wide and 13,000 feet long (runway A). Consider flying into a field with a runway only 150 feet wide and 9,000 feet long (runway B). On a normal glidepath to runway B, the narrower and shorter runway appears to be farther away. You may perceive you are too high on your glideslope. Therefore, you could descend below the correct glideslope in order to make the visual image of runway B match your mental picture of what runway A should look like. As a result, you could land short of the runway. Conversely, landing at a base with a wider and longer runway (runway C) than your home field may give the perception you are lower and closer to the runway than you really are. Therefore, you may slow your descent and fly above the required glideslope in order to make the landing runway look like your preconceived mental picture. Flaring too high is a common problem in this situation.

CONTENTS !!!
PREVIOUS

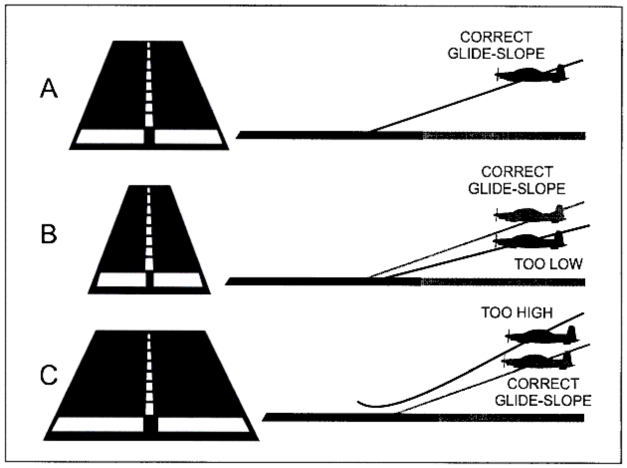

Figure 5-7 — Runway Width and Length

Unless you have experience flying approaches and landing on runways shorter or longer than what you are accustomed to, you may use your mental picture of what a runway is *supposed* to look like and adjust your visual picture to match. These illusions are increased by fatigue, when your ability to consciously prioritize information is slower and you subconsciously rely on your experience to provide cues.

Midair Collision Avoidance (MACA)

Another critical aspect of vision is its role in midair collision avoidance (MACA). The Federal Aviation Administration's "see and avoid" principle is founded on the crewmembers' ability to maintain visual separation from other aircraft.

The speed of jet aircraft, increased air traffic density and the amount of information processed during critical phases of flight requires good vision and alertness on your part to effectively apply the "see and avoid" principle. Now that we have seen the importance of MACA and the "see and avoid" principle, let's take a look at the primary threats associated with trying to employ the "see and avoid" principle. Those threats are perception and reaction.

Perception and Reaction

Reaction time is a measure of how quickly an organism can respond to a particular stimulus (Marieb, 2003). Perception and reaction time has been widely studied, as its practical implications may be of great consequence. As seen in a host of aviation mishaps, perception-reaction time limitation can have grave consequences.

Approximate perception and reaction time should be taken into account in the consideration of all types of sensory perception. This is especially true pertaining to aviation where a moment of inattention or a habit of poor attention management can cause the loss of a combat asset, or even worse, the loss of life.

It should be noted that there is no data suggesting an exact human reaction time as it varies based on cue time, frequency, distance, fatigue and alertness conditions, as well as reaction and perception ability. However, Benson & Strughold (1969) suggests it takes approximately 6.1 seconds for an average aviator to make a decision with a resultant motor input (Figure 5-8).

Strughold's Perception and Reaction Times	
Detect and Visualize	0.4 sec
Recognize	1.0 sec
Decide What to Do	2.0 sec
Foveal Perception	0.2 sec
Direct Movement	2.5 sec
Total Time	**6.1 sec**

Figure 5-8 — Strughold's Perception and Reaction Time

The times change for a variety of reasons, including type of aircraft, physical and physiological state of the crewmembers, mental state of the crewmembers, time of day and weather conditions. Certain physiological and physical variables are under your control, including most self-imposed stresses. For example, fatigue can directly affect your ability to detect another aircraft, perceive its position in relation to your aircraft and decide how to react. However, you can minimize fatigue's effect by ensuring proper crew rest.

CONTENTS !!!
PREVIOUS

Early Visual Acquisition and Scanning Technique

So, with regard to MACA early visual acquisition of another aircraft is critical due to the aforementioned physiological limitations. First, because of the geometry, you lose motion as a cue to acquire the other aircraft with your peripheral vision while in mid-air. When a collision occurs, the other aircraft has little or no apparent motion on the windshield. Therefore, you must acquire the target aircraft with your focal vision, which is a small portion of your total visual field. Second, depending on the size and aspect angle of the target aircraft, the physical ability to visually acquire an aircraft is also limited. For example, attempting to visually acquire a large transport aircraft, traveling in the same direction but on a converging course, is much easier than spotting a small, private aircraft (like a Cessna 150) on a head-on collision course. Therefore, in order for you to visually acquire another aircraft in-flight, the target must be in your focal field of vision so it is focused on the fovea. Getting the target aircraft focused on the fovea is accomplished by using an appropriate scanning technique.

Performing a proper **scanning technique** significantly decreases the chance of a mid-air collision. Maximum scanning effectiveness is achieved by a series of short and controlled, regularly-spaced eye fixations (movements). A common scanning technique is to take an area of sky and divide it into sectors (Figure 5-9). Look in each sector, then scan into the next by using a “Z” pattern or a “Diamond” or Off-Center pattern at night (5-10). In order to see a target, the target must fall on the fovea long enough for it to be perceived. So, let your eyes stop, focus in a sector, then continue your scan.

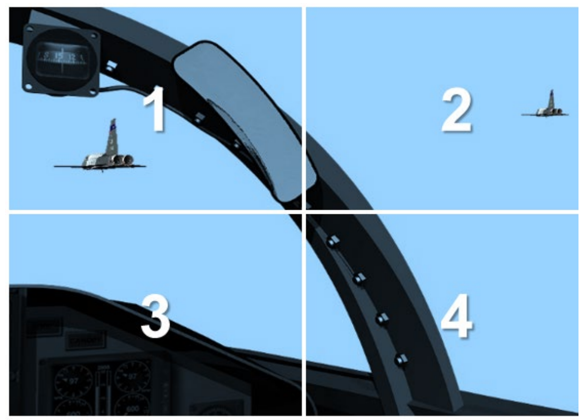

Figure 5-9 — Scanning Technique

During flight, you must continually scan in addition to performing other flight duties. Therefore, all crewmembers are vital keys in the “see and avoid” environment. Crewmembers knowing how to correctly scan for aircraft are invaluable assets, especially in high density traffic areas. Ultimately, aircrew should try to find threats, clear all turns, listen for and adhere to all radio calls.

What areas of the flight are higher risk for mid-air collision? Usually, lower altitudes have higher density traffic and therefore a higher risk. The majority of near mid-air collisions in the United States occur below 12,500 feet MSL. Most military flights are at greater risk during the takeoff, landing and low-level phases of flight over land. During departures, you are busy establishing the aircraft on the departure path, receiving clearances from air traffic controllers, running checklists and navigating, in addition to flying the aircraft. You must also actively scan for other aircraft that may conflict with your flightpath. During the landing (terminal) phase of flights, you must fly the approach, monitor aircraft position, run approach and landing checklists, talk on the radios, *and* scan for other aircraft. Additionally, during terminal phases of flight you are more likely to be fatigued, dehydrated, and possibly hypoglycemic. These factors degrade your perception/reaction time. Similar threats occur in the low-level environment.

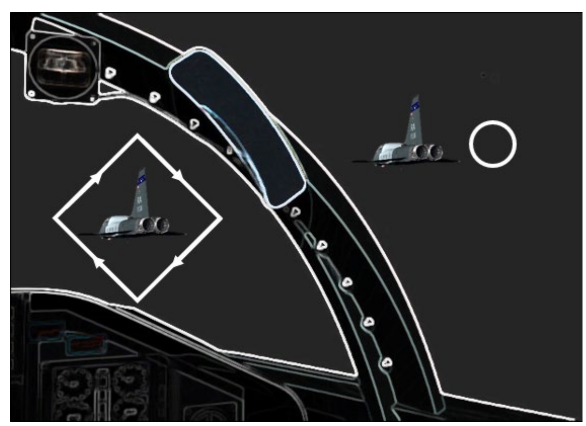

Figure 5-10 — Diamond (Off-Center) Scanning

In the low-level environment, aircraft travel faster than during terminal phases of flight and are at low altitude for longer periods of time. Consequently, your time to react is lowered by the increased aircraft speed and your exposure to the threat of a mid-air collision increases because of the increased time spent in a low-level environment. Like terminal phases of flight, low-level flights are also task intensive, detracting from your ability to scan. Additionally, many low-level altitudes are below air traffic control radar coverage. As a result, you lose air traffic radar as an aid to MACA.

CONTENTS !!!
PREVIOUS

Therefore, be especially alert to MACs in addition to terrain clearance and mission accomplishment. During these critical phases of flight, it is vital that you remain keenly aware of your responsibilities and limitations.

A second mid-air threat results not from other aircraft, but from birds. The majority of birdstrikes occur below 2,000 feet AGL. Unfortunately, birds are more difficult to see than aircraft and they tend to fly just beneath or just above cloud layers. So as you fly out of the clouds on final approach, don't be surprised if you must avoid birds while looking for the runway.

Another more subtle limitation (tending to increase perception time/reaction time) is *expectancy*. Once you are notified of conflicting traffic, and especially if you are given the type of conflicting aircraft, you form a mental picture of your target. Unfortunately, your mental picture may not accurately reflect what you should really be seeing. For instance, your mental picture of what a C-130 looks like at 3 miles may not be accurate, leading you to misjudge your time to react.

Because of the physiological and perceptual limitations to detecting other aircraft in-flight, it's critically important that all aviators know how to correctly scan. The more crewmembers knowing how to correctly scan for aircraft means there is a greater chance of detecting and avoiding possible mid-air threats.

Physiology of Night Vision

Night vision uses different photoreceptive cells than those used during the day. Therefore, the physiological characteristics of night vision and the factors affecting it are different.

As previously mentioned, there are two types of sensory receptors in the retina: rods and cones. The rods are responsible for vision under very dim illuminations (scotopic vision) and the cones for higher illuminations (photopic vision). Remember, cones enable color perception. This is commonly known as the "duplicity theory of vision," in that the presence of rods and cones enables the human eye to function over an impressively wide range of lighting conditions. A common misconception is that the rods function only at night (dark conditions) and the cones function only during the day (light conditions). Actually, both rods and cones function over a wide range of light intensities, and at intermediate illumination levels they function simultaneously.

As discussed earlier, rods and cones are not uniformly distributed through the retina. Cones are concentrated primarily in the center of the retina, while rods are primarily parafoveal and absent in the foveal (macula). There are 20 times more rods than cones in the retina (approximately 100 million). Normal high resolution visual acuity is a result of the densely packed and centrally located cones. Therefore, under photopic conditions, the cones are functioning as intended and visual acuity is optimized in the fovea. As lighting condition reduces to mesopic, visual acuity is reduced in relation to the reduced cone function.

Under scotopic (night) conditions, cones cease to function, and, correspondingly, visual acuity is poorest. Further, under scotopic lighting, the central area of vision (cone vision) becomes a central area of no-vision (the physiologic night blind spot).

Physiologic Night Blind Spot

The night blind spot is a second blind spot in the eyes, since the cones in the fovea require high light levels to function. Normally, you reflexively focus an object on the fovea in order to identify it. At night, however, there may not be enough light emanating or being reflected from a target to stimulate the cones in the fovea. If this is the case, the target is not seen if it is focused on the fovea. Therefore, the fovea is usually not useful in identifying targets at night. In order to avoid this problem, learn to focus a target about 10 to 15 degrees off the fovea so it falls on an area of the retina that contains a greater concentration of rods (night vision scanning technique). It takes conscious effort to move the focused image of the target off the fovea by placing the object of interest on the densest rod distribution, enabling rod vision to overcome the physiological blind spot. The "diamond scanning" technique involves looking above, below, and to each side of an object in a diamond-shaped scanning pattern to keep the dimly lit object from bleaching out and disappearing.

Dark Adaptation

The rods' ability to function in low-light environments is high but their adaptability to low-light levels is fairly slow. For example, when you walk into a dark room or building after being in the bright sunlight, a certain amount of time elapses before the eyes adapt and see images. Remember, rods are unable to distinguish color and are found primarily in the periphery of the retina. Because of their location, night vision is in the peripheral visual field and depth perception and visual acuity are severely degraded. Since night vision depends on the use of rod cells, your focal vision will be diminished, so expect to rely more on your peripheral vision than you normally would.

Both rods and cones undergo a chemical change when exposed to light that initiates visual impulses in the retina. The retinal photopigments regenerate to continue light detection. Under dark adaptation, the retinal photopigment cells become fully regenerated, and retinal sensitivity is at its maximum. Rods and cones differ in their rate of dark adaptation. Rods require 20 – 30 minutes (or longer) in absolute darkness to attain maximal sensitivity. Cones reach maximum sensitivity in about 5 – 7 minutes.

Nighttime Visual Illusions

The rods' extreme sensitivity to changes in blood oxygen levels causes certain physiological factors to affect night visual acuity. For example, an increase in cabin altitude decreases night visual acuity. Carbon monoxide (smoke and fumes or tobacco smoke) also decreases visual acuity at night.

Aviators must be aware of how changes in altitude and oxygen levels affect visual acuity. As a result, certain factors (physical and perceptual) can increase aircrew vulnerability to night time visual illusions. While flying at night, you may want to consider breathing 100 percent oxygen to improve your vision.

Nighttime visual illusions are similar to daytime illusions in that they are caused by a loss or confusion of a visual horizon and can cause problems in all phases of flight. The following section discusses illusions caused by false horizons and lack of a horizon, the perceptual mistakes made by crewmembers and what you can do to correct and avoid these mistakes.

Black Hole Illusion

The black hole illusion is produced during night landing, when there are no visual references except runway lights. The situation may worsen when the lights of a city near the end of the runway make the approach appear high (no distinct horizon). To make the perception match expectation, the pilot lowers the aircraft and lands short. A similar situation is produced by blowing snow or sand and also when the runway and nearby terrain are covered by fresh snow or sand.

If a pilot makes a visual approach at night into an area of low cultural lighting and does not use glide slope guidance, inevitably, the pilot will fly the approach below the normal approach angle and often find himself quite a bit short of the threshold or overrun. This fact has been repeatedly demonstrated to be true, yet the exact reason is not well understood. Some have attributed it to a visual angle seen by the pilot that causes the pilot to maintain the visual angle, resulting in an "undershoot." Others have shown how the lack of cultural lighting causes the pilot to inadvertently descend prior to safe minimum altitudes. Regardless of the reason, pilots should know that if they make a black hole approach and do not use glide path assistance, such as VASI or precision approach path indicator (PAPI), they will land short of the runway.

One solution to the black hole effect is to fly published instrument approaches, preferably an approach providing glidepath information. If a visual approach is chosen, the approach should be backed up with an instrument approach or a published approach profile to prevent a descent below a safe altitude.

Autokinesis — Means "self-motion." This illusion occurs by staring at a single light source against a dark background. Autokinesis can occur by fixating on a star, stationary ground lights at night, or lights from other aircraft. After staring at the light for a few moments, it appears to move randomly. The cause of the illusion is not definitely known. Generally, the larger and brighter the object, the less the autokinetic effect.

Autokinesis can be hazardous. Pilots fixating on stars or ground lights have mistaken these objects for other aircraft, sometimes taking evasive action. Also, when intercepting or following a relatively stable aircraft, it may appear to move erratically. Making unnecessary control inputs based on an incorrect perception can be tiring at best or hazardous at worst. To prevent autokinesis, do not stare at the light. Use the night scanning technique and shift your gaze frequently to avoid prolonged fixation on a target. Always monitor your flight instruments to help prevent or resolve any perceptual conflicts.

Indistinct/False Horizons — At night can be caused by any series of lights in a linear formation. For example, an aircrew flying in a rural area of the country may see a series of street lights and perceive them as the horizon. In a case occurring over the ocean, a student pilot flying a night mission saw a line of fishing boats stretched out below and misperceived them as the horizon. Fortunately, the instructor pilot noticed the aircraft was in about 15 degrees of bank and corrected.

Another cause of false horizons occurs when flying toward land after a mission over the ocean or a large body of water. If you are flying toward a populated area of land with scattered lights, the true horizon with stars will tend to blend with the scattered ground lights. This visual picture may confuse you and cause you to use the water-land boundary as the horizon.

The best preventive measure to decrease or eliminate the problem of false horizons is to ensure a good instrument cross-check.

CONTENTS !!!
PREVIOUS

Lack of Horizon — If you are flying at night over featureless unpopulated terrain or the ocean, you may not see a visible horizon. This environment can cause you to use a false horizon (if one becomes available) or rely on your vestibular system (discussed in the Spatial Disorientation lesson) for orientation information.

Weather Effects at Night

Nighttime visual illusions can be caused by the same types of weather that cause daytime visual illusions. Shallow ground fog, rain, snow and haze all affect your visual ability to discern altitude, attitude and distance. At night, however, there are some distinct differences in how these environmental factors affect you.

Haze and ground fog tend to decrease your forward and slant range visibility just as they do during the daytime. At night, haze and ground fog tend to cause runway lights to be dimmer than usual and makes them appear farther away than they actually are. Additionally, bright flashing lights, like sequenced flashing lights found in some airfield lighting systems, can disorient you at night in foggy or hazy weather. The brightness of the flashers reflected in the weather may give you a false sense that the aircraft is nose low in relation to the horizon. You may also believe you are closer to the light source than you actually are because of the apparent size of the light. The lights appear larger because of the diffusing and scattering of the light by the fog or haze.

Rain and snow can cause light from aircraft landing lights to be reflected back into the cockpit. As a result, you may sense an overwhelming visual sensation of the aircraft pitching up or down. This sensation is caused by the high speed of the illuminated rain drops or snowflakes passing by the windshield. If rain or snow is encountered, in addition to lowered visibility, your ability to transition to visual flight for landing may be impaired. Deviations from the desired flightpath may occur. Therefore, keep the aircraft in a position to make a safe landing.

Visual System Improvement Measures

You can use a number of different techniques to maximize visual acuity in the cockpit at night. Ensure the windshield and your helmet visors are clean and scratch free. If the mission involves formation flying or visually intensive work, but does not allow for an increase in cockpit lighting levels, consider breathing 100 percent oxygen. Additionally, you can keep the cockpit lights low to allow for maximum dark adaptation. Finally, be aware that weather, expectancy and fatigue degrades perception/reaction time, leaving less room for error.

Overcoming Illusions

- Education
- Training
- Thorough preflight
- Use all available NAV aids
- Visual Approach Slope Indicator (VASI)
- Velocity Vector/flight path markers
- VVI, altimeter
- Increase crosscheck frequency

Note — The problem of night visual illusions increases because you are flying at times that are usually out of alignment with your normal sleep-wake cycles and you tend to be fatigued. The problem also increases when traveling across time zones. Therefore, self-imposed stresses play a significant role in nighttime visual illusions.

Laser Awareness

In Los Angeles, on November 2009, a Southern California man who aimed a laser beam at two airliners as they approached an airport was sentenced to 2½ years in federal prison for disrupting the flights (Associated Press, 2009). The U.S. Attorney's Office in Los Angeles says Dana Christian Welch of Orange was the first person in the U.S. to be convicted at trial of interfering with pilots by aiming lasers at their planes. Authorities say the 37-year-old aimed a handheld laser at two Boeing jets as the passenger planes were about to land at John Wayne Airport on the night of May 21, 2008. The laser beam struck one pilot in the eye, causing "flash blindness," and interfered with pilots' ability to land the other plane.

A U.S. News and World Report article from June 2014, revealed the following facts: There were fewer than 300 reports of aircraft being targeted by lasers during 2005. By 2013, that number had risen to nearly 4,000 (Soergel, 2014). In

CONTENTS
PREVIOUS

response to this alarming trend, the Federal Bureau of Investigation (FBI) instituted a targeted program to combat lasing of aircraft near major airports around the country. The program offered rewards of up to $10,000 for information leading to the arrest of individuals using lasers to illuminate aircraft (FBI National Press, 2014). The FBI credited this program with the recent sentencing of a Clovis California man to 14 years in prison for repeatedly lasing two helicopters with an extremely powerful handheld laser. As of December 2013, the FBI has confirmed at least 141 arrests, 107 cases forwarded for prosecution, and 84 convictions related to aircraft lasing incidents (Soergel, 2014).

These scenarios demonstrate not only the alarming rise in the number of aircraft/laser interactions, but they also underline the seriousness with which the Federal Aviation Administration (FAA) and the FBI treat these incidents. Civilian and law enforcement pilots are now being targeted by individuals using handheld lasers in an attempt to disrupt operations, or possibly "just for fun." Military pilots flying in civilian airspace are experiencing similar encounters with lasers. In addition, military pilots must also be prepared for lasers used on the battlefield. These lasers may be used for targeting in an attempt to damage the aircraft or weapons payload, or as "dazzle lasers" intended to disrupt or degrade flight operations. Lasers are currently used as defensive measures by the US military, and they have even been posited as offensive weapons.

As far as we can tell, all laser exposure incidents that occurred during flight have been due to Low Energy lasers. Despite being called Low Energy, they are capable of blinding a person at tactically significant ranges (greater than 5 miles). Our discussion will focus on low energy lasers. However, high energy devices are an emerging technology and a policy concern in terms of laser weapons.

No matter what the intent of the laser/aircraft interaction, flight crews need to understand the threat various types of lasers pose to ensure not only mission effectiveness but crew/aircraft survival.

Laser Basics

The word "Laser" is an acronym for Light Amplification by the Stimulated Emission of Radiation. Just as there are unique terms in the kinetic weapons environment, there are unique terms in the laser world.

Collimation

Lasers produce light that doesn't spread out in all directions or diverge like normal white light sources. Because the laser beam stays together, it passes through space very efficiently in a collimated beam. Collimation or directionality refers to how straight the beam propagates without spreading. To put things into perspective, a flashlight has some collimation while an incandescent light bulb has none. Laser pointers, collimated beams of light, can be used like a flashlight to find and identify targets.

Monochromatic

Generally, lasers are a single color; one wavelength or a very narrow band. The wavelength that a laser emits is a key factor in analyzing the hazards and physical properties of the laser. There is an inverse relationship between wavelength and frequency. Shorter wavelengths have higher frequencies while longer wavelengths have lower frequencies. Higher frequencies are associated with higher energy. As a rule of thumb, if all other parameters of a given laser are equal, a shorter wavelength will have higher energy and will be more dangerous to human tissue.

Biological Effects of Lasers on the Eye

What makes lasers so dangerous to the human eye? Lasers can be hundreds of times "brighter" than the sun, and high intensity can be projected over long distances. Also, light can be sharply focused by the eye. The energy of the light is transferred to the retina. If the energy is high enough, the retina can be burned resulting in permanent damage. The portion of the retina that is most sensitive to detail and color discrimination is the fovea and of greatest concern because it is the area where color vision and visual acuity occur.

Lasers are especially dangerous at night when the pupil is fully dilated and there is a greater risk of a damaging laser beam entering the eye. The wavelength or color of light emitted from a laser also has a very important role in determining the hazard potential of a laser beam. A green laser is in the heart of the visible spectrum where it receives the maximum magnification when passing through the cornea of the eye. The cornea and lens combination of the human eye has the capability to focus light by a factor of 100,000 (Sliney and Wolbarsht, 1980). This means that a relatively small amount of laser light can have very damaging effects on the retina.

Laser damage potential for flight crews can be characterized by the following terms:

CONTENTS ⁝⁝⁝
PREVIOUS

Dazzle

Imagine you are driving home, heading west into the setting sun, and your pitted windshield is almost impossible to see through.

Glare Blindness or Flash Blindness

Imagine you have momentarily looked at the sun, or possibly Uncle Bill used the flash on his camera right in your face. You will see spots that gradually fade away, but for several seconds or even tens of seconds your vision is impaired.

Retinal Burns

At this point you have a permanent blind spot. The laser has impacted the retina with sufficient energy and time on target to overwhelm the retina's capacity to wick away the heat, and the tissue is now burned. You have a scar. If the scar is off axis you will likely suffer no lasting perceptible effects because the brain is very good at averaging out small errors. If the burn is on the fovea or optic nerve, the news is not so good. Most minor retinal burns heal over time and the individual can still function normally.

Laser beams can impact a pilot very differently depending on the distance from the laser source to the pilot. These types of lasers can be purchased on-line for less than $200 and cause distraction hazards at approximately 11 miles!

When optical radiation is absorbed, the action on the absorbing biological tissue is either photochemical or thermal. In the ultraviolet region, the action is primarily photochemical. In the infrared region, the action is primarily thermal. In the visible region, both effects are present. When the intensity of the radiation is sufficiently high, the effects are of such a magnitude that damage to the absorbing tissue will result.

The damage from optical radiation may range from relatively mild, from which there is complete recovery, to severe, where there is little, if any, recovery.

The location of the exposure within the eye determines the degree of incapacitation from a retinal injury of a given degree of severity. The fovea (the central two degrees of the visual mechanism) is the region of the retina, which is most sensitive to detail. The rest of the retina, the fovea to the peripheral retina, is increasingly more sensitive to the light as one moves away from the fovea. However, these parts of the retina are not as sensitive to detail. Therefore, an injury to the fovea can severely reduce visual functioning in terms of resolution. An injury to the peripheral retina is less incapacitating in the same terms.

A laser lesion in the peripheral areas of the retina may not be noticed or cause a significant reduction in visual functioning (i.e., visual acuity) because the vision in those areas is very poor compared to vision in the fovea. Lesions in areas other than the fovea are referred to as "off axis" damage or hits. Most are benign.

Laser Eye Protection

A laser threat is defined as any laser light that could alter operations without causing catastrophic structural damage to platforms. With that definition in mind, even relatively low power hand held devices can pose a risk to aircraft during low level flight operations or during take-off or landing. Landing is the most vulnerable portion of any flight profile and gives the aircrew the fewest options. Laser eye protection (LEP) may be the most beneficial during this portion of the flight. Wavelength and optical density (OD) are the two most critical factors in determining what LEP should be used in a particular laser threat environment. Most LEP devices are developed and manufactured for a specified set of wavelengths so they are considered wavelength specific.

Optical density is a measure of the amount of light transmitted by a filter, such as eye protection spectacles. This term is defined such that high OD equates to low transmission of light. The OD is critical because it specifies how much of a certain wavelength's energy is blocked (reduced), thus the degree of protection. The OD, or protection factor of the LEP, is designed to bring the energy level to below the maximum permissible exposure. The range from the laser, the magnification of optics being used, and the energy density of the laser are used to calculate OD for unique situations. The scale is logarithmic such that an OD of 0 equates to 100% transmission and a reduction factor of 1, an OD of 1 equates to 10% transmission and a reduction factor of 10, an OD of 2 equates to 1% transmission and a reduction factor of 100, etc. Sunglasses have an OD of about 1.

LEP choices will usually be a balance between protection from incident laser beams and visible light transmission allowing the aircrew to still see cockpit displays and the airspace around them. Many LEP devices resemble dark glasses with various degrees of wrap around for added protection.

CONTENTS ⁝⁝⁝
PREVIOUS

The current spate of green laser pointer incidents is especially troubling because it is more difficult to protect aircrew from these lasers while still allowing aircrew members to have full access to cockpit displays. Many cockpit instruments use green in their displays, so blocking green light with LEPs can make it difficult to see all of the information displayed on cockpit instrumentation. Very narrow band LEPs are available; however, they are expensive and their protection can be of limited value for off-axis laser exposure.

LEP comes in many formats and styles, such as spectacles, goggles and wrap around. They also come in single band and multi-band wavelengths. There are also different types of filter technologies commonly used in LEP. Absorptive filters are one of the most popular types. Absorptive filters are dye-based and made of polycarbonate material. These LEP are designed to absorb particular bands of wavelengths by adjusting the concentration of dyes to protect from a band or bands of wavelengths.

Procedures after Exposure

If you detect the laser energy (remember it may be IR and undetectable by the unaided eye), look away immediately and use whatever shielding action you can reasonably take and still maintain aircraft control. You may need to transfer all visual references to your flight instruments to prevent further exposure and maintain aircraft control. This is especially important at night when the pupil dilates and is capable of allowing more light energy in to be focused on the retina.

Report the laser you detected or suspected to other flight members both within your aircraft as well as to those in the same airspace so they can avoid exposure/confirm detection. Report the laser to any controlling agencies (traffic, ground, etc.) as well so they can re-direct other aircraft in flight to avoid the area/be aware of the threat.

Upon landing, report immediately to the flight surgeon who will perform a laser-injury specific exam and treatment if injury is detected. The flight surgeon will also have you fill out a detailed report on the specifics of the incident which will help in their evaluation of potential injury as well as aid in your report to Intel, the SOF, squadron supervision, and aircraft maintenance.

Using the acronym LASER for the reporting details will help flush out the required items needed to enable a thorough investigation.

Location of the source: GPS coordinates/direction of beam/terrain characteristics/building descriptions

Appearance: Color and brightness can help with determining the wavelength, power estimates, and the potential type of laser used.

Scanning or tracking: Did the laser appear to be tracking your flightpath or was it moving about as if trying to find something to lock onto?

Effects: Any symptoms experienced such as pain, stinging, tearing, popping sounds in the eyes, dazzle effects with or without symptoms, sensor interruption, red-out of visual field, flash blindness

Regularity: Pulsed/flashing or continuous beam effect

CONTENTS
PREVIOUS

Summary

Vision is the primary means to collect information about your environment and your position in it. It can be viewed as a two-part system, the physical visual imaging part and the mental perceptual part. The cones on the retina of the eye are responsible for the ability to see color and operate most efficiently in bright light. They are scattered throughout the retina (with the greatest concentration in the fovea) and primarily used in focal vision; the area of greatest visual acuity.

Rods are found outside the fovea and in the peripheral areas of the retina. They are roughly 10,000 times more sensitive to light than cones and give you the ability to see in a low-light level environment. Rods perceive only black and white, allowing for distinction between shades of gray. They are the photoreceptors used in peripheral vision.

The retina contains two blind spots, the anatomical blind spot formed by the optic disk and the night blind spot caused by the concentration of cones in the fovea.

You must incorporate an effective scanning technique in order to see an object. The scanning technique involves taking the visual field and dividing it into sectors. Search each sector, then let your eyes stop and focus before moving on because an image is not perceived unless it is focused on the retina. This scanning technique may be used during the day or night. However, the night scan must make allowances for the night blind spot by focusing the image 10° to 15° off the fovea.

Vision and visual perception are affected by self-imposed stresses, such as fatigue, weather conditions, physiological conditions (hypoxia), and expectancy (what the eyes see is not necessarily what the mind expects to see). Be aware of these problems and be prepared to counteract them if they occur.

To maintain the high level of alertness required, ensure you are well-rested, fed, and hydrated and have thoroughly planned and briefed your mission. Be aware of the visual illusions you could encounter on your mission and how you can deal with them. And lastly, know your threats to include lasers and how to prepare for and how to combat laser exposure threats.

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Review Exercise AP105

Complete the following review exercise by choosing the correct answer(s) or filling in the blanks. Answers follow the questions.

1. The retina is the innermost layer of tissue of the eye.
   a. True
   b. False

2. The rods and cones are light sensitive cells distributed over the retina.
   a. True
   b. False

3. Determine if the following are characteristics of (A) the rod cells or (B) the cone cells:
   a. Most dense at the periphery of the retina
   b. Require high light levels to function
   c. Allow you to see gray tones under conditions of dim light
   d. Densest in the center of the retina
   e. Provide for peripheral vision
   f. Allow you to see detail under bright light conditions
   g. More sensitive to light

4. What is the primary function of focal vision?
   a. To orient oneself to the environment
   b. Recognize and identify objects
   c. Monitor fluctuations in high-light levels
   d. Conscious perception of peripheral cues

5. What is the primary function of peripheral vision?
   a. Conscious perception of peripheral cues
   b. Recognize and identify objects
   c. Monitor fluctuations in low-light levels
   d. To orient oneself relative to the environment

6. An object requires less motion to be seen in a clear blue sky than an object in a partly cloudy sky.
   a. True
   b. False

7. In mid-air collisions, the primary peripheral visual cue of __________ is not available. Therefore, you must acquire the target aircraft with your __________ vision, using the scanning technique.

8. Perception/reaction time is affected by physiological and perceptual limitations.
   a. True
   b. False

9. Maximum scanning effectiveness is achieved by a series of short (long enough for the eye to focus), regularly spaced eye fixations.

   a. True

   b. False

10. What is the acronym used for reporting laser exposures?

CONTENTS
PREVIOUS

Answers to Review Exercise AP105

1. a
2. a
3. a. A
   b. B
   c. A
   d. B
   e. A
   f. B
   g. A
4. b
5. d
6. b
7. motion; central
8. a
9. a
10. LASER

AP106 — Night Vision

Hours and Medium

1.0 Hour (IBT)

Objective

1. Apply threat mitigation techniques with regard low light conditions.

   Samples of Behavior:

   a. Identify dark adaptation's influence on night vision.

   b. Demonstrate methods used to prevent the autokinesis illusion.

   c. Identify how flash blindness produces debilitating effects on dark adaptation.

   d. Identify the reduction in visual acuity, loss and shift of color perception, focal and peripheral vision degradation.

   e. Apply methods to improve unaided night vision.

Assignment

Following the classroom presentation, your class will be divided into control and experimental groups for the night vision demonstration. These groups will analyze the benefits of dark adaptation, experience autokinesis and experience flash blindness.

Introduction

The unaided night vision trainer is a modified projector that is used in a classroom to simulate the low-light environment encountered in night flying operations. The unaided night vision trainer presents a visual representation of the night-time flying environment. The trainer can replicate a range of scenarios including totally darkened, lights-out environment to that of a dark adapted individual.

Information

Unaided Night Vision Demonstration

The unaided night vision trainer is used during initial physiological training to demonstrate unaided night vision limitations.

References

Air Force Manual 11-403, *Aerospace Physiological Training Program*

Air Force Manual 11-202, Volume 3, *Flight Operations,* 09 June 2020

Gradwell D., Rainford D.J. (2006). *Ernsting's Aviation Medicine*, 5th Edition.

Air Force Research Laboratory (2016). *Handbook of Aerospace and Operational Physiology*, 2nd Edition.

AP107 — Situational Awareness

Hours and Medium

1.5 Hours (IBT)

Objectives

1. Know the fundamentals of AMT and SA.

   Samples of Behavior:

   a. Identify the two primary types of information processing.

   b. Outline the levels and components of SA.

   c. Recall SA theory and its implications on operations.

2. Comprehend the causes of a loss of situational awareness

   Samples of Behavior:

   a. Identify the predominant causes of the loss of situational awareness (LSA).

   b. Identify predominant attention management limitations and their impact on SA.

   c. Give examples of current mishaps which involve attention management and LSA as either casual or contributory.

3. Know the characteristics of SA by identifying how to recognize, prevent, and treat a loss of situational of awareness.

   Samples of Behavior:

   a. Identify methods to improve SA and attention management.

   b. Identify cues for preventing and recognizing a loss of situational awareness.

   c. Identify mechanisms to recover from LSA.

Assignment

Read AP107 in the SG and answer the review questions.

Introduction

Situational Awareness (SA) is a primary concern because loss of SA is either the primary factor or a contributing factor in most human performance related mishaps. As a result, SA and SA theory has gained great interest in both civilian and military aviation communities. Subsequently, a number of definitions, theoretical models, and methodical approaches for the assessment of SA have been developed over the years in an effort to truly understand and improve SA (Salas and Dietz, 2011). For instance, Tolk and Keether (1982) state, “SA is the ability to envision the current and future disposition of both red and blue aircraft and surface threats.” Endsley (2000) submits, “SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.” Whitaker and Klein (1988) suppose, “SA is the pilot’s knowledge about his surroundings in light of his mission’s goals.” Finally, the Air Force definition in Air Force Instruction 11-290 states, “In flying, this refers to an aircrew’s continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission, and the ability to forecast, then execute, tasks based upon that perception.

Regardless of the varying SA definitions, the end state is the same: aviator awareness of what did happen, what is happening, and what could happen next. SA is the key element in most USAF aviation undergraduate, graduate, and continuing education courses. For example, Air Force Instruction 11-290, *Cockpit/Crew Resource Management* states, “A desired end state of CRM training is a high state of situational awareness.” Simply stated, great SA is critical to the maximization of USAF combat capabilities and the preservation of its combat assets.

This lesson covers SA theory, its associated attention management threats, and the predominant causes of loss of situational awareness (LSA). The lesson also covers recommended tools to prevent LSA and recovery techniques when encountered in flight. After completing this lesson, you will know the fundamentals of AMT and SA, comprehend LSA causes, and finally, know how to recognize, prevent, and treat loss of SA in a flight environment.

Information

Introduction to Situational Awareness

From the earliest cockpits fitted with rudimentary gauges, to 5th generation airframes wired for helmet-mounted displays; the impetus for developing a philosophy rooted to situational awareness has always been grounded in the human's capacity to process environmental cues. As previously mentioned, the concepts encompassing the term SA are broad, but the reader may benefit by the following USAF Aerospace and Operational Physiology definition as the starting point in the understanding of SA: "The *accurate* perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" *(Handbook of Aerospace and Operational Physiology*, Chapter 4.5, page 4-88, 2016*)*.

SA theory supposes that SA is only good if a person has an accurate perception of his or her environment and its cues. Perception itself is the receipt of sensory information followed by conscious attention directed to the information for analysis. Yet, this analysis does not mean situational awareness, it only means perception.

Situational awareness applied, is the result of the processing and the integration of informational cues received through the human being's many sensory systems (Figure 7-1). Most information comes from the visual system. This is usually the most reliable information for awareness and orientation. The problem is when visual information is unreliable, it can take you by surprise, just because you are so used to relying on visual information. The auditory system is the least reliable. The vestibular system is the source of our "sense of balance," and can be tested by walking with our eyes closed. Without a vestibular system this simple feat would be virtually impossible. In traditional flying, almost anything done in an aircraft exceeds the design specifications of the vestibular system.

