High Altitude Flight

Overview

- Altitude and Air Density
- Hypoxic Hypoxia
- Time of Useful Consciousness
- Supplemental Oxygen Systems
  - Oxygen System Types
  - Pulse Oximeters
  - FAA Oxygen Regulations (14 CFR 91.211)
- Pressurization
  - Pressurization System Components
  - Turbocharged Pressurized Aircraft
  - Pressurization Control
  - Cabin Instrumentation
  - Decompression

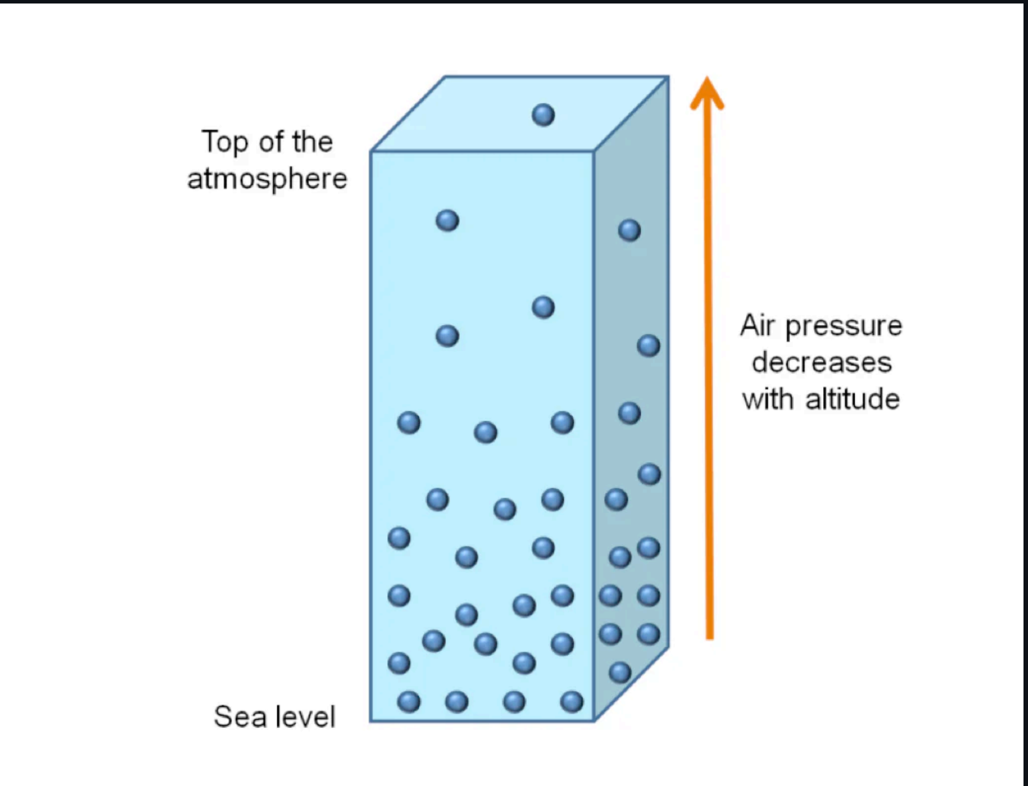
Objective

To understand the physiology, equipment, and regulations regarding high altitude flights, including pressurization and oxygen systems

