This is Aerospace Medicine

Presented by the

Aerospace Medical Association

Overview

Introduction

Flight Environment

Clinical Aerospace Medicine

Operational Aerospace Medicine

Aerospace Medicine vs. Traditional Medicine

Medical Discipline	Physiology	Environment
Traditional Medicine	Abnormal	Normal
Aerospace Medicine	Normal/Abnormal	Abnormal

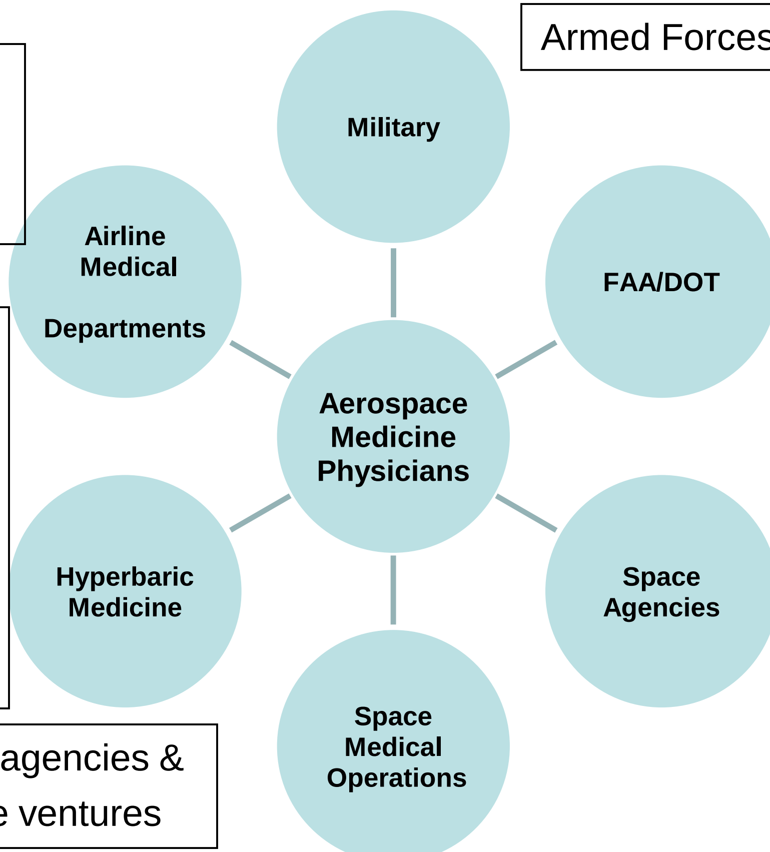
Brief History of Flight Medicine

- Advent of powered flight presented new physiologic demands such as altitude exposure
- Aviation Medicine driven by WWI high losses of life due to physically unfit pilots
- Development of manned space flight led to evolution of Aviation Medicine into Aerospace Medicine

Aerospace Medicine Practitioners

- Address needs of all who work, recreate, and travel in the air, sea, and space
- Trained in medicine, with special knowledge of operating in extreme environments of flight, undersea, and space
- Uniquely equipped to make decisions on selection and retention of aviators, divers, and space mission and space flight participants.

Aerospace Medicine Practitioners



Armed Forces across the globe

Crew & Passenger Health

Safety Policy

Regulatory Compliance

Certification & Appeals

Aeromedical Examiner training & oversight

Accident Investigation

Evaluation & treatment : pathologic bubble formation

Osteo & soft tissue radionecrosis

Wound Infections

Thermal burns

Astronaut selection & training

Clinical & basic science studies

Development of countermeasures

Longitudinal Health

Support to space agencies & commercial space ventures

Aerospace Medicine Practitioners

- Aviation Medical Examiners (AMEs)
  - Designated, trained, and supervised by the FAA Flight Surgeons
  - Examine/certify civilian pilots
  - Training provides an understanding of aviation related problems, physiology, standards, and administrative processes
  - One week course with mandatory refresher courses
- International Aviation Medical Examiners
  - European Aviation Safety Agency (EASA)
  - Training provides an understanding of aviation related problems, physiology, standards, and administrative processes
  - 60 hr basic and 60 hr advanced courses

Aerospace Medicine Practitioners

- Military Flight Surgeons
  - Caring for aviators and their families, manage aerospace medicine and public health programs
  - Special training programs:
    - Residency in Aerospace Medicine (RAM)
    - Non-RAM military courses

Aerospace Medicine Practitioners

- National Aeronautics and Space Administration (NASA) Flight Surgeon Duties
  - Medical care for astronaut corps and their families
  - Astronaut selection and mission training
  - Develops physiologic countermeasures for spaceflight
  - Ensures crew health and safety
  - Research promoting a better understanding of medical issues associated with spaceflight environment