Seat-of-the-pants is the phrase used to describe an additional sensory system called the somatosensory system. This system is essentially a collection of sensors throughout the body that gives information on muscle tension, joint position, and pressures on skin and deep tissue. At ground level, this system can give you a sense of your in-range (within touch or reach) environment. The risk here is that it is difficult to ascertain who or what is touching you without cueing information from another source (i.e. visual or auditory cues). In flight, the vestibular system gives you a constant sense of where the G vector is. The problem is, in an aircraft, G is not always the same as down. Finally, the auditory system also provides awareness and orientation information. While it doesn't give a lot of information, what it does give can be useful and life-saving (i.e. gear and flap movement or the sound of thunder).

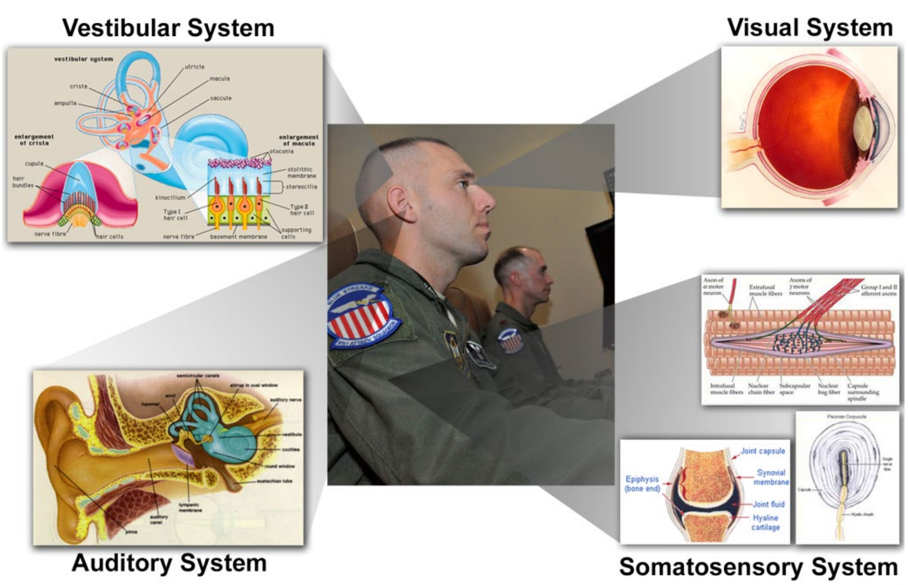

Figure 7-1 — Applied Situational Awareness

Over time, these cues provide aircrew with not only a sense of location in the environment, but also a sense of their place or role in occurring events. This is accomplished by effectively processing critical information using one of two types of information processing mechanisms; the conscious or subconscious processors.

CONTENTS
PREVIOUS

Primary Types of Processing Mechanisms

Conscious

The *conscious* part of our minds is considered a serial processor. This is the level at which we actively process information; we are at our best when we do one thing at a time (serially). The conscious level is aware of its existence and the existence of other things and situations. It's also the seat of situational awareness. The conscious level is much slower than the subconscious level but much less prone to illusion and habit pattern interference. Learning to fly begins at the conscious level and is slowly transferred to the subconscious level as flying skills develop. The same can be said with driving, riding a bike, or even reading.

Subconscious

The *subconscious* part of our minds is considered a parallel processor. This level is capable of doing more than one thing at a time and can do them very quickly. Habit patterns, memory, and skills are kept in the subconscious. You can ride a bicycle, drive a car, or fly an airplane at the subconscious level of attention, but conscious attention must be used to oversee what the subconscious is doing. This oversight ensures the validity of information being used by the subconscious and the appropriateness of its actions.

Both the conscious and the subconscious processors work in tandem and operate predominantly on cue familiarity and/or level of stimuli. Cue familiarity is the human's ability to recognize facts, hints, verbiage, voice tone and voice pitch, information, warnings, or other environmental clues.

Information Processing Loop

When a set of cues is repeated or recurring, the human brain commits it to memory (the subconscious) in an effort to exert less energy and waste less time. This memorized information is stored in the brain and when the same or similar cues present themselves again, instantaneous memory rehearsal prompts the subconscious to dominate the processing loop leading to an action or execution.

Memory driven action can provide aircrew with major benefits during time-critical scenarios (e.g. Boldface). However, this process also omits 50 percent of the processing loop which includes forecasting and prediction based on training and experience, and evaluation of the resultant outcome based on risk-assessment and priority. Subconscious processing utilizes the inner-ring only, which is depicted in Figure 7-2.

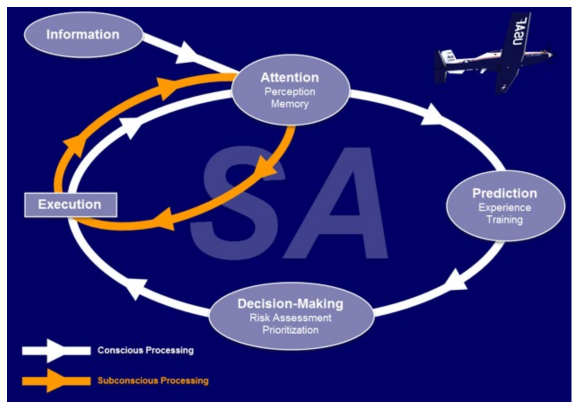

Figure 7-2 — Information (Cue) Processing Loop

Memory-based (subconscious) decisions are largely responsible for mistakes which often lead to the loss of life or the loss of combat assets. Aviation examples are gear-up landings, failure to complete checklist items, and switch or input errors. More common errors are missing a commonly used exit during the commute home, misreading a commonly read passage or script, and even misjudging the steps leading to the second level of your home.

As seen by the outer ring, conscious decisions have further to travel, yet, it conservatively completes all areas of the processing loop. The distance traveled during the conscious processing ring typically requires approximately 5.0 – 5.5 seconds and leads to a well thought-out and appropriately assessed action or execution. Unfortunately, the flight environment is inherently capricious and does not always afford aviators the time needed to make a conscious decision. Therefore, having a healthy balance of memorized (current) data, rehearsed emergency procedures, in-flight emergency scenarios, and technical knowledge provide aviators the ability to maximize the pros of both types of processing mechanisms.

Primary Components of SA

According to the HAOP (2016), the context of SA can be further divided into components (or areas) of *geographical SA*, *spatial/temporal SA*, *system SA*, *environmental SA*, and *tactical SA*; each subarea identifies the conditions and dynamic flow of activities within a period of time. Prevec and Ercoline (2004) further divide these SA components as follows:

1. **Geographical SA**

   Geographical SA includes knowledge of the location of one's own aircraft, other aircraft, terrain features, airports, cities, waypoints, navigation, fixes and position relative to designated features, runway and taxi assignments, and climb and descent points. It is critical to understand that a loss of Geographical SA can precipitate a loss of Spatial/Temporal SA and in many cases may even lead to spatial disorientation (SD). Spatial disorientation is a subset of SA related to the flying environment and will be discussed later in this course.

2. **Spatial/Temporal SA**

   Spatial/Temporal SA includes, but is not limited to, knowledge of the aircraft's altitude, attitude, heading, velocity, vertical velocity, G-loading, flightpath, aircraft capabilities, projected flightpath, and project landing time. Although similar in nature, both Geographical and Spatial/Temporal SA differ in that Geographical SA is in relation to topography while Spatial/Temporal SA is in relation to the earth.

3. **System SA**

   System SA includes system status, functioning and settings, radio settings, altimeter and transponder equipment, flight modes and automation settings, impact of malfunctions and system degradation, fuel, time, and distance available of fuel.

4. **Environmental SA**

   Environmental SA includes knowledge of weather formations, temperature, icing, ceilings, clouds, fog, sun, availability, visibility, turbulence, winds, microbursts, instrument flight rules (IFR) vs. visual flight rules (VFR) conditions, areas and altitudes to avoid, projected weather conditions.

5. **Tactical SA**

   Tactical SA includes identification, tactical status, type, capabilities, targeting, threat prioritization, location and flight dynamics of other aircraft, aircraft detections, launch capabilities, imminence and assignments, current and projected threats intentions, firing and maneuvering, mission timing and status.

Levels of Awareness

A person may correctly perceive their spatial and positional relationship to earth and may even perceive their position in relation to other aircraft, but may not perceive a serious system malfunction occurring in the aircraft because of a poor or improper crosscheck. As a result, they are not situationally aware. To be situationally aware, a person must: (1) sense various aspects of their environment, (2) attend to that information and perceive it, (3) integrate that information at an intellectual level, (4) produce an awareness of the situation at that instant, and (5) constantly update this awareness as a result of new sensory information.

Situational awareness is dependent on one's knowledge, information availability, predictive capability and ability to direct attention to the right information at the right time, and the ability to integrate information into a current concept of the situation. Maintenance of situational awareness requires tremendous coordination and timing capacity to direct the conscious to the appropriate information at the appropriate time and then be able to develop a concept of what is occurring. Making it even more difficult is the requirement to project the nature of the situation into the future and the requirement to conceive and execute actions based on that projection. There are a multitude of factors which can both positively and negatively affect these abilities. For example, forecasting and executing are based on one's initial perception as well as their training, experience, and their ability to effectively manage stress during demanding scenarios.

To perform a task, you must invest some level of attention to it, and depending on urgency and risk, certain levels of awareness must be employed. SA theorist Micah Endsley (*Toward a Theory of Situational Awareness in Dynamic Systems*, 1995) supposes there are three levels of awareness:

Level 1: Perception (Basic)

Level 2: Comprehension (Intermediate)

Level 3: Prediction (Advanced)

CONTENTS
PREVIOUS

Level 1: Perception (Basic)

The first (basic) level of situational awareness is the raw cue received and processed by our sensory systems; most often referred to as *perception* (Figure 7-3), but it's important to note that the signal may be present without awareness if there is background *noise* or inattention to a particular signal. This is the root cause of loss of SA; without signal identification you cannot move to the next level of awareness.

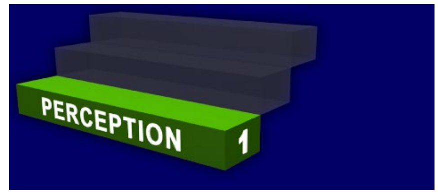

Figure 7-3 — Perception

Level 2: Comprehension (Intermediate)

The second (intermediate) level of situational awareness is based on the comprehension of the situation (Figure 7-4). For instance, all of the sensory inputs processed in a given period of time are channeled to a central processing station for racking and stacking in terms of priority. Once processed, the signals help to form a holistic view of the environment. If an environmental cue is not processed due to competing signals, then the picture may not be as clear and the level of SA is not fully formed at the comprehension level.

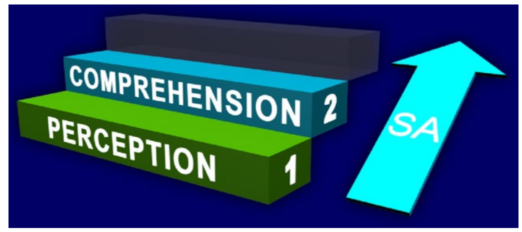

Figure 7-4 — Comprehension

Level 3: Prediction (Advanced)

Once the comprehension of environmental cues is established, the next level of situational awareness (advanced) is *projection* or a prediction of "what happens next?" (Figure 7-5). The link to this level of SA is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation. In other words, a combination of both level one and level two SA. The prediction of future actions is typically focused on the near term. The next few minutes of the mission relies upon advanced experience and judgment formed by technical knowledge of the system or situation.

Figure 7-5 — Prediction

CONTENTS
PREVIOUS

Processing SA Cues

Presentation and processing of SA cues is critical to good SA. In the flight environment these cues are presented in various ways, such as instrumentation clusters and gauges, clouds and other weather phenomena, warning tones and lights, among other engineering mechanisms such as the stick shaker. Though these cues often save lives and preserve combat assets, the human's ability to process those cues is limited to the four previously mentioned sensory mechanisms; visual (sight), vestibular (orientation), somatosensory (touch/feel), and auditory (hearing).

Each of these mechanisms is reliant on appropriate cue levels, types, and frequencies to affect good SA. Some cues may not be strong enough, or are not delivered using the right method to illicit or drive a response from the aviator. Cues such as altitude warning horns may be loud; but if they are not the right tone and pitch, a crewmember cannot effectively discriminate the warning horn from other loud noises. Another example is a nuisance warning light while flying in the pattern to an engine fire light during takeoff. A decision (aircraft input) must be made, and sometimes the decision is to do nothing.

Predominant Causes of Loss of Situational Awareness (LSA)

Perception

When a crewmember is presented with too much, too little, or incorrect information, adequate information processing and reaction time must also be provided. Processing time is critical because humans' ability to transform presented information into an accurate perception is highly dependent on how much time is available. Additionally, more time is required to convert that accurate perception into a physical action (or inaction). Using our previous example, how long did it take the pilot to read and recognize the engine RPM gauge read zero? Additionally, how long before she directed the boom operator to check the circuit breaker? For humans, conscious perception with resulting motor input doesn't happen automatically, and this human factors limitation greatly affects the interaction between Liveware and the other four HSI components.

Perception is the acquisition and processing of sensory information which guides a response based on those objects (Blake and Sekuler, 2006). According to Benson & Strughold (1969), perception follows a definite chronological pattern. After a stimulus has been applied, a certain period elapses before the sensation is perceived; the sensation then increases to a maximum, after which it begins to fade. Hence, before the sensation becomes manifest, it is preceded by a latent phase. This span of time is the perceptual latent period (Figure 7-6), i.e., the period between the onset of the stimulus and the onset of its perception.

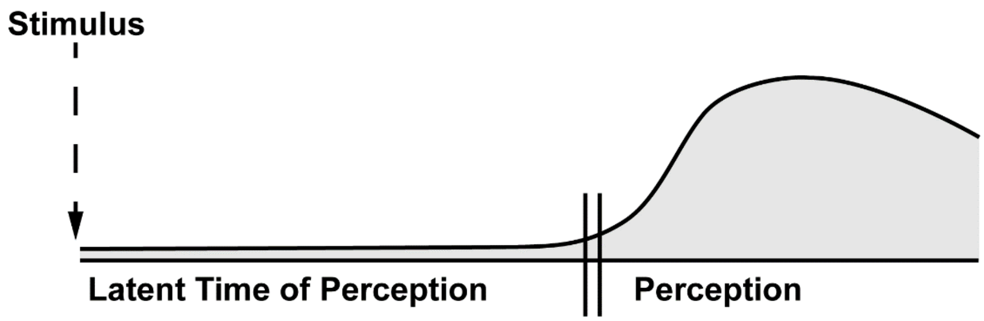

Figure 7-6 — Perceptual Latent Period

In early Air Force aviation, perceptual latency generated very little interest until the evolution of aircraft flight decks and cockpits. Advancements such as glass instrumentation, heads-up/heads-down displays, helmet-mounted cueing systems, night vision devices, etc. highlighted the need to understand the amount of time needed for aviators to safely process key information, especially during critical phases of flight. Perception, decision, and reaction times are particularly important in remote aviation due to the inherent Information Technology (IT) latency associated with remote aviation.

Reaction Time

The perceptual latent period is also part of the reaction time, forming its first or sensory part. Reaction time is a measure of how quickly an organism can respond to a particular stimulus (Marieb, 2003). Reaction time has been widely studied, as its practical implications may be of great consequence, e.g. a slower than normal reaction time while driving can have grave results.

In an effort to mitigate the risks associated with perceptual latency and reaction time limitations, Blake and Sekuler (2006) suggest a concept termed Active Perception. Active Perception drives sampling behavior. When aviators sample their environments purposefully, they look (visual), listen (auditory), touch (proprioceptor), rather than waiting on cueing events to happen, ignoring cues and making no decision at all. Additionally, active perception promotes temporal preparation; and just like event preparation reduces the number of response alternatives, temporal preparation improves perception and reaction time.

Many factors have been shown to affect reaction times, including age, gender, physical fitness, fatigue, distraction, alcohol, personality type, and whether the stimulus is auditory or visual. Perception and recognition scenarios vary based on phase of flight, time of day, crew or formation make-up, while perception and reaction time may vary based on a number of factors such as those listed in Figure 7-7 — Perception and Reaction Time Factors.

CONTENTS
PREVIOUS

Perception Factors
Attitudes
Motives
Interests
Experience
Expectations
Time of Day
Work/Social Setting
Type of Stimulus (Frequency, strength, and Location)
Available Time

Reaction Time Factors
Age
Gender
Physical Fitness
Fatigue
Distraction
Alchohol
Personality Type
Type of Stimulus (Frequency, strength, and Location)
Available Time

Figure 7-7 — Perception and Reaction Time Factors

Mitigating Perception-Reaction Threats

Aircrew can prepare for a given event by visualizing that event in advance. For example, carefully considering the steps to take during an emergency procedure can give aircrew a performance benefit when that emergency occurs.

According to Jennings, and Coles (1991), they distinguish two types of preparation: *event preparation* and *temporal* or *time preparation*. In the first case, one has advance information about the features of the upcoming stimulus or the associated response and hence, the response alternatives are reduced. In short, one knows *what* stimulus will be delivered and *which* response is required. In the second case, one has advance information about the temporal moment of the upcoming stimulus, that is, one knows *when* the stimulus will be delivered.

For an example of event preparation, assume a driver steering a car on a curvy road in the mountains. Various traffic signs announce whether the next curve is a leftward or a rightward curve. The driver can use this information to prepare the necessary steering movements, even though he might not yet be able to see the next curve.

Rosenbaum (1980) developed the so-called pre-cuing procedure in which a pre-cue provides participants with advance information about the reaction time (RT) response movement that has to be executed. He observed that advance knowledge about one or more parameters of the required response movement (e.g., side, direction, or distance) decreased RT. Similarly, Osman et al. (1995) found that pre-cues reducing a four-alternative to a two-alternative choice task decreased reaction time and more specially, the motor part of reaction time.

To sum up, when participants know in advance what kind of response is required by the target stimulus, they can prepare motor aspects of the response in advance and hence, respond faster. Everyday examples for temporal preparation can be found in various situations, for example, in sport. Assume a drag car racer waiting to go. Before the light turns green and he can actually accelerate, the yellow light will appear. Or, assume a runner performing a 100-meter sprint and listening to the shouting of “Ready, steady, go!” In both examples, the start signals, that is, the green light or the shouting of “go!” are announced by a warning signal, that is, the yellow light or the shouting of ‘steady.’ The driver and the runner can use these warning signals to anticipate, and thus prepare for, the occurrence of the start signals and hence initiate an earlier acceleration or start, respectively. Just like event preparation reduces the number of response alternatives, temporal preparation reduces the potential time points of stimulus presentation and thus improves reaction time.

Attention Management Threats

General Attention Management Threats

Many major mishaps are due to lost situational awareness involving attention threats. Attention threats hamper or prevent proper situational awareness. They can occur when the conscious level of awareness is distracted, has too many tasks to manage, or fails to monitor the environment.

Self-imposed stresses make attention threats more likely. Poor nutrition, fatigue, poor physical condition, and medications all have the tendency to affect your ability to allocate your attention appropriately. As a professional, it’s your responsibility to prepare yourself both physically and mentally for the challenges inherent in being a crewmember, including seeing the flight surgeon when you don’t feel well.

CONTENTS
PREVIOUS

According to the Air Force Safety Center the most predominant attention management threats are captured in the *Person-Level Factors* section and categorized under *Physical and Mental State*. The mental and physical states of individuals are how people know, think, learn, understand, perceive, feel, hurt, guess, recognize, notice, want, wish, hope, decide, expect, remember, forget, imagine, and believe. There are four sub-categories to Physical and Mental State:

Physical Problem (PC300) is defined as medical and physical conditions that can result in unsafe situations.

Substance Effects

Physical Illness/Injury

Fatigue

Dehydration

Body Size/Movement Limitations

Physical Strength & Coordination

Nutrition/Diet

Effective/Efficient Attention Allocation through Preparation

Chair Fly (Identify challenge areas)

Effective Mission Pre-Brief and Step Brief

Self-Assessment

Physical and Mental Condition

Know Capabilities and Limitations

Enhance Working Memory

Mission Briefings

Rehearsal - Review of Probable Events

Task Management Plan

Figure 7-8 — Tools for AMT Improvement

State of Mind (PC200) is defined as when an individual's personality traits, psychosocial problems, psychological disorders, or inappropriate motivation creates an unsafe situation.

Psychological Problem	Life Stressors	Personality Style	Overconfidence
Pressing	Complacency	Motivation	Mentally Exhausted (Burnout)

Sensory Misperception (PC500) are factors resulting in degraded sensory inputs (visual, auditory, or vestibular) that create a misperception of an object, threat, or situation.

Motion Illusion is degraded	Turning/Balance Illusion	Visual Illusion
Misperception of Changing Environment	Misinterpreted/Misread Instrument	Temporal/Time Distortion
Misinterpretation of Auditory/Sound Cues	Spatial Disorientation	

Mental Awareness (PC100) is defined as factors of an attention management or awareness failure that affects the perception or performance of individuals.

Not Paying Attention (Inattention)	Fixation	Inaccurate Expectation
Negative Habit Transfer	Distraction	Interference/Interruption
Technical/Procedural Knowledge Not Retained	Task Over-Saturation/Task Under-Saturation	

Task Inattention

Interestingly, the human body considers decision making a mundane task and quickly teaches itself to memorize tasks as to exert as little energy as possible. The physiological truth is that human beings are lazy by nature, always searching for the most energy-conserving and quickest ways to accomplish tasks. This phenomenon is always present and is even more active after accomplishing the same task for extended periods of time. In the cognitive arena, this is also known as the Boredom Effect or Boredom Proneness. Boredom Effect reflects that human performance is influenced by a lack of concentration or boredom when participating in an assignment that has too many tasks, or if a single task is too lengthy or tedious.

Preventing, Recognizing, and Recovering From LSA

Tools for Improving Attention Management

Attention management threats can be mitigated through mission preparation and an honest awareness (assessment) of your current capabilities and limitations (both physical and mental). Additionally, a systematic evaluation of each crewmember's proficiency and currency (e.g., pre-step operational risk management (ORM)), in conjunction with

CONTENTS
PREVIOUS

thorough preflight preparation (i.e., effective mission pre-briefs and mission planning) will significantly reduce the likelihood of inattention errors. Also, mission or flight rehearsal (chair flying) allows for faster reaction time to events with less probability of error. This also reduces the possibility of unanticipated events and uncertainty. These actions (Figure 7-8) can all help free-up attention allocation and reduce the risk of distraction, fixation, task saturation, or other technical errors that increase attention requirements. In addition, building a mission plan based on your current abilities identify potential safety of flight issues thereby reducing the potential for a mishap.

Tools for Preventing LSA

SA can vary from day-to-day and from mission-to-mission, depending on factors such as your physical condition, experience, and mission complexity. Crewmembers should be vigilant of their own condition. There are many tools a crewmember can use to build and keep SA in flight such as these listed below:

Constantly Assess Your Own Performance (and of Others)

Upon arriving at the aircraft, while reviewing the forms and conducting the preflight, analyze how discrepancies will affect the mission. Use risk management tools to determine if any aircraft factors will render the flight environment, or crew capabilities, unsafe. While in flight, planning for the next phase of flight is another tool for preventing LSA. If you're not doing something or planning for the next phase of flight, there is an opportunity to lose situational awareness. Stay ahead of the aircraft and environment and always have a way out. The *"I'M SAFE"* checklist is just one of many recommended strategies to assist aviators with self-assessment.

The "I'M SAFE" Checklist

Illness — Are you currently suffering from any illness or recovering from a recent illness?

Medication — Avoid taking any medications while flying. All medications must be approved by the flight surgeon.

Stress — What is your stress level? Mental? Physical?

Alcohol — Are you still under the influence of alcohol, including its residual effects?

Fatigue — Do you currently feel fatigued or tired?

Eating — Are you maintaining your hydration, and have you eaten a nourishing meal prior to the mission?

Establish Contracts during Mission Briefs/Discuss Broken Contracts during Post-Flight Debriefs

Another tool for improving situational awareness is to establish pre-agreed actions and communications procedures during pre and post-flight briefings. This technique reduces indecision due to sudden emergencies and other high intensity situations; this is especially useful during critical phases of flight such as departure and landing, gaining or losing altitude, or a kinetic event. Parts of the contract might include brevity and communication expectations, emergency actions and techniques, and other pre-agreed crew expectations.

Mission pre briefs, step briefs, or hand-over briefs, provide opportunities to increase awareness by asking "What if?" questions. Use these briefings to fill knowledge gaps and to acknowledge known threats and ensure mission objectives are clear and concise.

Additionally, post-flight debriefs provide opportunities for the entire crew to discuss what happened and why. It also allows for techniques, tactics, and procedures to be shared amongst team members to further mitigate potential safety of flight issues. Oftentimes, discussing what did not happen, is just as important as discussing what did happen; especially as it pertains to broken contracts between crewmembers, or other pertinent operators such as Air Traffic Control (ATC), Ground Forward Air Controller (GFAC)s, Flight-Leads, Mission Control Center (MCC)s, etc.

Minimize and Manage Interruptions

Interruptions (e.g., due to ATC communications) and distractions (e.g., due to a conversation among others on the flight deck) occur frequently during flight. Some cannot be avoided and therefore must be coped with by the flight crew. Others can be minimized or eliminated through training, adoption of effective procedures, discipline and the use of good judgment. According to the skybrary website (2019), you should avoid the most frequent causes of interruptions and distractions including: non-flight-related conversations, distractions by cabin crewmembers, and non-flight-related radio calls.

CONTENTS
PREVIOUS

If the number of interruptions and distractions is not minimized or the impact of residual interruptions and distractions is not controlled, flight safety can be affected. In particular, when a flight crew is disturbed while monitoring or controlling the aircraft, errors can occur and go undetected (Skybrary, 2019).

Delegate Tasks

Whether flying in a two-ship low on fuel and having problems finding a tanker or carrier, or flying an RPA providing real-time intelligence to ground forces, the delegation of tasks helps ensure that all the bases are covered and the entire aircrew isn't focused on just one aspect of the problem to the exclusion of all other activities. Delegation matrices can also be established as a part of the mission pre-brief.

Situational Awareness Recovery (SAR)

After reductions in SA, a skilled operator must reassess the environment to recover SA. Gartenberg et al. (2013) call this process Situation Awareness Recovery (SAR) and is defined as the process of restoring SA when SA has been reduced. What do you do if you recognize lost SA? First, reassess and reprioritize in-flight tasks and then communicate.

Prioritize Tasks

In-flight tasks can be prioritized in the following three categories:

1. Terrain clearance tasks — ***Fly the aircraft***. Get away from dirt, trees, and rocks; call "knock-it-off"; and reevaluate your situation.

2. Mission critical tasks — These tasks are essential for the successful completion of the mission.

3. Noncritical tasks — The completion of these tasks makes no significant contribution to the mission. However, a noncritical task could become elevated to a higher level task if not attended to at the right time.

Communicate

Communication can go a long way in clearing an LSA episode. Talk to other flight members, crewmembers, or other agencies to build SA.

Declare an Emergency

If needed, declare an emergency. Declaring an emergency has several positive effects for regaining SA. Doing so communicates with everyone involved and lets them know you have a problem and need help to resolve it and gets immediate attention and priority of air traffic control. Declaring an emergency focuses your attention to the task at hand — flying the aircraft and landing safely.

Recognizing LSA

When aviators lose SA, it is be helpful for them to know their own warning and/or red flag indications. Additionally, keep in mind that loss of situational awareness is often insidious and may not be obvious until the severity of the situation rises — then what?

The following are some cues for recognizing a loss of SA.

1. Fixation — During emergencies, extended Intelligence, Surveillance and Reconnaissance (ISR) tasks, or kinetic events.

2. Distraction — Zoning-out or silence to include the repetition of old information.

3. Complacency — The "I've done this a hundred times" trap.

4. Gut feeling and/or confusion — Subconscious is delivering a warning which requires an action.

5. Poor communication or slow to respond — Missed radio calls or challenge and response items.

6. Failure to meet targets — Low-level entry time, Estimated Time of Arrival (ETA) and/or Actual Time of Arrival (ATA) discrepancies, checkpoints.

7. Improper procedures — Deviations from regulations, Rules of Engagement (ROE)s, or checklist procedures.

8. Unresolved discrepancies — Two independent sources disagree and remain unresolved.

9. No one flying the aircraft — Everyone is involved with other tasks.

Manifestations of these individual threats may be subtle and difficult to pick up. Attention threats and inappropriate motivations discussed earlier are some of the many ways loss of SA can present itself.

Tools for Improving SA Aptitude

It could be argued that, with practice, the resources required to maintain control in the most cognitively demanding situations can be efficiently used to ensure a successful outcome. The cognitive constructs and processes thought to underpin the SA process have received great attention by organizational and aviation psychology and now human factors engineers. The bottom-line is that SA doesn't just happen, it requires effort and practice. Here a few tools for improving SA:

Tool 1: Constantly update SA threats due to aircraft modifications .Stay up to speed on MDS improvements, revisions and updates.

Tool 2: Improve reaction and perception time. Examples: Mindbluff and Humanbenchmark.com

Tool 3: Stay smart of mishap trends involving LSA.

Air Force Safety Automated System (AFSAS); Air Force Safety Center (AFSEC) monthly, quarterly, and annual data; Air Force Military Flight Operations Quality Assurance (MFOQA); Aviation Safety Action Program (ASAP); Line Operations Safety Audit (LOSA); AP Professionals, Flight Surgeons, SQ/SE and WG/SE agencies

Tool 4: Sense various environmental aspects Examples: KIMs games

Summary

Whether it's due to task fixation, distraction, supervisory pressure, or one of the numerous other causes, loss of SA continues to be a major cause of human factors-related mishaps. The challenge for the aviator is to first understand what SA is and how to build it. Then, by assessing their own risk for problems maintaining SA in flight as well as effective preflight, inflight, and post flight planning, and appropriate task delegation, the crewmember is on their way to preventing a loss of SA.

Unfortunately, high levels of SA are not possible at all times on all missions. Therefore, it becomes imperative for aircrew to know the warning signs for diminishing SA, to recognize loss of SA in themselves and in others, and to rebuild SA through task prioritization and communication. Applying these and other attention management skills will improve the SA of the entire crew/flight and go a long way towards preventing human factors-related mishaps.

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CONTENTS
PREVIOUS

Review Exercise AP107

Complete the following review exercise by choosing the correct answer(s) or filling in the blanks. Answers follow the questions.

1. Briefly define the USAF Aerospace and Operational Physiology definition of situational awareness.

2. Match each SA component with its appropriate definition.

SA Component

a. _____ Geographical

b. _____ System

c. _____ Tactical

d. _____ Environmental

e. _____ Spatial/Temporal

Definitions

1. Knowledge of the location of one's own aircraft, other aircraft, terrain features, airports, cities, waypoints, navigation, fixes and position relative to designated features, runway and taxi assignments, and climb and descent points. It is critical to understand that a loss of Geographical SA can precipitate a loss of Spatial/Temporal SA and in many cases may even lead to spatial disorientation (SD).

2. Knowledge of the aircraft's altitude, attitude, heading, velocity, vertical velocity, G-loading, flight path, aircraft capabilities, projected flight path, and project landing time.

3. Knowledge of system status, functioning and settings, settings of radio, altimeter and transponder equipment, flight modes and automation settings, impact of malfunctions and system degradation, fuel, time, and distance available of fuel.

4. Knowledge of weather formations, temperature, icing, ceilings, clouds, fog, sun, availability, visibility, turbulence, winds, microbursts, IFR vs. VFR conditions, areas and altitudes to avoid, projects weather conditions.

5. Knowledge and identification of tactical status, type, capabilities, targeting, threat prioritization, location and flight dynamics of other aircraft, aircraft detections, launch capabilities, imminence and assignments, current and projected threats intentions, firing and maneuvering, mission timing and status.

3. SA theorist Micah Endsley (1995) supposes there are three levels of awareness; Level 1: __________, Level 2: __________, and Level 3: __________.

4. Type of Stimulus is a factor that affects both perception and reaction time.

   a. True

   b. False

5. Temporal (event) preparation reduces the potential time points of stimulus presentation and thus improves reaction time.

   a. True

   b. False

6. Chair flying, mission pre-briefings, self-assessment, and rehearsal of probable events are all effective tools for improving attention management.

   a. True

   b. False

CONTENTS
PREVIOUS

Answers to Review Exercise AP107

1. USAF Aerospace and Operational Physiology definition as the starting point in the understanding of SA: “The accurate perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.”

2. a. 1
   b. 3
   c. 5
   d. 4
   e. 2

3. Perception; Comprehension; Prediction

4. a

5. a

6. a

CONTENTS
PREVIOUS

AP108 — Spatial Disorientation

Hours and Medium

1.5 Hours (IBT)

Objectives

1. Know the characteristics of spatial disorientation.

   Samples of Behavior:

   a. Know the threats and impacts of the different types of spatial disorientation.

   b. List four sensory systems used in orientation.

   c. Define the relationship of the sensory systems to spatial disorientation.

2. Know characteristics of the orientation sensory systems.

   Samples of Behavior

   a. Select the sensory system providing the strongest, and usually the most reliable, orientation information.

   b. Describe the vestibular system.

   c. Define the relationship of the vestibular system and the two subsystems: semicircular canals and the otolith organs.

   d. Determine the reason for the somatosensory system's unreliability in-flight.

   e. Recall the location of tactile pressure receptors of the somatosensory system.

   f. Describe the somatosensory system's function in-flight.

3. Know the characteristics of the types of vestibular induced spatial disorientation.

   Samples of Behavior

   a. Identify the cause of each somatogyral illusion.

   b. Recognize the cause of somatogravic illusions.

4. Know the factors affecting spatial disorientation.

   Samples of Behavior:

   a. List items affecting environmental factors of spatial disorientation.

   b. Recall items affecting physiological factors of spatial disorientation.

   c. Identify other factors that affect SD.

5. Know how to prevent and/or overcome spatial disorientation.

   Samples of Behavior:

   a. Recall 5 methods used to prevent spatial disorientation.

   b. List 7 procedures used to overcome spatial disorientation.

6. Know the causes of and techniques to prevent/overcome motion sickness in flight.

   Samples of Behavior:

   a. Identify the most widely accepted theory of the cause for motion sickness.

   b. Identify techniques to help prevent and/or treat motion sickness.

Assignment

1. Read AP108 in the SG and answer the review questions.

2. Read AFPAM 11-417, *Orientation in Aviation*.
3. Reference AFMAN 11-217, *Flight Operations.*

Introduction

As “ground dwellers,” we’ve established a remarkable store of information about the “correctness” of two-dimensional movement within our environment. Over the years, we’ve relied on the accuracy of this information as input by our balance and orientation senses — the visual system, the vestibular system of the inner ear, the somatosensory system (pressure receptors of the body), and the auditory system.

When flying in visual meteorological conditions, all four sensory systems are working to provide for you spatial orientation relative to the earth’s surface. During instrument meteorological conditions (IMC), at night or in the weather, the eye does not provide adequate external visual information. As a result, the vestibular, somatosensory, and auditory systems remain to process the complex motions and forces of flight. Information processed by these systems alone is unreliable because of the ease at which they automatically adjust to whatever aircraft attitude you’re flying, right or wrong. Under these conditions, your brain compares the information detected by your remaining senses to the two-dimensional information you have relied on all your life. If they match, you remain oriented. However, a mismatch generates illusions capable of quickly placing your senses in conflict with reality and causing spatial disorientation.

Information

Definition and Classification

Definition

Spatial disorientation (SD) is defined as the inability to accurately orient yourself with respect to the earth’s horizon (Davis et al., 2008). We use four sensory systems to maintain our orientation and equilibrium (balance) — the visual system, the vestibular system, the somatosensory system and the auditory system. These systems are effective when a person is on the ground, in a 1G environment performing normal activities. Collectively, they convey an accurate message of orientation and balance. Unfortunately, when these sensory systems are used in-flight, they are not reliable orientation indicators. This fact is especially evident when visual cues are lost or become confusing. Therefore, be aware of the mechanisms, functions, and reactions of the sensory systems used for orientation in the flying environment.

In the following sections, types of SD, sensory systems and their related illusions, factors affecting SD, prevention of SD and recovery from SD are discussed. Additionally, the causes and preventive measures of motion sickness are discussed.

Classification

Spatial disorientation is classified into three types. Each type has different characteristics posing different threats to the crewmember.

Unrecognized Spatial Disorientation (Type I) — Is the most dangerous type of SD you can experience. Unrecognized SD occurs when you do not realize you are disoriented. In this case, you believe the aircraft is in a normal or desired attitude (pitch, roll, and/or yaw), when in reality the aircraft is in a different or unusual attitude. Unrecognized SD can occur while flying in clouds (no horizon) and relying on your vestibular and somatosensory systems to provide attitude information instead of the flight instruments. As a result, you think the aircraft is flying straight and level, when in reality it may be in a 30° left bank and nose low. Unrecognized SD can lead to controlled flight into terrain (CFIT), especially in high-speed, low-altitude environments.

Recognized Spatial Disorientation (Type II) — Is the least dangerous type of SD. You perform effective instrument cross-checks and identify the fact you are disoriented. As a result, you are able to recover from SD using your flight instruments.

The main purpose of SD training is to enable you to move from unrecognized SD to recognized SD. Recognizing SD allows for recovery of the aircraft or ejection (if necessary) before you are out of the ejection envelope.

Incapacitating Spatial Disorientation (Type III) — Occurs when you are so disoriented that you are incapable of recovering even if it is recognized. Fortunately, this type of SD is rarely experienced. However, there are documented cases where crewmembers realized they were disoriented, but were unable to recover because of the overwhelming sensory stimulation. In these cases, you can eject if you have the capability, or use other aids such as the autopilot or fellow crewmembers to help recover the aircraft.

CONTENTS
PREVIOUS

Orientation Sensory Systems

The visual system, the vestibular system, the somatosensory system and the auditory system can all be "fooled" into believing what they sense is "true and accurate" in the flying environment.

Information from each sensory system is sent to the brain, which coordinates all the input. If the input from each system agrees with the others, the individual is "oriented." However, if there is a mismatch between the systems, three things can occur. The individual becomes disoriented, motion sick or both. Figure 8-1 depicts the different sensory systems and their connections to the brain. The following describes the different systems, their function and their limitations in-flight.

