DISTANT ATPL ACADEMY

40 Human Performance and Limitations

HANDOUT CPL-IR-ATPL

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HORIZON
SWISS FLIGHT ACADEMY

Atmosphere

- Layer up to an altitude of ~700 km
- provides oxygen and carbon dioxide, the vital gases for man, animals and plants
- provides protection against intensive sunlight (UV)
- provides protection against cosmic radiation
- origin of the water supply
- guarantees a balanced temperature

Composition of the atmosphere

21% oxygen O_2
78% nitrogen N_2
~1% inert gases (Ar, He, Ne, Xe, Kr....)
0.03% carbon dioxide CO_2

- constant up to ~100 km
- above 100 km: atomic oxygen O
  atomic nitrogen N
  atomic hydrogen H
  helium

Atmospheric pressure

- Weight of the air column above the surface
- Standard pressure at sea level 1013.2 hPa = mbar
  760 mmHg
  29.92 inHg
  14.7 PSI

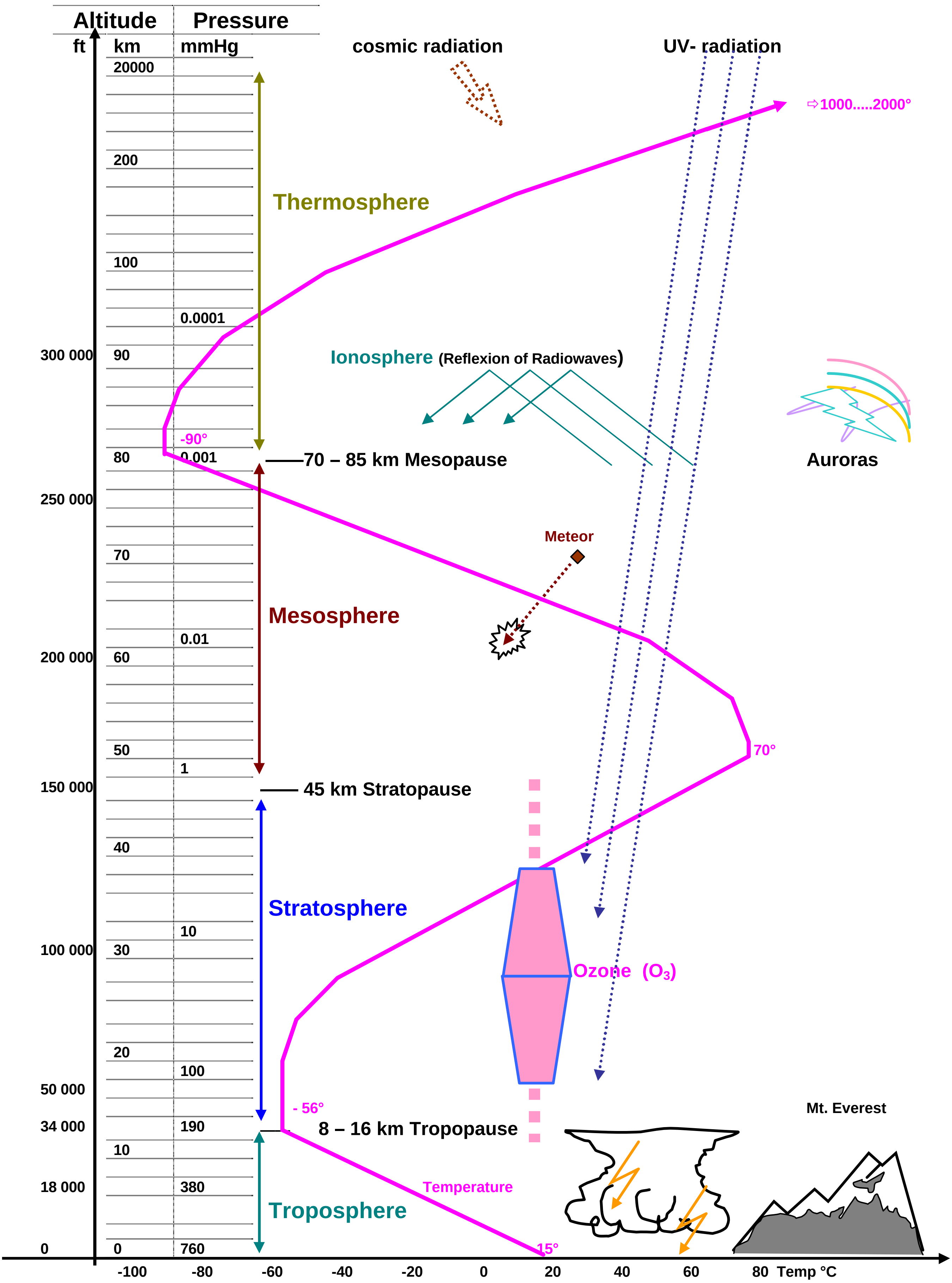
- Since air is compressible, pressure decreases in an approximately exponential manner as altitude increases.