Advanced Training in Aerospace Medicine

- United States
  - Civilian Residencies
    - University of Texas - Medical Branch
    - Wright State University
  - Civilian Fellowships
    - Mayo Clinic
  - Military Residencies
    - US Navy
    - US Army
    - US Air Force

- United Kingdom
  Subspecialty of Occupational Medicine
  - Civilian Fellowship: King’s College in London
  - Military Fellowship: Royal Air Force (RAF) Centre of Aviation Medicine

Aerospace Medicine Practitioners (Non-Physicians)

- Aerospace Experimental Psychologists
- Aerospace Physiologists
- Bioenvironmental Engineers
- Cognitive Psychologists
- Environmental Health Professionals
- Flight Nurses
- Human Factors Engineers
- Industrial Hygienists
- Radiation Health Professionals
- Systems Engineers

Advanced Training in Aerospace Medicine

- Other countries also have advanced training in aerospace medicine with military and civilian components

The Flight Environment

Theory of Flight

- Atmospheric flight
  Bernoulli and Newton described the concept of lift, when air flows over a wing.

- Space Flight
  Suborbital and Orbital
  Lunar and
  Interplanetary

The Atmosphere

Composition

Gases

- Nitrogen 78 %
  (at SL 592.8 mmHg)
- Oxygen 21%
  (at SL 159.6 mmHg)
- Other 1%
  (at SL 76 mmHg)

Additional Components

Solid particles

- Dust
- Sea Salt

The Atmosphere

- Gaseous mass surrounding Earth which is retained by the Earth’s gravitational field
- Governed by gas laws

Key Atmospheric Properties in Ascent

- Temperature
- Pressure
- Humidity
- Oxygen
- Radiation

The Atmosphere

Pressure: Units of Measurement	Pressure: Reference Measurements

- International Civil Aviation Organization (ICAO) standard atmosphere
- International Atmosphere
- US Standard Atmosphere

At sea level, (59°F or 15°C) atmospheric pressure is:

= 760 mmHg
= 29.92 inches Hg
= 1013.2 millibars

At 18,000 ft (5454.5m) atmospheric pressure is
380 mmHg

Atmospheric Pressure & Altitude

1 atmosphere pressure = 760 mmHg = sea level

¾ atmospheric pressure = 570 mmHg = 8,000 ft (2424 m)

½ atmospheric pressure = 380 mmHg = 18,000 ft (5454.5 m)

¼ atmospheric pressure = 190 mmHg = 33,500 ft (10,151.5 m)

Atmosphere

Biosphere	Characteristic Highlights
Troposphere	• Site of the majority of aviation activity • Temperature Lapse Rate • Temperature Decreases until Tropopause (30,000 ft or 9144 m) at poles & 60,000 ft (18,288 m) at equator
Stratosphere	• Contains Ozone layer, important for UV radiation protection
Mesosphere	• Coldest sphere • -110 ˚C at 290,000 ft (85 km)
Thermosphere	• Charged particles modified by solar flare
Exosphere	• Sparse particle collisions • Hydrogen & Helium • Edge of Space

Aerospace Physiology

Respiration

Cardiovascular System

Spatial Orientation

Bioacoustics

Vision

Sleep and Circadian Rhythms

Acceleration

Gravitational Effects

Vibration

Hypobaria

Hyperbaria

Other Physical Factors

Human Factors

Respiration: Gas Laws

- Pressure changes at different altitudes creates various physiologic stresses i.e., hypoxia, decompression
- These changes are governed by the Gas Laws such as Boyle's Law, Dalton's Law, Henry's Law
  - Example: Body cavity volume expansion (GI tract, middle ear, and teeth) with altitude is governed by Boyle's Law

Respiration

External Respiration

(Ventilation)

Exchange of gases between body and atmosphere

Internal Respiration

Chemical reaction at the cellular level of carbohydrates and oxygen, producing energy as well as carbon dioxide

Respiration: Gas Exchange

- Oxygen:
  - Transported in the body via hemoglobin in the red blood cells and very little in physical solution
- Carbon dioxide:
  - Transport of the waste gas mainly in solution in the blood and 5% via hemoglobin
- Gas exchange:
  - Occurs at the alveolocapillary membrane (oxygen diffuses from alveolus to capillary and combines with hemoglobin, CO_2 diffuses from blood into alveolus and is exhaled)

Respiration

Causes of Hypoxia

Hypoxic Hypoxia

Oxygen deficiency from ineffective gas exchange at lung or inadequate oxygen inspiration