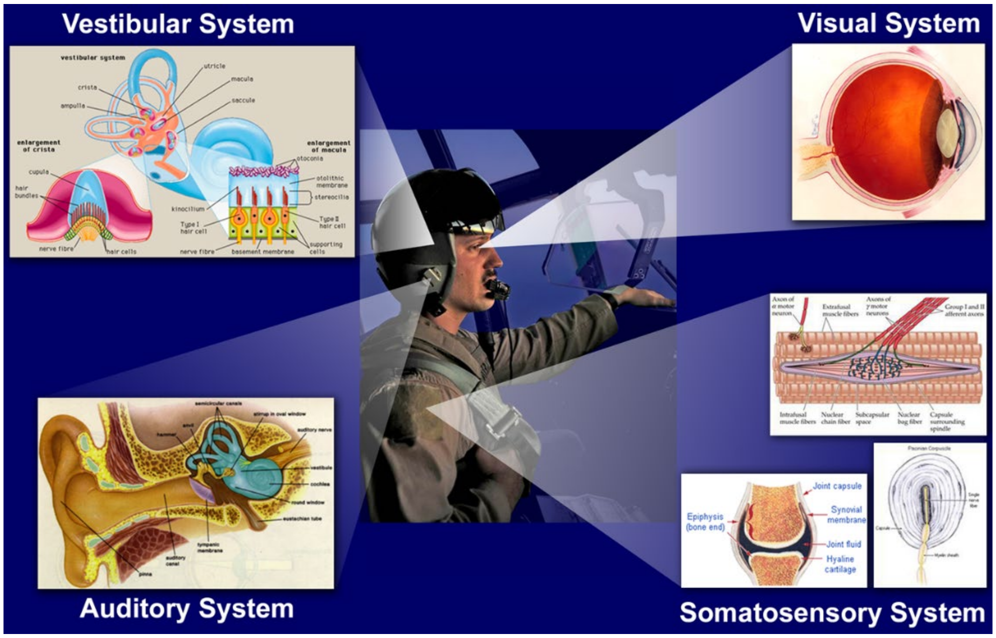

Figure 8-1 — Sensory Systems

The Visual System

The eyes provide the strongest and, usually, the most reliable orientation information during flight. Recall from the Vision lesson, peripheral vision is the primary means the visual system uses to collect orientation cues. The orientation cues provided by the eyes are strong enough to overpower all other orientation system inputs. Orientation cues from the peripheral visual field are primarily processed subconsciously, at much faster speeds than information from your focal vision. As a result, a "straight line" within the *visual field* is perceived by your *peripheral vision* as a horizon, regardless of the "straight line's" orientation to the surface of the Earth.

Most of the time, the information the eyes receive is correct. For instance, if you become disoriented flying in clouds (because of confusing vestibular input), and then fly out of the clouds and acquire an accurate horizon, the disorientation disappears almost instantly. However, when the horizon acquired is not correct, your vestibular disorientation disappears, but you may still experience visual illusions caused by the false horizon.

Visual illusions involving peripheral vision are difficult to avoid. Since information acquired by the peripheral visual fields is processed subconsciously, you must use your focal vision (requiring conscious attention) to override the peripheral input. Use your focal vision by concentrating on the flight instruments to ensure the aircraft flies correctly. Unfortunately, it's difficult to override the peripheral visual inputs and it takes practice, discipline and concentration to accomplish. If flight instruments are not used when visual horizon inputs are lost due to flying in clouds, at night or in haze, the brain reverts to the vestibular system for orientation information.

The Vestibular System

The vestibular system is located in the inner ear and consists of two subsystems — the semicircular canals and the otolith organs. Designed to work on the ground, they are responsible for two different categories of illusions in-flight depending on which subsystem is stimulated. If the semicircular canals are stimulated, the illusions are categorized as somatogyral

CONTENTS
PREVIOUS

illusions. If the otolith organs are stimulated, the illusions are somatogravic illusions. Figure 8-2 illustrates the vestibular system.

The Semicircular Canals — Located in each inner ear. There are three canals in each ear, oriented at right angles to one another in the pitch (vertical), roll (lateral), and yaw (horizontal) axes. They measure angular acceleration caused when the head is turned or tilted. For the semicircular canals to sense angular acceleration, the acceleration must reach a threshold in the range of 0.14°/sec^2 to .5°/sec^2 actual movement.

Each semicircular canal contains a fluid called endolymph, which is stimulated into motion when the head accelerates in the axis of the canal. When the head is accelerated, the fluid in the canal lags behind because of inertia. As a result, the apparent motion of the fluid is in the opposite direction of the acceleration. This motion causes a concentration of specialized nerve cells called the *cupula* to bend in the direction of the fluid motion. The bending of the cupula sends a signal to the brain which interprets the signal as changes in position or attitude. Use Figure 8-3, A and B for the following example. If a person rotates their head to the right, the acceleration causes the displacement of the fluid to the left and the cupula bends to the right. The brain interprets the bending of the cupula to the right as angular motion to the right.

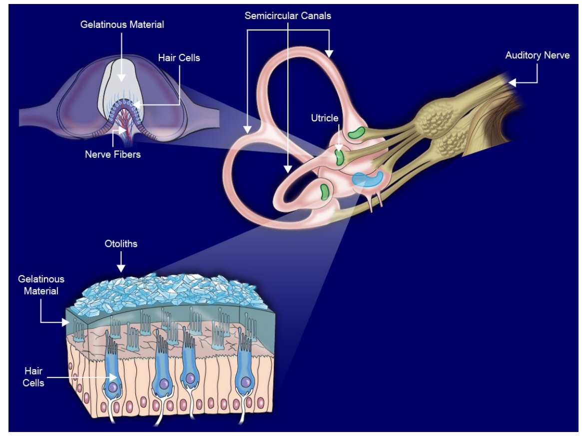

Figure 8-2 — Vestibular System Anatomy

On the ground, the semicircular canals are an excellent complement to vision as an orientation system. However, in-flight and without adequate visual cues, the semicircular canals have a strong and unreliable orientation input to the brain. Additionally, input from the semicircular canals can be strong enough to cause muscles to react and attempt to keep a crewmember upright.

There are maneuvers that stimulate the semicircular canals for extended periods of time. If the angular acceleration continues at a constant rate for a period of 10 to 20 seconds, the motion of the fluid in the canals equalizes with the motion of the canals. When equalization occurs, the apparent motion of the fluid is zero, the cupula are not deflected, and the brain receives a false impression that rotation has stopped (Figure 8-3, C). Therefore, in the absence of visual cues, you do not perceive you are in a bank, descent, or climb. If the motion stops or decelerates, the inertia of the endolymph causes it to continue in the original direction of acceleration. This stopping or deceleration results in the cupula being deflected in the opposite direction of the original acceleration (Figure 8-3, D). As a result, you experience the sensation of moving in the opposite direction of your original maneuver.

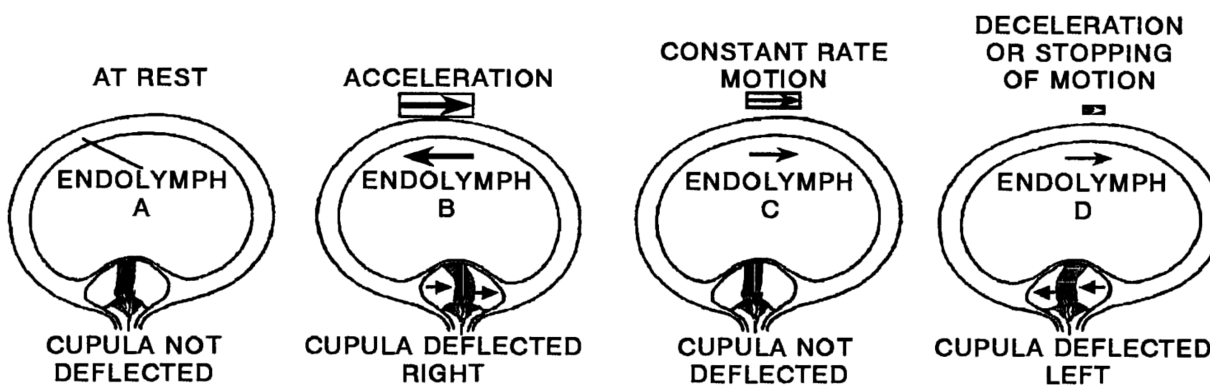

Figure 8-3 — Semicircular Canal and Angular Acceleration

An example of the effect of angular acceleration on the semicircular canals in-flight occurs when you enter a holding pattern while in the weather. In this case, the absence of a visual horizon results in the semicircular canal input being used for orientation. As you enter the holding turn, you roll the aircraft to 30 degrees of right bank (stimulating the roll canal) and begin a 180-degree turn, taking one minute. Within 10 to 20 seconds of the initiation of the turn, the endolymph

CONTENTS !!!
PREVIOUS

equalizes and there is no physical sensation of being in a bank. When you roll out of the turn, the fluid in the canal continues to move and displaces the cupula in the opposite direction. You sense the aircraft in an opposite left bank of the same magnitude as your initial bank when in reality you are in straight-and-level flight. If you are not using your flight instruments, you may react to the sensation of being in an opposite bank by rolling into a right bank to make your head "feel right." All three semicircular canals work on the principle depicted in Figure 8-3 (response to angular acceleration) and more than one canal can be stimulated at a time.

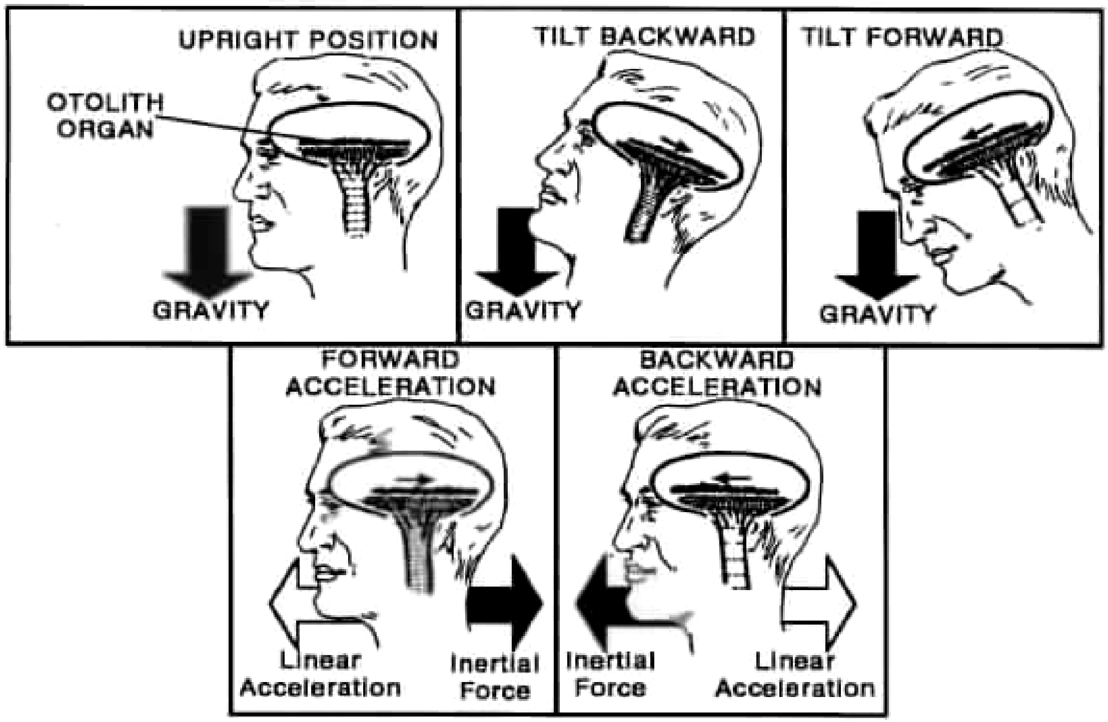

Figure 8-4 — Otolith Organs and Linear Acceleration

The Otolith Organs — Located near the base of the semicircular canals in the vestibular apparatus and sense linear acceleration (refer to Figure 8-4). They consist of a base of nerve cells with hair like appendages that are embedded in a gelatinous substance containing calcium carbonate crystals. As you tilt your head forward, the crystals slide forward and the nerves signal the brain that the head is tilted forward. Conversely, if you tilt your head back, the crystals slide backwards and the nerves signal the brain that a backward tilt is occurring. In-flight, forward or backward linear accelerations cause the crystals to slide backwards or forwards respectively in response to the inertial force. For instance, if you accelerate forward, the crystals slide to the rear and, in the absence of a visual horizon, you sense the aircraft is pitching up. Conversely, a rapid deceleration causes you to sense the aircraft is pitching down. In either case, you may react by pulling back on the stick or yoke or pushing forward to compensate for the perceived change in pitch attitude. Figure 8-4 shows the function of the otolith organs in normal situations and in response to linear accelerations.

The Somatosensory System

The somatosensory system consists of tactile pressure receptors in the skin, muscles, tendons, and joints. The pressure receptors are used to help maintain posture and balance. The somatosensory system is often called the "seat-of-the-pants" sense. Unfortunately, in-flight, the somatosensory system is useless as an orientation system in the absence of correct visual cues. Because most flight maneuvers are made in the positive-G environment, there are no variations in pressure cues. Therefore, the somatosensory system does not receive adequate input to tell the somatosensory receptors if the aircraft is in a bank, nose up, nose down or inverted attitude.

The Auditory System

The auditory system can help maintain situational awareness and spatial orientation through feedback. This feedback is related to aircraft speed and its relationship to the noise produced by the aerodynamic forces acting upon the aircraft. For

CONTENTS
PREVIOUS

example, in IMC, increasing airstream noise may indicate an undesired nose down attitude. This auditory information should cause you to check your instruments and take corrective action, if required.

Vestibular Induced Spatial Disorientation

The visual, vestibular and somatosensory systems work together to tell you where you are in relation to your environment. You can look at these three systems as a tripod, remaining stable as long as all three systems are working correctly. However, if one of these systems is not working correctly, it is like removing a leg from the tripod, which then becomes unstable. In-flight, the visual system is most likely to be lost. When loss of visual information occurs, you receive a majority of your orientation information from the vestibular system. Unfortunately, the vestibular system is very easy to corrupt and can readily provide erroneous information. The vestibular system also has a very strong input to neuromuscular pathways which, if the stimulus is strong enough, can cause you to reflexively move the aircraft controls in undesired directions. Most of the time, however, vestibular stimulation results from mild accelerations and leads to Type I/Unrecognized SD. Remember, vestibular illusions occur primarily in the absence of peripheral visual cues.

Illusions caused by each of the vestibular systems are discussed in the following section. Illusions caused by the interface between the vestibular and visual system (vestibulo-ocular illusions) are also discussed.

Somatogyral Illusions

Somatogyral illusions are caused by the stimulation of the semicircular canals due to angular acceleration. In this illusion, after you return to straight-and-level flight, you sense the aircraft is turning or banking in the opposite direction. Three major somatogyral illusions can occur in-flight — the Leans, the Graveyard spin/spiral and the Coriolis illusion.

The Leans — The most common vestibular illusion experienced in-flight. It is caused when the semicircular canal responsible for sensing acceleration in the roll axis is stimulated. If during the course of flight the aircraft is allowed to roll at a rate below the threshold, in the absence of any reliable visual cues, the roll will not be perceived. Once you realize the aircraft is in a roll or bank, however, you may correct with a roll in the opposite direction at a roll rate greater than threshold. As a result, you will perceive a bank or roll in the opposite direction even though you thought you were in a wings-level attitude. In some instances, you may find yourself physically leaning back to the opposite direction of the perceived bank, hence the term “the leans.”

Additionally, if the initial roll rate is greater than the threshold, the acceleration is great enough to cause the sensation of “roll.” Once the acceleration stops (motion may continue but at a constant rate), the endolymph reaches equilibrium and the cupula is not displaced. At this point, you don’t perceive the aircraft is in a bank or roll. When the aircraft rolls out to a wings-level attitude, the angular momentum of the endolymph, moving in the direction of the original bank or roll, continues because of inertia. The cupula is deflected in the opposite direction of the original bank and you perceive an opposite bank or roll of the same magnitude as the original maneuver, when in reality you are wings-level. If the roll to wings-level (deceleration) is rapid enough, you may physically “lean” in the opposite direction of the perceived roll or bank (Figure 8-5).

CONTENTS
PREVIOUS

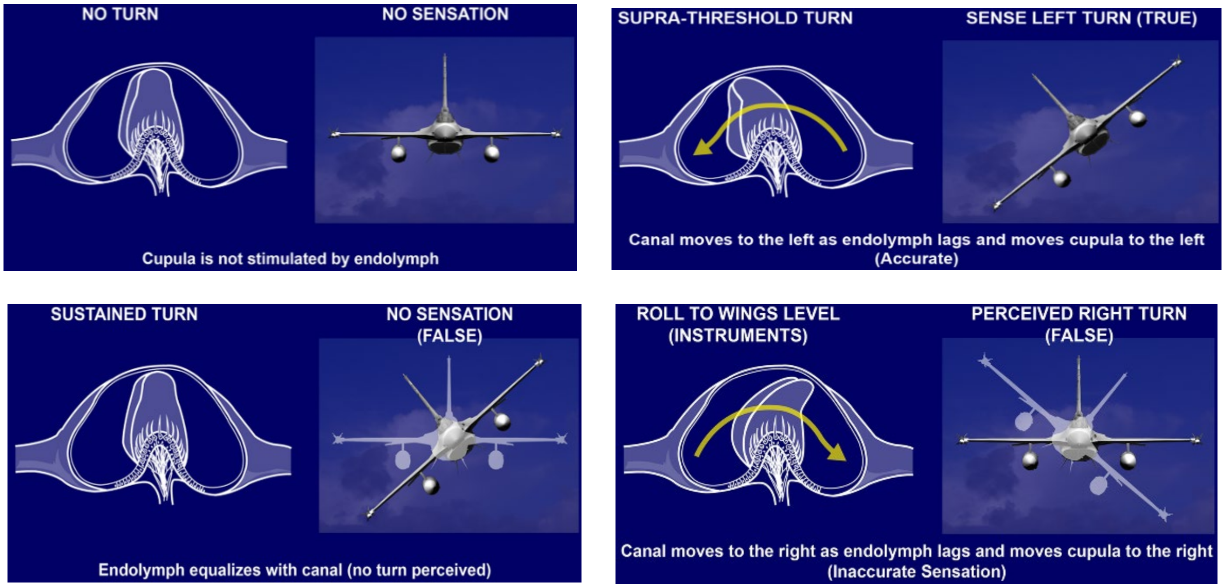

Figure 8-5 — The Leans

The Graveyard Spin/Spiral — An example of how deadly somatogyral illusions can be when flying in conditions of reduced visibility (night or instrument weather). Because of the mechanics of the semicircular canals, you become disoriented quickly when your aircraft is placed in a spin or spiraling turn (with no distinct horizon). To help illustrate the graveyard spin or spiral, let's use a crew who unintentionally spins their T-6 (to the left) into the clouds. The crew correctly perceives the initial spin direction because the angular acceleration causes the endolymph to displace the cupula in the yaw canals. However, as the spin continues at a constant rate, the endolymph stabilizes and the cupula are no longer deflected. The crew perceives a slowing and eventual stopping of the spin. When they check their instruments, they realize they are in a spin and apply the appropriate spin recovery procedures, stopping the aircraft from spinning. Because of the angular deceleration caused by the crew's application of the correction procedures, they perceive a spin to the right even though the aircraft is no longer spinning. If they are not aware of the possibility of this illusion, they may think they have entered a right spin, apply the spin recovery procedures for a right spin, and reenter a spin in the original direction.

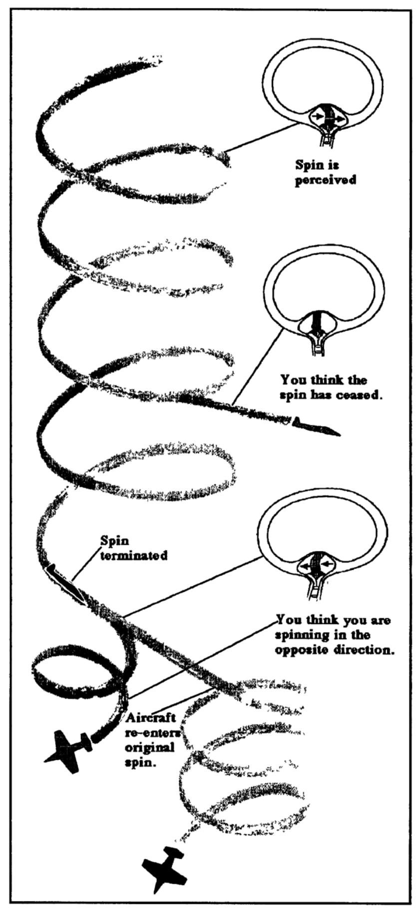

Figure 8-6 — The Graveyard Spin/Spiral

The graveyard spiral illusion occurs in situations where there is poor visibility and you are flying in instrument conditions. To illustrate this illusion, let's use the crew of an AC-130 gunship orbiting above a target with poor visibility at night. In this situation, the aircraft rolls into a turn with a moderate (30 degrees) amount of bank. After a number of seconds, the crew loses the sensation of turning because of the stabilization of the semicircular canals. Since the crew does not receive adequate input from their other sensory systems, they lose sensation of the increased bank. When the aircraft rolls wings-level, the crew feels they are not only turning in the opposite direction but also as if the aircraft is in an opposite bank. Unwilling to accept the sensation of making a wrong control input, the aircraft is rolled back into the original banked turn. Returning to the original banked turn satisfies the crew's sensation of straight-and-level flight, but the instruments show the aircraft is still turning and losing altitude (a banked aircraft loses lift and as a result can lose altitude). Believing the aircraft is flying straight and level but

CONTENTS !!!
PREVIOUS

losing altitude, the crew tries to stop the descent by adding power and pulling back on the yoke (which would normally stop the descent). Unfortunately, the aircraft is in a bank and pulling back on the yoke only tightens the turn. Unless you are aware of this illusion, properly interpret and believe your instruments, and make the necessary corrections, you will continue to descend in an ever tightening spiral. Figure 8-6 illustrates the graveyard spin/spiral.

The Coriolis Illusion — Occurs when two or more of the semicircular canals are stimulated (Figure 8-7). All crewmembers are susceptible to this illusion. The crewmember perceives a tumbling sensation that can be overwhelmingly disorienting. In the aircraft, the Coriolis illusion occurs in situations where the aircraft is turning, rolling, or changing pitch and the crewmember moves their head out of the plane of motion. To illustrate this, consider a fighter crew turning their heads to look at the placement of their bombs while pulling off the target. The aircraft is climbing and turning when the crew turn their heads to look over their shoulders. As they turn their heads they stimulate the yaw canal and perceive the aircraft is pitching down and rolling. Their initial reaction is to pull back on the stick and roll to an attitude they think is wings-level. Unfortunately, they don't roll to a wings-level attitude and may impact the ground.

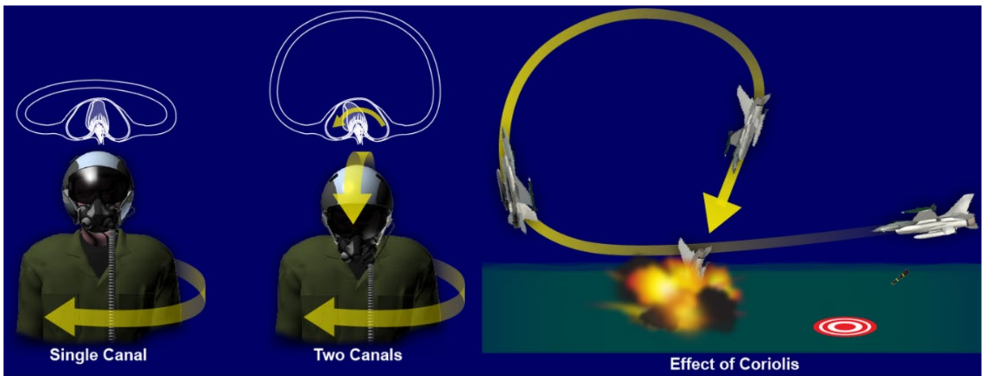

Figure 8-7 — The Coriolis Illusion

The Giant-Hand Phenomenon

The giant-hand phenomenon is a subconscious reflex behavior, generated by vestibular inputs interfering with your conscious control of the aircraft. It is largely thought of as a somatogyral illusion but can be experienced as a somatogravic illusion. The giant-hand phenomenon occurs when the vestibular stimulus is so strong that you cannot physically overcome the sensation of an opposite bank or roll. As a result, you reflexively roll the aircraft back to the original bank angle to defeat the sensation of opposite bank and cannot maintain a wings-level attitude. One pilot explained the phenomenon felt like a giant hand was pressing down on the wing of his aircraft. However, it's believed the false vestibular input results in a muscular reflex causing you to return the aircraft to an attitude eliminating the sensation of pitch or bank.

CONTENTS
PREVIOUS

To overcome this illusion, you should *momentarily* remove your hand from the aircraft controls to interrupt the reflex response from the illusion.

Somatogravic Illusions

Somatogravic illusions are caused by linear accelerations. The otolith organs respond to linear acceleration forces and the illusions usually involve the sensation of pitching up or down. However, there are other somatogravic illusions that are caused by G-forces and turns. The most common somatogravic illusions are the pitch-up/pitch-down illusion and the G-excess effect.

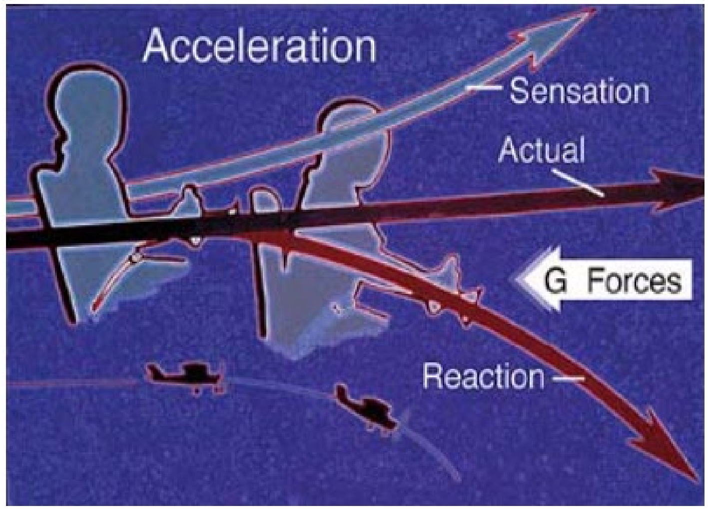

Figure 8-8 — Pitch-up Illusion

Pitch-up/Pitch Down Illusion — The illusion or sensation of pitching up or down when exposed to a linear acceleration. In the absence of a visible horizon, this illusion can be dangerous. If the aircraft accelerates rapidly, you can feel a pitch up motion caused by the otoliths sliding backwards in response to the acceleration. If you are not paying attention to the instruments, you may react by pushing the nose of the aircraft over to compensate for the perceived increase in pitch. Conversely, if the aircraft decelerates rapidly, you can perceive a pitch down motion caused by the otoliths sliding forward. You may pull the nose up to compensate for the perceived nose down attitude. As a result, the aircraft could stall. Figure 8-8 illustrates the pitch-up illusion.

The G-Excess Effect — Occurs when the aircraft is in a turn and you are looking outside the aircraft with your head up, towards the inside of the turn, or head-down looking towards the outside of the turn (Figure 8-9). The otolith organs respond to both the tilt of the head and the G force caused by the turn. If you are looking inside the turn, your head is tilted up with respect to the axis of the aircraft and turned sideways. The G force caused by the turn causes the otolith organs to slide towards the back of the head. The sensation perceived is a decrease in the bank angle. As a result, you perceive you are not banked as much as you should be, and you increase the bank; the nose of the aircraft begins to drop below the horizon and the aircraft loses altitude. This illusion is particularly dangerous if you are operating in a low-level environment. This illusion can also be dangerous when trying to turn the aircraft immediately after takeoff or during approach.

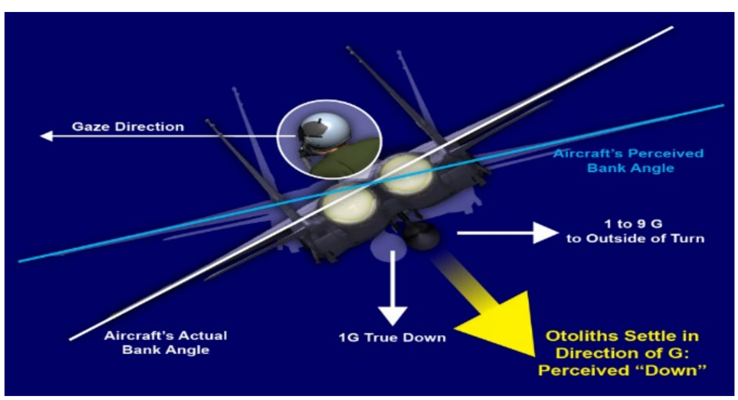

Figure 8-9 — G-Excess Effect

Factors Affecting Spatial Disorientation

There are many factors influencing crewmembers' susceptibility to SD. For the purposes of this course, they are divided into two major classifications, environmental and physiological.

CONTENTS
PREVIOUS

Environmental Factors

Environmental factors affecting spatial disorientation are those you have little or no control over. They include such things as the flight weather, type of mission, time of day of the mission and duration of the mission. Environmental factors also include cockpit and aircraft design and other aircraft engineering factors you cannot influence. Knowing these factors and how they can influence your susceptibility to spatial disorientation is important for safe flight.

Weather restricts visual cues used for orientation and can cause SD. Being aware of the forecast weather and the possible problems that could be encountered enroute greatly increases your capability to prevent a SD incident. If you know you are going to encounter IMC conditions, you can mentally prepare yourself for instrument flight. However, if you find yourself in an unexpected IMC situation, especially at a point in the mission where you are fatigued, you may be more susceptible to SD. For example, you encounter expected weather at your landing base. Therefore, you are prepared for a more difficult approach and can plan accordingly. Conversely, if you unexpectedly find yourself in the weather at your landing base, you may find yourself trying to change and replan the approach into the field. If this situation occurs, there is a higher chance for errors at a critical phase of the mission. This situation is compounded if you are mentally or physically fatigued.

Type of Mission can have an effect on the susceptibility to SD. Missions requiring formation flying at night or in marginal weather are likely situations for SD. Other types of missions, such as low-level missions or missions requiring night air refuelings, can also lead to SD.

Time of Mission and Mission Duration can change your perception based on the environment and your body physiological status. You must be prepared to fly any time of the day or night, in any weather for an extended period of time. Your ability to prepare and prevent SD mishaps from occurring depends on your awareness of the threats, mission preparation, and the physiological factors involved in SD. The fatigue that results from disruptions in your circadian cycle greatly increases your susceptibility to SD.

Physiological Factors

Physiological factors are those you have some control over. These factors are thoroughly discussed in the "Performance Threats Management" lesson. These factors are reviewed here to reinforce how influential they are in regards to SD and include alcohol, self-medication, dehydration, and fatigue.

Alcohol increases your susceptibility to SD even though you may have stopped drinking within the time limits mandated by regulation. Alcohol can produce nystagmus that can last up to 72 hours, depending on the amount of alcohol ingested. So, for 12 to 72 hours after ingesting alcohol, you have an increased susceptibility to SD. Additionally, the side effects of alcohol increase fatigue and dehydration, slowing your perceptual abilities and increasing your susceptibility to SD.

Self-Medication usually occurs when you do not feel well. Unfortunately, self-medicating increases your susceptibility to SD by increasing fatigue levels, depressing the central nervous system, causing dehydration, and can have a synergistic effect with the illness. For example, a crewmember who is flying with a cold and taking over-the-counter cold medicines to control congestion and fever, combines the depressant effect of the cold medicine with the fatigue resulting from the cold. This may cause them to be less alert and fail to recognize the SD situation, possibly resulting in a mishap.

Dehydration, in the flying environment causes you to fatigue more quickly, increasing susceptibility to spatial disorientation. Your ability to recognize and correct for illusions also decreases, placing you and your crew at a disadvantage.

Mental or physical fatigue increases your susceptibility to SD by decreasing your ability to react and perceive what is occurring. Additionally, when you are tired, your ability to accumulate and process information slows down. This effect means some cockpit tasks are relegated to the subconscious level. Unfortunately, the subconscious level relies on the vestibular system for orientation cues in the absence of peripheral vision cues. Therefore, if you are fatigued and find yourself in a situation where you can become disoriented, there is a greater chance the SD will be unrecognized. Fatigue also slows your ability to analyze and overcome the SD. It's every crewmember's responsibility to ensure they are sufficiently rested, both physically and mentally, to fly the mission.

Other Factors Affecting SD

Several other factors can influence SD. These factors include your experience in flying in IMC conditions, mission preparation, and your recency of experience (how long ago you flew in these conditions).

Experience in IMC — The more you fly in IMC, the better able you are to cope with its specific demands. A high time IMC crewmember will probably be better able to anticipate the situations that may cause SD (rolling out of a turn, moving

CONTENTS
PREVIOUS

your head to change a switch position, etc.) than a low time IMC crewmember. However, when SD is involved, *there is no guarantee* a high time IMC crewmember will be less susceptible to SD than a low time IMC crewmember.

Mission Preparation — Also has a direct effect on your susceptibility to SD. During mission planning sessions, review the portions of the mission that could present problems. Also evaluate your experience level with this type of mission. If it's a regularly flown mission, you are likely to be aware of the possible hazards. However, if the mission is flown infrequently, the hazards must be briefed accordingly. For multi-place aircraft, develop a plan and procedures to use in-flight should the pilot flying the aircraft become disoriented. For example, the pilot team should have a clear plan of attack for handling SD.

Recency of Experience — How often, and when, you have flown a certain type of mission. A crewmember with lots of recent day, VMC low-level experience is not necessarily proficient doing night, IMC, low-level missions. Therefore, a crewmember may be more susceptible to SD during night low-level missions since the usual day, VFR visual cues aren't available.

Good cockpit resource management is vital in situations where SD may occur. Effective communication between crewmembers can prevent or decrease the possibility of an SD incident by maintaining awareness of what the aircraft is doing and where it is in relation to the ground.

Spatial Disorientation Prevention

You can prevent SD occurrences by employing a variety of tools. The most important tools are your knowledge and awareness of SD, its causes, and what you can do to prevent an SD mishap. You need to understand your limitations, be prepared to remedy correctable factors, properly use your capabilities, recognize high risk situations, and stay alert.

Understand Limitations

Planning, training and awareness help keep you within your limits and prevent you from finding yourself in a SD situation you neither expected nor are capable of coping with. During mission planning, identify and understand your individual limitations and your crews' collective limitations to minimize the SD threat. Also, understand the limitations of your orientation systems and the illusions caused by the absence of clear visual cues.

Remedy Correctable Factors

Understanding limitations helps you identify and remedy correctable factors. For example, when was the last time you flew in instrument conditions? If you are noncurrent or have not recently flown in instrument conditions, request a simulator (if available) or fly simulated instrument conditions with an instructor. Be aware of experience levels and maintain coordination with fellow crewmembers. Thoroughly plan and brief the mission, identify those portions of the flight where SD is a major threat, form a plan to prevent an SD occurrence, and what actions to take if disorientation does occur.

All crewmembers must remain acutely aware of where the aircraft is in relation to the ground at all times. Every crewmember on the aircraft should know the responsibilities of other crewmembers in order to effectively back each other up, particularly in high threat situations.

Use Capabilities Properly

Use your individual and collective capabilities properly and do not overextend yourself to the point of exceeding your limits. Ensure you're aware of where the aircraft is in relation to the ground and notify fellow crewmembers of any deviation to aircraft attitude, altitude, and position. You must know the altitudes, airspeeds, and rough headings to be flown. Collectively, the crewmembers must use their knowledge and awareness of the aircraft, mission, and SD to keep the aircraft within safe operating limits.

Recognize High Risk Situations

During mission planning, identify and recognize any high risk situations that may occur during the flight. For instance, if you fly a low-level route, identify factors increasing susceptibility to SD (like a moonless night or weather hazards on the low-level route). Additionally, other situations, such as time of day of the flight and fatigue factors need to be considered. After recognizing the high risk situations, you can develop a plan to minimize or eliminate the SD risk while still completing the mission. Furthermore, you cannot forget that you are vulnerable to SD from takeoff to landing.

CONTENTS
PREVIOUS

Stay Alert!

Finally, stay alert to the fact that SD can be a threat at any time during the flight. You must be aware that even though you have completed the high threat portions of the mission, SD can still occur. For example, although the night, low-level portion of the mission is complete, the mission is not a success until the aircraft lands. And although the crew may be fatigued, everyone must remain alert. All crewmembers must actively monitor the approach airspeeds and altitudes to back up the pilot flying the aircraft. Always back each other up to ensure the mission is complete without loss of aircraft or crew.

Overcoming Spatial Disorientation

If you become spatially disoriented, you must transition from unrecognized SD to recognized SD as rapidly as possible. Recognizing and correcting for SD is vital to the safety and survival of crew and aircraft. You can ensure the crew corrects and overcomes SD by using the following procedures (summarized in Figure 8-10).

Overcoming SDO
• Transition to Instruments • Believe the Instruments • Back-Up the Pilot Flying on Instruments • Minimize Head Movements • Fly Straight and Level • Be Prepared to Transfer/ Assume Control • Egress

Figure 8-10 — Overcoming SD

1. Transition to Instruments

A highly disciplined instrument cross-check is the key to recovery from SD (especially while flying at night, in the weather and in formation). Removing ambient visual cues, by leaning forward, should place any distractions from canopy glare outside your peripheral visual field. Additionally, leaning forward causes the horizon line on the attitude indicator to fill a larger area of your visual field. The longer the line, the easier it is to keep your attention.

Immediately recognize and correct unusual deviations in attitude, altitude, airspeed, or position from the planned flight profile. Consciously suppress vestibular sensations by concentrating on your instruments and avoid fixating on any one thing.

2. Believe the Instruments

You must learn to ignore, overcome, or control false sensations perceived from your senses. Remember, the gauges are right. If the instruments indicate you are upside down, then you *are* upside down!

Note — In some cases where the pilot flying the aircraft is severely disoriented, the copilot and/or the navigator must also transition to instruments and prepare to assume control of the aircraft or initiate an ejection.

3. Back-up the Pilot Flying on Instruments

In multiplace aircraft, the pilot not flying the aircraft or the navigator must ensure the pilot flying the aircraft takes the correct actions to recover the aircraft in a SD situation.