  at 18 000 ' sea level pressure is halved
  at 27 000' 1/3
  at 34 000' 1/4

Structure of the atmosphere

- **troposphere**: sea level up to 26 000' (poles) ... 58 000' (equator), constant temperature lapse rate, water vapor, weather, turbulence
    - tropopause
- **stratosphere**: up to 45 km, uniform temperature in the lower part, no water, ozone layer between 15....35 km
    - stratopause
- **mesosphere**: up to ~80 km, temperature reaches a first peak of 70°C, then rapid decline in temperature as altitude increases. Layer where most meteors disappear
    - mesopause
- **thermosphere**: up to ~700 km, continuous temperature increase up to values of 1500°C dependant upon sun activity, but with little significance due to low density with practically no heat transfer
    - thermopause
- **exosphere**: true space

Atmosphere


Altitude
Pressure
ft
km
mmHg
20000
200
100
0.0001
300 000
90
-90°
80
0.001
250 000
70
0.01
200 000
60
50
1
150 000
40
10
100 000
30
20
100
50 000
34 000
190
10
18 000
380
0
0
760
cosmic radiation
UV- radiation
⇨1000.....2000°
Thermosphere
Ionosphere (Reflexion of Radiowaves)
Auroras
70 – 85 km Mesopause
Meteor
Mesosphere
70°
45 km Stratopause
Stratosphere
Ozone (O3)
- 56°
8 – 16 km Tropopause
Mt. Everest
Temperature
Troposphere
15°
-100
-80
-60
-40
-20
0
20
40
60
80 Temp °C

Temperature (Standard atmosphere)

- temperature at mean sea level 15°C
- decline of ~2°C per 1000' within the troposphere (lapse rate)
- isothermal layer in the lower stratosphere of –56°C up to 65 000' , above 65 000' temperature rises up to 70°C
- within the mesosphere temperature again drops to about –90°C
- within the thermosphere again increase to very high values, however with very low effect on heat-exchange (low air density).