Hypemic Hypoxia

Oxygen deficiency from reduced oxygen carrying capacity in the blood

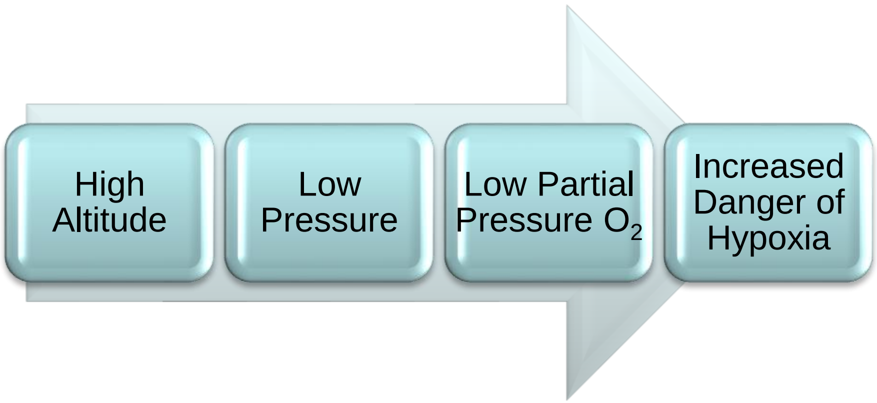
Histotoxic Hypoxia

Oxygen deficiency from inability to use oxygen at the molecular level

Stagnant Hypoxia

Oxygen deficiency from inadequate delivery of blood flow.

Hypobaria



Insidious onset makes hypoxia a real danger in high altitude flight.

Altitude (feet/meters)	Effective Performance Time
18,000/6,000	20-30 min
25,000/8,333	3-5 min
35,000/11,666	1 min – 30 secs
50,000/16,666	9-12 secs

Hypobaria: Decompression Sickness

Ascent

↓

Decompression

Barometric Pressure (P_B)

Decrease

↓

Supersaturation

$P_{N_2} > P_B$

↓

Pathologic (Nitrogen) Bubble Formation

↓

DCS

Altitude Decompression Sickness (DCS)

- Subset of Decompression Illness (DCI)
  - DCI includes:
    - **Arterial Gas Embolism (AGE)**
    - **Ebullism**
    - **Trapped gas**
- Result of decompression in accordance with Henry's Gas Law

.

Not all bubble formation with decompression leads to DCS.

Hypobaria: Symptoms of Altitude DCS

- ***Limb pain:*** at least 70% of all symptoms
  - Most common presentation
  - Typically joint or muscle pain

- ***Skin symptoms:*** about 13% of all symptoms
  - Mottling, pins & needles, tingling, prickling

- ***Neurologic:*** about 1-8% of all symptoms
  - Cold sweat, dizziness, edema, inappropriate or sudden onset of fatigue, headache, light headedness, loss of consciousness, motor and/or sensory loss, nausea, tremor (shakes), vertigo
- ***Pulmonary:*** about 3% of all symptoms
  - Cough, dyspnea (difficult or labored breathing), substernal distress (tightness and/or pain in chest, especially during inspiration); sometimes called Chokes

Altitude Hypobaria: Treatment of DCS

- Immediate treatment in the aircraft
  - 100% oxygen (until told to stop by qualified physician)
  - Descend as soon as practical
  - Declare In-Flight Emergency (IFE)
  - Land at the nearest airfield with qualified medical assistance available

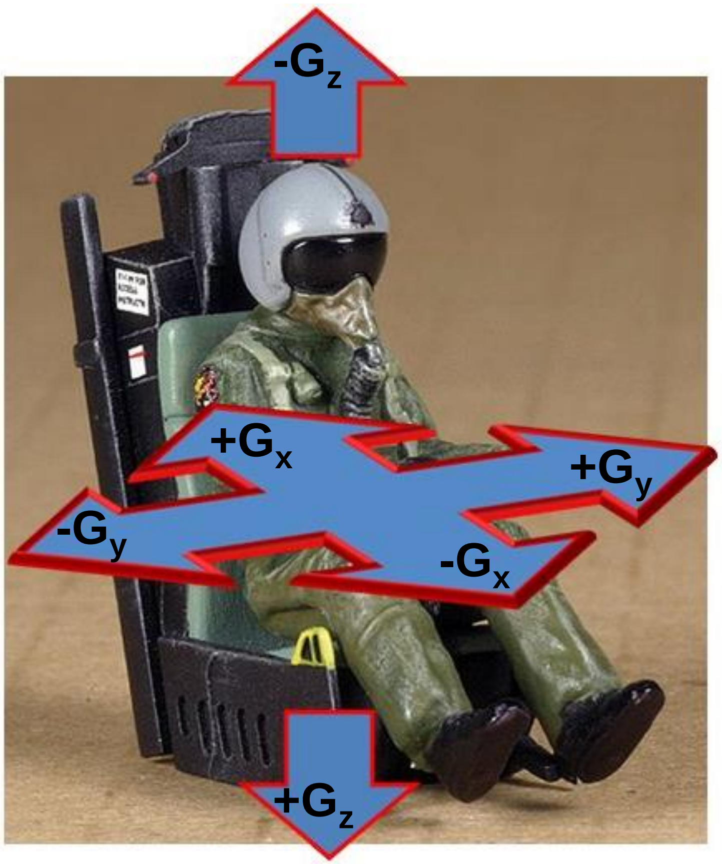
Symptoms may resolve during descent !