4. Minimize Head Movements

Avoid excessive head movements when flying formation in weather and briefly glance at your gauges using your eyes only. If you feel your head is spinning, rest your head against the seat back. Doing so reduces the chance of restimulating the vestibular system and the spinning sensation should subside within seconds.

5. Fly Straight and Level

30 to 60 seconds of straight-and-level flight while concentrating on your instruments should settle your semicircular canals. When flying formation, in the weather, on the wing you can become disoriented more easily because your attention is focused on the lead aircraft's position and not on your gauges. Under these conditions, the lead aircraft is your primary attitude indicator. Any unexpected attitude changes by the lead can further disorient you. Get to VMC if possible. In some fighter aircraft, the navigator can assume control and return the aircraft to straight-and-level flight if necessary.

6. Be Prepared to Transfer/Assume Control

The pilot should transfer control to the other pilot (in multi-place aircraft) or the WSO (fighter aircraft), if possible, because it is rare to have all crewmembers simultaneously disoriented. Use the autopilot to reduce task saturation and SD, but remember to maintain a constant cross-check of the instruments. Do not allow the autopilot to fly you into the ground.

CONTENTS
PREVIOUS

In fighters, the WSO can talk the pilot through the recovery procedures or ask for control of the aircraft.

7. Egress

If orientation cannot be reestablished, particularly during critical phases of flight, ejection or bailout may be your only chance for survival. In aircraft with ejection seats, you must be intimately familiar with your ejection seat's parameters (the ejection envelope). You must preplan how long you will attempt to recover the aircraft before ejection. *Therefore, the decision to eject is determined during mission planning and not in the air.* The loss of an aircraft because of SD is undesirable but the preventable loss of crewmembers is unforgivable.

Formation Flights

The potential for SD is greatest for formation flights during night or weather conditions. Crewmembers scheduled for formation flights in night/IMC should be current and proficient in instrument, night, and formation flying. The flight leader in the preflight briefing should cover specific procedures to manage a disoriented wingman.

There are two essential requirements for safe formation flight in weather. One, the flight leader must be experienced and competent. Two, the wingman must be proficient in formation flying. The wingman must have total confidence in lead and concentrate primarily on maintaining a proper wing position.

If weather encountered during formation flight is either too dense or turbulent to ensure safe flight, the flight leader should separate the aircraft under controlled conditions.

The flight lead should encourage a wingman to verbalize any feelings of disorientation. A few words from lead can reassure the wingman and may help form a mental picture of the flight's position in space.

Assuming the flight lead position may allow the wingman to transition to instruments and recover from the disorientation.

CONTENTS
PREVIOUS

Motion Sickness

The exact cause of motion sickness is unknown. However, the most widely accepted theory proposes motion sickness is caused by "sensory conflict." According to this theory, there is a conflict between the visual and vestibular system or between different components of the vestibular system. For example, flying with your head down in the cockpit during aerial maneuvers sets up a mismatch between the vestibular system (sensing the accelerations of the maneuvers) and the visual system (deprived of visual motion cues). The result of the mismatch is motion sickness. Susceptibility to motion sickness is increased by anxiety, fear, fatigue, dehydration, hypoglycemia, and disease. Heat, lack of air flow, an inadequate visual horizon or blocked visibility are environmental factors that may also increase susceptibility to motion sickness.

Symptoms

The symptoms of motion sickness are nausea, sweating, belching, cold and clammy feeling, and headache. In some cases, active vomiting occurs and sometimes prostration (inability to remain standing). The development and intensity of these symptoms depends on individual susceptibility, previous experience, frame of mind, and environmental stimuli.

Prevention

Motion sickness decreases if good outside visual references exist. However, these references are not always available, but there are other tools you can use to help prevent motion sickness.

One of the most important tools available to prevent motion sickness is your ability to *eliminate or minimize self-imposed stress*. You should be well hydrated before flight and continue to drink water during the flight. You should also ensure you are flying with some food in your stomach. Bland, starchy foods, like bread or crackers, help absorb excess acids produced by the stomach. Eliminate or severely decrease your consumption of alcohol in the 24 to 48 hours prior to flight. Finally, you should be well rested to concentrate on the mission, from beginning to end.

Treatment

Acquiring a good outside visual reference will usually remove the symptoms. Sometimes, cool air blowing across the body decreases the symptoms and breathing 100 percent oxygen also helps. If the symptoms persist, you can employ a technique known as diaphragmatic breathing to help the symptoms subside. When diaphragmatic breathing, close your mouth and inhale slowly through your nose. Your abdomen should expand more than your chest. This helps to prevent air swallowing and hyperventilation and seeks to stimulate the vagus nerve to pass gastric contents downstream. Then slowly exhale through your mouth. Puckering your lips helps to control the escape of air. Continue at a slow, comfortable pace. Resume normal breathing if you begin to feel dizzy; you may be hyperventilating. Also, resume normal breathing once your airsickness symptoms have been controlled.

Post-airsickness Procedures

In the event you become airsick, you must see a flight surgeon to ensure there are no underlying physiological illnesses that caused the episode.

Summary

SD is the inability of a person to accurately orient themselves with respect to the surface of the Earth. SD is categorized as Type I/Unrecognized (the most dangerous), Type II/Recognized (the least dangerous) and Type III/Incapacitating (rare, but dangerous).

The visual system is the primary mode of orientation. However, when the visual cues are removed (instrument flight conditions), the vestibular system becomes the primary source of orientation information. Unfortunately, in-flight, the vestibular system and somatosensory system are not only powerful but also untrustworthy.

Recognizing the environmental and physiological factors affecting susceptibility to SD helps you control them. The environmental factors (those you *cannot* control) include weather, type of mission, the time of day and duration of the mission. The physiological factors (those you *can* control) include self-imposed stresses, mental and physical fatigue, emotional well-being, and flight preparation.

You can help prevent SD by knowing your limitations, remedying correctable factors, using your capabilities properly, recognizing high risk situations, and staying alert. If you become disoriented, transition to instruments and believe the instruments. Basically, "***Get on the instruments and make them read right!***" SD is overcome by knowledge and awareness, effective crew coordination and minimized exposure to self-imposed stresses.

References

Davis, J.R., Johnson, R., Stepanek, J. Fogarty, J.A. (2008). *Fundamental of Aerospace Medicine*. 4th Ed. Lippincott, Williams, Wilkens, Philadelphia, PA.

CONTENTS
PREVIOUS

Review Exercise AP108

Complete the following review exercise by choosing the correct answer(s) or filling in the blanks. Answers follow the questions.

1. Match each category of spatial disorientation with the appropriate characteristic.

	Category of Spatial Disorientation		**Characteristics**
a. ____	Unrecognized SD (Type I)	1.	The least dangerous
b. ____	Recognized SD (Type II)	2.	Rarely experienced, but dangerous
c. ____	Incapacitating SD (Type III)	3.	The most dangerous

2. List the 4 sensory systems enabling you to maintain orientation, equilibrium, and balance.

   a.

   b.

   c.

   d.

3. The system primarily used for orientation is the __________ system. In the absence of __________ cues, the __________ system becomes dominant.

4. The primary means the visual system uses to collect orientation cues is __________.

5. The vestibular system's two subsystems are the __________ and the __________.

6. The __________ detect angular accelerations and are responsible for __________ illusions.

7. The __________ detect linear accelerations and are responsible for __________ illusions.

8. The __________ system is useless as an orientation system in the absence of accurate visual cues.

9. Match each somatogyral illusion with the correct definition.

	Somatogyral Illusion		**Definition**
a. ____	The Leans	1.	Results when you move your head out of a plane of motion and perceive a tumbling sensation.
b. ____	The Graveyard Spin/Spiral	2.	Set up by a roll rate below the threshold of 0.14°/sec^2 to 0.5°/sec^2 and then correcting with a roll in the opposite direction at a roll rate greater than the threshold.
c. ____	The Coriolis Illusion	3.	Results when you correct for a spin or spiral and sense you have entered a spin in the opposite direction or are turning in the opposite direction.

10. Somatogravic illusions result from the stimulation of which organs?

    a. Semicircular canals

    b. Eustachian tubes

    c. Otolith organs

    d. Tactile pressure receptors

11. The __________ occurs when the aircraft is in a turn and you are head-up looking towards the inside of the turn or head-down looking towards the outside of the turn.

12. The interconnection of the vestibular system with the visual system causes __________: a reflexive response of the eyes to stimulation of the semicircular or otolith organs.

13. Like all other vestibular illusions, the pitch-up illusion is increased when external visual cues are limited or absent.

    a. True

    b. False

14. Identify whether the following statements refer to (A) environmental or (B) physiological factors influencing susceptibility to spatial disorientation.

    a. _____ Factors you have little or no control over

    b. _____ Mental and physical fatigue

    c. _____ Alcohol and self-medication

    d. _____ You have some control over

    e. _____ Flight weather

    f. _____ Type and duration of mission

15. List three methods you can use to prevent or minimize the threat of spatial disorientation.

    a.

    b.

    c.

16. List four techniques you can use to overcome spatial disorientation.

    a.

    b.

    c.

    d.

17. Motion sickness increases if good outside visual references exist.

    a. True

    b. False

Answers to Review Exercise AP108

1. a 3
   b. 1
   c. 2
2. a. Visual
   b. Vestibular
   c. Somatosensory
   d. Auditory
3. visual; visual; vestibular
4. peripheral vision
5. semicircular canals; otolith organs
6. semicircular canal; somatogyral
7. otolith organs; somatogravic
8. somatosensory
9. a. 2
   b. 3
   c. 1
10. c
11. G-excess effect
12. nystagmus
13. a
14. a. A
    b. B
    c. B
    d. B
    e. A
    f. A
15. a. Understand limitations
    b. Remedy correctable factors
    c. Use capabilities properly
    d. Recognize high-risk situations
    e. Stay alert!
16. a. Transition to instruments
    b. Believe the instruments
    c. Back up the pilot flying on instruments
    d. Minimize head movements
    e. Fly straight and level
    f. Be prepared to transfer/assume control
    g. Egress
17. b

AP109 — Barany Chair

Hours and Medium

0.5 Hour (IBT)

Objective

1. Using a Barany Chair, trainees will accomplish instructor-directed physical maneuvers to gain a practical understanding, and recognition of visual and vestibular limitations and their susceptibility to error.

Samples of Behavior:

a. Recognize and become familiar with the following illusions: Graveyard Spin/Spiral, Nystagmus, and Coriolis.

b. Observe how other trainees respond to illusions to better understand the effects of SD and the various physiological responses to SD illusions.

Assignment

Read AP109 in the SG.

Information

Your instructor will conclude Spatial Disorientation education with disorientation demonstrations in the Barany chair (Figure 9-1). The Barany chair is a rotational seating device used to generate a response to motion within a trainee's vestibular system. Training applications for this device include spatial disorientation familiarization training and airsickness desensitization training.

Vestibulocular reflexes and somatogyral/oculogyral illusions can be demonstrated via the Barany chair by limiting additional orientation information from the visual, auditory, or somatosensory system. Instructors may direct various positioning causing an increased reaction in trainees, and providing a notable effect on the trainee's ability to interpret their orientation in two dimensional space.

Student volunteers will assist in the demonstration of various vestibular illusions. Each student will witness a volunteer student (or students) accomplish each of the illusions. Not all students will accomplish the Barany Chair demonstration due to time constraints. However, each student will receive training in the Spatial Disorientation trainer in Lesson AP118. Management of the Barany Chair demo and time constraints is based on the judgment of the instructor.

Note — Training device lesson hours are per student. Training schedule time must compensate for training device capacity and size of training class.

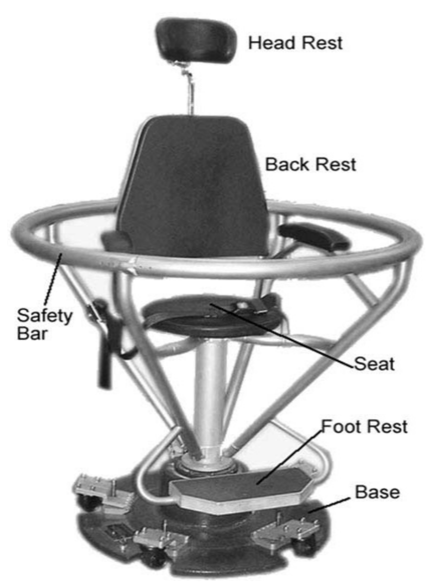

Figure 9-1 — Barany Chair

CONTENTS
PREVIOUS

AP110 — Noise and Vibration

Hours and Medium

0.5 Hour (IBT)

Objective

1. Know the characteristics of noise.

   Samples of Behavior:

   a. Define noise.

   b. List the characteristics of noises that affect hearing.

   c. Recall the definitions and units of measure of frequency, intensity, and duration.

2. Know the effects of hazardous noise on hearing capability.

   Samples of Behavior:

   a. List types of hearing loss associated with high intensity noise.

   b. Identify the potential nonauditory effects of noise on crewmembers' in-flight performance.

3. Know the protective measures used to minimize hazardous noise exposure.

   Samples of Behavior:

   a. List devices that help minimize hazardous noise.

   b. Describe techniques for minimizing hazardous noise exposure.

4. Know the potential effects of prolonged exposure to aircraft vibration.

   Samples of Behavior:

   a. Recall the definition of vibration.

   b. Identify how vibration energy is passed through the body.

   c. Describe symptoms of vibration exposure.

CONTENTS

PREVIOUS

Assignment

Read AP110 in the SG and answer the review questions.

Introduction

Noise and vibration are other stressors you must cope with during flight and ground operations. In this lesson, the characteristics of sound, how the human perceives sound, and the effects of both short- and long-term exposure to noise and the problems of noise-induced hearing loss and methods used to prevent hearing loss will be discussed. The characteristics of vibration will also be covered, in addition to their effects on performance (e.g., reaction time, visual impairment, and fatigue).

Information

Noise

Exposure to high intensity noise, like that produced by jet engines, can damage hearing sensitivity, resulting in permanent or temporary deafness. There are other effects of noise exposure that can be just as harmful. For instance, sleep disturbances, mental fatigue, and stress reactions can occur from overexposure to noise. Various factors influence the degree noise affects the hearing of exposed individuals. Crewmembers exposed to noisy environments must understand the risks of noise exposure, probability of permanent hearing loss, and preventive measures to protect their hearing.

Definition and Characteristics of Noise

Noise is *unwanted* sound. The characteristics of noise of concern to you are frequency and intensity of the noise, duration of exposure to the noise, and distance from the noise source. Noise becomes hazardous as a result of these characteristics.

Frequency — Sound waves are created by the alternate compression and rarefication of air, above and below atmospheric pressure respectively. The number of times each second that these oscillations occur is referred to as the frequency. By convention, one oscillation per second is termed one Hertz (Hz). Therefore, a frequency of 100 cycles per second is 100 Hz. The human ear is normally receptive to frequencies between 20 and 20,000 Hz. This is referred to as the audible range. Frequency is also referred to as pitch.

As a person becomes older, they naturally lose hearing in the higher frequencies (above 4,000 Hz). Crewmembers, however, tend to lose hearing in the upper-mid frequencies and show hearing loss in frequencies that relate to the type of aircraft they fly. For instance, crewmembers flying multi-place aircraft, such as P-3s and C-130s, show frequency loss in different ranges than those crewmembers flying fighter-type aircraft.

Loud, Louder, Loudest	
Jet engine (near)	140
Jet takeoff (100 feet), shotgun firing	130
Boom box, rock concert	120
Jackhammer, chain saw (gas)	110
Arcade game parlor, radio headset	100
Motorcycle, lawn mower (5 feet)	90
City traffic noise, hair dryer	80
Dishwasher, vacuum cleaner	70
Inside car (windows up), normal conversation	60
Quiet office	50
Refrigerator humming, living room	40
Broadcasting studio, whisper	30
Hearing test booth, rustling leaves	20
Sound just audible, normal breathing	10
Absolute threshold	0

Figure 10-1 — Common Noise Situations

Most noise that a crewmember is exposed to consists of many different frequencies (broad band), like an airplane at full thrust. However, there are instances where the crewmember is exposed to predominantly single-frequency noise (narrow band). In environments where there is narrow band, high intensity noise, more damage occurs to the crewmember's hearing.

Intensity — The magnitude of an acoustic event and is a measure of pressure of sound waves in the ear canal. Sound pressure levels increase millions of times between the normal threshold of human hearing and the maximum safe level. To avoid the use of awkward numbers, a more convenient term, the decibel (dB), is used to measure these pressures. The decibel is a logarithmic expression of the ratio of the sound pressure being measured to the lowest sound pressure detectable by the normal human ear at 1,000 Hz. As an example of the logarithmic nature of the expression dB, the sound pressure buffeting the eardrum increases 100 times between 100 and 120 dB. Figure 10-1 illustrates several common noise situations and their corresponding intensity levels. Figure 10-2 provides noise intensities of various aircraft. Numbers are based on ground readings for aircraft flying 1000' overhead.

CONTENTS
PREVIOUS

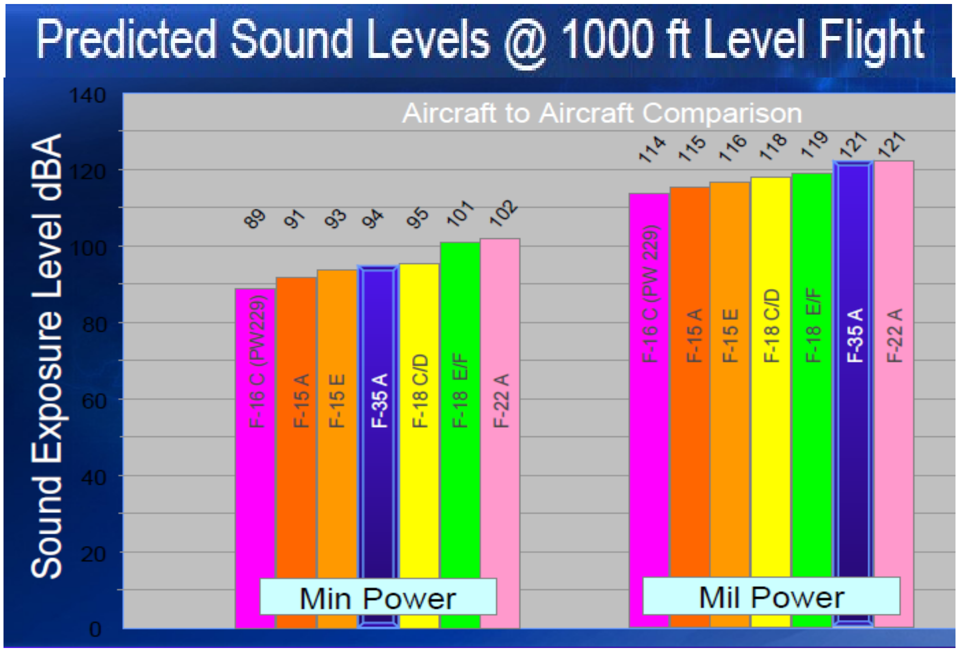

Figure 10-2 — Aircraft Noise Levels

The intensity threshold at which humans are susceptible to hearing loss is 85 dB. At noise levels of 85 dB and above, hearing protection should be worn. A rule of thumb used to gauge whether certain noise levels are intense enough to require protection is the "shout test." If one has to shout to be heard at a distance of one meter, then the noise level is intense enough to require hearing protection. The threshold for pain is 130 dB and physical damage occurs at noise levels of 150 dB and above.

Distance plays an important role in determining how hazardous a noise source may be. If noise traveled through the air efficiently (perfect conditions) there is a 6 dB decrease in intensity as distance from the source is doubled (beyond 30 meters from the source). For instance, if a jet aircraft starter unit (JASU) is emitting 100 dB at 30 meters, and you are standing 60 meters from the JASU, you are exposed to 94 dB. If you stood at 120 meters, the intensity drops to 88 dB. However, the intensity may be modified by environmental factors such as temperature and humidity.

The length of exposure to noise plays a fundamental role in determining how much irreversible damage is inflicted on your hearing. Figure 10-3 depicts the time a human can be exposed to different intensities of noise without protection. The rule for figuring exposure times is for every 3 dB increase, the time of exposure is reduced by one-half. For instance, the maximum allowable time unprotected exposure to 85 dB is eight hours. If the noise intensity is increased to 88 dB, the allowable time of exposure is four hours. At 112 dB, the maximum allowable exposure is less than one minute.

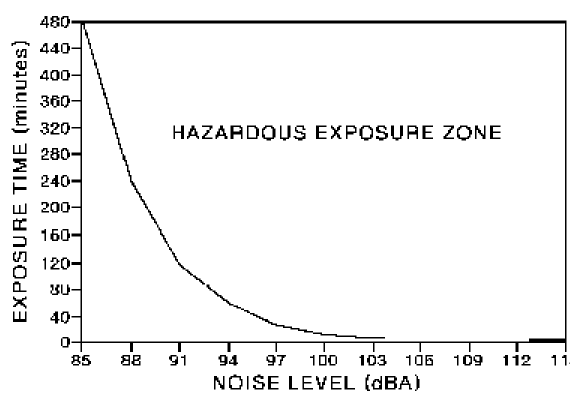

Figure 10-3 — Exposure Limits to Noise

Environmental factors that affect sound transmission through the air can either increase or decrease the intensity of noise. Terrain, wind direction, wind velocity and air density significantly affect the intensity of the noise at a given distance.

Perception of Sound

The human ear is divided into three sections — the external ear, middle ear and inner ear. Figure 10-4 shows the anatomy of the human ear. For one to perceive and identify sound, the signal must be converted from the mechanical energy of sound waves to electrical energy. The electrical energy is then transmitted to the brain via the auditory nerve.

Figure 10-4 — Perception of Sound

The external ear collects sound waves and directs them to the middle ear. The middle ear consists of an eardrum and three small bones (ossicles), acting to transmit sound (vibrations) from the external ear to the inner ear. The vibrations are transmitted into the spiral-shaped, fluid-filled cochlea of the inner ear. Vibrations received by the cochlea set up a fluid motion which is perceived by tiny hair cells. These hair cells are connected to the auditory nerve. Movement of the hair cells caused by fluid motion results in the production of nerve impulses. These impulses flow to the auditory center of the brain for interpretation.

Effects of Hazardous Noise

Two types of hearing loss can occur when you are exposed to high intensity noise — conductive or sensorineural (nerve-damage).

Conductive Hearing Loss occurs when one of the parts of the ear that is designed to transmit mechanical energy fails. For instance, a ruptured eardrum cannot transmit the sound energy to the ossicles of the middle ear. Another example of conductive hearing loss is failure of one of the middle ear bones, or the joint between the bones, to vibrate correctly. Incorrect vibration causes inefficient transmission of the sound energy. Each of these examples illustrates the loss of the ability of the ear to conduct sound energy of all frequencies to the inner ear.

Sensorineural Hearing Loss — Occurs when the hair cells of the cochlea are damaged, destroyed, or degenerated due to overexposure to noise. When a person is exposed to loud noise, the pressure waves in the cochlea are so strong that they can cause the base membrane of the cochlear duct to vibrate excessively. The excessive vibration causes the hair cells to brush against the upper membrane of the cochlear duct with enough force to cause damage to the hair cells. If the noise is intense enough or exposure long enough, the hair cells can actually be broken off. Depending on the amount of damage to the hair cells, you may suffer from temporary or permanent sensorineural hearing loss.

1. Temporary threshold shift — A *nonpermanent* loss of hearing in a frequency or range of frequencies after exposure to loud noise. For instance, after listening to a live band, there may be a feeling of fullness in the ears accompanied by a dullness in hearing. Additionally, there may be a ringing in the ears (tinnitus).

When a person is exposed to loud noise, the hair cells become fatigued and sometimes damaged. Fortunately, a temporary threshold shift is not permanent. If you are exposed to noise levels that can cause a temporary threshold shift, sitting in a quiet spot for a couple of hours will usually return your hearing to almost normal. However, normal or almost normal hearing levels may not return for as much as one to two days. A crewmember who has experienced a temporary threshold shift should not expose their hearing to that particular noise environment again since hair cell damage has occurred and further damage may lead to a permanent threshold shift.

2. Permanent threshold shift — Occurs when the cochlea's ability to convert a certain frequency or frequencies to electrical signals is lost because of hair cell damage. Once hair cells are destroyed or damaged to the point they are no longer functional, the ability to hear the affected frequencies is *permanently* lost. Unfortunately, crewmembers work in an environment that is very hazardous to their hearing; this environment can cause permanent damage very quickly if preventive and protective measures are not taken.

Non-Auditory Effects of Noise — These effects on crewmembers can pose problems in the flying environment. Excessive noise masks sound entering the ear and can make speech unintelligible. Masking of other crewmember's speech can lead to misinterpretation of communication and cause the crew to make a mistake.

CONTENTS !!!
PREVIOUS

In addition to auditory masking, excessive noise increases stress. Excessive noise increases fatigue levels, leading to lower levels of alertness. Sleep disturbances may be encountered, leading to sleep loss and an increase in anomalies of attention. There is also an increase in crewmember irritability, distraction, and uncooperativeness. In the flying environment where alertness, accuracy, and attentiveness play vital roles in mission success, noise protection is important to keep the crewmember safe and effective.

Protection from Noise

The aviation environment is noisy and can cause permanent hearing loss in crewmembers very quickly. Therefore, you must protect your hearing. A number of devices are available that attenuate noise and protect hearing, including earplugs, ear muffs (“Mickey Mouse ears”), headsets and flight helmets. Techniques for protecting your hearing include decreasing the time of exposure and increasing your distance from the noise source.

Earplugs — Communication in the voice range is not disrupted or degraded when using earplugs. They protect your hearing by lowering the intensity of noise reaching the cochlea and by filtering the high frequencies, making speech reception clearer and less distorted.

There are many types of earplugs available to the crewmember and are basically classified into two major categories — formable and molded plastic.

1. Molded plastic earplugs must be fitted to the ear canal, are reusable for long periods of time, can be washed, and are very effective at attenuating noise. The V-51R molded earplug and a similar version, the triple-flanged earplug, are the most common types. Both are very effective in attenuating noise in the 2,000 Hz to 6,000 Hz range and provide from 24 to 30 dB of protection at these frequencies. However, molded earplugs provide an airtight seal in the external ear canal and can prevent equalization of pressure during descent. Therefore, they should not be used underneath a flight helmet. They are most often used by ground crew personnel and crewmembers who do not wear flight helmets. Some molded earplugs, however, such as the Attenuating Custom Communication Earpiece System (ACCES®), are specifically designed for pilots and can be used in flight.

2. Formable earplugs are designed to fit everyone. They are made of compressible material that expands to form-fit the external ear canal. One of the most popular types of formable earplug is the E-A-R® earplug made of vinyl polymer. The E-A-R® is compressed by rolling it between the forefinger and thumb, and then inserting it into the ear. It should be held in place for approximately 20 seconds, until it has a chance to fully expand. When properly fitted, E-A-R® type earplugs provide roughly 25 dB protection in the 2,000 Hz to 6,000 Hz frequency range.

To ensure maximum protection with formable earplugs, they must be clean and dry. Formable earplugs can be washed but will lose some of their protective capabilities. Therefore, it’s best to use a new pair of earplugs after one or two flights. E-A-R® earplugs are very popular and effective in undergraduate flying training.

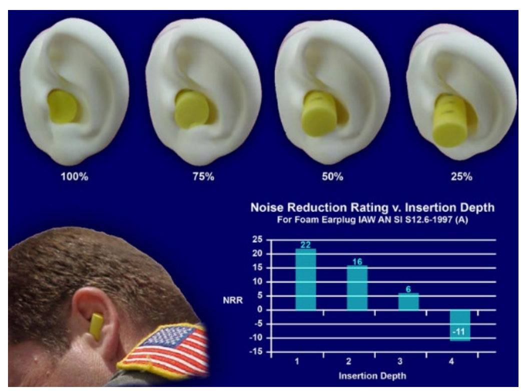

Figure 10-5 — Improper Ear Plug Insertion

Ear Defenders, Headsets, and Flight Helmets also provide noise protection. The amount and effectiveness of the protection depends on a tight seal between the earcup and the ear. Without a tight seal, sound energy can enter the ear. The effectiveness of noise protection is decreased if you wear glasses or place cloth sweat bands under the earcups. Sunglasses or eye glasses should be fitted to allow for a minimum break in the earcup seal with the ear.

The amount of noise protection is also dependent on the mass of the helmet, earplug, or headset being used. The lighter and less dense the device, the less the protection.

Combination of Protective Devices are the most practical protection available to you, other than limiting or preventing exposure to noisy environments, is the use of a combination of protective devices. Using earplugs under headsets or helmets increases the protection provided to you and allows for clearer radio and interphone reception. Protective devices, used in combination, can provide 28 – 32 dB of protection.

Limiting Exposure to dangerous noise levels is the best protection against hazardous noise. However, limiting exposure to noise is not always possible, especially if your aircraft is inherently noisy. Therefore, you must use protective devices to attenuate the noise. Limiting one’s exposure to loud noise environments off-duty also decreases hearing loss.

CONTENTS
PREVIOUS

Vibration

Vibration is defined as the rapid movement of an object in a back and forth motion. Vibration is described with the same parameters as sound — frequency, intensity and duration.

Frequency Ranges

Vibrations occur throughout the frequency spectrum; however, vibration of very low frequency and high intensity are of most concern. The approximate range of 1 to 100 Hz is most hazardous to humans. When the skull is exposed to vibration between 20 and 30 Hz, and the eyeball between 60 and 90 Hz, these frequencies are particularly distressing to the individual. Vibration energy may be passed to the body acoustically or by direct mechanical linkage. Isolation of the vibration source and restraint of the body may be necessary to provide physiological protection.

Effects on Performance

Low altitude, high speed flight in weather causes the most severe vibration exposures. Vibration can affect your ability to perform at peak levels.

Tracking can be affected, horizontal tracking is generally not affected by vibration. However, vertical tracking is significantly impaired with vibration. Low frequency vibrations can produce tracking error up to 40 percent greater than in an environment without vibration.

Reaction Time of executing tasks delegated to the subconscious level showed marked deterioration during vibration. However, studies indicate that vibration does not typically influence crewmember reaction time to tasks executed at the conscious level.

Visual Impairment can be caused by vibration. It can cause blurred vision and therefore reduce your visual efficiency. Vibration in the frequency band ranges of 25 to 40 and 60 to 90 Hz are particularly degrading to visual acuity. Vibration causing blurring of the instrument panel makes accurate reading of the instruments very difficult. Proper design of visual instruments and displays and an increase in their illumination and contrast reduces the effect of the vibration.

Fatigue — Vibration contributes to fatigue, a prime factor in *decreased* crewmember performance.

Symptoms of Exposure

Symptoms which may result from exposure to harmful vibration frequencies are loss of appetite, complacency, perspiration, salivation, nausea, headache, and vomiting. Severe vibration can also result in fatigue, discomfort, and actual pain. There is indication that long-term vibratory exposures can lead to chronic stiffness of articulating joints and appear to develop in much the same manner as noise-induced hearing loss.

Summary

The noise and vibration produced by the aircraft is one of the many stresses you must cope with while flying. Noise is simply defined as unwanted sound and can become a problem to you as a result of the noise's frequency, intensity, or duration. The process of perceiving sound involves the conversion of the mechanical sound wave to electrical energy that can be interpreted by the brain. Proper protection from hazardous noise is most effectively accomplished through the use of a combination of devices in order to minimize the possibility of hearing loss or other non-auditory effects of noise. Finally, the hazard of vibration is greatest at a low frequency and high intensity. These hazards include effects on performance such as impaired vertical tracking, degraded reaction time, visual impairment, and fatigue as well as causing physical symptoms.

CONTENTS
PREVIOUS

Review Exercise AP110

Complete the following review exercise by choosing the correct answer(s) or filling in the blanks. Answers follow the questions.

1. Noise is __________.

2. The primary characteristics of noise concerning crewmembers are __________, __________, and __________.

3. The number of times (each second) compression and rarification of air occurs is __________.

4. Noise (sound) intensity perceived by the human ear is measured in __________.

5. The two types of hearing loss you can suffer are __________ hearing loss and __________ hearing loss.

6. Crewmembers on the flightline are being exposed to 97 dB of noise. Their time of maximum unprotected exposure to this noise before they must leave is __________ minutes.

7. What is the most practical method of noise protection for you?

   a. ANR headset

   b. Combination of protective devices

   c. Flight helmet

   d. Ear plugs

8. Select the statements describing vibration. **(Select all that apply)**

   a. Approximate range hazardous to humans is 1 to 100 Hz.

   b. Relaxes the crewmember.

   c. Occurs throughout the frequency spectrum.

   d. Midfrequency and intensity are of most concern.

9. Select the effects of severe vibration on crewmember performance. **(Select all that apply)**

   a. Low frequency vibrations can significantly impair horizontal tracking, increasing tracking error by up to 40 percent.

   b. Vibration reduces reaction time for those events/tasks executed at the conscious level.

   c. Vibration can cause blurred vision and degrade visual acuity.

   d. Vibration is a major contributor to fatigue.

CONTENTS
PREVIOUS

Answers to Review Exercise AP110

1. unwanted sound
2. intensity; frequency; duration
3. frequency
4. decibels
5. conductive; sensorineural
6. 30
7. b
8. a; c
9. c; d

AP111 — Acceleration

Hours and Medium

2.0 Hours (IBT)

Objective

1. Know the definition and characteristics of G forces.

   Samples of Behavior:

   a. Identify the three types of acceleration.

   b. Identify the three types of G force.

   c. Recall the definition of each type of G force.

   d. Identify the physical symptoms associated with each type of G force.

2. Know the characteristics of the factors that determine the effects of G forces on a crewmember's body.

   Samples of Behavior:

   a. Recall the five factors determining the effects of G force on a crewmember's body.

   b. Identify the four principle physiological effects and associated symptoms of exposure to G forces.

   c. Recognize what causes blackout and how it is different than G-induced loss of consciousness (G-LOC)

3. Know the characteristics of G-LOC.

   Samples of Behavior:

   a. Describe the symptoms of each of the phases of incapacitation.

   b. Explain the impact of relative incapacitation on the total time required to regain control of the aircraft after G-LOC.

4. Know the methods used to help prevent G-LOC.

   Samples of Behavior:

   a. Identify methods to increase G tolerance.

   b. Recall G-suit function and level of protection provided.

   c. Identify the elements involved in correctly performing the AGSM.

5. Know the common errors in performing the AGSM.

   Samples of Behavior:

   a. Recall errors involved in performing the AGSM.

   b. Identify common mission characteristics that are likely to cause AGSM errors.

6. Know the characteristics of the methods used to increase a crewmember's tolerance to positive G-forces.

   Samples of Behavior:

   a. Recall physiological factors related to increased performance in a positive G force environment.

   b. Recognize the role self-imposed stressors play in decreasing G force tolerance.

Assignment

Read AP111 in the SG and answer the review questions.

CONTENTS
PREVIOUS

Introduction

As we stated before, the crewmember, rather than aircraft design, is the limiting factor in military flying. You face more physiological threats of greater degree than ever before. Modern fighter aircraft routinely operate in a high-G environment — a high sortie rate and sustained operations is the “norm.” Therefore, you must be in excellent physical and mental condition to perform your duties, whether in training or in combat.

An understanding of acceleration on the human body is important to your in-flight performance because of its effects on the cardiovascular, pulmonary, and vestibular (orientation) systems. The ability to overcome the effects of acceleration will become more important as you are exposed to aircraft with greater maneuverability and performance. Your ability to combat the adverse effects of G forces depends directly on your level of physical condition and your ability to reduce negative life stressors.

Note — After the classroom presentation, you will demonstrate the AGSM to the satisfaction of your instructor.

Information

Before G forces are discussed in depth, we will define several terms so you can understand acceleration and how G forces are generated.

Physical Principles and Types

Physical Principles

Speed — Rate of motion (or how far) one travels in a certain amount of time, irrespective of direction. An example is flying at 360 knots groundspeed.

Velocity — Describes both a rate of motion (speed) and direction of travel. An example of velocity is 360 knots groundspeed on a heading of 180 degrees.

Acceleration — The change in velocity per unit time and is generally expressed in feet per second per second (ft/sec^2) or meters per second per second (m/sec^2). *Acceleration is produced when either speed, direction (or both) change.*

The most familiar type of acceleration is gravity. Gravity affects anything on or near the Earth. The acceleration produced by gravity (g) is a constant with a value of 32 ft/sec^2 or 9.8 m/sec^2. Therefore, a free-falling body will increase its velocity by 32 ft/sec or 9.8 m/sec for every second it falls. The inertial force resulting from the linear acceleration of gravity acting upon a mass is termed 1 G. Therefore, when we discuss G forces in the flying environment, we are referring to the inertial force resulting from acceleration.

Types of Acceleration

Linear Acceleration — A change in speed (increase or decrease) without a change in direction (Figure 11-1). This reflects a change of speed in a straight line. This type of **acceleration** occurs during take-off, landing, or in level flight when a throttle setting is changed.

Figure 11-1 — Linear Acceleration

CONTENTS
PREVIOUS

Radial Acceleration — A change in direction without a change in speed (Figure 11-2). Radial acceleration occurs when an aircraft pulls out of a dive, pushes over into a dive, or performs an inside or outside turn (and does not change its speed). In these examples, the aircraft's direction changes, but the airspeed remains the same.

Figure 11-2 — Radial Acceleration

Angular Acceleration — A simultaneous change in both speed and direction (Figure 11-3). Angular acceleration occurs during most aerial maneuvers. For instance, when an aircraft performs a split-S maneuver, the aircraft's speed and direction change simultaneously and the crew experiences angular acceleration.

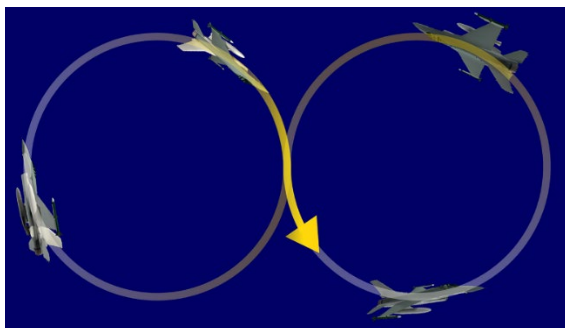

Figure 11-3 — Angular Acceleration

G Forces

As an aircraft accelerates in one direction, inertial forces act on your body in the opposite direction of the applied force. The inertial force causes the body to experience a G force. The following section discusses the types of G forces a crewmember experiences and the physical factors influencing the effects of G forces on the body.