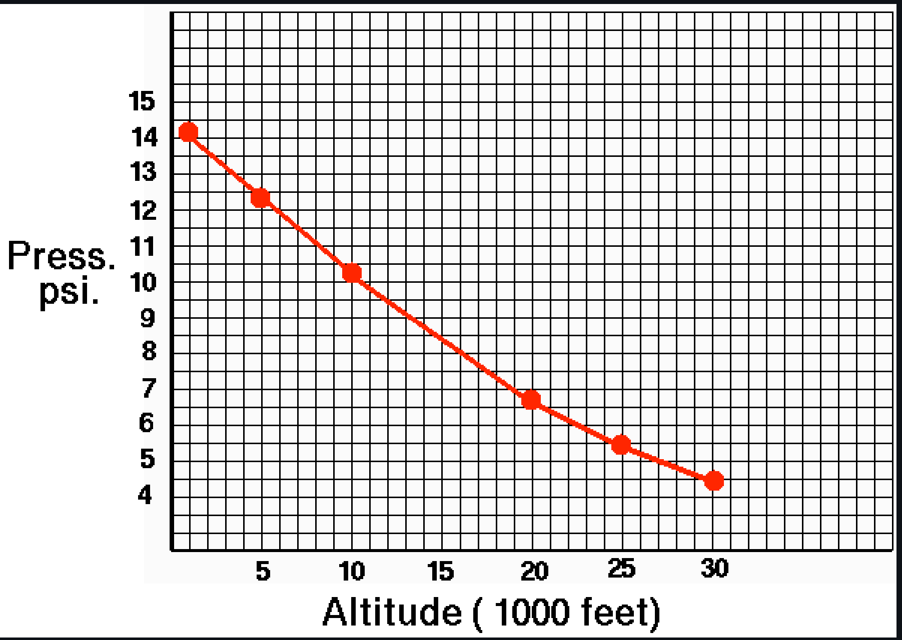
Motivation

High altitude flight presents unique risks and challenges that must be mitigated through various equipment requirements. A commercial pilot preparing to fly at high altitudes needs to understand the equipment and human factors involved.

Altitude and Air Density



- Air density decreases with altitude
- At 18,000 feet, air density is about half that at sea level
    - The percentage of oxygen in the air remains above the same (around 21%)
    - Because of the reduced pressure, your lungs aren't exposed to as much oxygen
- To remedy this we can:
    - Increase the pressure of the air
    - Increase the percent of oxygen we're breathing



Hypoxic Hypoxia

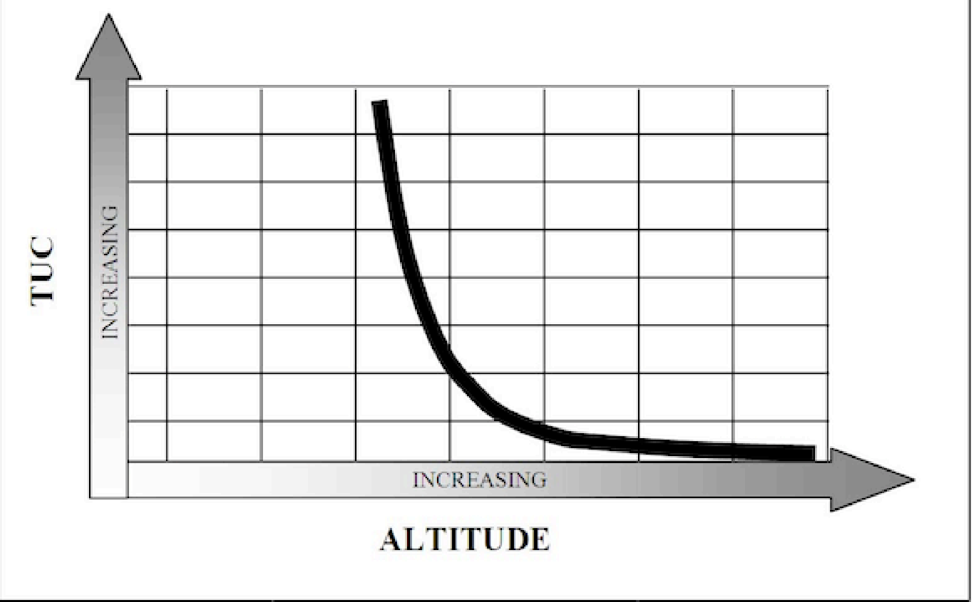
Hypoxia is a state of oxygen deficiency in the body sufficient to impair functions of the brain and other organs.

Hypoxic hypoxia is caused by the reduction of barometric pressure at altitude.

Symptoms of Hypoxia

- Cyanosis (blue fingernails and lips)
- Headache
- Decreased response to stimuli and increased reaction time
- Impaired judgment
- Euphoria
- Visual impairment
- Drowsiness
- Lightheaded or dizzy sensation
- Tingling in fingers and toes
- Numbness

Time of Useful Consciousness



ALTITUDE	TUC/EPT	Following Rapid Decompression
18,000	20–30 min	10–15 min
22,000	10 min	5–6 min
25,000	3–5 min	1.5–2.5 min
28,000	2.5–3 min	1–1.5 min
30,000	1–2 min	30 s–1 min
35,000	30 s–1 min	15–30 s
40,000	15–20 s	Nominal
43,000	9–12 s	Nominal
50,000	9–12 s	Nominal