- After landing
  - Hyperbaric Oxygen Therapy (HBOT): compresses bubbles, increasing circulation, and provides more O_2 to tissues
  - Specialty care for serious DCS symptoms (respiratory or neurologic) or those which do not resolve during descent/repressurization; possible neurologic consult

Hypobaria: Protection from DCS

- Adequately pressurized cabin
- Denitrogenation by preoxygenation
  - Pre-Breathing 100% oxygen to “off-gas” nitrogen
    - Before decompression
    - Same value, if done below 16,000 ft

Acceleration, Inertial Forces & Cardiovascular System



CO = MAP/ TPR

Represents the ability of the system to provide adequate blood flow

- Accelerative stress challenges the CV system's ability to maintain blood flow to all vital organs, especially the brain
- Accelerative forces may also impede venous blood return to the heart
- Goal: Adequate End Organ Perfusion

Acceleration Effects

High Performance Aircraft

- G-induced Loss Of Consciousness (G-LOC): state of unconsciousness when the G-forces reduce blood flow to the brain below the critical level
- Push Pull Effect: Decreased $+G_z$ tolerance resulting from preceding relative $-G_z$

Acceleration

Human Tolerance to $+G_z$

Long duration (>1 sec)

- $+ 2\ G_z$
  - Compression into seat
  - Movement Difficult
- $+ 3\ G_z$
  - Extreme heaviness of limbs and body
  - Impossible to move or escape from aircraft
- Greater than $+3\ G_z$
  - “Dimming” or “ graying” of vision, and possible G-LOC

Short duration (<1 sec)

- Up to $+40\ G_z$ depending on body position

Space Flight Effects

- Microgravity affects blood and interstitial fluid flow (approximately 1-2 liters shift towards the head and torso)
- Bone demineralization leads to increased loss of calcium in urine and increased risk of kidney stones
- Muscle mass reduction
- Space motion sickness
- Radiation exposure
- Decreased immune system function
- Psychology/Human factors

Spatial Orientation

- Visual (most important), vestibular, somatosensory (seat-of the-pants), and auditory systems
- Easily confused when moving in 3 planes of motion (pitch, yaw, and roll)
- Disorientation is a leading contributor to many fatal aircraft accidents

Vision

- Vision is a key factor for spatial orientation in flight
- Errors may occur in visual perception
- Color vision deficiencies can affect up to 8% of men and 2% of women.

Identifying these deficiencies is becoming more important as aircraft and air traffic control displays utilize colors and visual cues to display critical information.

Bioacoustics

Noise in aviation can be detrimental to hearing & communication

dBA	Sound
20	Whisper at 5 ft.
50-70	Normal Conversation
100-110	Power Lawn Mower
130	Pain Threshold for Humans
140-160	Jet Engine
167	Saturn V Rocket

Vibration

- Vibration is oscillatory motion in dynamic systems
- Human body most sensitive to vibration in vertical direction
- Vibration affects a variety of body systems
  - General discomfort at 4.5-9 cycles per second (cps)
  - Abdominal pain at 4.5-10 cps
  - Lumbosacral pain at 8-12 cps
  - Head sensations at 13-20 cps

Other Physical Factors Associated with Flying

- Thermal
  - Extreme temperature swings in aviation (e.g. hot in cockpit on tarmac & freezing cold at altitude)
- Radiation
  - Air travel at high altitudes
  - Risk for commercial aviation and spaceflight crews
- Toxicology
  - Importance of knowledge of toxins in aviation (jet fuels, release of toxic fumes in fires, alcohol in blood versus vitreous, etc.)

Human Factors

- By definition, Human Factors is the impact of human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use.
- The goal of Human Factors is to apply knowledge in designing systems that work, accommodating the limits of human performance.