Types of G Forces

The direction of force determines the type of G force you experience. Three types of G forces you can experience are discussed. They are transverse G, negative G, and positive G.

Transverse G Force — The force applied to the front (+G_x) or back (-G_x) of the body (Figure 11-4). +G_x and -G_x forces are normally encountered during takeoffs, acceleration in level flight, and landing. The maximum transverse G tolerable to humans is roughly 15 Gs in the +G_x direction and about 8 Gs in the -G_x direction. Catapult shots from a carrier deck would be a good example of +G_x and Carrier landings a good example of -G_x.

Note — Lateral G forces (the G_y direction) are experienced during spin or roll; however, the effects are negligible.

CONTENTS
PREVIOUS

Figure 11-4 — Transverse G Force

Negative G Force — Defined as the force being applied from the feet towards the head and is expressed as $-G_z$ (Figure 11-5). Negative G force is not tolerated well by humans and is seldom experienced in high levels during normal flight. Normally, $-G_z$ is experienced when the nose of the aircraft is lowered during a "pushover" or when experiencing turbulence. Human tolerance (physical discomfort) to $-G_z$ may be as low as 3 Gs for 5 seconds.

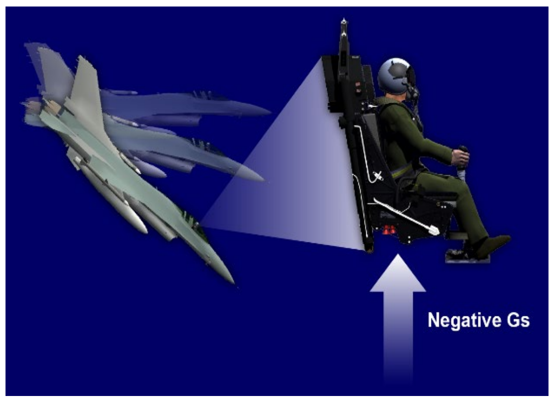

Figure 11-5 — Negative G Force

The physical symptoms of $-G_z$ are a sense of weightlessness, congestion in the head and face, headache and visual blurring. Some flyers have reported a phenomenon called "redout," a reddening of vision during sustained negative G_z flight. The causes of *redout* are not completely understood. The progressive effects of $-G_z$ are illustrated in Figure 11-6.

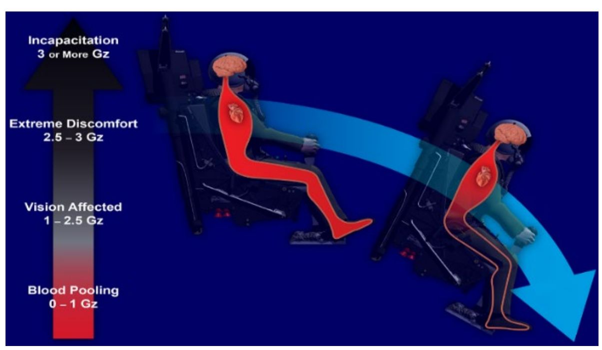

Figure 11-6 — Effects of Negative Acceleration

There is no practical method to counteract the effects of $-G_z$. Under normal conditions, the only way to combat the effects of $-G_z$ is to reduce aircraft maneuvering and return to a 1 G environment.

Positive G Force — A force applied from the head towards the feet. It is expressed as $+G_z$. It occurs during turns and dive recoveries and is the G force most often experienced by crewmembers. Therefore, much of the remaining information deals with the physiological effects and symptoms of $+G_z$ and methods to increase one's tolerance to $+G_z$. Crewmembers' average resting tolerance to $+G_z$ is 5.5 G. The average levels and the progressive effects of $+G_z$ are illustrated in Figure 11-7.

CONTENTS
PREVIOUS

Figure 11-7 — Effects of Positive Acceleration

Factors Determining the Effects of G Forces

Physical Considerations

The five factors (or physical considerations) determining the effects of G forces are discussed below. These factors help explain why certain G forces have different effects on the body and why the body reacts to certain types of G forces in different situations. Some of these factors are interrelated and have a combined effect on the crewmember.

Magnitude of the G Force is the size of G force applied to the body. The greater the magnitude of acceleration and accompanying inertial force, the greater the G force. For instance, a crewmember pulling +6 G_z is being accelerated to six times the gravitational force of the Earth, or 192 ft/sec^2. Modern fighter aircraft, like the F-18 and F-16, are capable of exposing you to sustained eight to nine Gs.

Duration of Exposure to the G Force is another determinant of the effects of the G force on the body. For example, jumping from a table one meter high results in a deceleration force of about 14 Gs for a fraction of a second, usually with no ill effects. But, being exposed to 14 Gs for over two seconds will result in significant physical and physiological effects. These effects are further discussed later in the lesson. The T-6 does not maintain a high sustained G load due to excessive energy loss.

Rate of Application (G onset) directly influences the effect of a G force. Rate of G force application is expressed in G per second (G/sec). To illustrate the effect of G onset, imagine dropping a brick on someone's foot versus placing a brick of identical mass on the person's foot. The dropped brick has a greater physical effect on the foot than the brick placed, even though both bricks are identical in mass. The difference is in the rate of acceleration and the resultant inertial force.

Aircraft with long, straight, rectangular wing platforms like the T-6 typically have rapid G onset rates. The T-37, for example, had the highest G onset rate in the USAF inventory. The average time to a visual symptom (grayout) of $+G_z$ exposure is determined by the rate of G onset. The slower the onset, the longer the time to grayout in the low to moderate G ranges.

Direction of Force defines the axis of the body the G force is applied. The G force can be applied through the X, Y, or Z axis of the body (Figure 11-8). By determining the direction of the force, the type of G can be identified. For instance, a force applied from the head towards the feet is a $+G_z$ force and a force applied from the feet towards the head is a $-G_z$ force. G forces can be experienced along other axes as well, but the force applied along the +Z axis has the most significant effect on crewmember performance.

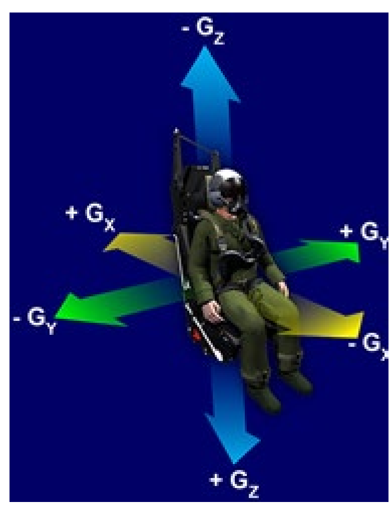

Figure 11-8 — X, Y, and Z Axes

Previous G Exposure — The Push-Pull Effect (PPE) is a phenomenon of reduced $+G_z$ tolerance when preceded by exposure to Gz that is less than +1 G_z. It is thought that the less than $+1G_z$ exposure causes a cardiovascular relaxation which can affect subsequent $+G_z$ tolerance. $-G_z$ exposure for a duration of less than 2 seconds can significantly affect $+G_z$ tolerance, possibly reducing tolerance by up to 1.5 Gs (dependent upon magnitude and duration of the $-G_z$ exposure). Maneuvers that produce the PPE are found in some training aerobatics and tactics which include dive attacks, extensions, air combat maneuvering guns defense and split-s maneuvers.

CONTENTS

PREVIOUS

Another aspect of previous G exposure is the fact that the body can be prompted to prepare for increased Gs. The G-warm-up is a maneuver you will fly at the beginning of most sorties. The G-warm-up consists of a very controlled exposure to increased G which prepares you for the higher G follow-on maneuvers. You will be briefed on the specific procedures of the G-warm-up maneuver before your first high-G sortie.

Note — An accelerometer (G-meter) monitors G forces during flight. It displays instantaneous G, maximum positive G, and maximum negative G. The dial also indicates the maximum permissible G force the aircraft can sustain, both positive and negative.

Physiological Effects and Symptoms

Prolonged exposure to G forces affects the body in four principle ways — restricting mobility, affecting the cardiovascular system, stimulating the vestibular system, and reducing visual acuity.

Mobility — A 150 pound crewmember weighs 600 pounds when exposed to $+4\ G_z$. This increase in weight severely restricts movement in the aircraft. For example, your head weighs about 29 pounds when wearing a helmet and oxygen mask. At $+4\ G_z$, your head weighs approximately 116 pounds. If you are not prepared, this increased weight could force your chin into your chest when a loop is initiated. Combined with other physiological effects of $+G_z$, decreased mobility interferes with your ability to function at peak levels during high-G flight.

Cardiovascular Reflex — As $+G_z$ forces increase, cranial blood pressure begins to decrease. Each $+G_z$ drops blood pressure approximately 22 mmHg. The cardiovascular system attempts to compensate for the drop in blood pressure by constricting peripheral blood vessels and increasing the heart rate. This compensation is known as the *cardiovascular reflex*. The G-time tolerance curve (Figure 11-9) represents an extremely important concept regarding physiological reactions to $+G_z$.

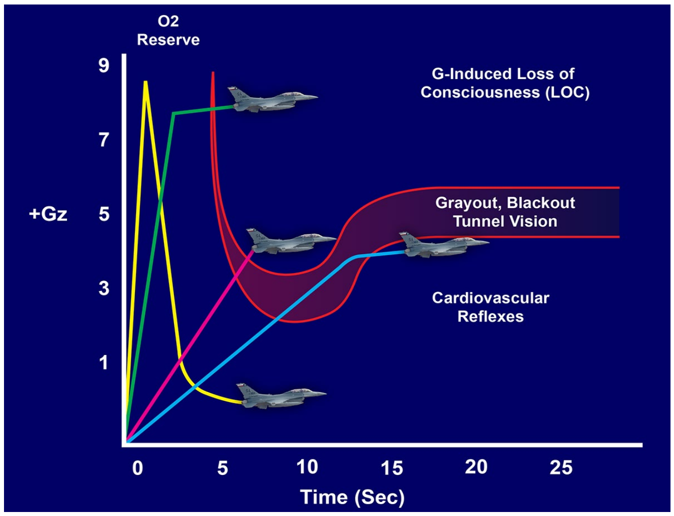

Figure 11-9 — G-Time Tolerance Curve

1. Yellow Line — The eyes and brain contain sufficient oxygen to maintain vision and consciousness for 4-5 seconds after blood stops flowing to the head. Here, a high $+G_z$ load is applied very rapidly for a short duration without experiencing visual symptoms (e.g., yanking the stick suddenly as during a threat avoidance maneuver).

2. Green Line — Illustrates the severe danger of rapidly-applied, *sustained* G loads. The first several seconds of such a G load is symptom free because of the oxygen reserve in the eye and brain. However, as blood in the eyes and brain is depleted of the oxygen reserve, G-induced loss of consciousness (G-LOC) occurs. In this situation, there is essentially no warning from visual symptoms (grayout, tunnel vision, blackout, etc.) to indicate imminent G-LOC. For example, crewmembers expecting to pull a rapidly-applied 9 G load until grayout (and then unload if necessary), would almost certainly experience G-LOC.

3. Magenta Line — Between 5 and 10 seconds, when the oxygen reserve is depleted and the cardiovascular reflex has not become fully effective, a trough occurs in the curve — G tolerance is at its lowest. Applying $+G_z$ at a moderate rate, causes symptoms of G stress at a lower $+G_z$ level than when Gs are applied more rapidly or more slowly, which results in G-LOC.

4. Blue Line — The cardiovascular reflexes mobilize after about 10 seconds of $+G_z$ stress. This reflex increases blood flow to the head, increasing G tolerance by about 1 G. Therefore, when the $+G_z$ load is applied slowly, this reflex helps G tolerance and leads to visual symptoms without G-LOC.

Vestibular effects and their symptoms play a critical role in spatial disorientation and balance. The otoliths are stimulated by gravity and linear acceleration forces to provide you a sense of direction. The semicircular canals respond to angular acceleration to provide another sense of direction. If you do not rely on your instruments and visual cues, acceleration forces can provide stimuli that induce disorientation.

CONTENTS
PREVIOUS

Visual — For blood to enter the retina, the cardiovascular system must overcome about 13 – 18 mm Hg of intraocular pressure. As the G forces increase and the blood pressure in the brain begins to drop, there is insufficient blood pressure to overcome the intraocular pressure. Therefore, the tissue in the eye that detects light (retina) starts losing its blood supply.

As the blood supply is decreased, peripheral vision is affected and you experience a dimming, misting, or graying of your vision referred to as *grayout* or you may experience tunnel vision, where the only vision remaining is in the center of your visual field. At this point, you must perform a more intense anti-G straining maneuver (AGSM) or unload the Gs immediately. (Exactly how you perform an effective AGSM will be discussed in subsequent paragraphs.) As the G force increases, the blood pressure drops to where it cannot overcome the intraocular pressure and all vision is lost, referred to as *blackout*. *It is important to note that blackout does not mean you are unconscious*. However, you are in imminent danger of G-LOC.

Note — With high G onset rates, unconsciousness can happen without any preceding visual cues, so always load up the body with an effective AGSM before you load up the aircraft.

G-Induced Loss of Consciousness

The brain has a 4 to 5 second oxygen reserve. Once blood flow ceases and the oxygen reserve is used, unconsciousness (G-LOC) results. The AGSM sustains blood flow during this critical period of G onset. The effects of G-LOC are described as two phases of incapacitation — *absolute* and *relative*.

Absolute Incapacitation

In absolute incapacitation you are actually unconscious for roughly 9 to 21 seconds, with an average time of 15 seconds. When you become unconscious, you could relax your grip on the flight controls and the aircraft could return to 1 G flight. If you return to 1 G flight, the cardiovascular system is able to pump blood to the brain and consciousness is restored. However, you could also maintain your grip on the flight controls and perhaps fly the aircraft into the ground.

During the latter stages of absolute incapacitation, you may experience marked involuntary skeletal muscle contractions and spasms just before regaining consciousness. These contractions can cause your arms to flail, leave the flight controls, or hit other aircraft controls. Once you regain consciousness, you enter the second phase of incapacitation.

Relative Incapacitation

Unfortunately, when you regain consciousness, you do not instantly return to an alert and functional state. You may experience mental confusion, disorientation, stupor, apathy, or memory loss. During this time, you are incapable of consciously flying the aircraft, making decisions, taking action against a threat, or communicating effectively. The time of relative incapacitation usually mirrors that of the absolute incapacitation.

Protection Against Positive G Force

The human body has a limited ability to compensate for the effects of G force. However, there are effective artificial methods you can use to increase your G tolerance and protect against G-LOC.

Protection Methods

Anti-G Suit, sometimes referred to as a G-suit consists of a pair of pant-like covers fitting tightly over your legs and lower abdomen. Air bladders in the thigh, calf, and abdomen areas of the suit are automatically inflated by an anti-G valve on the aircraft. However, the G-suit is not the primary means of G-LOC protection and used by itself, only allows for 1 to 1.5 G of protection. Your primary defense against G-LOC is a properly executed AGSM. The T-6 is equipped with a G-suit; however, it does not provide the majority of the protection from G-LOC.

Anti-G Straining Maneuver

There are two components of the AGSM — lower muscle straining and the cyclic air exchange technique.

1. Muscle tensing is the forceful contraction of legs, buttocks, and abdominal muscles to compress the blood vessels in the lower body. This skeletal muscle tensing helps prevent pooling of blood in the abdomen and lower extremities and improves the circulation of blood back to the heart (in a high $+G_z$ environment, blood will naturally pool anywhere below the heart). Muscle tensing is mandatory every time you pull Gs and the intensity should be in proportion to the G-load experienced.

In today's high performance combat aircraft and trainers, skeletal muscle tensing alone is not effective enough protection against G-LOC. Therefore, a second element of *cyclic air exchanges* is used in conjunction with muscle tensing. The

CONTENTS
PREVIOUS

increased chest pressure compresses the heart and blood vessels in the chest cavity and provides an artificial pumping action that, in turn, raises blood pressure in the head. As a result, blood flow to the eyes and brain is maintained during G stress.

2. Cyclic air exchanges begin with a calm prep breath (normal inhalation) while engaging the abdominal muscles at the same time. The breath is held at the glottis and the chest pressure must be maintained for approximately 3.0 (±0.5) seconds, broken only by a rapid air exchange (exhalation and inhalation) of no more than 0.5 second duration. The initial inspiration is performed after the muscles are tensed and before the G level is increased above 1G. Cyclic air exchanges must be accomplished simultaneously with muscle tensing. In a high G environment, failure to maintain muscle tension during the air exchange element increases the amount of blood pooling in the lower extremities and deprives the heart of necessary blood pressure. The rapid air exchange reduces intrathoracic pressure and enhances venous return thereby improving cardiac output and head level blood pressure.

AGSM Performance

Muscle Tensing is needed to be totally effective and prevent G-LOC, begin the AGSM *prior* to G onset. It's especially important to tense the calves, thigh, buttocks, and abdominal muscles; these muscles are below the heart and have the greatest effect on preventing pooling of blood in the lower extremities. When tightening the abdominal muscles, it should not be a crunching of the core but more of an "abs out" method, like bracing for a punch to the stomach or stabilizing ones core against a weight belt. *Maintain* the muscle tension until the aircraft returns to 1 G flight.

The muscle tensing element of the AGSM may be sufficient to maintain consciousness in the lower G environments. However, preventing blood pooling in the lower extremities and abdomen by muscle tensing can be overcome by a subtle increase in the G force. The increased G force can cause visual disturbances and/or G-LOC. Therefore, crewmembers should perform all elements of the AGSM and then back off their strain as needed. It's better to strain too much then ease up, than to strain too little and not be able to catch up. A properly performed AGSM can raise tolerance to G by 4 Gs.

Cyclic Air Exchanges are air exchanges in 3 second cycles to maintain optimum chest pressure, maximize venous return to the heart and oxygen flow into the lungs. If the air exchange cycle is too rapid then the chest pressure is not adequately maintained, fatigue sets in, and there is a threat of hyperventilation. Conversely, if the cycle is too long then the chest pressure remains too high and venous return to the heart is restricted. This restriction decreases the blood available to be pumped by the heart to the eyes and brain.

Other keys to the AGSM are the timing of the air exchange cycle and, importantly, anticipating the G forces in order to increase blood pressure in the head. With time and experience, performing the AGSM becomes easier and more natural. In the beginning, the problems crewmembers have with the AGSM mostly relate to the breathing cycle and leading the G force.

Note — The goal must be to employ the AGSM as a subconscious partner to G-onset, thereby freeing up conscious attention to focus on other aspects of flying. This can only be accomplished with persistent repetition.

Common Errors of Performance

The most common cause of G-LOC is *an improperly performed AGSM*. The most common errors involve the breathing cycle, the timing of the strain, loss of situational awareness, and insufficient lower body muscle tensing.

Timing — The primary timing error is starting the AGSM after the onset of the G force. Starting the strain late occurs more often if you are not at the controls of the aircraft. You may not be aware the pilot is about to perform a high-G maneuver. Experience will help overcome this disadvantage. The key to preventing this error is good crew coordination and communication. Anticipate the G onset and start the AGSM before the G force is encountered.

Note — If you are aware of potential G onset and perform an effective straining maneuver, you will decrease the chance of grayout, blackout, and most importantly G-LOC. If you are not flying the aircraft, your chance of experiencing G-LOC is greater than the crewmember flying the aircraft.

Another timing error is the failure to maintain the AGSM until the aircraft has returned to 1 G flight. Crewmembers sense the G force decreasing and relax. Unfortunately, there is still sufficient G force remaining to force the blood from the brain and cause G-LOC. Remember, maintain the AGSM until the aircraft returns to a 1 G flight environment.

Breathing — For inexperienced crewmembers, one of the more difficult aspects of the AGSM is the coordination and timing of cyclic air exchanges. These problems are readily corrected with practice and experience.

Common breathing errors include holding the breath too long, not holding the breath long enough (e.g., 2 second cycle), taking too much time to exchange air, exchanging too much air, and failure to exchange air at all. The primary method of correcting these errors is to practice and establish a rhythm.

Taking too much time to exchange the air or exchanging too much air causes the chest pressure to drop and decreases blood flow to the brain.

Failing to exchange air occurs when you have a good lung-full of air and are tensing the skeletal muscles properly, but forget to exhale and try to continue inhaling. Unfortunately, you can only put so much air into your lungs; there must be an exchange. This error eventually leads to decreased venous return to the heart and stagnant blood flow, resulting in G-LOC.

A final error associated with breathing is the relaxation of the lower body strain during the air exchange. If the lower body strain is not maintained during the air exchange, excessive blood pooling will occur.

Loss of Situational Awareness — Often times an improperly performed, late, or absent AGSM is because of a loss of situational awareness. Individuals channelize their attention, are task saturated, or misprioritize tasks to the detriment of performing an effective AGSM. Student inexperience makes them more susceptible to these attention management problems. Combined with the high-G onset rate of most trainers, this student susceptibility to loss of situational awareness causes trainer aircraft to have much higher G-LOC rates than operational aircraft. Fortunately, most, but not all, of the G-LOCs that occur in trainer aircraft happen during dual sorties, allowing the IP to recover the aircraft. Students must work to constantly maintain situational awareness to ensure a timely and proper AGSM whether they are flying the aircraft or not.

Other Errors — Allowing air to leak from the throat, holding the breath in the mouth instead of catching it in the back of the throat, and insufficient muscle strain are additional errors in performing the AGSM. Allowing air to leak past the glottis causes the pressure in the chest to drop. It also irritates the vocal cords and makes communication difficult. Air leakage is evidenced by a groan when you strain.

Insufficient muscle strain allows too much blood into the lower extremities. This most common error of not maintaining lower body leg tension causes vision loss. Development of muscle strength and tone with an anaerobic exercise program will remedy this error.

Waiting for the G-suit to inflate before executing the strain is another common mistake. By the time the G-suit is inflated a substantial volume of blood is pooled in the legs and will be lost to free circulation until you return to 1 G flight. You must begin the strain *before* you load up the aircraft!

Tolerance to Positive G Force

G tolerance changes from day to day and hour to hour based on a number of variables. Understanding the reasons for these variables helps you maximize your tolerance and minimize the threat of G-LOC. The following section describes some of the physiological factors and their effects on G tolerance.

Physiological Factors

Physical Conditioning — Mentioned previously as a method to improve muscle strain during the AGSM. Physical conditioning is also important in decreasing the fatigue levels and increasing stamina required for multiple G maneuvers. Two types of physical conditioning are encouraged — anaerobic and aerobic.

Anaerobic Conditioning — The AGSM is essentially an anaerobic maneuver. The muscles used to perform the AGSM rely upon anaerobic energy sources (energy sources not requiring oxygen). Crewmembers flying high performance aircraft are encouraged to develop a weight training program to maximize their muscle strain ability. Weight training is the primary method of anaerobic conditioning and decreases your chances of injury, particularly neck injury during high-G maneuvers.

Anaerobic conditioning increases the muscle's ability to contract and sustain the contraction throughout the G stress. Without sufficient anaerobic conditioning the muscles fatigue quickly and your AGSM loses its efficiency. However, developing a conditioning program based solely on anaerobic exercise is not complete. Aerobic conditioning must complement your anaerobic conditioning.

Aerobic Conditioning — Even though the AGSM is primarily an anaerobic maneuver, you need to be aerobically fit to combat fatigue and recover from multiple G maneuvers. Aerobic exercise programs require oxygen to produce the

CONTENTS
PREVIOUS

necessary energy. Aerobic conditioning increases stamina and resistance to fatigue. (G-LOC typically occurs towards the end of engagements during the fatigue period.)

Overall, for crewmembers that fly in high performance aircraft, a sound anaerobic training program coupled with a sensible aerobic exercise program will help maximize their G tolerance. However, exercising prior to high G flight without proper recovery time, may leave you in a fatigued and dehydrated state and is not recommended.

The Role of Self-Imposed Stress

Dehydration — Crewmembers generally drink less water than they need and are slightly dehydrated most of the time. Dehydration reduces G-performance markedly by depleting blood plasma volume. Aircrews must drink plenty of non-caffeinated, nonalcoholic fluids (even when not thirsty) prior to (and during) flight. You suffer a 35 percent decrease in ability to do anaerobic work and a 20 percent decrease in ability to do aerobic work if you are 3 percent dehydrated. Therefore, you can only maintain an AGSM for one-half the time you normally would. For instance, if you can normally pull 9 Gs for 10 seconds, the effects of dehydration will limit you to 9 Gs for 5 seconds.

Fatigue and Sleep — Fatigue significantly decreases G tolerance. Crewmembers that are fatigued or are lacking sleep tend to experience lapses in mental function and a lower ability to maintain muscle tension during the AGSM.

Mental fatigue slows your response and anticipation of high G maneuvers. Physical fatigue lowers your capability to maintain adequate muscle strain during the AGSM and also lowers your capability to perform subsequent strains.

Take advantage of your crew rest, stay well rested, and maintain good sleep patterns prior to flying.

Drugs and Self-medication — Self-medication with over-the-counter drugs can potentially decrease overall performance. You must always perform at peak levels in a high G environment. Do not self-medicate, report to the flight surgeon and obtain qualified medical treatment.

Alcohol/Hangover — Alcohol misuse, and the accompanying hangover, drastically reduce your G tolerance. The reduced G tolerance is primarily due to alcohol's dehydrating effects. In addition, a hangover clouds your mental capabilities, slows the thinking and decision-making process, as well as your ability to effectively judge situations.

Alcohol use should be avoided prior to flight. AFMAN 11-202, Volume 3 restricts crewmembers from alcohol consumption 12 hours prior to flight. In addition, some detrimental aftereffects can last as long as 48 to 72 hours. Alcohol also contributes to fatigue and hypoglycemia.

Hypoglycemia and Missed Meals — Missing meals or not taking the time to eat correctly directly affects your ability to withstand increased G force. You do not have the fuel in your system to maintain high levels of activity for extended periods of time if you do not eat or you eat improperly. Take the time to eat a nutritious meal prior to flight. Your food is the fuel you must rely on to function in a high G environment.

CONTENTS
PREVIOUS

Summary

G forces are the result of inertial forces acting on the body. G is a dimensionless number expressed as a ratio of a body's acceleration to the force of gravity (32 ft/sec^2 or 9.81 m/sec^2).

The magnitude, duration of exposure, rate of application, direction of force applied and previous G exposure are physical factors influencing the body's physiological response to a G force. These factors define the G force and can predict the effect the G force will have on you.

$+G_z$ is the force of greatest concern to you. It is regularly encountered in-flight. The effects of $+G_z$ are decreased mobility, visual disturbances like grayout and blackout, and finally G-LOC. You can increase your tolerance to $+G_z$ by correctly performing the AGSM.

The AGSM is performed by tensing the skeletal muscles (particularly in the lower extremities and the abdomen), cyclic air exchanges and a closed glottis. Start the AGSM prior to G onset and do not stop the AGSM until the aircraft returns to 1 G flight.

Physiological factors will increase or decrease your G tolerance. These factors include your physical condition and self-imposed stresses (fatigue, dehydration, self-medication, alcohol use, and nutrition). Staying in shape, avoiding self-imposed stresses, and performing an effective AGSM will help increase your G tolerance.

References

Air Force Manual 11-202, Volume 3, *Flight Operations,* 09 June 2020

Review Exercise AP111

Complete the following review exercises by selecting the correct response or filling in the blanks. Answers follow the questions.

1. An F-15E crew is on takeoff roll. They accelerate to 165 KIAS in 10 seconds. They experience __________ acceleration and __________ G forces.

2. An F-18 rolls into a dive toward a target, releases weapons, and begins a pullout. He is climbing, turning, and increasing speed from 360 KIAS to 450 KIAS. This time the pilot experiences __________ acceleration.

3. A positive G_z force is defined as the force being applied from the __________ toward the __________.

4. Define negative G_z force.

5. An aircrew is having problems figuring out the attitude of their aircraft. As the pilot makes a control input, the crew experiences congestion in their heads and lightweight feeling. What type of G force causes these symptoms?

   a. Transverse

   b. Negative

   c. Positive

6. List the five factors determining the physical effects of G forces.

   a.

   b.

   c.

   d.

   e.

7. Why would it be unadvisable to give aircraft control back to a crewmember immediately after recovering consciousness after a G-LOC incident?

8. During a dual T-6A sortie, a student pulls 5 Gs in less than a second and experiences a G-LOC. When questioned by an Aerospace Physiology member about symptoms, the student said grayout or blackout did not occur prior to the G-LOC. Why would the student not experience any visual cues prior to G-LOC?

9. The elements of the AGSM are

   a. __________ tensing

   b. __________ breathing

10. The most common cause of G-LOC is an improperly performed AGSM. What do the most common errors involve?

    a. __________ __________

    b. __________ of the __________

    c. Insufficient __________ __________ muscle __________.

CONTENTS
PREVIOUS

11. A properly performed AGSM can increase your $+G_z$ tolerance by as much as 4 Gs.

    a. True

    b. False

12. Differentiate between blackout and G-LOC.

13. You can decrease your overall G tolerance by not eating properly and/or getting insufficient rest.

    a. True

    b. False

14. Determine if the following effects of acceleration are caused by (A) $+G_z$ or (B) $-G_z$.

    a. _____ Visual loss (grayout)

    b. _____ Headache

    c. _____ Mental confusion

    d. _____ Blood pooling in lower extremities

    e. _____ Extreme feeling of congestion in the head

    f. _____ Feeling of increased weight with resultant loss of mobility

    g. _____ Blackout and possible unconsciousness

Answers to Review Exercise AP111

1. linear; transverse
2. angular
3. head; feet
4. Force acting from feet to head
5. b
6. a. magnitude
   b. rate
   c. duration
   d. direction
   e. previous exposure
7. G-LOC victims may be disoriented for some time after regaining consciousness.
8. Rapid G-onset rate gives little or no visual warning prior to G-LOC
9. a. skeletal muscle
   b. cyclic
10. a. breathing cycle
    b. timing; strain
    c. lower body; tensing
11. a
12. G-LOC results in unconsciousness whereas blackout results in vision loss only.
13. a
14. a. A.
    b. B
    c. B
    d. A
    e. B
    f. A
    g. A

AP112 — Performance Threats Management

Hours and Medium

1.5 Hours (IBT)

Objectives

1. Know the aircrew performance effects over-the-counter (OTC) drug use.

   Samples of Behavior:

   a. Identify the types of OTC medications and nutritional supplements.

   b. Recognize the potential performance effects of nutritional supplements and OTC medications.

   c. Memorize Air Force policy on OTC medications and nutritional supplements.

2. Know the aircrew performance effects of alcohol use.

   Samples of Behavior:

   a. Identify both the immediate and residual effects of alcohol on the body.

   b. Memorize Air Force policy concerning alcohol consumption by crewmembers.

3. Know the aircrew performance effects of smoking and chewing tobacco use.

   Samples of Behavior:

   a. Recall the immediate and residual effects of smoking and smokeless tobacco.

   b. Recall the physiological effects of Carbon Monoxide.

4. Know the aircrew performance effects of both poor and proper diet and nutrition.

   Samples of Behavior:

   a. Identify the effects of hypoglycemia.

   b. Memorize hypoglycemia prevention methods.

   c. Recognize the signs and symptoms associated with dehydration.

   d. Memorize dehydration prevention methods.

5. Know the aircrew performance effects of both acute and chronic fatigue.

   Samples of Behavior:

   a. Recall definition of both chronic and acute fatigue.

   b. Identify the causes (scenarios) of acute and chronic fatigue.

   c. Memorize fatigue countermeasures.

   d. Identify both the advantages and disadvantages of GO/NO-GO Pill usage.

6. Know the aircrew performance effects of caffeine usage.

   Samples of Behavior:

   a. Recall both the negative and positive effects of caffeine on the body.

   b. Recognize hypercaffeination effects, post-usage and withdrawal threats.

   c. Recall strategic caffeine consumption tactics.

CONTENTS
PREVIOUS

7. Know the aircrew performance effects of thermal stress.

   Samples of Behavior:

   a. Identify impacts to performance resulting from hot/cold stress.
   b. Recall thermal stress countermeasures.
   c. Identify the exacerbating effects thermal stress causes on the other physiological threats.

8. Know the aircrew performance effects of stress.

   Samples of Behavior:

   a. Recall "overload" and ways to reverse the effects it has on the flying environment.
   b. Identify common stressors to everyday life that can affect the flying environment.
   c. Recall life style changes that can decrease the negative effects of stress.
   d. Recall stress countermeasures and stress management methods.

Assignment

Read AP112 in the SG and answer the review questions.

Introduction

In military aviation, a substantial percentage of Class A mishaps are attributed to human error. The self-imposed stresses discussed in this lesson are directly linked to human errors.

Self-imposed stresses decrease your capability to function in high stress environments where physical and mental capabilities must be optimal. Figure 12-1 (Critical Interface Concept) illustrates the compounding effects of self-imposed stresses, attention problems, environmental stresses, and aircraft problems on an aircrew's capacity to cope with normal flight stresses. Line A of the model contains the stresses most within your control. Line B of the model depicts environmental stresses beyond the crewmember's control. For the most part, environmental stresses are based on the type of aircraft flown, time of day the mission is flown and mission profile. However, unpredictable stresses, like weather or mechanical problems, are also included in environmental stresses. The area between lines A and B represent the crewmember's capacity to cope with any unknown stress the aircraft or mission places on them.

Your capacity to cope is decreased by self-imposed stresses like alcohol misuse or self-medicating with over-the-counter (OTC) drugs. This decrease in capacity to handle stress is depicted by a dip in line A of Figure 12-1. The more stresses you subject yourself to, the more you decrease your capacity to cope. If environmental stresses increase to the point where the capacity to cope and environmental demands intersect (critical interface), you lose the capability to effectively cope with the flight situation. In most mishaps, there is seldom just one major factor causing the mishap. Instead, mishaps usually occur when many small factors add up to disrupt the crew's capacity to fly the aircraft.

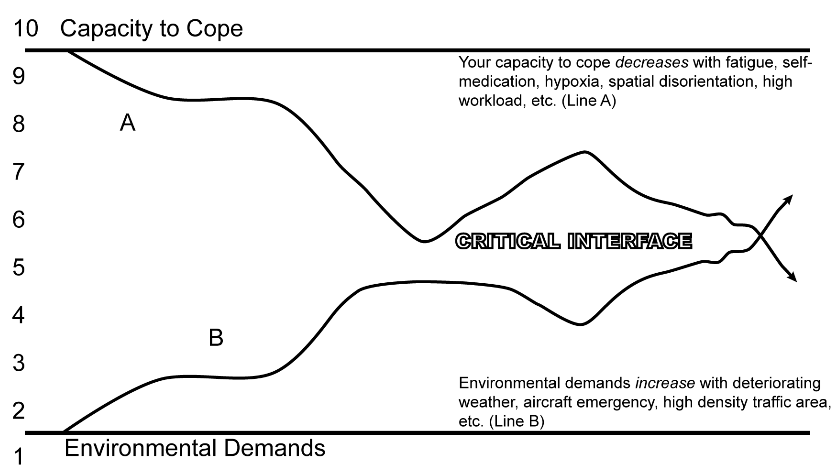

Figure 12-1 — Critical Interface Concept

CONTENTS
PREVIOUS

Therefore, you must understand the importance of decreasing your exposure to self-imposed stress. The closer you are to 100 percent capable, the greater your ability to cope with unexpected problems or stresses arising during flight.

Self-imposed stresses result from actions taken by the crewmember. They can include the use of OTC drugs, caffeine, alcohol, or tobacco. Self-imposed stresses also include nutrition, physical condition, and life-style. These stresses, as well as circadian rhythm problems, can contribute to fatigue. All of these stresses strain your ability to function at an optimum level in the aircraft. Self-imposed stresses decrease your performance, impair your judgment, and decrease your tolerance to other in-flight stresses.

Self-Medication

Use of Over-The-Counter (OTC) Drugs

In the civilian world, a person who catches a cold, comes down with the flu, or physically feels bad, can take one of the many OTC drugs available. Aircrew members will not normally self-medicate. Air Force regulations (AFMAN 11-202, Volume 3, *Flight Operations*, and AFI 48-123, *Medical Examinations and Standards*) contain directives on the use of OTC drugs ("self-medicating") or flying while under the influence of medications.

Nonprescription medications are designed to alleviate the symptoms of an illness without treating the cause of the illness. Therefore, OTC drugs only mask the symptoms to make you feel better and the masking of symptoms may delay treatment of a medical problem. The negative effects and the various types of OTC drugs are discussed in the following sections. Figure 12-2 lists common OTC drugs misused by crewmembers.

Common OTC Drugs

- Decongestants
- Antihistamines
- Vasoconstrictors
- Pain Killers
- Diet Pills

Figure 12-2 — Types of OTC Drugs

Effects of OTC Drugs

OTC drugs interfere with or modify normal body functions in different ways. The effects of OTC drugs are divided into primary, side, synergistic and idiosyncratic effects.

Primary Effect of each type of drug is the desired (intended) effect of the drug on the individual. For instance, a person takes an OTC decongestant because they are congested. The primary effect of a decongestant is to dry up the nasal passages and sinuses.

Side Effects are those effects known to accompany a drug but are additional to its desired effect. For example, the person who takes a decongestant to clear up their sinuses may also experience the side effects of increased heart rate and blurred vision.

Synergistic Effects occur when the primary or side effect of a drug is modified in function or intensity when taken in combination with another drug. The effect of the combined drugs is greater than would be expected from the individual drugs (in a synergistic reaction the sum of the whole is greater than the sum of the parts, or 1+1 = 3). For example, combining a decongestant with caffeine increases the stimulant effect above the normally expected level.

Idiosyncratic Effects are those effects on an individual that are unusual and unexpected. Just as certain individuals have unexpected allergic reactions to types of food, people may have unexpected adverse reactions to types of drugs. Although rare, a crewmember self-medicating with an OTC drug may experience an unexpected reaction to the drug.

Decongestants are normally found in "cold-remedies" and act as a stimulant. Decongestants are used to shrink inflamed mucous membranes and clear up a person's nasal passages and sinuses. OTC decongestant medications may contain only a decongestant. However, other medications may contain antihistamines and pain killers in combination with the decongestant.