- The time you can function effectively without supplemental oxygen
- Decreases rapidly as altitude increases
  - 20-30 minutes at 18,000 feet
  - 15-20s seconds at 40,000 feet
- This motivates the supplemental oxygen rules in 91.211

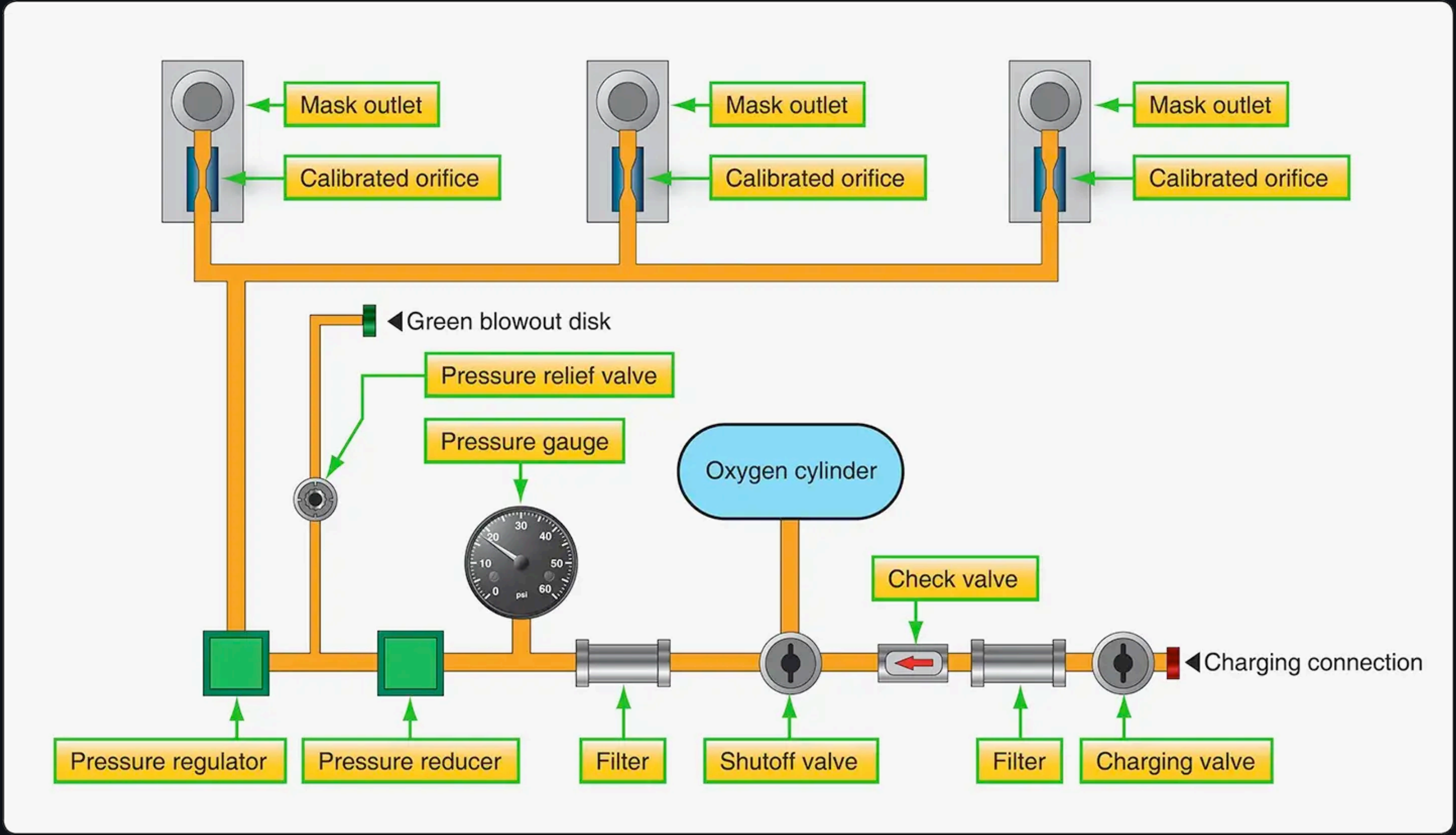
Supplemental Oxygen Systems

- Continuous-flow and Pulse-Demand Systems
  - With a cannula: Good to ~18,000 ft.
  - With a rebreather bag: Good to ~25,000 ft.
- Diluter-demand systems: Good up to 40,000 ft.
- Pressure-demand system: Can be certified up above 40,000 ft.