Human Factors

- Human-Machine Interface
  - Human Error implicated in 60-80% of accidents in complex, high technology systems
  - Task and information overload is critical issue
  - Science of color, size, position of switches/knobs, etc. and relevance to mission drive design

Human Factors

Sleep & Circadian Rhythms

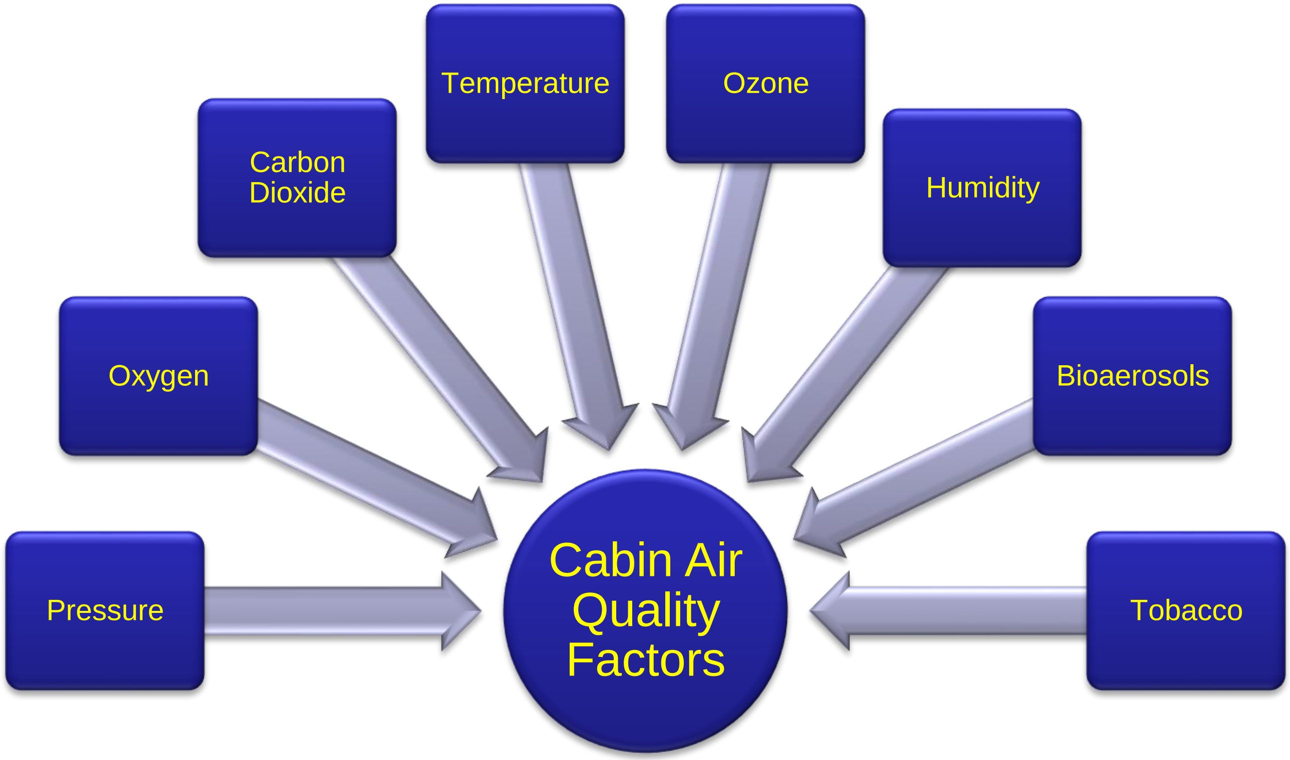
- Internal body clock shifts with travel and work schedule and may impairs performance
- Need to plan crew work-rest cycles to avoid accidents

Life Support Systems

Oxygen Systems

- Dilutor Demand
  - Flow of oxygen proportional to cabin altitude [100% oxygen at 33,000 ft (10,058 m)]
- Pressure Demand
  - Oxygen supplied with slight overpressure > 10,000 ft to full pressure breathing
  - > 38,000 ft (11,582 m)
  - UK: >40,000 ft (12,192 m)
- Pressure Demand with Regulator
  - Mounted on panel, seat or mask
  - Regulator attached to mask directly or via hose
- Continuous Flow
  - Passenger system, exhaled air collected in bag to economize oxygen use
  - May be chemically generated for short term emergency use

Cabin Air Quality



Cabin Air Quality

Relative Humidity

- At altitude in cabin ~ 6-10%, flight deck ~ 3%
- Due to very dry ambient air at altitude
  - Air conditioned air entering AC cabin has relative humidity < 1%
  - Irritation of eyes / sense of dry mucous membranes
- Plasma osmolality maintained by homeostatic renal function

Air Recirculation

- Complete air exchange every 3-4 min (homes q 12 min)
- Up to 30-50%
- High efficiency particulate air filter filtration (efficient to 0.3 micrometers)

Carbon Dioxide

- 0.5 % by volume (sea level equivalent)