The side effects of decongestants are detrimental to crewmembers. Decongestants can produce shakiness, increased heart rate, blurred vision, increased dehydration, dizziness, nausea, and headaches. Therefore, self-medicating with decongestants increases your physiological stress levels and decreases your capacity to cope.

Antihistamines are used to reduce nasal congestion due to allergies and colds. They are normally found in OTC drugs combined with other compounds such as decongestants. Common OTC cold remedy drugs contain both antihistamines and decongestants. Antihistamines relieve congestion by blocking the release of histamine — responsible for the swelling of the nasal mucous membranes in an allergic reaction. The result is a decrease in mucous production and possible relief from the itching and watering of the eyes.

CONTENTS
PREVIOUS

Antihistamines' undesirable side effect is the depressant nature they have on the central nervous system (CNS). Drowsiness is the most common effect, but they also cause diminished alertness and increased reaction times. If alcohol or other CNS depressants are also consumed, a synergistic effect occurs, increasing the depressant effect of antihistamines. The danger of a mishap is greatly increased. This synergistic effect is particularly pronounced if you take an OTC drug high in alcohol. These OTC drugs usually contain both an antihistamine and up to 25 percent alcohol (50 proof). Idiosyncratic effects may include dizziness, muscular incoordination, nervousness, and tremors.

Vasoconstrictors can be topical drugs sprayed in the nose (nasal sprays). They act to constrict blood vessels in the nose and sinuses, resulting in a reduction of inflammation and swelling. The dangers of using these drugs, without being under the supervision of a flight surgeon, are twofold. Dizziness, blurred vision, tremors, and headaches may occur if a vasoconstrictor is used prior to flight. There is also the chance of the medication wearing off prior to descent and landing, allowing the tissues to swell and increasing the chance of blocked sinuses or ears. The second danger with vasoconstrictors occurs after prolonged use (roughly three days) when the nasal tissues become addicted to the drug. If vasoconstrictor use is discontinued after the tissues are addicted, the tissues increase mucous production. The resulting congestion is usually much worse than the original case of congestion. Additionally, extended use can deteriorate the nasal mucosa.

Pain Killers (Analgesics) are used by most everyone. Primary OTC pain killers are aspirin or acetaminophen (Tylenol® or Naproxen®). Aspirin is used to relieve mild pain or headache and to relieve fever. Aspirin and acetaminophen can cause stomach irritation as a side effect. Ibuprofen is a third type of OTC pain killer. Unfortunately, the side effects are more serious than with aspirin or acetaminophen. Side effects may include dizziness, skin rash, heartburn, gastrointestinal disturbances, and blurred vision.

Diet Pills contain the same medications found in decongestants. They are stimulants with unwanted side effects. Including nervousness, tremors, increased blood pressure and heart rate, dehydration due to increased sweating, and sleep disturbances. There is a significant synergistic effect when diet pills are used in conjunction with caffeine. This effect includes a marked increase in blood pressure and increased dehydration.

If you feel a need to lose weight, you can do so without diet pills. A sensible diet and a regular exercise program is a much healthier and safer alternative for losing weight.

In summary, do not self-medicate. If you are ill, consult a flight surgeon and don't fly.

Alcohol and Tobacco Use

Alcohol

Perhaps the oldest drug known to man, alcohol is a legal drug having toxic effects on the body. It is a central nervous system depressant. Alcohol is absorbed through the stomach and upper tract of the small intestine and distributed throughout the body by the circulatory system. The concentration of alcohol in the brain and nervous tissues rapidly approaches the same concentration as in the blood because of the extensive blood flow through these tissues. As the alcohol reaches the tissues, it's absorbed by the cells and causes histotoxic hypoxia by disrupting cellular metabolism.

Short-Term Effects are a result of the histotoxic effects of alcohol on the brain and nervous tissues, higher brain function is impaired. Marked psychological reactions are experienced, the most common being the impairment of judgment and performance, reduction of inhibitions, abnormal behavioral shifts, and a bolstered sense of immortality. Physiologically, the crewmember becomes anesthetized, suffers degraded sensory and motor skills, decreased visual acuity, degraded communication ability and loss of balance. Figure 12-3 summarizes the common psychological and physiological reactions to alcohol.

Alcohol has other effects on the body that are of particular concern to crewmembers. Alcohol affects the fluid in the inner ear that is used for orientation. This effect may contribute to spatial disorientation and airsickness. Additionally, small amounts of alcohol are sufficient to significantly disrupt sleep patterns, leading to mental and physical fatigue. Alcohol, being a sedative, deprives the body from receiving the necessary mental restorative sleep called rapid eye movement (REM) sleep. Failure to achieve REM sleep leads to attention problems and decreases your ability to cope with in-flight stresses.

CONTENTS
PREVIOUS

Psychological	Physiological
• Impairment of Judgment and Performance • Reduced Inhibitions • Abnormal Behavior Shifts • Bolstered Sense of Immortality	• Anesthesia • Degraded Sensory and Motor Skills • Decreased Visual Acuity • Degraded Communication Ability • Loss of Balance

Figure 12-3 — Reactions to Alcohol

Residual Effects of alcohol on the crewmember depend on the amount of alcohol ingested. The body metabolizes pure alcohol at a constant rate of 1 ounce in 3 hours. Therefore, if you drink a six-pack of beer (72 ounces), six glasses of wine (18 ounces) or six shots of whiskey (6 oz.), you ingest approximately 3 ounces of alcohol (0.5 ounce of alcohol per 12 ounces of beer, 3 ounces of wine, or 1 ounce of distilled spirits). In this situation, it takes your body at least 9 hours to metabolize the alcohol.

AFMAN 11-202 Volume 3, "Aircrew members will not fly if any alcohol is consumed within 12 hours prior to takeoff (or assuming aircraft control for UAS) or if impaired by alcohol or any other intoxicating substance, to include the effects or after-effects."

Therefore, you can calculate the amount of alcohol you drink, stop drinking twelve hours prior to takeoff/flight planning, and be legal and safe, right? Unfortunately, no, it is not that simple. Remember, AFMAN11-202v3 states "...to include the effects or after-effects." This means, if you are suffering a hangover, or even a headache as the result of alcohol, you are not legal to fly. The bigger picture, however, is not one of legality but safety. You may be *legal* after 12 hours, but are you *safe*?

The effects of alcohol consumption can manifest themselves for longer than 12 hours after drinking is stopped. Some of these residual effects are known as a hangover and include dehydration, headache, and nausea.

When alcohol is consumed, it disrupts the body's ability to regulate water and leads to dehydration. The production of antidiuretic hormone (ADH) decreases, causing the body to think there is more water in the system than required. Therefore, water is lost through increased urination. When this excessive urination happens, water is lost from the spaces between cells (interstitial spaces) and tissues shrink, creating abnormal tension on body organs. This abnormality is particularly prevalent in the tissues surrounding the brain, resulting in a painful headache. Additionally, your body is hypoglycemic, hypoxic (histotoxic hypoxia), fatigued, and telling you that you must rest and recuperate. Unfortunately, the only cure for a hangover is time, rest, drinking plenty of nonalcoholic fluids (preferably water), and eating a balanced diet.

The best method to avoid the dilemma of suffering a hangover and the residual effects of alcohol is *abstinence*. If this option is unrealistic or undesirable, moderation of alcohol intake, drinking plenty of water with the alcoholic drink, and not drinking 24 hours prior to flight increases your ability to successfully complete the mission.

Hazards Associated with Tobacco Products

Smoking is the leading cause of preventable death." Also states: "Cigarette smoking is responsible for more than 480,000 deaths per year in the United States, including more than 41,000 deaths resulting from secondhand smoke exposure. This is about one in five deaths annually, or 1,300 deaths every day (CDC, Nov 2019).

The primary problems of tobacco and tobacco products are the effects of nicotine and the effects of carbon monoxide. Crewmembers are usually exposed to nicotine through smoking, chewing, dipping, or inhaling (snuff) tobacco products. If you smoke cigarettes or other tobacco products, you also expose yourself to carbon monoxide (CO) and other toxic by-products of the burning tobacco.

Nicotine is classified as a drug of abuse because of its addictive characteristics. Nicotine is also a highly toxic drug. For example, if 60 milligrams (mg) of nicotine (an amount approximately one-half the size of a match head) is ingested it is sufficient to cause death in humans within minutes. The amount of nicotine contained in three average cigarettes can cause death if injected intravenously.

Smoking is the primary means by which Americans expose themselves to nicotine. Nicotine is readily absorbed in the lungs and reaches the brain within 8 seconds after inhalation. The acute effects of nicotine on a person, who has not developed a tolerance to the drug, includes increased blood pressure, heart rate, hand tremors, nausea, salivation, vomiting, cold sweat, headache, dizziness, disturbed vision and hearing, mental confusion, and marked weakness.

CONTENTS
PREVIOUS

Nicotine acts primarily as a CNS depressant but, if combined with caffeine, it has the opposite effect (stimulant). People eventually develop a tolerance to nicotine, become dependent on the drug, and do not readily show the adverse effects of nicotine. However, even chronic smokers experience increased blood pressure, heart rate, and hand tremors after one or two cigarettes.

With the increased social stigma attached to smoking and the increased awareness of the health hazards associated with it, many people think that switching to "smokeless tobacco" is a favorable alternative. "Dipping" and "chewing" involves placing tobacco in the mouth, either between the cheek and gum or chewing leaf tobacco. Nicotine is not absorbed well in the mouth and if swallowed causes severe gastric upset and vomiting. Unfortunately, chewing or dipping tobacco increases the incidence of mouth, gum, tongue, and cheek cancers.

When tobacco burns there are roughly 4,000 chemical compounds given off and inhaled by the smoker. Tobacco smoke can be separated into gaseous and particulate phases. The gaseous components contain CO, ammonia, hydrogen cyanide (HCN), volatile hydrocarbons, and other toxic agents. The particulate components of tobacco smoke are water, nicotine, and numerous documented cancer causing agents. The particulate phase also contains several radioactive compounds, like polonium 210, contributing to the cancer causing effects of other compounds.

Carbon Monoxide is one of the major byproducts of tobacco smoke. The danger to you from CO is its effect on the oxygen carrying capacity of the blood (hypemic hypoxia). CO binds to red blood cells with roughly 200 to 250 times greater affinity than oxygen. According to FAA research, smoking can raise the body's physiological altitude anywhere from 2,000 to 7,000 feet because of the increased amount of carbon monoxide in the blood. Your visual acuity is decreased because of decreased oxygen transport to the eye. There are other problems caused by a combination of the CO and other combustion by-products.

The effects of smoking on the crewmember are decreased resistance to hypoxia because of the CO load on the red blood cells and the HCN inhaled. Motor skills may also be affected because of the effect of nicotine on the nervous tissues and peripheral blood vessels. The long-term effects of smoking include increased stress on the respiratory system due to lung damage, increased cardiovascular disease due to increased atherosclerosis (blocking and hardening of the arteries), increased threat of forming blood clots, and the danger of cancer and other long term diseases caused by tobacco smoke by-products.

In summary, the use of tobacco will reduce a crewmember's tolerance to other flight stress and can decrease performance.

Nutrition

In order for the human body to function, it must have fuel to burn. The fuel the human body uses is a sugar called glucose. When you eat, the glucose liberated during the digestion process enters the blood stream and is transported to the organs and tissues needing it, or taken to the liver where it is stored as glycogen.

Nervous tissue (the nerves and brain) and retinal tissue (photoreceptive tissue in the back of the eye) are both dependent on blood sugar levels to function. When glucose levels in the blood fall below levels adequate to supply these tissues, the liver converts glycogen to glucose and releases it into the blood stream.

Hypoglycemia

Hypoglycemia results when the glycogen stores in the liver are depleted and there is not enough glucose in the blood stream. Hypoglycemia means "low blood sugar" and has a variety of causes. The most common cause is skipping meals or eating foods that are predominantly simple sugars. Other causes of hypoglycemia are high protein/low carbohydrate diets and diets where a crewmember does not eat for extended periods of time (fasts or starvation diets).

Short-Term Symptoms of hypoglycemia are shakiness, decreased mental ability, physical weakness, irritability, fatigue, and sleepiness. These symptoms arise within 4 to 6 hours after your last meal. However, if you had a meal of complex carbohydrates, like pasta, potatoes, or whole wheat breads, hypoglycemia does not occur as quickly. If your last meal consisted of simple carbohydrates, like those found in

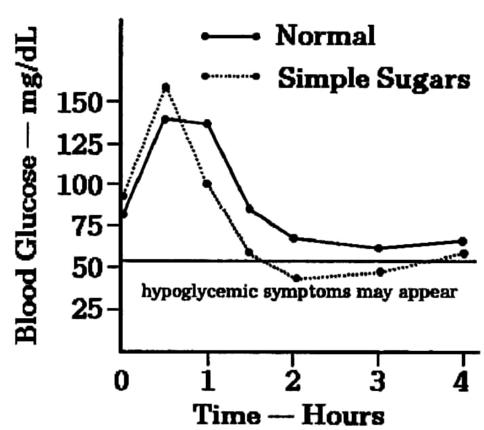

Figure 12-4 — Blood Sugar Levels

CONTENTS
PREVIOUS

candy and soft drinks, then hypoglycemia occurs much more quickly because of the rapid digestion and rapid metabolism of the simple sugars.

Complex carbohydrates, proteins, and fat require more time for digestion and utilization. Their glucose is slowly released into the blood and stored in the liver over a period of time, avoiding erratic shifts in metabolism. Simple carbohydrates are absorbed into the blood quickly, causing the blood sugar level to rise dramatically. As the blood sugar rises, the brain senses there is too much glucose in the blood and signals the pancreas to release insulin into the blood stream which acts to remove glucose from the blood and take it to the liver. Unfortunately, if the blood sugar levels are high, insulin removes most of the sugar, leaving a blood sugar level that is lower than before the candy was eaten. Figure 12-4 shows a hypothetical time line of blood sugar levels for a crewmember flying while following a diet consisting of simple sugars. As clearly shown in Figure 12-4, relying on a typical "Coke and candy" meal sets you up for hypoglycemia.

Long-Term Symptoms can include convulsions and fainting, usually occurring as a result of large swings in blood sugar levels. One of the major effects of hypoglycemia is a lapse in mental processes. When the brain cannot get the glucose it needs from the blood, it begins to slow down. For a crewmember, common symptoms are math errors, checklist errors, and decreased attention span which causes missed-communication errors and perception errors.

Prevention of Hypoglycemia is to eat regularly. When meals are missed, snacks of complex carbohydrates are more beneficial than candy and soft drinks. Figure 12-5 lists some snacks that keep the amount of sugar in the blood at a constant level.

The bottom line on nutrition and flying is to eat sensible meals containing complex carbohydrates low in fat, at regular intervals. If you are accustomed to eating three meals a day, then try not to skip a meal since the glycogen stores in your liver may become depleted. Avoid fad diets or high protein/low carbohydrate diets designed to build bulk. Furthermore, protein is an inefficient source of energy and is primarily used to build muscle and bone. Carbohydrates, however, are efficient sources of energy and are easily converted to glucose.

Complex Carbohydrates
• Bagels • Pretzels • Fig or Fruit Bars • Granola Bars (low in sugar) • Yogurt • Milk • Fresh Fruits and Vegetables

Figure 12-5 — Recommended Snacks

Thermal Stress

Dehydration

Dehydration, like hypoglycemia, is a major contributor to fatigue. There are varying degrees of dehydration, with different symptoms. Unfortunately, most people are constantly in a slightly dehydrated condition. When dehydration is combined with the flying environment, you fatigue quickly and are at a higher risk of experiencing decompression sickness, spatial disorientation, visual illusions, airsickness, and loss of situational awareness.

A common first indication of dehydration is a sensation of thirst. At this point, your body's water content is 1-2 percent low. If you are flying in a pressurized cockpit while 2 percent dehydrated, this level of dehydration increases rapidly. In an aircraft, the cockpit air is frequently 5 to 10 percent relative humidity, causing water loss as you breathe. Combine this water loss with the diuretic effects of caffeinated drinks (coffee, colas) and you can quickly become 3 percent or more dehydrated.

At a dehydration level of 3 percent, you may experience sleepiness, nausea, mental impairment, and mental and physical fatigue. If you fly after a night of drinking alcoholic beverages, you will reach the 3 percent dehydration level more quickly than other crewmembers because of the diuretic effects of alcohol. In addition to mental impairment, dehydration decreases your ability to do physical work (performing an anti-G straining maneuver for example).

The best method to prevent the problems of dehydration in the aircraft is to drink plenty of water before, during, and after a flight. If water is unappealing or unpalatable, drinks that are low in sugar, nonalcoholic, and decaffeinated can be substituted. Many crewmembers prefer "sports drinks" like Gatorade®. These drinks are fine but some contain higher amounts of salt the body normally needs. In addition, some of the drinks are heavily sugared. Usually, you don't lose enough salts or electrolytes during normal activity to warrant the use of these types of drinks. However, if you prefer sports drinks to water, then drink whatever you like best providing it is not alcoholic, caffeinated or heavily sugared. Staying hydrated before, during, and after flying has a pronounced positive effect on how well you perform flight duties.

CONTENTS
PREVIOUS

Fatigue

In any human-machine system, including weapons systems, the most unpredictable component in the system is the human. After training and currency, the greatest contributor to that human variability is fatigue.

Fatigue is defined as a state of diminished mental and physical efficiency. Unfortunately, fatigue is an insidious stressor because crewmembers usually become mentally fatigued before they become physically fatigued. If you self-medicate and fly when you are sick, suffer from a hangover, are dehydrated, hypoglycemic, or any combination of these stresses, you increase fatigue's effect on your ability to safely accomplish the mission. Therefore, all the self-imposed stresses discussed previously have a direct effect on your fatigue levels.

Types of Fatigue

Fatigue is divided into three categories, acute fatigue, cumulative fatigue, and chronic fatigue.

Acute fatigue is short-term fatigue caused by the normal daily activities of the crewmember or an extended duty day or an "all-nighter." It's remedied with a good night's sleep. Unfortunately, if you fail to remedy acute fatigue, then you begin to suffer from cumulative fatigue.

Cumulative fatigue builds up across several waking and duty periods when there is inadequate sleep or recovery between the duty periods. Recovery from cumulative fatigue cannot be accomplished in one good-quality, nocturnal sleep period.

Chronic fatigue is long-term fatigue and is caused by a variety of factors. Chronic fatigue may set in after 1 to 2 weeks of cumulative fatigue. Other major causes of chronic fatigue in crewmembers include interrupted or poor sleep patterns, circadian rhythm shifts, illness, successive long missions with minimal recuperation time, and succumbing to self-imposed stresses. Additionally, chronic fatigue may also be due to motivational exhaustion, or chronic night work/shifts.

Fatigue Symptoms

Each aircrew member must be aware of their individual symptoms of fatigue and become sensitive to signs of fatigue. A simple mistake may be due to a loss of situational awareness or sleep. But you are more susceptible to a loss of SA when you are fatigued. You have to recognize symptoms in yourself and in your crew. The main effect of fatigue is a progressive withdrawal of attention. When people must continue working beyond the point at which they can effectively perform their tasks they experience a disinclination to continue work. Eventually, withdrawal is so insidious that operators may be unaware of it and unable to recover. Here is a list of common symptoms of fatigue:

Feeling of being "behind"	Micro sleep
Poor performance on basic tasks	Accept lower standards
Trouble focusing	Lack of patience
Disconnected thoughts	Increased reaction times
Erratic control (e.g., driving)	Decreased motivation
Poor conversation	Decreased attention span
Irritable/loss of patience	Reduced situational awareness

Fatigue is normally caused by the common day-to-day activities a crewmember performs. However, problems also arise when the crewmember fails to gain adequate sleep and acute fatigue evolves into chronic fatigue.

Required Sleep Time

According to the National Sleep Foundation, the amount of sleep needed always depends on the individual (Figure 12-6). Usually, the minimum amount of sleep to maintain performance during sustained operations is 6–8 hours per day. Fragmented sleep is less effective than continuous sleep (e.g., sleep 6–8 hours, not 3–4 hours twice). Every hour less than what is needed has a negative impact on performance. An individual may not notice it on the first day, but sleep loss is cumulative. For example, if on two consecutive days an individual only gets 7 hours, 2 hours of sleep is lost that needs to be made up.

The average sleep length in humans is 7–9 hours per day. For most airmen, the normal sleep length can be reduced by 1–2 hours for an extended period without significantly affecting performance, but once the sleep restriction period ends, airmen have to revert to their normal sleep length. Five hours of sleep per night should be considered the absolute minimum for longer-term operations (e.g., 14 days). Greater sleep restrictions result in adverse effects on behavior, physiology, and performance. Sudden or significant sleep deprivation should be expected to degrade mental skills, mood, and motivation.

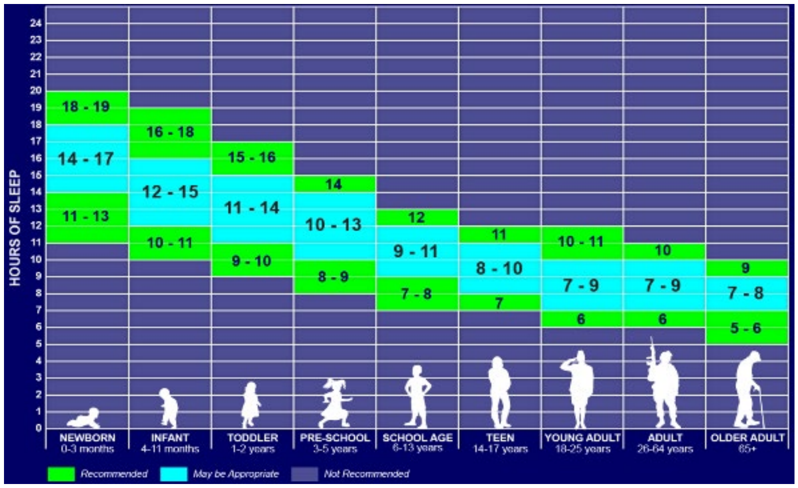

Figure 12-6 — Required Sleep Time

Sleep Latency

Sleep latency is the amount of time it takes you to fall asleep. It is used to determine the amount of sleep deprivation and may be used to determine if an individual has a disorder. The time it takes to fall asleep is also dependent on the time of day. Obviously, when the body is at a circadian low, the body falls asleep more easily. A normal time is 10–15 minutes during the afternoon low. Most Americans take 5–10 minutes, and most Americans are sleep deprived. Any less than 5 minutes indicates a severe sleep deprivation or a medical disorder.

Sleep Cycle

Rapid Eye Movement (REM) sleep, indicated by darkened bars in Figure 12-7, and Non-REM (NREM) alternate throughout the sleep period. Most deep sleep occurs in the first half of the sleep period and REM periods become longer and more regular later in the sleep period. Sleep periods occur in natural cycles that are about 90 to 100 minutes long, plus time for sleep latency (the time to fall asleep).

The body continues on 90 minute cycles for the duration of sleep. REM sleep is just a step away from wakefulness. It is where dreaming occurs. It is the mind's way of restoring itself. You need dream sleep as much as the physical recuperation. When you remember your dreams, you awoke in the REM stage.

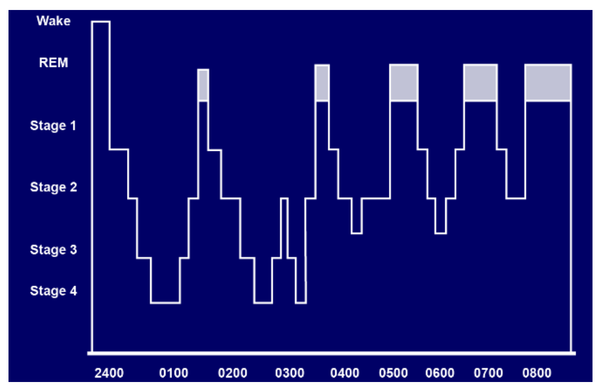

Figure 12-7 — Sleep Cycle

For example, if you have awakened in the middle of the night, remembering your dreams, you naturally awoke from REM sleep. You usually feel refreshed. Then, you go back to sleep, are awakened by the alarm, you can't remember your dreams, and now you feel worse than you did when you awoke a couple hours ago. This illustrates sleep inertia and waking up in NREM sleep.

NREM sleep is the physical recuperation and the body stays in deep sleep longer than REM sleep to recover the body. The more sleep deprived you are, the faster you enter deep sleep. However, in the second half of the night, once the body has completed most of its physical recuperation, it does not need to enter such a deep stage and it may not need to be in that stage for very long. The drawback to entering deep sleep is the possible sleep inertia when you are awakened from it.

Alcohol can promote relaxation and thereby help a person fall asleep, but it also produces easily disrupted, lighter sleep. It suppresses REM sleep in the first half of the night, leading to REM rebound and withdrawal effects in the second half.

CONTENTS
PREVIOUS

Circadian Rhythm

There are normal, inherent, unavoidable, 24-hr rhythms in human cognitive and physical performance (Figure 12-8). Most of these circadian rhythms oscillate between a high point late in the day to a low point in the pre-dawn hours with a peak-to-trough amplitude of about 5% to 10% of their average value. Human circadian rhythms are slightly longer than one cycle per day but are normally slaved, or entrained, to exactly one cycle per day by external time cues (often referred to by the German word for time cues, *zeitgebers*), especially the daylight-darkness cycle.

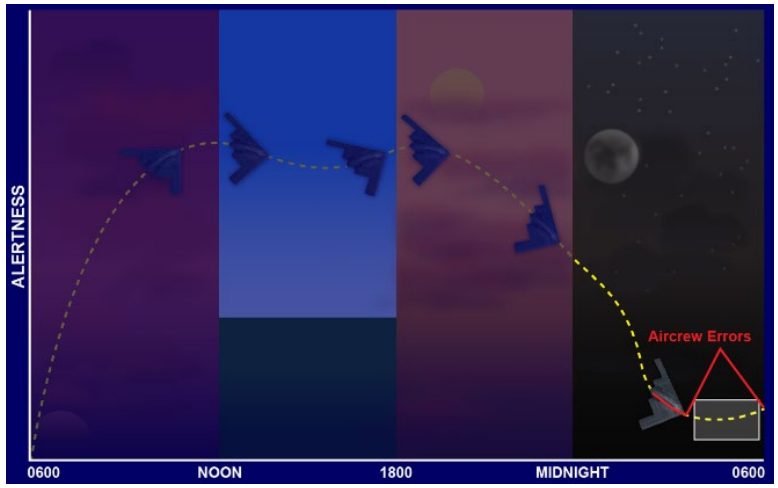

Figure 12-8 — Circadian Rhythm

Everyone has a circadian (circa = about, dian = a day) rhythm or "body clock," which is roughly a 23–26 hour cycle of body functions. These cyclic body functions include endocrine gland function (hormones, etc.), metabolic processes, and body temperatures. These functions help control sleep-wake cycles and directly affect your alertness and performance. This cycle is repetitive day in and day out with little change. When your circadian rhythm is disrupted, chronic fatigue can become a major factor in your performance. There are two basic types of circadian rhythm problems: *sleep cycle disruptions* and *circadian desynchronization* due to rapid time zone changes.

Sleep Cycle Disruptions — Occur when you must fly during hours you would normally be sleeping. Examples are night or early morning (0100 hours to 0600 hours) flights. Additionally, crewmembers involved with war games or exercises (remaining on duty for extended periods of time) suffer sleep cycle disruptions. If you're forced to wake-up early over a long period of time, 7 to 10 days for instance, then you lose a part of your sleep cycle that is vital to mental alertness. You can experience mental fatigue resulting in decreased attention span, concentration, and an increase in thinking and perceptual errors. Additionally, you fall asleep much easier and can experience "microsleeps" in which the brain briefly slips into dream activity. Fortunately, microsleeps only last a few seconds but are insidious and indicate that you are very fatigued. You can attempt to minimize or eliminate sleep cycle disruptions by adjusting the time you go to bed. This adjustment compensates, to a degree, for the early morning wake ups and your circadian rhythm eventually adapts to getting up early. Circadian rhythm desynchronization, however, is much more involved and difficult to remedy.

Circadian Rhythm Desynchronization — Occurs when you cross time zones (transmeridian travel). This problem is commonly known as "jet lag." For the crewmember, jet lag is a serious problem that can jeopardize safety of flight. Physiologically, the body requires 24 hours to completely recover from every one hour shift in time zone. To a non-flying officer arriving in Germany on a permanent duty assignment, this time zone shift is not a problem since they stay in one location and do not need to fly. However, it *is* a problem for crewmembers landing in England after an 8 hour (and eight time zone change) flight from the U.S. They may not be able to take the required time to completely recover from the time shift, since operational demands rarely permit crewmembers 8 days off to resynchronize.

For crewmembers that do not remain in one time zone for more than 24 hours, the problem of circadian desynchronization is compounded. The negative effects of circadian desynchronization, and subsequent sleep loss, on a crewmember's ability to function mentally and physically are critical. Most of the problems relate to decreased mental information processing abilities, decreased mental agility, impaired judgment/decision making skills, decreased communication and problem solving skills, and increased irritability. Unfortunately, there are no set rules or procedures to follow regarding adaptation to changes in time zone. However, there are some techniques that you can use in an attempt to deal with time zone changes and circadian desynchronization.

When you change time zones, you basically have four options at your disposal. First, you can attempt to stay on home time. Second, you can slowly adapt to the new time zone naturally. Third, you can force your routine and conform to the local time in order to rapidly adapt to the new time zone. Finally, you can combine aspects from the first three options. In any case, the decision should be based on your personal judgment but also should consider the following variables.

CONTENTS
PREVIOUS

Variables Affecting Circadian Rhythm

Direction of Travel — Transmeridian flight involves traveling east or west across different time zones. If you travel eastbound, you are essentially traveling ahead in time. For example, if you leave the west coast and fly directly to Rhein-Main AB in Germany, you experience a time shift that is 10 hours ahead of your local time. If you depart the west coast at 0800 hours Pacific Standard Time (PST) and fly for 12 hours to Rhein-Main AB, Germany, you land at 0600 hours (the following day) local German time (Takeoff 0800 + 12 hour flight + 10 hour time zone change = Land at 0600). Unfortunately, your body clock is set to PST. So physiologically, you are landing at 2000 hours. Your body is preparing for rest and sleep while the local population is just waking up. You probably experience one good night's rest the evening you arrive because of the acute fatigue but start having sleep-cycle problems on the second day and night.

Aircrews experiencing an eastbound circadian shift experience trouble falling asleep at local times, trouble rising at normal local times, and lose mentally restorative sleep. These problems are similar to those associated with westbound travel with one major problem added. Because their body clock is slow to respond naturally to the new time zone (24 hours to adapt to a one hour change in time), they do not obtain the sleep necessary to correct for fatigue.

The body has an easier time adjusting to westbound travel. Circadian desynchronization is still evident but the physiological signs are not as severe as eastbound travel. The primary reason westbound travel is easier on the crew is that the crew is traveling backward in time. A crew taking off from San Antonio, Texas and flying to Hickam AFB, Hawaii (an 8 hour flight) experiences a 7 hour time shift. If the crew takes off at 0800 Central Standard Time (CST), they land at 0900 hours Hawaiian time (Hawaii's local time is 7 hours behind CST.) The effect on the crew is that they become tired and sleepy earlier in the day and wake up earlier in the morning. The result is the crew is mentally efficient in the mornings but their capabilities decrease more rapidly towards the afternoon. It still takes the crewmember 7 days to naturally adapt to their new time zone but they can tolerate the physiological changes better than eastbound travelers.

Magnitude of Time Zone Change — You need to consider how many time zone changes you are experiencing. The number of changes gives you an idea of the degree of jet lag you are going to encounter and helps you decide how to deal with its effects. If a crew flies eastward and only crosses three time zones, they may not experience serious circadian desynchronization. However, if they are flying to Saudi Arabia (11 hours ahead of a west coast base) they may experience serious performance decrements within a day or two of their arrival.

Interval Between Arrival and Departure of Next Flight — This variable requires consideration to estimate the possible negative effects circadian desynchronization has on follow-on flight activity. How long you stay in one time zone impacts the methods you use to cope with circadian rhythm disruption. If the time between landing and your next flight is short (13-24 hours), you need to plan your rest periods differently than if you have a longer time between flights.

The shorter the time interval between landing and the next flight, the more you need to maintain your home-time rest and sleep habits. If the duration between landing and flight is long, then you should adjust your rest and sleep cycles in an attempt to adjust your circadian rhythms to local time and gain the rest needed before flight.

Relative Difficulty of Next Flight — A major consideration. Many times a crew experiences new flying environments that have different local procedures than their home base. If they fly in a foreign country, the terminology used by controllers could be different and cause confusion in the cockpit. If the crew is fatigued, their ability to adapt to new flying environments and demands is decreased.

Additionally, aspects of the flight itself need to be considered. Are there portions of the flight requiring above average alertness on the part of the crew? For instance, is low-level flight, aerial refueling, ordnance delivery, or other high attention related tasks required? Is weather likely to be a factor? For example, is there icing, thunderstorms, visibility restrictions caused by rain, snow, or fog? Is the mission scheduled as a day or night sortie? How are the crew's circadian desynchronization and the timing of the flight likely to affect their performance? Finally, what is the experience level of the crew for the type of mission scheduled? Experience not only includes the crew's overall flying experience but their recency of experience (when was the last time they flew a mission of this sort?) and specificity of experience (have they flown this type of mission before?). Consideration of this particular variable guides the crew in forming a plan to cope with fatigue. Additionally, it increases their awareness of the fatigue factor during the later stages of the flight.

Availability of Dining Facilities — In addition to rest, the body needs nourishment to provide energy. One of the ways to help adapt to a new time zone is a good diet. However, if the local dining facilities are closed when you land, then you need to consider adjusting your schedule prior to their next scheduled duty period to include time for eating a good meal. If dining facilities are unavailable, you should make plans to take "combat snacks" (nonperishables consisting of complex carbohydrates). Also, starting a weight loss diet on the road is not wise. Most common weight loss diets (low calorie intake) are an added stressor the body must cope with in addition to circadian desynchronization.

CONTENTS
PREVIOUS

Direction of Next Destination — If you are not going to stay in one location for an appreciable length of time, but are going to travel on, you need to consider the direction (east or west) of your next destination and the effect it has on your circadian rhythm. If the direction of travel is north or south, the time zone does not change and there isn't any effect on circadian rhythm. If you travel east or west, circadian disruption can worsen or improve depending on the direction of travel in relation to your home base.

Adapting to a New Time Zone — There are no hard and fast rules or effective procedures on how to adapt to a new time zone. Regardless of whether or not you decide to adapt to the new time zones, there are techniques that can guide you on dealing with circadian desynchronization.

If you decide to rapidly adapt to the new time zone, you should force yourself into the local routine. Use your willpower and alarm clock to force yourself to wake up at normal local times in the morning. To help go to sleep at night, try mild to moderate exercise and a relaxing shower or bath (if available). Above all, moderation or elimination of alcohol and caffeine helps.

As one can see, the problem of circadian rhythm desynchronization is complex and has many variables to take into account during mission planning. Between sorties, ensure you and your crew are able to get adequate crew rest along with nutrition. Allow either the aircraft commander or your supervisor to know when you feel you are too fatigued to fly. Remember, as long as you are aware of your options, including Air Force and major command (MAJCOM) policy, you should be able to form a plan to reduce the effect circadian rhythm shifts have on your performance.

Other Factors Affecting Sleepiness

Physical or physiological fatigue can be described as the temporary loss of the ability to respond due to repeated or continuous stimulation of the muscles (e.g., during strenuous exercise). Thus, aircrews can suffer from physiological fatigue as a result of engaging in intense physical work.

Mental fatigue or boredom is the feeling of weariness that results from repetitive performance of nonphysical tasks. Aircrews can be affected after only a few minutes of performing monotonous work. Repetitive performance of even fairly complex tasks can result in mental fatigue. Mental fatigue can also be caused or made worse by anxiety, apprehension, frustration, and stress.

A sense of fatigue is the first indicator that people are getting tired, but generally is not recognized in our motivated flying population. In a normally close-knit squadron interpersonal dynamics, everyone's sense of humor may be the first thing to change. As a management tool this can be a useful clue for aircraft commanders.

Fatigue and Alcohol Effects Similarities

Both alcohol intoxication (Brust, 2004) and fatigue arising from sustained wakefulness (Broadbent, 2013) have long been known to have detrimental effects on cognitive function. However, studies directly compared the effects of fatigue and alcohol intoxication on performance in the same cognitive tests (Dawson and Reid, 1997; Lamond and Dawson, 1999; Williamson and Feyer, 2000). The findings from all three studies agree that as little as 18–24 hours of sustained wakefulness could induce impairments in the speed and accuracy of cognitive performance that were equal to or greater than the severity of impairment seen in individuals with blood alcohol concentrations (BAC) of 0.1%. While there were differences in the extent to which the high levels of alcohol and fatigue affected different cognitive functions, measures of performance speed were always impaired by both conditions.