Oxygen System Types - Continuous Flow

- Deliveries continuous flow of oxygen to mask or cannula
- Usually has individual adjustment on the tube prior the mouth piece
- Simple operation: On/off, plus flow adjustment
- **Altitude-compensating** systems adjust the flow of oxygen for you as you climb

Continuous Flow System Diagram



Oxygen System Types - Electrical Pulse-Demand

- Electronically-controlled regulator
- Detects user's inhalation and only provides oxygen
- Doesn't waste oxygen during exhalation like a continuous-flow system
- Many pulse-demand system are also altitude-compensating

Cannulas and Masks for Continuous Flow

Rebreather bag, basic cannula, oxymizer cannula

Oxygen System Types - Diluter Demand

- Demand-systems deliver oxygen when the user inhales
- A diluter demand system mixes cabin air and 100% oxygen from a tube
- These require a tight-sealing mask
- Can be used to up 40,000'
- Common on airliners

Oxygen System Types - Pressure Demand

- Similar to diluter-demand, except oxygen is delivered under pressure
- Allows the user lungs to be pressurized with oxygen

Pulse Oximeters

- Measure blood oxygen saturation
- Values above 90% are considered good

FAA Oxygen Regulations (14 CFR 91.211)

- **Unpressurized aircraft**:
  - Above 12,500' MSL up to 14,000' MSL: crew must use oxygen for duration of flight longer than 30 minutes
  - Above 14,000' MSL: Crew must use oxygen at all times
  - Above 15,000' MSL: Oxygen must be provided to all occupants
- **Pressurized aircraft**:
  - Above FL250: 10-minute supply for each occupant in case of decompression
  - Above FL350: One pilot must wear and use an oxygen mask, unless both have quick-donning masks and are below FL410

Pressurization

Principle of Pressurization

- Cabin is kept at a higher pressure than ambient air around the aircraft
- Allows flight at higher altitudes without the need for supplemental oxygen
- Cabins are usually pressurized to a pressure equivalent to 6000-8000 ft.

Pressurization System Components

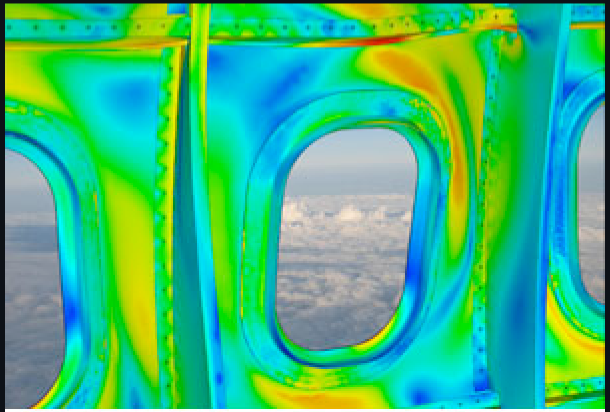
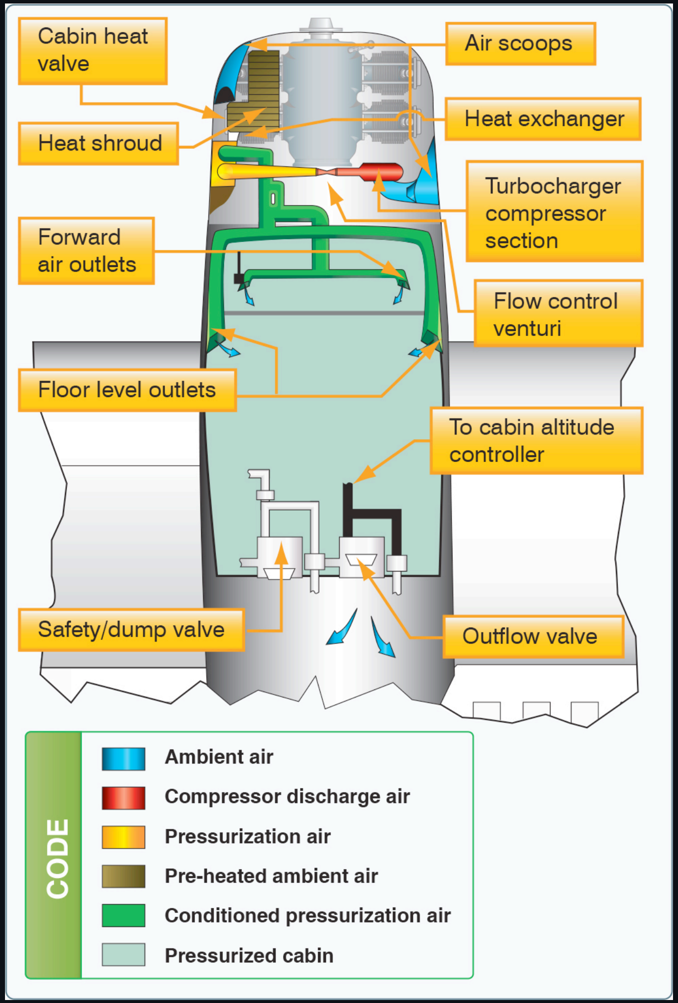