Life Support Systems

Airline Medical Systems

- Minimize risks to passengers
- Avoid unscheduled diversions
- Onboard emergency medical capabilities are limited (airline medical kits)
- Communication with ground support from internal airline medical staff or contracted staff
- Passengers requiring medical oxygen must make separate arrangements with the airline
- Cockpit emergency oxygen is via a compressed oxygen system and is separate from passenger emergency oxygen
- Emergency oxygen: 10-20 minute supply for passengers produced with chemical oxygen generators
  - Limited number of walk-around bottles for crew

Clinical Aerospace Medicine

Fitness for Duty & Return to Flight Status

- Screen aviators, astronauts, air traffic control personnel for risk of sudden incapacitation or degradation in skills
- Applies to all areas of medicine
- Applies to all types of aviators, i.e. military, commercial pilots, private pilots, and flight crew

Fitness for Duty & Return to Flight Status

Medical Standards

- Civilian standards (i.e. FAA, NASA, EASA) and military standards (Air Force, Navy, Army) may differ due to different aircraft, mission requirements, and operating environments. Examples include:
  - Type of aircraft - Multi-crew Aircraft vs. Single Seat Fighter Jet
  - Type of Operation/Environment
    - Recreational vs. Airline Transport Operations
    - Wartime, Remote environments
- Initial selection vs. Maintenance of Standard

Fitness for Duty & Return to Flight Status: Multisystem Approach

Cardiology

Pulmonology

Ophthalmology

Otolaryngology

Psychiatry and Psychology

Neurology

Other Conditions

Fitness for Duty & Return to Flight Status

Cardiology

Assessment important to mitigate risk of sudden/ subtle incapacitation in aviation and space travel

- Arrhythmias
- Coronary disease
- Valvular disease
- Syncope
- Pacemakers

Fitness for Duty & Return to Flight Status

Pulmonology

- Trapped gas (like bullae, for example) increase risk of barotrauma with changes in pressure
- Lung disease leading to hypoxia under hypobaric conditions may increase need for oxygen in flight and impact safety
- Sleep apnea and resulting fatigue can impact aviation safety

Fitness for Duty & Return to Flight Status

Ophthalmology

Importance of Vision in Aviation

- Distant, Intermediate & Near Vision
- Target acquisition (less important with modern weapons)
  - Ability to safely operate the aircraft
  - See and be seen in visual flight rules (VFR)
- Color Vision
  - Instrument displays
- Depth perception and stereopsis
  - Terrain avoidance
  - Landing
- Maintenance of visual acuity
  - Refractive surgery
  - Refractive correction with glasses /contact lenses

Otolaryngology: Key Issues

- Hearing and hearing protection
- Vestibular system
- Barotrauma due to trapped gas in sinus and ear cavities

Fitness for Duty & Return to Flight Status

Psychology & Psychiatry

The absence of significant psychiatric disease, including psychosis and personality disorders, is an important prerequisite to safe operation of aerospace systems

Psychological and psychiatric factors important with long term isolation and in small groups (multi-crew aircraft)

- Long-duration spaceflight
  - Exploration, Orbital
- Commercial aircraft - locked cockpit door
- Commercial Spaceflight/Spaceflight participants

Fitness for Duty & Return to Flight Status

Neurology

Neurological evaluations for flight fitness optimize safety and performance by focusing upon conditions with the potential to lead to sudden/subtle incapacitation

- Seizures
- TIA & Stroke
- Traumatic Brain Injury
- Unexplained Loss of Consciousness
- Intracranial Masses & Cancers
- HIV & AIDS
- Sleep Disorders
- Disqualifying Medications

Fitness for Duty & Return to Flight Status

Other Medical & Surgical Conditions

Evaluation of any condition or treatment that may potentially:

- Impact flight safety
- Influence crew performance in flight
- Influence behavior or cognitive processing
- Lead to sudden/subtle incapacitation

Aerospace Practitioners Continuously Review Changing Medical Practices, Procedures, and Medications for Use in the Flight & Space Environments

Fitness for Duty & Return to Flight Status

Health Maintenance of Aircrew

Well-being: Interaction between physical, psychological and emotional factors

- Importance of regular crew rest cycles
- Importance of exercise and diet
- Importance of avoidance of self induced stressors, i.e., alcohol, nicotine, caffeine
- Importance of maintaining balance on life
  - Work/family life

Fitness for Duty & Return to Flight Status

Longitudinal Health & Wellness Surveillance

- Ensure aircrew have long, safe, and productive careers
- Measure and evaluate emerging occupational risks/exposures or environmental threats

Clinical Hyperbaric Medicine

- **Hyperbaric Oxygen Therapy (HBOT)** addresses pathologic bubble formation most frequently encountered in flying diving and space operations activities, selected infections, wounds and traumatic injuries.
- Recent investigations have provided a better understanding of basic science mechanisms underlying Undersea & Hyperbaric Medicine Society approved clinical indications
- Training options : Comprehensive Hyperbaric Medicine Fellowship (1 yr.) , board certification and courses