CONTENTS
PREVIOUS

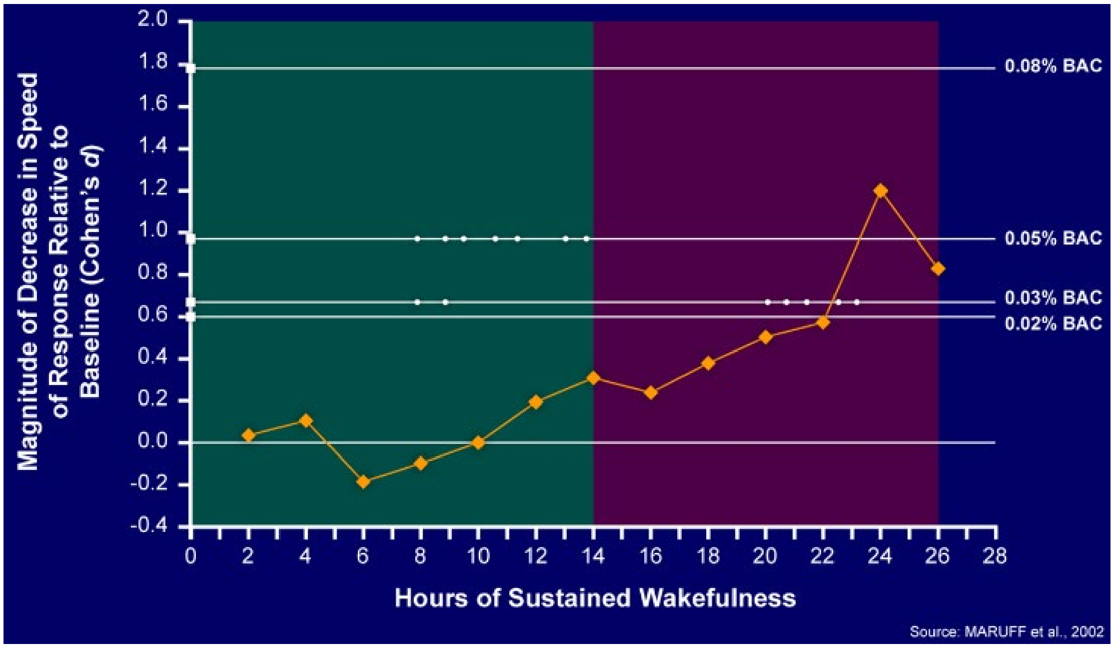

Figure 12-9 — Fatigue and Alcohol Effects Similarities

Cognitive performance is impaired by fatigue arising from sustained wakefulness and alcohol. These papers (Dawson and Reid, 1997; Lamond and Dawson, 1999; Williamson and Feyer, 2000) directly compared the effects of increasing fatigue and blood alcohol concentration (%BAC) to provide a framework for understanding fatigue-related cognitive impairment. While the expression of fatigue-related cognitive impairments in terms of %BAC equivalents is sound, the methodology in each study was flawed in that the statistics used to compare the effects of %BAC and fatigue on cognition did not account for variation between or within each condition. The point estimates of the difference between a baseline and any level of fatigue or %BAC provided no indication of the size of difference that could reasonably be expected by chance. Importantly, all studies showed that variation increased as cognitive performance declined because of both increasing fatigue and %BAC.

The graph above is extracted from a current study (Falleti et al., 2003) which compared the effect of increasing levels of %BAC and fatigue on the simple reaction task from their CogState® test battery on 40 healthy adults using statistical methods that account for intra-individual and within-group variability in performance. After 24 hours of sustained wakefulness and with 0.08%BAC, individuals showed maximal cognitive impairment; however, the magnitude of impairment found for fatigue was equivalent only to that observed for 0.05%BAC. Despite Falleti's study (2003) detecting smaller impairments in fatigue-related cognitive impairment than has been reported previously, the "magnitude of impairment we did observe is still serious." Even accounting for intra- and inter-subject variability, the cognitive impairment found at 24–26 hours of sustained wakefulness was greater than that associated with %BAC levels at which many jurisdictions consider the operation of a motor vehicle to be unsafe and therefore illegal.

Individual Factors Cause Fatigue to Affect Individuals Differently

Each person treats their crew rest differently. Who actually got sleep? How long have you been awake? Those are questions that you may have to answer. Older individuals do not sleep as long, but the quality of sleep is not as great. The more physically fit you are, the less susceptible you are to fatigue. Is the day hot? Is a person suffering from a hangover? Dehydration increases fatigue. Drink plenty of water before and during the sortie to combat against it.

How is the sortie itself? How long is it? Is it a CT ride? What are the deviations to the norm? Just like a Risk Management checklist for the mission, you must do an ORM checklist for yourself.

Decreasing the Effects of Fatigue

Prior to Flight — There are many ways crewmembers can try to compensate for the effects of fatigue. First, always start your scheduled flights well rested, especially when scheduled for extended missions or transcontinental travel. This proper rest often requires cooperation from family members. Good sleep hygiene involves proactive sleep scheduling and quantity, good sleep habits, and a good sleep environment. The following are considered good sleep habits that will generally lead to better sleep quality:

Stick to a consistent wake-up time and bedtime every day of the week

Use the bedroom only for sleep and sex.

Resolve daily dilemmas outside of the bedroom.

Establish a bedtime routine.

Establish an aerobic exercise routine and stick to it.

Create a quiet and comfortable sleep environment.

Don't be a clock watcher.

Don't consume caffeine within 4 hours of bedtime.

Don't use alcohol as a sleep aid.

Don't take naps during the day (if you have trouble sleeping at night.)

Don't smoke cigarettes immediately before bedtime.

Get out of bed and go to another room if sleep doesn't come in 30 minutes.

Naps (not longer than two hours) are strongly recommended prior to night flights or continuing an extended trip. You should also **minimize the use of tobacco and alcohol**, and ensure you are well hydrated.

You can also use **diet** to reduce the effects of fatigue. Avoid high fat, high carbohydrate meals to reduce drowsiness. Instead, emphasize a meal moderately high in protein with moderate carbohydrates. Additionally, avoid eating large, filling meals prior to flight to reduce the chance of drowsiness. It's more beneficial, in this instance, to eat several smaller meals (snacks) rather than a full meal at a single seating.

To help maintain an adequate diet, you can carry "emergency rations" or "combat snacks." This option is invaluable if you are not fond of box lunches. You can take a supply of canned fruit, canned meat (tuna, ham, chicken), beef jerky, trail mix or other complex carbohydrate and protein rich foods with you. This food is also a benefit should you sleep through the dining facility hours.

During the Flight — You can reduce the effects of fatigue by staying active. It is also important to identify potential problem or lull areas of the sortie. If at night, dusk, or dawn, the cockpit lights can be turned up in-flight and turned down again 30 minutes prior to landing to restore night vision. Also, snacking and chewing also helps with in-flight alertness.

When fatigued, it is important to increase your awareness of coordinated critical flight functions, such as approach, landing or low-level operations. Be aware of the potential for increased errors due to fatigue and cross-check fellow crewmember activities. This is especially critical during flights over the pond and/or cross-country flights with extended loiter times.

Caffeine Use

Caffeine is a tasteless substance occurring naturally in plants and found in a variety of beverages, medicines, and foods. Coffee is the most popular source of caffeine in the American diet. Crewmembers can also receive significant amounts of caffeine from carbonated beverages, tea, OTC drugs, and chocolate.

Caffeine acts as a powerful CNS stimulant. Caffeine's popularity is due to its ability to elevate mood, mask feelings of fatigue, and increase the capacity for work. In low doses, caffeine may not be harmful. However, ingestion of high levels of caffeine may be related to a variety of acute and chronic ailments. Most people regard caffeine as a safe stimulant and do not actively monitor their intake. As they consume caffeine-loaded products, they remain unaware of the potential negative side effects of caffeine. Figure 12-10 illustrates the effects of too much caffeine and associated withdrawal symptoms.

Addiction — Caffeine *is* addicting. A person requiring 400 mg of caffeine in a 24 hour period to function is considered addicted to caffeine. Figure 12-11 shows the amount of caffeine present in common food/beverages and OTC drugs. If you ingest too much caffeine, you can experience the effects depicted in Figure 12-10. However, you can also develop sensitivity to the drug. If a person is addicted to caffeine, they can experience some withdrawal symptoms when, and if, they decide to quit. The withdrawal symptoms commonly include headaches but can be as severe as muscle cramps, nausea, aches in joints and muscles, and psychological feelings of anxiety, dread, and irritation. If you are addicted to caffeine, it is advisable to reduce intake gradually instead of quitting altogether.

Effects of Caffeine
• Dehydration • Restlessness • Nervousness • Faulty Thinking • Disturbed Sleep
Withdrawal Symptoms
• Headaches • Restlessness • Sense of Disquiet • Anguish • Aching Joints & Muscles

Figure 12-10 — Caffeine Effects/Symptoms

Caffeine has synergistic effects when used in combination with other drugs. Its stimulant effect on the body is significantly increased when used in combination with decongestants or nicotine. An example of the deliberate use of caffeine as a synergistic drug is its use in OTC diet pills. Until recently, diet pill manufacturers combined caffeine with decongestants in order to increase the body's metabolic rate. Unfortunately, the negative side effects of this combination, sweating, increased blood pressure and heart rate, sleep disturbances, and shakiness or tremor, are not desirable in crewmembers. Dehydration is another, more common, synergistic effect of caffeine.

Caffeine Amounts			
Food/Beverage	**mg/Serving**	**OTC Drugs**	**mg/Dose**
• Coffee	110 – 140	• No-Doz®	100
• Tea	10 – 50	• Anacin®	64
• Soft Drinks	30 – 60	• Excedrin®	130
• Cocoa	10 – 40	• Coryban-D®	30
• Chocolate	5 – 20	• Dristan®	32
• Energy Drinks	50 – 500	• Triaminicin®	30
		• Dexatrim®	200
		• Prolamine®	280

Figure 12-11 — Caffeine Amounts

Dehydration — If you drink caffeinated beverages during flight, ensure you also drink water. The combination of a pressurized cabin (humidity below 9 to 11 percent increases water lost during respiration) and the diuretic (makes one urinate more often) effect of caffeine causes an increased dehydration rate. The result is increased mental and physical fatigue and decreased performance. Drinking water, or other non-caffeinated beverages, during flight helps offset the negative effects of caffeine.

Go/No-Go Pill Program

Flight Medicine establishes a program to ground test, dispense, and control pharmacological agents for fatigue management IAW AFI 48-123, AFMAN 11-202v3, and current AF policy. The SGP counsels, with the Go Pill approval authority (wing or deployed commander), the medical utility of using Go Pills for a particular mission or mission set. The SGP will ensure appropriate non-pharmacological fatigue prevention strategies and operational countermeasures are utilized prior to concurring with operational Go Pill use.

Go/No-Go pill **ground testing** and operational use is voluntary. The flight surgeon (FS) offers ground testing for Go/No-Go pills to select eligible aircrew prior to use in an operational setting. Documentation of successful ground testing or deferral is entered in the medical record of eligible aircrew. All aircrew are "duties not involving flying" (DNIF) while ground testing both Go and No-Go Pills.

Eligibility for the operational use of pharmacologic sedatives (No-Go) requires appropriate ground testing and approval of the local FS. **Aircrew will declare themselves DNIF** after use of sedative for the specified time as annotated in the Official AF Aerospace Medicine Approved Medications list and as instructed by the FS.

CONTENTS !!!
PREVIOUS

Thermal Stress

With exposure to thermal stressors (i.e., heat, cold), the body must maintain the core temperature through the balance of heat gain and heat loss. If the rate of heat production (i.e., environmental, metabolic, hormonal, or food thermogenesis) is greater than the rate of heat loss, then the net is a heat gain and the positive heat storage results in hyperthermia. Conversely, if heat loss (i.e., through conduction, convection, radiation, and evaporation) is greater than heat gain, then the net is heat debt and the negative heat storage results in hypothermia. Three stages of heat stress:

Heat exhaustion (99.5 – 101 °F)

Performance decrements occur

Process starts with only a 1-degree increase in body temperature

Poor correlation between early stage of declining performance and appearance of any physical symptoms

May be an initial increased feeling of confidence

Any symptoms are important

Minor discomforts, confusion, disorientation, memory loss etc., cannot be taken for granted or accepted as inevitable

Regular self-evaluations of performance and how you are feeling should be SOP

Heat cramps (101 – 105 °F)

Normally caused by severe physical work (individually relative) in the heat

Highly dependent on individual work capacity and level of acclimatization

If symptoms are not ignored, they can act as a fail-safe to avoid heatstroke (stop work before heat stroke temperature is achieved).

However, it’s possible to push yourself into a heatstroke.

A red face and hot skin are common signs of emerging heat illness.

Fatigue

Nausea/vomiting

Giddiness

Cramps

Rapid breathing

Fainting

Heat stroke (>105 °F)

This is a medical emergency, immediate cooling is necessary

Rarely encountered in operational environment (chemical defense gear would increase susceptibility)

More likely to be encountered in highly aerobically conditioned individuals as they are used to working with high body temperature (101 – 103 °F)

Body’s heat control mechanism stops working — sweating may or may not be present

Mental confusion

Disorientation

Thermal Stress Risk Factors	
• Dehydration • Electrolyte depletion • Lack of acclimatization • Poor physical condition • Excessive body weight	• Skin Disorders • Medications • Alcohol • Illness/disease • Genetics

Figure 12-12 — Risk Factors

Symptoms

Dry mouth

Headache

Dark yellow urine

Dry lips

General fatigue

Dizziness

Individuals should not wait for any of these symptoms to occur, they should drink throughout the day.

The best way to know if you are dehydrated is look at the color of your urine. It should be clear to near clear and you should be going to the restroom about every 2–3 hours. Your body can only absorb ½ liter of water per hour so if you are going to the bathroom more than every 2 hours, you are drinking too much fluid. If you are waiting longer than 3 hours to go to the bathroom, you are not drinking enough fluid.

Heat Stress Countermeasures

Working in hot environments may result in the production of 6–8 liters of sweat during the work day. The normal thirst mechanism is not sensitive enough to keep up with this fluid loss rate.

Acclimatization refers to the physiologic adaptation which occurs over a succession of days in individuals exposed to environmental heat stress which results in reducing the strain caused by the heat stress. For example, acclimatization results in increased and more efficient sweating. That is, the sweat rate increases while the amount of sodium lost per unit of sweat decreases. Sweating also begins at a lower core body temperature after acclimatization. Acclimatization also results in lowered cardiovascular strain manifested primarily by a lower heart rate.

Do not skip meals. Food replaces the minerals lost in sweat as well as provide the needed calories. Salt food to taste, and do not take salt tablets.

Inadequate rest can nullify the effects of heat acclimatization. Several medical and physiological conditions can make adjustment to hot environments more difficult. Sustained activity in hot environments assume work clothing is permeable and consists of not more than the customary long-sleeved work shirt and trousers (or equivalent). Clothing, which lowers air and vapor permeability, interferes with body cooling, decreasing heat tolerance.

Cold Stress Management

The physiological response to cold stress exposure is not the only variable military personnel need to be concerned about when performing operational duties; the psychological aspect of human performance is affected as well. Mission-critical duties might fail to be completed due to the decrease in morale and/or cognitive performance.

Prevention

Cold injuries are avoidable by proper use of preventive measures. Cold-weather clothing systems are designed to accommodate a variety of weather conditions and activity levels. Cold-weather clothing protection is based on the principles of insulation, layering, and ventilation. Proper clothing is made of material that water vapor can pass through and allows the wearer to unzip and open the clothing periodically to increase ventilation. Sweat evaporation is compromised when clothing is dirty.

CONTENTS
PREVIOUS

Combatting Stress

Stress is the normal reaction to any demand placed on you, either physically or mentally. You need stress because it serves as a motivator and an indicator (increased heart rate, respiration, perspiration, etc.) which helps prepare you to respond. If there is too little stress, you are under-aroused and inattentive. On the other hand, if there is too much stress you are limited in your ability to perform.

Inherent in man is a biological response to a crisis situation. For example, when suddenly confronted by a crisis situation, an involuntary physiological process begins. Adrenaline is produced, causing the eyes to dilate, increasing heart rate, stopping digestion, directing blood to the large muscle groups, and increasing perspiration. These responses prepare you to confront the crisis or run away from it (a response known as "fight or flight").

Financial, family, professional, and social responsibilities are a few of the stresses which may confront you. Many of these are self-imposed. Even if these stresses are not self-imposed (stresses you are personally responsible for), they may lead to negative behavior associated with self-imposed stress.

Aviators live in a success oriented and competitive society and are often placed in stressful environments. For example, it's obvious that an in-flight emergency evokes stress, but a checkride is also a form of stress. Both elicit the same physiological response of fight or flight. Stress is useful if you control it. If you don't control it, it will control you. Therefore, effective methods for controlling or relieving stress are necessary.

Psychological Stress

The chart is the Yerkes-Dodson Law (1908), and illustrates the link between the physiological condition and performance (Figure 12-13). For instance, it is believed that if a crewmember is fatigued and experiencing low blood sugar, the effect of stress on performance will be greater than in a fit, rested person. The nature of our human condition is to cope or adapt to the environment; autonomic adjustments allow for adjustments to physical stress, but adaptation to psychological stress is much less pronounced and harder to measure. Despite the reasonable ease of measuring heart rate in flight and the natural correlation between heart rate and situational arousal, it is important to consider concomitant factors such as workload (physical and mental) as well as responsibility on the flight deck when assessing the overall effects of stress on performance. Considering the "whole person" of a flyer, one must also be aware of any acute or chronic life-situational stressors outside the aviation arena: those of family, career, health, finances, or legal problems, for instance. (HAOP, 2016, p. 4-3)

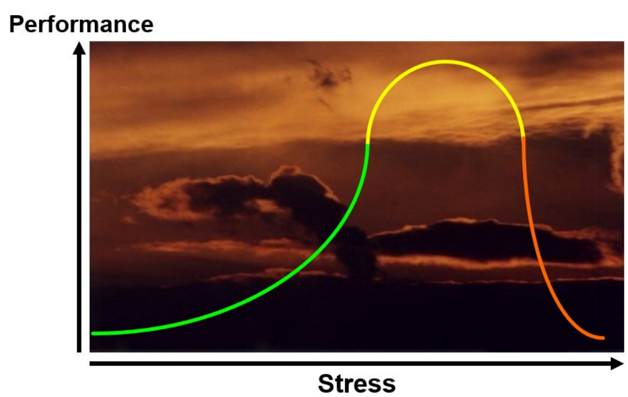

Figure 12-13 — Stress Chart

Overload has deservedly received much attention as an important stressor. In overload the demands are such as to exceed the individual's ability to meet them.

An example of overload is role conflict. This can be viewed as a situation in which a person finds, in essence, opposed demand being made on him. A person may often be asked to work on one assignment when he/she already has some other assignment. That person may have to stop what he/she is doing at that time. When the issue concerns merely the sum total of work that must be done irrespective of its difficulty, we talk about quantitative overload. The person has more work than can be done in a given period of time. That person may be fully competent in the work but time restrictions are what elicit the stress reaction. Quantitative overload could involve working for long hours without appropriate rest periods.

CONTENTS
PREVIOUS

When the work is overloading because it requires skills, abilities and knowledge beyond what the person has, then we talk about qualitative overload. The work may demand continuous concentration, innovation, and meaningful decision. An important factor contributing to qualitative overload is job complexity. The higher the inherent difficulty of the work, the more stressful the job.

In some job situations there is a combination of both quantitative and qualitative overload; this is frequently encountered in aviators, particularly student aviators.

Underload may also create stress. A job may fail to provide meaningful stimulation or adequate reinforcement. Thus, jobs which involve dehumanizing monotony, no opportunity to use acquired skills and expertise, an absence of any intellectual involvement and repetitive performance provide instances of underload. Boredom can result from too high a degree of specialization. This is a rare occurrence in student aviators.

Stress Management

Each crewmember is a successful competitor or would never have been selected for a military flight program. Competition is usually a healthy environment in which to function but can also be a source of stress. Constantly trying to succeed in a pressure environment, impressing your instructor, and outperforming your peers provide a continual source of stress.

Stress can be both positive and negative. How you manage it is important to you in both your personal and professional life. To be an effective crewmember, you must learn to manage the stresses that are part of your everyday life. To begin managing stress, you have to first understand what it is and what it does — how it affects you physically and mentally.

Place Demands into Perspective — Doing well in flying training, living comfortably, and being a good parent are all worthwhile aspirations, but they are not life threatening situations. You can't control the reflexive physiological process that activates in a crisis situation, but you can control what you perceive as a crisis situation — so don't overreact. Keep your supervisor or flight commander informed. They may be able to help you deal with some of these stresses.

Maintain a Healthy Diversity in Your Life — Entertainment and hobbies provide a healthy balance to life. You need to save some of your energy for yourself. A healthy balance will make the energy you expend on your job and your family more effective or meaningful. The flying environment, particularly flying training, is a demanding one, constantly changing and requiring a total mental and physical commitment from you, the crewmember. Any factor or condition that bothers you — distracting you from your work — is important and must be given adequate attention.

Eliminate Self-Imposed Stress — Smoking, excessive drinking of alcohol, self-medicating, poor nutrition, and lack of exercise are stressful in themselves, and make it more difficult to deal with other stresses. Avoiding these behaviors eliminates their effect on the crewmember, minimizing self-imposed stress.

Have Good Self-Assessment Habits

One technique of self-evaluation is to think about a mishap write-up in your head. If your 72-hr history has significant stressors and "red flags" that could contribute to a bad situation or a mishap. Try to keep the Positive outweighing the Negative, and don't forget the I'MSAFE Checklist!

Summary

Roughly 85 percent of military aircraft mishaps are caused by aircrew error. Some of the major contributors to aircrew error are self-imposed stresses that decrease the crew's capacity to cope with unforeseen environmental or aircraft stresses.

The major self-imposed stresses are self-medication with OTC drugs, alcohol and tobacco use, hypoglycemia and dehydration. Each of these contributes to fatigue, which is the crucible from which increased susceptibility to stresses such as spatial disorientation, visual illusions, and G-induced loss of consciousness arise. Fatigue is also a result of sleep cycle disruption and circadian rhythm shifts caused by transmeridian travel.

Overall, you can ensure your flights are safe and productive by eliminating or minimizing self-imposed stresses. Flying sick, with a hangover, dehydrated, or on OTC drugs are invitations to a miserable flight at the least and the loss of life at the worst.

Unnecessary stress can be controlled or avoided with observance of crew duty day, rest regulations, adequate recreation, good living quarters, and attention to morale factors. The demands of flying are in no way compatible with emotional stresses. Recognition, treatment, or better yet, avoidance of emotional stress is essential for maintaining situational awareness and ultimately safety. Resolution of the problems prior to flight is the only way to prevent them from adversely

CONTENTS !!!
PREVIOUS

affecting you and your mission. If individual efforts to resolve these stresses are unsuccessful, seeking professional help is essential.

You can increase your capacity to cope by eliminating or minimizing exposure to self-imposed stresses. However, stresses such as fatigue are not always controllable. Therefore, your awareness of the causes and effects of fatigue is key to decreasing the negative manifestations. Develop plans to cope with situations where fatigue, like circadian rhythm desynchronization, is a threat. The best way to cope with fatigue is to minimize or eliminate self-imposed stresses and ensure you are in good physical shape. Exercise is one of the best methods to increase your tolerance to not only fatigue, but also spatial disorientation, positive Gs, and visual illusions. You must be both aerobically and anaerobically fit.

Aerobic exercises are those causing the muscles to use oxygen to produce energy. They are activities such as running, bicycling, walking, and swimming. Activities causing an increase in respiration, heart rate, and sweating are also aerobic. Stay in your aerobic training zone by monitoring your heart rate.

Anaerobic training isolates muscle groups and forces them to produce energy without immediately relying on oxygen. Weightlifting, sprinting, sit-ups, pull-ups, and push-ups are examples of anaerobic exercises. If you are just starting a weightlifting program, you should start gradually and build up to reduce the chance of injury.

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Review Exercise AP112

Complete the following review exercises by selecting the correct response or filling in the blanks. Answers follow the questions.

1. Match each OTC drug with the appropriate undesirable side effects..

OTC Drug	**Side Effect**
a. _____ Decongestants	1. Stomach irritation, dizziness, skin rashes, heartburn, blurred vision
b. _____ Antihistamines	2. Nervousness, tremors, increased blood pressure and heart rate, dehydration due to increased sweating, sleep disturbances
c. _____ Vasoconstrictors	3. Shakiness, increased heart rate, blurred vision, increased dehydration, dizziness, nausea, headaches
d. _____ Pain killers	4. Dizziness, blurred vision, tremors, headaches
e. _____ Diet pills	5. Drowsiness, diminished alertness, increased reaction times

2. Air Force policy does not allow crewmembers to fly within __________ hours after consuming alcoholic beverages. Furthermore, you must not act as a crewmember of an aircraft while under the influence of alcohol or its __________.

3. What is the ***best*** way to avoid the effects alcohol has on your performance as a crewmember?
   a. Do not fly within 24 hours after consuming alcoholic beverages.
   b. Drink only beer; it has lower alcohol content.
   c. Practice abstinence.
   d. Eat plenty of food before you drink alcohol and drink plenty of coffee the next day.

4. What is the immediate danger of carbon monoxide from cigarette smoke?
   a. It inhibits the body's ability to remove nitrogen during denitrogenation.
   b. It inhibits the blood's oxygen carrying capacity.
   c. It increases your chance of mouth and gum cancer.
   d. It acts as a depressant on the central nervous system.

5. Bagels, pretzels, granola bars, fresh fruits, vegetables, etc. are recommended snacks containing complex carbohydrates. What is the advantage of these foods over a coke and a candy bar?

6. List five signs and symptoms of dehydration.
   a.
   b.
   c.
   d.
   e.

7. Chronic fatigue is caused by the normal daily activities of a crewmember and is remedied with a good night's sleep and rest.

   a. True

   b. False

8. Caffeinated beverages can increase your dehydration rate. As a result, your __________ and __________ fatigue increases and your __________ decreases as you become dehydrated.

9. Identify four methods of combating stress in the flying environment.

   a.

   b.

   c.

   d.

Answers to Review Exercise AP112

1. a. 3
   b. 5
   c. 4
   d. 1
   e. 2

2a. 12; aftereffects

2b. 12; mission plan (brief)

3. c

4. b

5. Avoids hypoglycemia

6. a. Thirst
   b. Sleepiness
   c. Nausea
   d. Mental impairment
   e. Fatigue

7. b

8. mental; physical; performance

9. a. Place demands into perspective
   b. Maintain a healthy diversity in your life
   c. Eliminate self-imposed stress
   d. Exercise

AP113 — Oxygen Equipment

Hours and Medium

1.0 Hours (IBT)

Objectives

1. Know the five types of oxygen storage and the two types of oxygen delivery systems.

   Samples of Behavior:

   a. Describe the characteristics of the five types of oxygen storage systems.

   b. Describe the characteristics of the two types of oxygen delivery systems.

   c. Describe the operational and emergency ceilings of the pressure demand regulator.

2. Know the functions and components of the T-6 On-Board Oxygen Generating System (OBOGS).

   Samples of Behavior:

   a. Describe the functions of the OBOGS panel regulator.

   b. Identify the components of the OBOGS panel regulator.

   c. Describe the characteristics of the emergency oxygen systems.

3. Know the components of MBU-20A/P oxygen masks, the emergency oxygen system, and how to perform an operational check of the oxygen system.

   Samples of Behavior:

   a. Identify the components of the MBU-20A/P oxygen masks.

   b. Identify the component parts of emergency oxygen systems.

   c. Describe the procedures necessary to perform a Regulator — Indicator — Connections — Emergency (RICE) check.

   d. Describe the proper care of the mask and helmet.

   e. Using a functional oxygen regulator, mask, and helmet, practice:

      (1) Operating the regulator

      (2) Donning and doffing the mask and helmet

      (3) Performing a RICE check

      (4) Breathing on the regulator

      (5) Pressure breathing

      (6) Speaking while pressure breathing

Assignment

1. Read AP113 in the SG and answer the Review Questions.
2. Read Oxygen System, Section I, Air Force T.O. IT-6A-1/Navy (NAVAIR) A1-T6AAA-NFM-100, *Flight Manual*

Introduction

Assisted breathing is required for high-altitude flight. Supplemental oxygen provides protection from the effects of reduced barometric pressure at high altitude. These systems include various types of oxygen equipment. Air Force Manual 11-202, Vol. 3, *Flight Operations*, states that normally, aircrew will use supplemental oxygen anytime the cabin altitude exceeds 10,000 feet mean sea level (MSL). When mission essential, aircrews trained IAW AFMAN 11-403, *Aerospace Physiological Training Program*, may operate aircraft unpressurized above 10,000 feet MSL without supplemental oxygen IAW MAJCOM guidance and some restrictions. Supplemental oxygen is either a mixture of oxygen

CONTENTS
PREVIOUS

and ambient air or 100% oxygen. Supplemental oxygen may be stored as a gas, liquid or solid. It must be free from contaminants.

An aircraft oxygen system consists of the storage container or concentrator, delivery system to regulate mixture and pressure, and the oxygen mask. The final and most critical component of this system is you, the knowledgeable user.

Before we discuss the individual components of oxygen systems, we need to identify a few precautions to ensure the integrity of the mask and helmet.

Facial medications and make-up (cosmetics) should not be used with supplemental oxygen and oxygen equipment. These materials include lipstick, face creams and powders, eye make-up, and false eyelashes. Residue buildup clogs valves and restricts oxygen flow.

Information

Oxygen Storage Systems

Oxygen can be carried in cylinders or containers mounted in the aircraft. The location depends on the aircraft, but normally they can be found in the under-deck area near the cockpit. Military oxygen systems are classified by the storage state (e.g., gas or liquid) and the pressure (e.g., high or low).

Low Pressure Gas

Low pressure oxygen is stored in yellow cylinders. The system is considered full at 425 pounds per square inch (psi) ± 25 psi (400-450 psi). A low-pressure system reduces the possibility of explosion, requires little maintenance, but limits the volume of oxygen compared to high pressure and liquid systems. This limited volume requires immediate descent below 10,000' MSL anytime pressure drops below 100 psi. Low pressure systems will not be used for flight if the indicated pressure is below 100 psi (operationally empty).

High Pressure Gas

High pressure systems are color coded green. The system is considered full when the pressure is 1,800 psi to 2,000 psi and operationally empty at 200 psi. The cylinders must be heavily constructed to contain the high pressure. Reinforced cylinders reduce the danger of explosion, but increase weight. The emergency oxygen incorporated in the egress system is a high pressure system.

Liquid Oxygen (LOX)

The LOX system is one of the more advanced oxygen systems. Oxygen is stored in a liquid state and converted to gas by a converter. Since one unit of liquid oxygen yields about 860 units of gaseous oxygen, storing the oxygen in liquid form saves storage space and weight. Because of the extremely low temperature of LOX (a boiling point of -182.8°C), handling, and servicing the system are its only disadvantages. Low pressure LOX systems are normally found in single/dual seat aircraft and maintain a line pressure of approximately 70-90 psi. High-pressure LOX systems, found on multi-place aircraft, and normally maintain a line pressure of 300 psi. More importantly, the oxygen is measured in liters by a quantity gauge and is considered full at 95%; empty at 10%.

Solid State

New processes can produce oxygen from a solid state. The sodium chlorate candle is such a system. It provides emergency oxygen to passengers in the C-5B Galaxy via a chemical reaction. The system is contained in a canister and is activated by removing a continuous flow mask from the canister. The user may detect a harmless amount of chlorine for about the first 12 seconds. The amount of oxygen supplied depends on the size and reaction rate of the candle. The Emergency Escape Breathing Device (EEBD) provided in the T-1A is another example of a portable solid state oxygen storage system.

On Board Oxygen Generating System (OBOGS)

The OBOGS, utilized by the T-6, provides each pilot with an unlimited supply of regulated oxygen as long as the engine is operating normally. Oxygen is extracted from engine bleed air through a molecular sieve. The OBOGS distribution network also includes a plenum that provides a limited supply of oxygen in case of OBOGS failure. Duration of the plenum supply is based upon cockpit pressure altitude, aircraft altitude, oxygen regulator setting, and pilot demand.

Oxygen Delivery Systems

Regardless of the basic configuration, all oxygen delivery systems serve the same purpose. Oxygen flows from containers or an oxygen generating system through distribution lines, regulated at a suitable flow rate or pressure, and delivered to the mask. Two basic oxygen delivery systems used in today's aircraft are continuous flow and pressure demand. With the exception of the oxygen generating system, which must be aircraft mounted, each type can be provided in a fixed system (aircraft mounted) or a portable system (walk-around bottle).

Note — Any discussion of supplemental breathing systems requires an understanding of altitude designation. The transition level is the altitude where the crewmember selects an altimeter setting of 29.92 during climb out and returns the altimeter to the local setting on descent. In the United States the transition level is 18,000' MSL (transition levels may vary between countries). Above the transition level, altitude is described in flight levels. For instance, an aircraft at 25,000 is typically described as flying at FL250, which provides a convenient shorthand during radio transmissions.

Continuous Flow

The continuous flow delivery method is just as the name implies — the regulator delivers continuously regardless of demand. To get oxygen, the aircrew opens a supply valve on the regulator. The more the valve is opened, the greater the flow of oxygen. A gauge on the regulator can be referenced so the oxygen flow can be adjusted with varying cabin pressure altitudes. In emergency situations, some systems contain a face piece and reservoir bag to direct the flow of oxygen to the nose and mouth. The operational ceiling for this system is FL250 and in an emergency, can be used to FL300. Some continuous flow systems are modified for use at higher altitudes and are normally installed in transport, medical evacuation, and commercial aircraft. The emergency oxygen cylinder in the ejection seat is a continuous flow system for emergency use up to FL500.

Pressure Demand

High-performance aircraft routinely fly above FL400, which means their cabin altitude will be above FL280. At these altitudes, 100% oxygen is insufficient to maintain normal levels of blood oxygen saturation, the regulator will then supply safety pressure and positive pressure breathing will become necessary. Positive pressure breathing is necessary to increase the lung pressure above the atmospheric pressure. This increase is necessary to survive at altitudes above FL280. Narrow panel regulators are the most widely used safety pressure regulators in modern aircraft. The term narrow panel regulator refers to a series of regulators that are essentially the same in appearance and operation. As a result of the automatic features of these regulators, you are not distracted from flight duties to make the manual adjustments that were necessary with earlier models. Regulators include types CRU-68/A, CRU-69/A and CRU-73/A. The pressure demand system has an operational ceiling of FL430 and an emergency ceiling of FL500 for very short durations.

OBOGS Panel Regulator

Figure 13-1 — T-6 Oxygen Regulator

An oxygen regulator (Figure 13-1) is installed on the right side console in the T-6 cockpit. Each regulator has a supply lever, a concentration lever, a pressure lever, a built in test (BIT) button, a flow indicator (blinker), and a maximum concentration flow light. Each regulator panel controls OBOGS electrical power and oxygen flow for the respective cockpit.

CONTENTS
PREVIOUS

Regulator Function

Advances in aircraft design and performance demanded improvements in early regulators. An aneroid assembly was incorporated to react to cabin pressure changes and deliver oxygen under positive pressure, as it always is trying to provide approximately 1 in Wg (inch of water gauge) safety pressure. Oxygen concentration with the lever in NORMAL position will range from 25% to 70% for altitudes from sea level to 15,000 feet MSL, and from 45% to 95% for altitudes from 15,000 feet MSL to 31,000 feet MSL. When the concentration lever for either regulator is set to MAX, the OBOGS concentration supplies the highest possible oxygen concentration (95% oxygen, 5% inert gas) to both regulators. The maximum concentration light illuminates any time either concentration lever is in the MAX position. The OBOGS regulator provides slight positive pressure continuously while the supply lever is in the ON position. A detailed knowledge of the components and operation of the regulator is very important. The following section provides facts to properly operate the regulator. Reference Figure 13-1 as you study these components.

Regulator Components

Oxygen Supply Lever — The supply lever has two positions, placarded "ON" and "OFF." When set to "OFF", OBOGS electrical power and oxygen flow are cut off to the respective regulator. However, if the supply lever for either regulator (front or back seat) is "ON", the OBOGS system is operative and if left in this position long enough, the aircraft battery will be run down if the engine is not running. Both supply levers must be "OFF" to disable the OBOGS system.

Oxygen Concentration Lever — The concentration lever has two positions, placarded "NORMAL" and "MAX." When the lever is set to the "NORMAL" position, the regulator directs the OBOGS concentrator to provide the proper oxygen mix for the cockpit pressure altitude. When the lever is set to "MAX", the regulator directs the OBOGS concentrator to supply the highest possible oxygen concentration. The maximum concentration light illuminates any time the lever is in the "MAX" position.

Oxygen Pressure Lever — The pressure lever has three positions placarded, respectively, "EMERGENCY," "NORMAL," and "TEST MASK." The "EMERGENCY" position supplies the pilot with the positive pressure necessary during emergency situations such as cockpit smoke and fumes. When the lever is set to "NORMAL", the regulator supplies a slight positive pressure to the crewmember. The "TEST MASK" position supplies highly pressurized flow to check the face-to-mask seal.

OBOGS Annunciators - OBOGS status is indicated by two annunciators on the annunciator panel in each cockpit. The first is the OBOGS FAIL light. This is a warning annunciator that will light when the low pressure switch is closed. This occurs whenever there is low bleed air pressure before the concentrator (less than 6.5 psi) and could illuminate prior to engine start or when a loss of bleed air occurs. The second is the OBOGS TEMP light. This is a caution annunciator that is activated by the temperature sensor just past the heat exchanger. The light will become illuminated if the temperature out of the heat exchanger goes above 200 degrees Fahrenheit.

Regulator BIT Button — The built in test (BIT) button activates the initiated OBOGS BIT (I-BIT) any time after engine start and the three minute warm-up. The I-BIT provides verification that the OBOGS sensor and "OBOGS FAIL" annunciator are operating properly. Momentarily pushing the BIT button opens a valve in the concentrator that allows ambient air into the concentration monitor. Once the oxygen concentration drops below normal (approximately 20 to 30 seconds), the "OBOGS FAIL" light should illuminate. Once the valve closes and oxygen concentration in the monitor returns to normal, the "OBOGS FAIL" annunciator should extinguish within two minutes. If the annunciator fails to illuminate or extinguish as expected, either the annunciator or the monitor has failed.

Oxygen Flow Indicator — The flow indicator provides a visual indication of gaseous flow through the regulator. As each inhalation takes place, the flow indicator will show white, and upon exhalation, it will show black. Additionally, when performing an oxygen mask seal check, it will show white if a leak is detected and show black if the seal is good.

T-6A OBOGS

For T-6A OBOGS (Figure 13-2), bleed air is tapped from a port on the left side of the T-6A engine. This bleed air is sent through an oxygen system shutoff valve, an OBOGS heat exchanger and a high temperature which ensures it's not too hot. Then it will pass through a drain valve to remove excess condensation before passing across a low pressure switch that ensures adequate air pressure and into the OBOGS unit in the fuselage right side avionics bay. This unit extracts oxygen from the conditioned engine bleed air. A concentrator in the OBOGS unit automatically adjusts the oxygen concentration for the current altitude based on the current cockpit pressure. The oxygen then flows from the OBOGS unit to a plenum. This plenum functions as a holding tank between the OBOGS unit and the regulators. It is a small container located out-of-view below the concentrator.