Figure 2. Mechanical stresses on aircraft fuselage interior resulting from cabin pressure (Image courtesy CADFEM and Airbus Deutschland GmbH)

1. Airtight fuselage
2. Compressed air delivery system
3. Pressure controller
4. Safety dump valve

Turbocharged Pressurized Aircraft



- Turbocharged airplanes often use compressed air from the turbocharger for pressurization
- Hot air from the turbocharger is ducted through a heat exchanger, then into the cabin
- Pressurization controller controls the "leaking" of cabin air pressure to maintain a set cabin altitude
  - Outflow valve regulates air leaving the cabin
- Dump valve for rapid depressurization if needed

Cabin Differential

The altitude at which the standard air pressure is equal to 10.9 psi can be found at 8,000 feet.

At an altitude of 28,000 feet, standard atmospheric pressure is 4.8 psi. By adding this pressure to the cabin pressure differential of 6.1 psi difference (psid), a total air pressure of 10.9 psi is obtained.

Atmosphere pressure	
Altitude (ft)	Pressure (psi)
Sea level	14.7
2,000	13.7
4,000	12.7
6,000	11.8
8,000	10.9
10,000	10.1
12,000	9.4
14,000	8.6
16,000	8.0
18,000	7.3
20,000	6.8
22,000	6.2
24,000	5.7
26,000	5.2
28,000	4.8
30,000	4.4

- **Max differential pressure**: The maximum pressure difference between the inside and outside of the cabin
  - Determined by the strength of the fuselage
  - A typical differential for a piston airplane is 5.5 PSI
- This differential is usually set my a controller in the cockpit

Pressurization Control

- Differential pressure: Settable by the pilot, determine cabin altitude
  - Usually set just above cruise altitude during climb
  - Set to just above airport elevation during descent
- Rate valve: Determine how fast the cabin will change pressures

Cabin Instrumentation

- Cabin altimeter: Measure barometric pressure inside the cabin
- Cabin rate-of-climb indicator: Change of cabin air pressure
- Differential pressure gauge: PSI difference between cabin and atmosphere

Decompression

- **Slow decompression**: Depressurization in > 10 seconds
- **Rapid decompression**: Lungs decompress faster than cabin, can cause discomfort
- **Explosive decompression**: Cabin loses pressure in 0.2–0.5 seconds
    - Risk of lung damage, hypoxia, loss of consciousness, decompression sickness
    - Fog, debris, and noise may occur

Summary

- Altitude and Air Density
- Hypoxic Hypoxia
- Time of Useful Consciousness
- Supplemental Oxygen Systems
  - Oxygen System Types
  - Pulse Oximeters
  - FAA Oxygen Regulations (14 CFR 91.211)
- Pressurization
  - Pressurization System Components
  - Turbocharged Pressurized Aircraft
  - Pressurization Control
  - Cabin Instrumentation
  - Decompression

Knowledge Check

What is hypoxia and why is it dangerous at high altitudes?

Knowledge Check

At what cabin pressure altitudes must the crew use supplemental oxygen, and when must it be provided to all occupants?

Knowledge Check

What are the main components of a pressurization system?

Knowledge Check

What are the differences between slow, rapid, and explosive decompression?