Indications for HBOT

Decompression Sickness
Air Gas Embolism
CO/CN Poisoning
Compromised Flaps & Grafts
Crush Injury
Exceptional Blood Loss Anemia
Thermal Burns
Intracranial Abscess
Necrotizing Soft Tissue Infection
Refractory Osteomyelitis
Delayed Radiation Injury (Osteoradionecrosis & Soft Tissue Radionecrosis)
Central Retinal Artery Occlusion

Operational Aerospace Medicine

Operational Aerospace Medicine

- Address challenges of operating aerospace vehicles in a physiologically challenging environment
- Conducted in military and civilian setting
- Management and prevention of medical events during operations

Operational Aerospace Medicine

- Issues in civilian operations
  - Commercial air transport flight operations
    - Deep vein thrombosis prophylaxis in susceptible individuals,
    - Circadian rhythm issues
    - Potential for spread of infectious diseases
    - Consideration of radiation exposure
  - Commercial spaceflight operations

Operational Aerospace Medicine

- Military crew members can be required to operate at very high altitudes for the purposes of reconnaissance, combat, or routine training operations

- The unique stresses of extreme altitude operations require special protective equipment and training

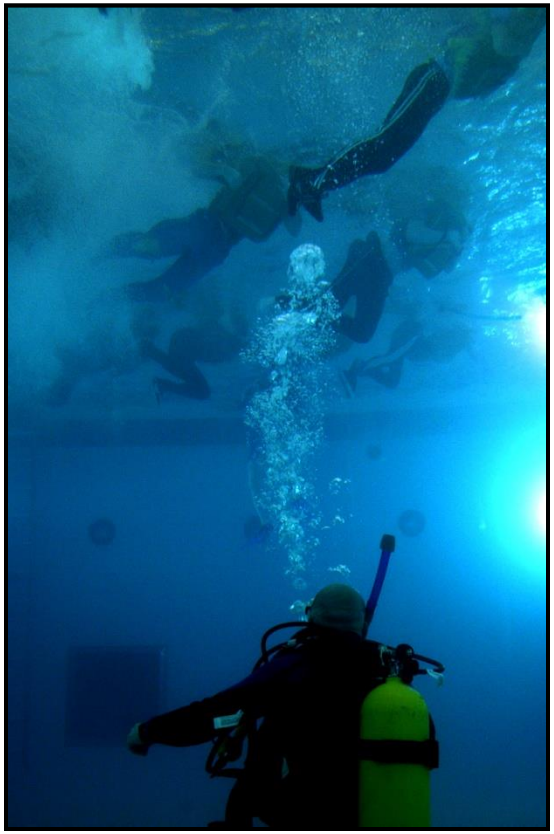
Photographs courtesy of the Federal Aviation Administration

Operational Aerospace Medicine

- Aeromedical Transportation encompasses the transport and inflight care of patients of different acuity levels.
- Noise, vibration, communication, pressure changes and combat activities can impact ability to deliver care in these settings.
- These transports include fixed-wing aircraft and rotary wing aircraft.

Photographs courtesy of the Federal Aviation Administration

Operational Aerospace Medicine

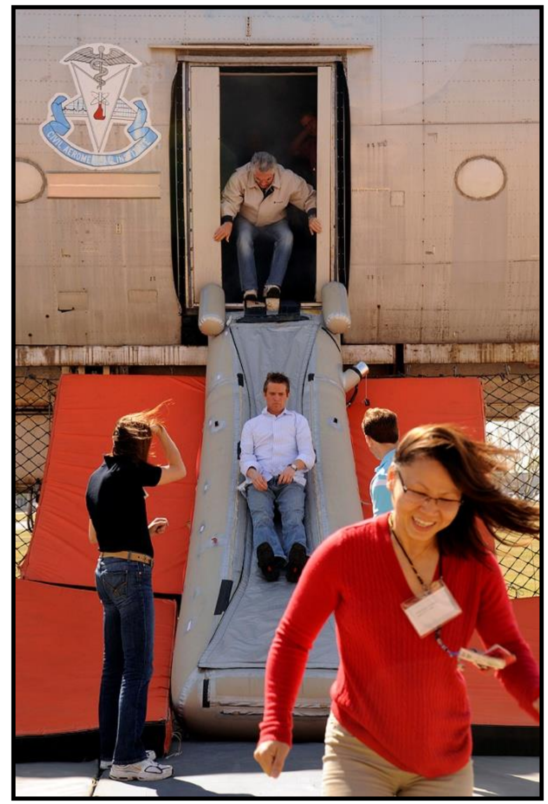


- Hyperbaric Medicine Practitioners support a variety of occupational, training, and remote diving activities
  - Oil Industry
  - Astronaut Dive Training for Extravehicular Activities
  - Underwater Search & Rescue Support