CONTENTS
PREVIOUS

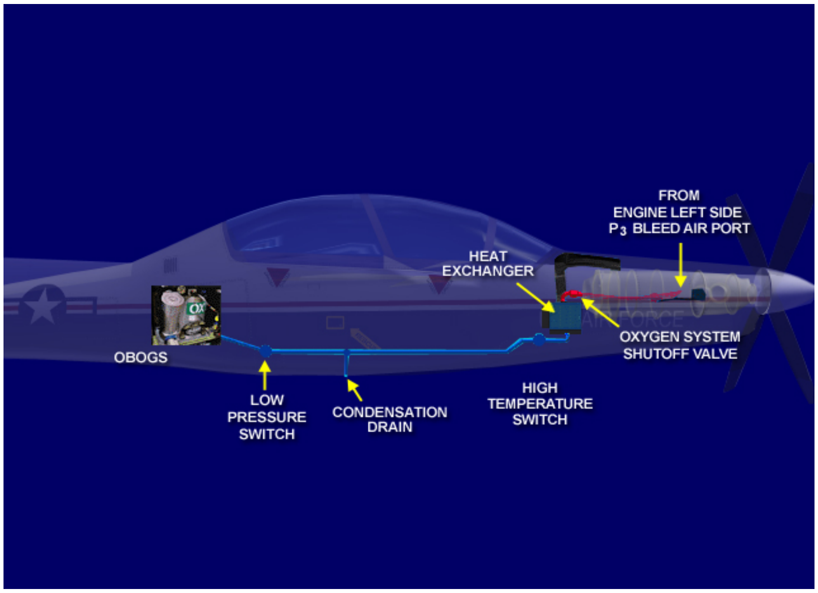

Figure 13-2 — T-6 OBOGS Components

In the event of OBOGS system failure, the plenum will provide a very limited supply of oxygen (approximately one breath) for the aircrew until the emergency oxygen system is activated. The duration of this supply depends on factors such as cockpit pressurization, aircraft pressure altitude, pilot regulator settings, and pilot demand.

Emergency Oxygen Systems

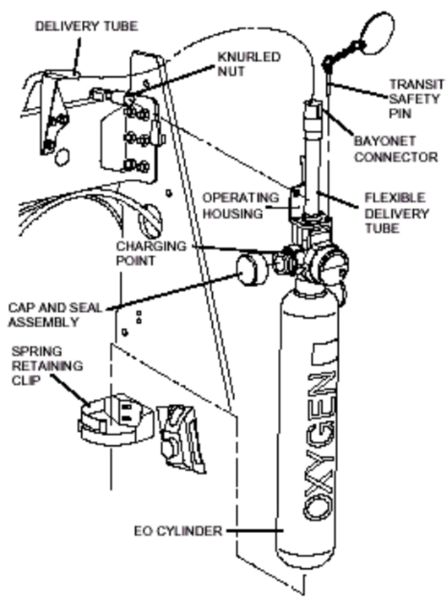

Figure 13-3 — Emergency Oxygen System

Emergency Oxygen Cylinder

The emergency oxygen system (Figure 13-3) is a high-pressure gas, continuous flow oxygen system. It provides 100% oxygen for the first two to four minutes. After that time, the anti-suffocation valve or CRU-60/P (if ship supply hose is disconnected) mixes an increasing amount of ambient air until the emergency bottle is depleted. Activate this emergency system when the normal aircraft oxygen system is interrupted due to failure, depletion, contamination, or egress at altitudes up to FL500. Figure 13-3 depicts the emergency oxygen system components.

CONTENTS
PREVIOUS

The cylinder is installed on the left side of the ejection seat. The emergency oxygen cylinder has a pressure gauge to indicate the amount of oxygen available. The system supplies the crewmember with oxygen automatically during ejection. The system may be activated for use on board the aircraft if the OBOGS does not function properly. Approximately 8-10 minutes oxygen is available for emergency use.

Ejection automatically starts the positive flow of oxygen to the crewmember. Emergency oxygen flow continues for approximately 8-10 minutes or until seat/man separation. The emergency oxygen cylinder is sufficiently charged for flight if the contents gauge pointer is anywhere within the black band.

Emergency Oxygen Manual Control

A green control loop (Figure 13-4) is located on the left side of each seat and forms part of the emergency oxygen operating lever. Should the OBOGS fail, the emergency oxygen supply may be activated by performing a rearward pull on the control handle. The emergency oxygen cylinder will supply oxygen for approximately 8–10 minutes.

Note — Once activated, ejection seat emergency oxygen cannot be shut off and will provide oxygen flow until the cylinder is depleted (approximately 8–10 minutes).

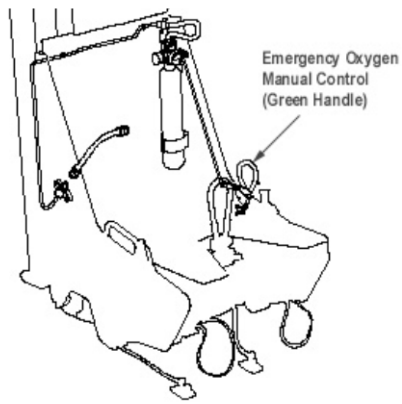

Figure 13-4 — EO Manual Control Handle

Helmet Assemblies and Oxygen Masks

Protective Helmets

Air Force aircrews use the HGU-55/P helmet. It is designed for use in high-performance aircraft. The HGU-55/P helmet shown in Figure 13-5 is gray, low-profile model made of lightweight material and with a detachable visor. The HGU-55/P provides:

Protection from head injury and ambient noise

Mounting for the visor and oxygen mask

Communications

It is available in three sizes — medium, large and, extra-large.

New fighter aircraft require a lighter weight oxygen mask that does not slide down the face during high-G maneuvering, provides lower bulk and better visibility (lower profile), and reduces pressure points or “hot spots” during normal flight (comfort).

Advanced masks were designed to withstand positive pressure. The MBU-series masks are designed for pressure demand oxygen systems and hold internal pressures in excess of ambient or outside pressure.

Figure 13-5 — HGU-55/P Helmet

CONTENTS
PREVIOUS

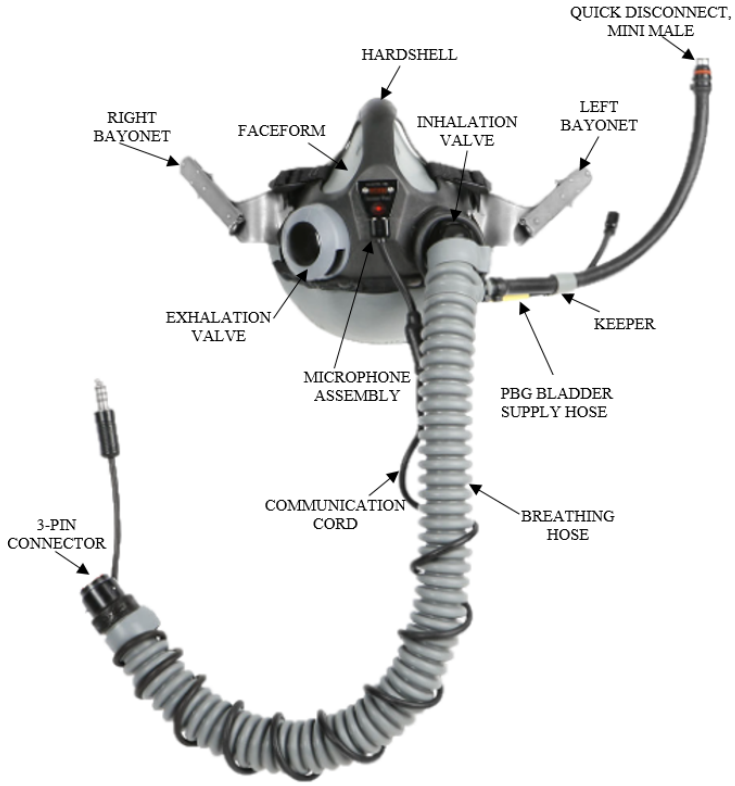

Figure 13-6 — MBU-20/P Oxygen Mask

CONTENTS
PREVIOUS

MBU-20/P Oxygen Mask

The MBU-20/P pressure demand oxygen mask (Figure 13-6) has separate faceform and hardshell assemblies. The mask was designed to provide pressure breathing for G (PBG) capability to tactical aircrew, while reducing the probability of G-induced loss of consciousness. The mask offers a low-profile for increased downward field of view, has lower inhalation and exhalation resistance, and increases the range of fitting for aircrew members. The MBU-20A/P is a variant of the MBU-20/P for non-PBG applications. The MBU-20A/P comes in five sizes – X-small narrow, small narrow, medium narrow, medium wide, and large wide.

The components of the mask include separate faceform and hardshell assembly, a low-resistance delivery tube (mask hose), mask connector, anti-stretch cord, microphone, communication cord, oxygen mask retention bayonets and separate inhalation/exhalation valves. The PBG bladder supply hose is removed for the MBU-20A/P variant.

Oxygen Mask Visual Inspection

1. Inspect oxygen hose for cuts, breaks, dust, and dirt.
2. Inspect microphone assembly for damage, loose connection, and proper seating. Do not pull on microphone assembly.
3. Inspect strap and buckle assembly for damage, raveled fabric, fraying, loose stitching, insecure attachment, and bent other damaged grommets.
4. Inspect face piece assembly for damage and deformation.
5. Inspect self-locking screws and T-nuts for damage or loose fit.
6. Inspect communication cable for cuts and split or frayed insulation.
7. Inspect offset bayonet connectors for proper operation.
8. Inspect security of hose clamps.
9. Inspect delivery hose tolerance

Regulator-to-seat kit hose visual inspection

1. Inspect hose for damage, wear, fraying, and kinks.
2. Inspect quick disconnects for operation, damage, corrosion, and loose or missing pins.
3. Ensure components are clean and free of foreign matter.
4. Inspect housing for damage, discoloration, and wear.
5. Inspect fittings for damaged threads, rounded hexagonal nuts, and corrosion.

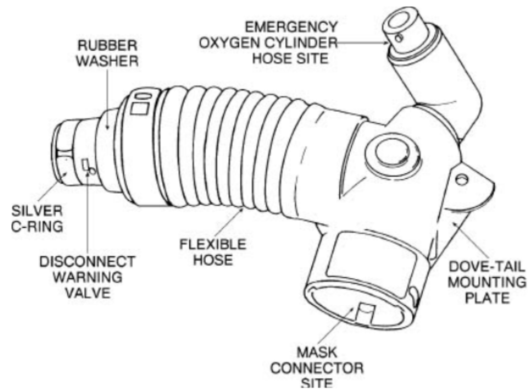

Figure 13-7 — CRU-60/P

Connector Assembly, CRU-60/P

The CRU-60/P is an oxygen mask-to-regulator connector assembly (Figure 13-7). It is a three-way connector providing connection sites for the regulator hose, the mask connector, and the emergency oxygen cylinder hose. The CRU-60/P attaches to the parachute harness, at the intersection of the horizontal chest strap, by securing a dovetail mounting plate into a receiving bracket on the harness.

Regulator hose site — is on the end of the two-inch flexible hose and is a simple push-pull connection. A silver C-ring provides 12 to 20 pounds of disconnect tension. This tension is enough to maintain the connection during normal flight operations but permits automatic disconnect during ejection or ground egress. The two-inch flexible hose permits a 180 degree swing in any direction and contains an anti-stretch cord to prevent over-stretching during disconnect. The connection site also incorporates a rubber gasket to ensure an airtight seal and a disconnect warning valve to offer resistance of flow during inhalation if the inlet is not properly inserted into the aircraft oxygen regulator hose. This airflow restriction warns the aircrew of a disconnect from the aircraft oxygen system. The valve also relieves excess pressure from the continuous flow emergency oxygen cylinder**.**

Mask connector site — is the hard portion of the connector assembly and contains a black O-ring in a recess to ensure another airtight seal. The oxygen mask hose connects to this site with a push-turn action. Normal disconnect from the regulator hose is at the mask connector site.

Preflight Checks

Pressure
Regulator
Indicator
Connections
Emergency

Figure 13-8 — PRICE Check

CONTENTS !!!
PREVIOUS

A preflight check of personal equipment and the aircraft oxygen system is mandatory. Before going to the aircraft, you are required to inspect your personal oxygen equipment and test it with the MQ-1 Tester in the life support section. This brief inspection ensures the proper operation of the mask and helmet, independent of the aircraft system. As part of the aircraft preflight, you are required to check the proper function of the oxygen system. Traditionally, all military aviators have resorted to a concise acronym to describe the steps of this preflight check. It is the "PRICE" (Figure 13-8) check with each letter in the acronym representing a discrete step in the preflight inspection of the aircraft oxygen system, mask, and regulator.

Note — The T-6 OBOGS does not have a pressure requirement; therefore, this step in the PRICE check may be eliminated making it a RICE check for this aircraft.

SCOT Communications and Oxygen System Tester

The SCOT Tester allows testing the operational capability of helmet, oxygen mask, and communications prior to leaving the life support section and proceeding to the aircraft. The tester allows leak testing at three pressure levels, simulating regulator pressures at 41M (41,000 ft), 43M (43,000 ft), and 45M (45,000 ft) settings. A red light illuminates when a flow of five liters or greater occurs. Communications are tested by attaching the microphone and headset to a jack on the control panel, or by an audio cable attached to the control panel (the audio cable is configured for the active noise reduction system). To test communications, speak into the microphone and you should hear your voice in the headset. Continuity of communication components is performed by switching the audio select switch to the CONT position. If the impedance of the earphone is correct, a green light will come on. A second green light will come on if the impedance of the microphone is correct. If either is shorted, its light will turn red.

Use the following SCOT Tester preflight procedural checklist:

1. Power switch ON
2. Place the mask switch in the normal position
3. Position place ALT SELECT switch in the 41M position
4. Toggle the TEST switch to the HOLD position and wait until the READY green light comes on
5. Don oxygen mask and breathe in deeply, then breathe normally

MBU-20/P third locking position

If breathing is difficult, the valve is defective…see life support

6. Toggle the MASK switch to the ALTITUDE position
7. Momentarily stop breathing, observe the LEAK light indicator
8. Repeat the previous step in the 43M and 45M altitude positions
9. Place the ALT SELECT switch in the 45M position
10. Exhale slowly, if excessive resistance to exhalation is evident, the valve is faulty. See Aircrew Flight Equipment.
11. Reset all switches to their original position, unit off.
12. Connect oxygen mask communications cord to SCOT tester

    Check communications, should be able to hear yourself in the helmet

Note — If any aspect of the oxygen or communications checks is faulty, return the helmet and mask to Aircrew Flight Equipment personnel for corrective action. Then, repeat the checklist procedures.

RICE Check

The RICE check is not restricted to aircraft preflight, but should be used by the aircrew as a troubleshooting technique anytime the oxygen system is suspect.

R — Regulator.

1. Check the general external condition and appearance of the regulator. Visually inspect the regulator for dents, cracks, and flow indicator lens. There should not be oil, grease, water, etc. on the regulator. Inspect for proper lever movement (indicators/switches).

2. Check the internal condition and function (integrity) of the regulator with the mask on and connected to the aircraft regulator hose. Use the following steps to perform the internal check:

a. SUPPLY lever — "ON"

b. Concentration lever — "MAX"

c. Pressure lever — "EMER"

d. Breathe normally for a minimum of three cycles; monitor the flow indicator for alternate black and white indications.

e. Hold breath. If the flow indicator remains black, system integrity is confirmed. If white, then a leak is indicated. Check mask, connections, regulator configuration, and then aircraft system in that order.

f. Concentration lever to "NORMAL." The flow indicator should remain black. White indicates a leak.

Note — It's possible to cause a leak indication with excessive head movement. To receive an accurate indication, hold your head still and look straight into the flow indicator. If a leak is suspected, locate the cause, correct and repeat steps a through f.

Warning — *Correct all oxygen leaks prior to flight.*

I — Indicator. With the Concentration lever in the "MAX OXYGEN" position, check the flow indicator for proper operation. Once proper operation is verified, return the Concentration lever to the "NORMAL" position. The indicator can also be used to monitor your rate of breathing if you suspect hypoxia or hyperventilation.

C — Connections. Check the regulator hose for wear, tear, and deterioration. Check the regulator hose site of the connector assembly for the presence of the silver C-ring and rubber washer. A 12 to 20 pound pull is required to separate the regulator hose from the connector. Confirm proper connections of the oxygen mask hose and the regulator hose. Check the three communications cord connection sites.

E — Emergency. Ensure the emergency oxygen cylinder hose is properly connected to the connector assembly and in good condition. Check the pressure gage for a reading of 1,800 psi.

Mask and Helmet Care

Do

1. Have the aircrew flight equipment section inspect the mask at least every 30 days.

2. Inspect and test mask for operation before leaving the life support section (SCOT Tester).

3. Clean the mask at the end of each flying day. Use cleaning solution and gauze to wipe interior and to remove perspiration, facial oils, and foreign matter.

4. Check helmet prior to each flight for overall condition. Check security of chin and nape straps, visor lens for cracks and scratches, cleanliness and visor operation, and communication connectors.

5. Check mask and helmet daily for wear and tear. Have items replaced as necessary.

6. Check bayonet connectors and ensure that locking pins operate freely.

7. Whenever possible, transport the helmet assembly in a helmet bag. When unable to carry the assembly in a helmet bag, carry the helmet and mask by the chinstrap like a bucket.

8. Have the life support section inspect your helmet any time it is dropped or cracked.

Don't

1. Don't paint the helmet. Mark only as directed and then IAW the applicable technical orders.

2. Don't carry the helmet by the communications cord or mask.

3. Don't allow the helmet to strike objects that would damage the protective surface.

4. Don't disassemble the mask. This operation requires special tools and should only be done by qualified life support personnel.

5. Don't modify or alter the mask.

CONTENTS
PREVIOUS

6. Don't store the helmet/mask in direct sunlight or near heat for extended periods or in the aircraft when off station.
7. Don't puncture the mask.
8. Don't use pencils, pens, or sharp objects to loosen valves.
9. Don't loan equipment. It was fitted for you.

Remember, this aircrew flight equipment is yours. Routine professional care and maintenance ensures trouble-free operation. Direct any questions or concerns regarding this equipment to the aircrew flight equipment technicians.

Summary

Oxygen storage and delivery systems, combined with your personal oxygen equipment, provide you the supplemental oxygen you need because of the atmospheric changes that occur with altitude. Air Force publications require the use of supplemental oxygen during high altitude flights. While there are several types of oxygen storage and delivery systems, the T-6 uses OBOGS as the primary source of oxygen and the high pressure bottle in the ejection seat as the emergency source. OBOGS provides oxygen throughout the flight regime and is capable of providing up to 95 percent oxygen. The most critical component of the effectiveness of this system is your knowledge of the capabilities of the OBOGS system and how to care for and use your personal equipment.

CONTENTS

PREVIOUS

Review Exercise AP113

Complete the following review exercise by choosing the correct response. Answers follow the questions.

1. Determine if the following characteristics refer to (A) high pressure gas, (B) low pressure gaseous oxygen storage systems, or (C) on board oxygen generating systems (OBOGS).

   a. _____ Full pressure — 1,800 - 2,000 psi

   b. _____ Full pressure — 400 - 450 psi

   c. _____ Unlimited oxygen duration

   d. _____ Green cylinders

   e. _____ Yellow cylinders

   f. _____ Oxygen source is engine bleed air

   g. _____ Empty pressure — 100 psi

   h. _____ Empty pressure — 200 psi

2. Study the Oxygen pressure regulator in Figure 13-9. Place the correct number beside the following components:

   a. _____ Maximum concentration light

   b. _____ Supply lever

   c. _____ Concentration lever

   d. _____ Flow indicator

   e. _____ Pressure lever

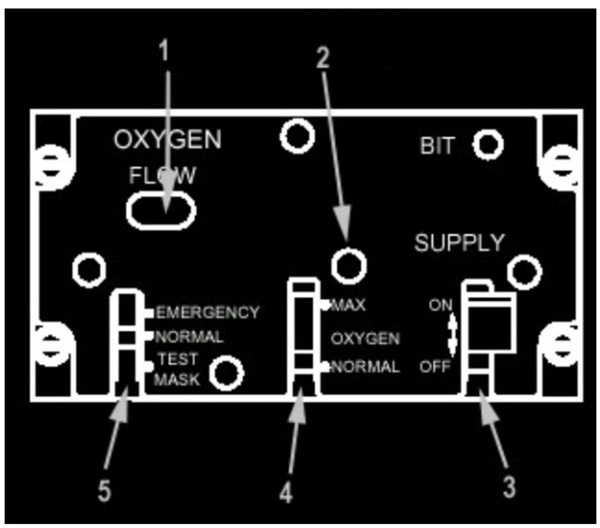

Figure 13-9 — Question 2

CONTENTS
PREVIOUS

3. Study the MBU-20/P oxygen mask in Figure 13-10. Place the correct number beside the following components:

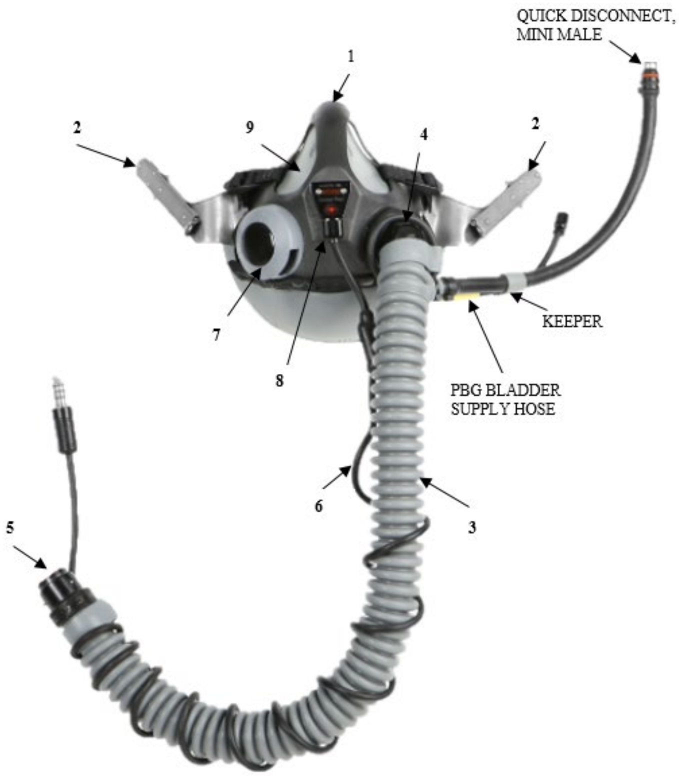

Figure 13-10 — Question 3

a. _____ Hardshell Assembly
b. _____ Delivery Tube (mask hose)
c. _____ 3-Pin Connector
d. _____ Faceform
e. _____ Microphone Assembly
f. _____ Communication Cord Assembly
g. _____ Oxygen Mask Retention Bayonets
h. _____ Inhalation Valve
i. _____ Exhalation Valve

CONTENTS
PREVIOUS

4. Place the appropriate letter of the **RICE** check next to its corresponding correct statement.

   a. _____ Check the emergency oxygen assembly for pressure.

   b. _____ Check for neoprene O-ring (rubber washer).

   c. _____ Concentration lever to "MAX" and check flow indicator.

   d. _____ Check supply lever — "ON."

   e. _____ Check proper connection of the mask hose to the CRU-60/P.

   f. _____ Check regulator hose for wear, tear, and deterioration.

   g. _____ If the flow indicator is white while holding your breath with the emergency lever in the "EMERGENCY" position, either the mask or the aircraft oxygen system is leaking.

5. List five "Do's" and "Don'ts" for proper care of the oxygen mask and helmet.

"Do's"

   a.

   b.

   c.

   d.

   e.

"Don'ts"

   a.

   b.

   c.

   d.

   e.

6. Place an "X" in the box of each statement below that describes the purpose, duration, and/or operation of a high pressure gaseous emergency oxygen system.

   a. _____ It has a duration of approximately 3 to 5 minutes.

   b. _____ Normally provides a 10 minute supply of oxygen.

   c. _____ It has a duration of approximately 12 to 15 minutes.

   d. _____ The oxygen flow can be shut off.

   e. _____ The oxygen flow cannot be stopped once it has been activated.

   f. _____ It delivers 100% oxygen on demand.

   g. _____ It delivers 100% oxygen continuously.

   h. _____ It is activated automatically on ejection.

   i. _____ It may be activated in the event of oxygen system failure.

   j. _____ It may only be activated prior to ejection.

Answers to Review Exercise AP113

1.
   a. a
   b. b
   c. c
   d. a
   e. b
   f. c
   g. b
   h. a

2.
   a. 2
   b. 3
   c. 4
   d. 1
   e. 5

3.
   a. 1
   b. 3
   c. 5
   d. 9
   e. 8
   f. 6
   g. 2
   f. 4
   h. 7

4.
   a. E
   d. C
   c. I
   d. R
   e. C
   f. C
   g. R

5. Do's
   - Have the life support section inspect the mask at least every 30 days.
   - Inspect and test the mask for operation before leaving the life support section
   - Clean the mask at the end of each flying day. Use cleaning solution and gauze pad to wipe interior of the mask faceform to remove perspiration, facial oils, and foreign matter (required by AETCI11-301).
   - Check the helmet prior to each flight for overall condition. Check security of chin and nape straps, visor lens for cracks and scratches, cleanliness and operation of lens, attachment of communication of connectors, and operation of communication connectors.
   - Check the mask and helmet daily for wear and tear. Have items replaced as necessary.
   - Check the bayonet connectors and ensure that the locking pins operate freely.
   - Whenever possible, transport the helmet assembly in a helmet bag. When unable to carry the assembly in a helmet bag, carry the helmet and mask by the chinstrap like a bucket.
   - Have the life support section inspect your helmet any time it is dropped or cracked.

   Don'ts
   - Don't paint the helmet. Mark only as directed by applicable technical orders.
   - Don't carry the helmet by the intercom cord or mask.
   - Don't allow the helmet to strike objects that would damage the protective surface.
   - Don't disassemble the mask. This requires special tools and should be done only by qualified life support personnel.
   - Don't modify or alter the mask.
   - Don't store the helmet/mask in direct sunlight or hot environments for lengthy periods of time, or in the aircraft when off station.
   - Don't allow sharp objects to come in contact with the mask because any puncture could damage the mask
   - Don't use pencils, pens, or sharp objects to loosen troublesome or sticking valves.
   - Don't loan equipment. It was fitted and intended for personal use only.

6. b, e, g, h, i

CONTENTS !!!
PREVIOUS

AP114 — Oxygen Equipment Lab

Hours and Medium

1.0 Hours (IBT)

Objectives

1. Know how to perform an operational check of the oxygen system.

   Samples of Behavior:

   a. Describe the procedures necessary to perform a Regulator — Indicator — Connections — Emergency (RICE) check.

   b. Using a functional oxygen regulator, mask, and helmet, practice:

      (1) Operating the regulator

      (2) Donning and doffing the mask and helmet

      (3) Performing a RICE check

      (4) Breathing on the regulator

      (5) Personal Equipment

      (6) Speaking while pressure breathing

Assignment

1. Read Oxygen System, Section I, Air Force T.O. IT-6A-1/Navy (NAVAIR) A1-T6AAA-NFM-100, *Flight Manual*

Information

Oxygen Equipment Lab

At the conclusion of the classroom presentation or in conjunction with the Type 4 Hypobaric Chamber Flight, you will receive an oxygen equipment laboratory. The laboratory will:

a. Familiarize you with the hypobaric chamber and its equipment.

b. Ensure the proper operation and function of your oxygen equipment.

c. Reinforce the objectives of the oxygen equipment classroom presentation and moderate anxiety about hypobaric chamber operation.

Using a functional oxygen regulator, mask, and helmet, practice:

a. Operating the regulator

b. Donning and doffing the mask and helmet

c. Performing a RICE check

d. Breathing on the regulator

High Pressure Emergency Oxygen Demonstration

1. Demonstrate proper pressure breathing techniques
2. Demonstrate the ability to speak over comm while pressure breathing

You will receive training on the high pressure emergency oxygen system. Positive pressure breathing requires that you monitor your rate and depth of breathing. Remember, passive inhalation and active (forceful) exhalation, with a pause between, will help prevent hyperventilation. Your lecturer will have you activate the high pressure system. The lecturer may ask for a communications check during this time; break your words up into syllables and forcefully speak against the pressure. The combined effects of pressure breathing and gas expansion at altitude may make it very difficult to perform flight tasks proficiently. This training simulates activating the aircraft emergency oxygen system which would be initiated by pulling the green ring in the T-6.

CONTENTS
PREVIOUS

AP115/116 — Initial Chamber Flight and RD

Hours and Medium

3.0 Hours (IBT)

Objective

1. Comprehend aircrew procedures for treating or preventing physiological effects related to altitude.

   Samples of behavior:

   a. Identify the proper techniques for pressure breathing
   b. Perform preflight and in-flight checks of oxygen equipment
   c. Perform the procedures to treat hypoxia
   d. Perform the procedures to prevent trapped gas disorders in-flight
   e. Identify the proper use of emergency oxygen systems and portable oxygen equipment
   f. Identify visual problems resulting from decreased oxygen during night flying conditions
   g. Perform the procedures to prevent hypoxia, trapped gas, and evolved gas disorders after a rapid decompression
   h. Identify the physical signs of a rapid decompression
   i. Identify the physiological effects of a rapid decompression

CONTENTS
PREVIOUS

Introduction

The Initial Chamber Flight provides practical experience in, and demonstrates the effects of, barometric pressure change. Figure 15-1 provides the Initial Chamber Flight profile. Remember, the altitude chamber is an extension of the classroom and the chamber flight is intended to enhance your learning experience. A rapid decompression chamber flight (Figure 15-2) is part of the chamber experience as well.

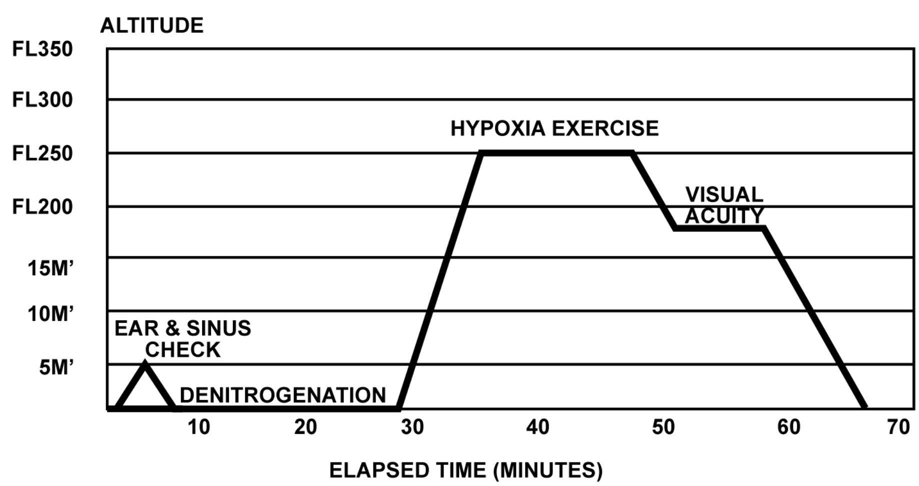

Figure 15-1 — Initial Chamber Flight Profile

Information

Preflight Briefing

A preflight briefing is conducted to ensure safe and efficient operation and completion of the chamber flight. You will be briefed on the flight profile, purpose and procedure. You will may out a questionnaire in order to determine your immediate physical status (colds, headache, abdominal pain, medication, etc.) before the chamber flight. If you have any medical concerns please notify the instructor. At the conclusion of the preflight briefing, you will be given an altitude chamber seat number and directed to the chamber. The main purpose of the chamber flight is to validate student proficiency with performance based objectives designed around hazards encountered during flight.

Chamber Flight for T-6 Pilots

Enter the altitude chamber and sit in your preassigned seat. The chamber crew personnel will assist you in performing a PRICE check to guarantee the integrity of your oxygen equipment. Denitrogenation time (30 minutes) begins after all students and inside observers have completed a PRICE check and are breathing 100 percent oxygen. A communications check is conducted after all students and crew personnel are in position. An ear and sinus check is conducted to identify any potential difficulties. The Valsalva maneuver is necessary only on descent. After the ear and sinus check is completed, the remainder of the denitrogenation time is used to review the PRICE check and practice pressure breathing.

At FL250, a hypoxia demonstration is conducted to allow you to experience your signs and symptoms of hypoxia. Once all students have experienced hypoxia symptoms and recover, you will begin your descent to FL180. Students will remove their masks once again at FL220 to experience the effects of mild hypoxia on vision.

Equalizing the pressure in the middle ears and sinuses is your main concern during the final descent to ground level. The remaining demonstration of the chamber flight is with the emergency oxygen cylinder. Remember your pressure breathing technique as you use the emergency oxygen cylinder. Once ground level is reached, do not disconnect from the regulator hose or the communication cord until instructed to do so.

Rapid Decompression

As part of your altitude chamber experience, you are assigned to a group (with one Inside Observer (IO)) for the rapid decompression chamber flight. Enter the lock portion of the altitude chamber and follow the instructions of your IO. A preflight check of your oxygen equipment and an intercom check are conducted after your group and the IO are in position. The door is closed and you will be briefed on the phenomena of a rapid decompression. After the briefing is complete, a rapid decompression will occur without prior notice. Figure 15-2 provides an example of a rapid decompression flight profile. The decompression causes an ascent from ground level to about 10,000 feet in approximately two seconds. The final altitude will be determined by the field elevation, but will be around 10,000 feet. Your responsibilities are to *not* hold your breath, gangload your regulator and check your connections.

Final descent begins after everyone recovers, a communications check is completed, and the emergency lever is returned to NORMAL. Equalizing the pressure in the middle ears and the sinuses is your main concern during descent. Your inside observer will discuss the physiological effects and physical characteristics of a rapid decompression, pointing out their significance to an actual event on an aircraft. Once ground level is reached, do not disconnect from the regulator hose or the communication cord until instructed by the IO.

CONTENTS

PREVIOUS

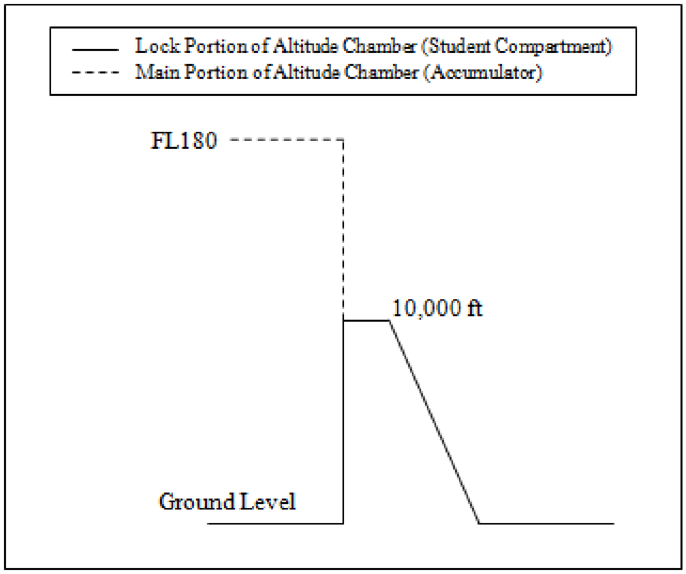

Figure 15-2 — Rapid Decompression Flight Profile (Example)

Post Flight Briefing

The postflight briefing reviews the chamber flight and emphasizes the learning outcomes. You are given instructions to follow in the event of a delayed reaction and restrictions you must adhere to following the chamber flight.

Because nitrogen in body tissue comes out of solution during exposure to low barometric pressure, you are restricted from strenuous activity for 12 hours following the chamber flight. These precautions help prevent postflight DCS.

There is also the possibility of experiencing a postflight ear block (delayed reaction) after breathing 100 percent oxygen for an extended period of time. As the 100 percent oxygen diffuses out of the middle ear space into the surrounding tissues, a relative low pressure area results. The low pressure area allows the now greater ambient pressure on the exterior surface of the ear drum to deflect the ear drum inward, dulling the hearing and producing pain. So, continue to perform the Valsalva maneuver as necessary following the chamber flight.

CONTENTS
PREVIOUS

AP118 — Spatial Disorientation Experience

Hours and Medium

0.5 Hours (IBT)

Objective

Recognize the effects of three types of spatial disorientation while performing basic flight maneuvers inside the spatial disorientation trainer.

Introduction

Instinctively, people rely primarily on their visual/audible (sight & sound), vestibular (position and motion detection), and proprioceptor ("seat-of-the-pants") perceptions for their sense of direction and physical orientation cues. Quite naturally, during daytime flights, many aircraft pilots tend to rely heavily on visual cues from the horizon to maintain good spatial orientation. However, these instinctive sensory methods can easily fail to detect real changes in altitude, attitude, or motion, and can even synthesize false cues for each. In addition, it has been proven that the semi-circular canals of the human ear are not very effective or reliable when serving as "change-in-velocity" sensors.

Information

Spatial Disorientation Trainer

The Spatial Disorientation Trainer (Figure 18-1) is an interactive, multifunctioning training system with built-in flexibility to accommodate the training needs of all flight students from first-time trainees to experienced pilots. It consists of a single occupant cockpit assembly mount on a sophisticated motion base, and simulates a T-6A Texan Flight Training Aircraft. The cockpit includes a pilot seat, closed-loop interactive flight controls, forward out-the-window visual display, front panel instrumentation gauges, and real aircraft sounds.

The Spatial Disorientation Trainer offers an economical approach to simulating physiological disorientation effects and can be used in flight navigation training and refresher situations by allowing a series of realistic virtual problem scenarios to be experienced without placing the pilot's life in any danger.

Note – Training device lesson hours are per student. Training time must compensate for training device capacity and size of training class.

Figure 18-1 — Spatial Disorientation Trainer

CONTENTS
PREVIOUS

CE190 — Final Examination

Hours and Medium

2.0 Hours (CBT)

Objectives

1. Complete the T-6 combination examination in the allotted time and within the academic standard.
2. Critique all errors on the examination to 100 percent.

Assignment

1. Review Lessons AP101 through AP114, LL06 (formerly JS103), JL103, JL106 (or SS06 as required), JL103 and LL02 (formerly JL104). If you have any questions concerning the objectives, be prepared to discuss them in class.
2. Complete any review exercises that were not previously accomplished.

Introduction

This examination is designed to test the achievement of selected objectives presented in the T-6 Physiology course.

Information

1. Complete the examination within the academic standard.
2. Critique any errors on the examination to 100 percent.