Photograph courtesy of the Federal Aviation Administration

Survival, Search & Rescue

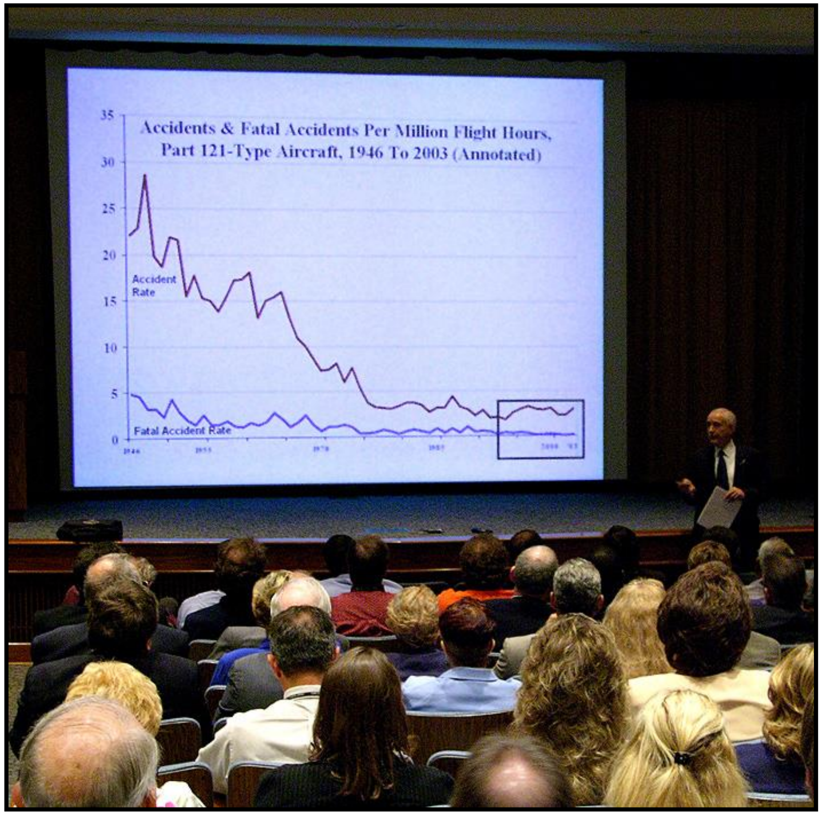
- Crash Worthiness – Primary/Secondary Protection
  - The aircraft and its systems are a life support system and its thoughtful design may greatly aid in the survivability of a crash
- Search & Rescue Systems
  - Beacons
  - Increased use of satellite technology
  - Organized systems in civilian environment and military
  - Importance of survival training



Photograph courtesy of the Federal Aviation Administration

Accident Investigation

- Significant improvements in accident rate and data since the 1960s due to:
  - Improved operational procedures
  - Technological developments
  - Application of lessons learned from accident investigations



Photograph courtesy of the Federal Aviation Administration

Accident Investigation

Methodical & multidisciplinary evaluation of aspects that may have contributed to an accident

Civilians and Military use similar resources

- **Flight Surgeons**
- **Emergency Response Teams**
- **Hazardous Materials Specialists**
- **Aviation Experts**
- **Airframe Maintenance & Engineering Experts**
- **Air Traffic & Air Field Experts**
- **Pathologists & Toxicologists**
- **Dentists**
- **Coroners**
- **Law Enforcement Officers**

Accident Investigation

- Accident Summary
  - Nature of Accident
  - Communication with ATC
  - Flight Data Recorder
  - Witness Reports
  - Weather Conditions
- Pilot Information
  - Certification & Class
  - Age & Health History
  - Historical Flight Performance
  - Assigned AME
- Aircraft Certification
  - Type of Aircraft
  - Vehicle Maintenance Information
- On Scene Investigation
  - Fire, Blast, Acceleration Evidence
  - Grid Debris and Victims
  - Mechanism of Injury
    - Photography
    - X-Rays
  - Toxicology
    - Body Fluids & Tissues of Key Crew Evaluated
  - Forensics
    - Forensic Dentistry
    - DNA
- Corroboration with Archival Accident Data

Acknowledgements

- Anthony Artino PhD
- Professor Michael Bagshaw
- Eilis Boudreau MD PhD
- Yvette DeBois MD MPH
- Marvin Jackson MD
- Jeff Myers MD
- David Rhodes MD MPH
- Philip Scarpa MD
- Erich Schroeder MD MPH
- Greg Shaskan MD
- Jan Stepanek MD MPH
- Jeffrey Sventek MS
- James Webb PhD