Humidity

0... .4% water vapour, 90% within the first 8 km

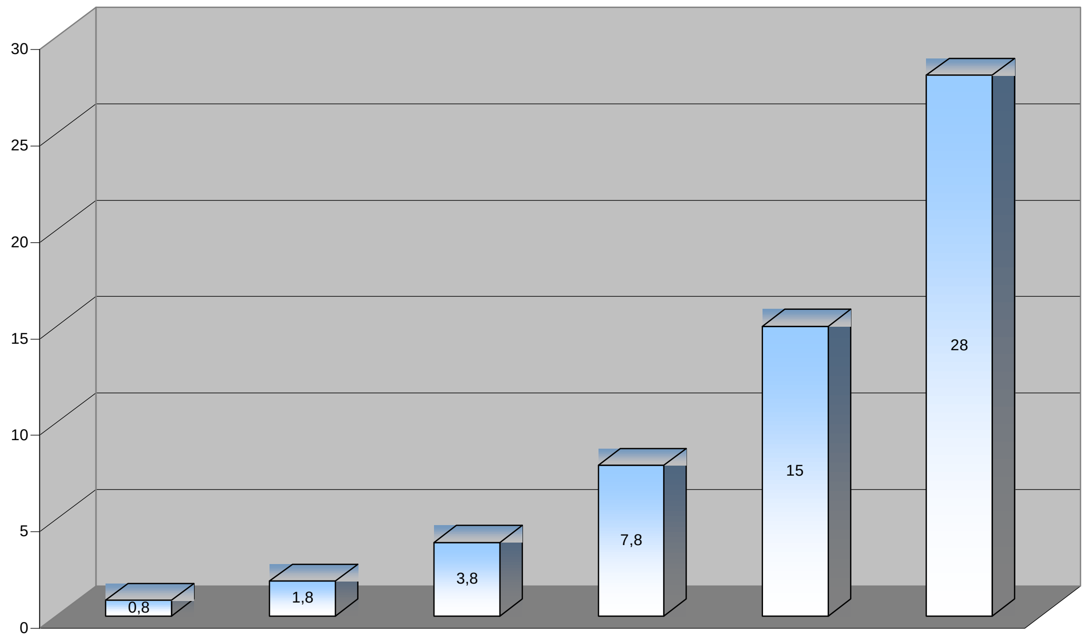
Relative humidity

- amount of water vapour in the air measured as percentage of the maximum amount possible at a given temperature (saturation).

Keep in mind:

The higher the temperature, the greater the amount of water that can be retained in the air.

maximum water vapor (g water per kg dry air)



Temp °C: - 20 - 10 0 10 20 30

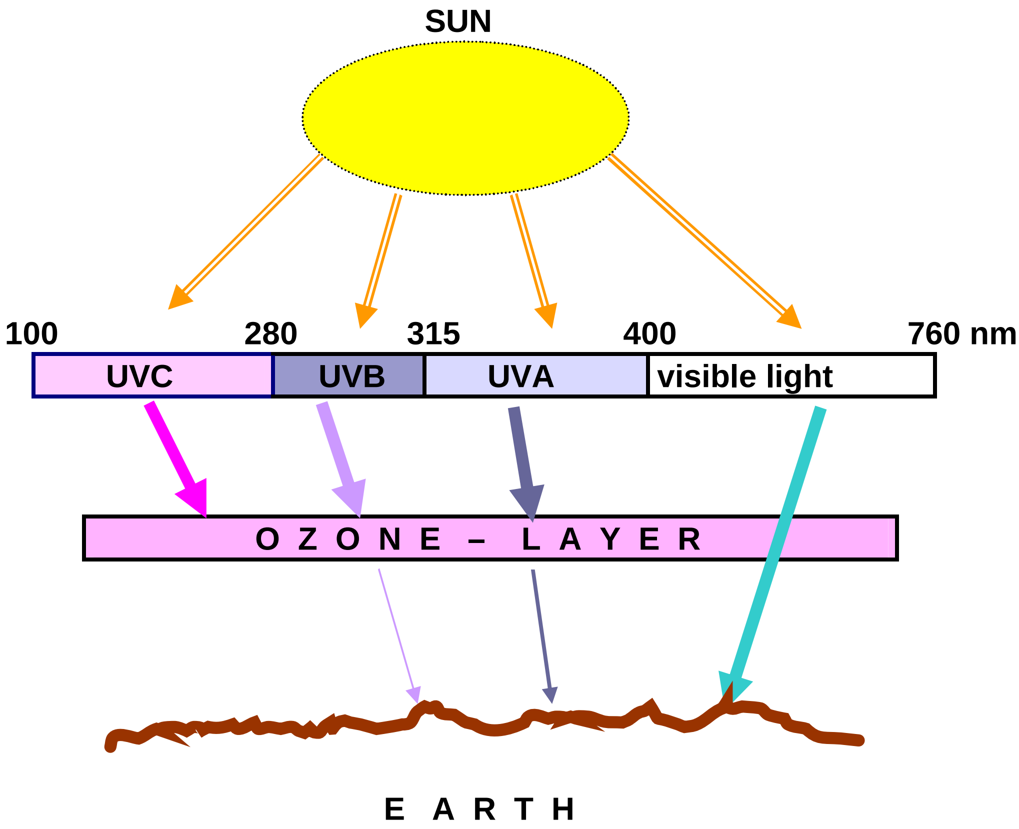
Humans feel comfortable at a relative humidity of 60....70 %

Ultraviolet Radiation (UV) and Ozone

UV-radiation is the part of the sunlight which lies beyond the visible spectrum at its violet end. Since the wavelength of UV is shorter than that of the visible light, its energy is higher. In accordance with the effect on human beings, in medicine we distinguish three different areas of UV radiation:

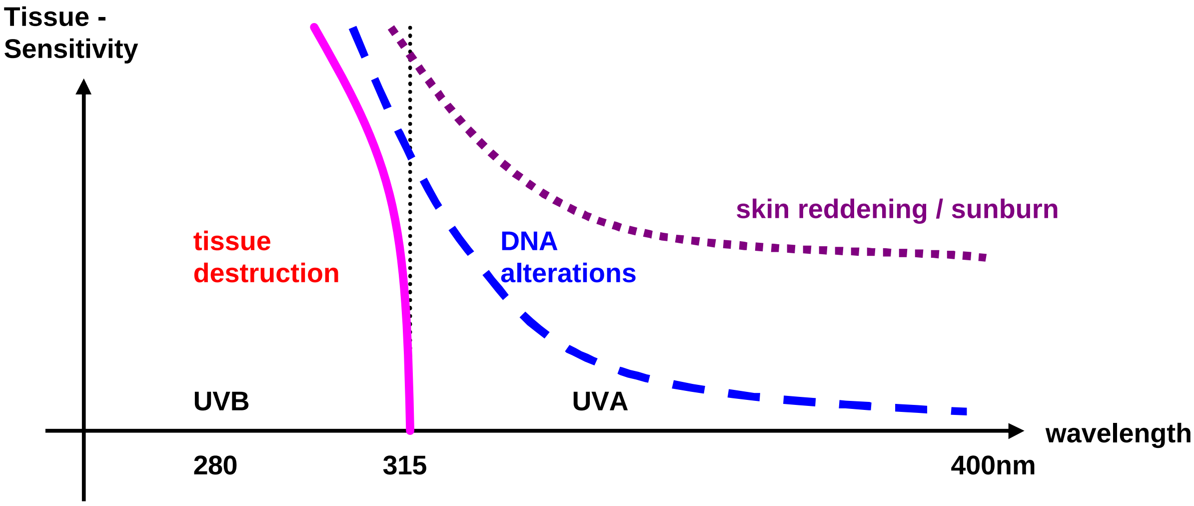
UVA 400..... 315 nm
UVB 315..... 280 nm
UVC 280..... 100 nm

The ozone layer in the stratosphere absorbs UV radiation almost completely up to a wavelength of 290 nm. UV of longer wavelength is partially absorbed. The part of UV radiation, which finally reaches the earth, consists of about 95% of UVA and 5% of UVB.



Effect of UV radiation on the human being

Skin:



Dependent on the wavelength, the skin is more or less sensitive to UV radiation.
UVA penetrates deeply into the skin and causes reddening and sunburn. However, UVA has low effect on the DNA.
UVB penetrates less and reaches just the upper layer of the skin. Due to its higher energy it causes damage of the DNA which can lead to cell degeneration and eventually cause skin cancer.
The harmfulness of the UV radiation depends on the skin type of a person. Light-skinned, blond and blue-eyed people are most sensitive to UV, dark-skinned, black-haired and brown-eyed people are least sensitive. The intensity of the UV radiation increases with increasing altitude. Therefore, precautions are crucial during long and/or frequent flights.

Eyes:

Acute UV exposure causes an inflammation of the cornea (photophthalmia or snow blindness) which is extremely painful (e.g. after hiking on a glacier without sunglasses).
With **chronic** UV exposure a phacoscotasmus (cataract = lens opacity) can result, which obviously interferes with vision (dazzling, reduced vision)

Keep in mind

> **Using UV absorbing skin lotions and wearing UV absorbing sunglasses is crucial for the flight deck.**

Ozone

- triatomic form of oxygen (O_3)
- unstable, blue, temperature sensitive and strong oxidizing gas
- splits quickly into O and O_2 in presence of warm water vapour
- produced in the stratosphere by irradiation of molecular oxygen (O_2) by shortwave UV (photodissociation of O_2 into atomic O and recombination with another O_2 molecule to form O_3)
- absorbs short wave UV radiation
- the ozone layer extends from 10 .... 50 km with a maximum concentration of approximately 10 ppm by 30km. 90% of the total amount of ozone concentrates between 15 and 35 km.

Effect of ozone

- for man highly toxic, especially for the respiratory tract and the eyes
- acute exposure to concentrations of 0.1 .... 0.2 ppm can cause coughing and shortness of breath with sensitive people
- exposure to 1.0 ppm usually causes lung irritation, while 10ppm or more cause fatal pulmonary edema
- impairs night vision

- < 10% of the total amount of ozone is produced within the lower troposphere, over industrial zones and urban areas
- In presence of special pollutants such as nitric oxide (NO_X), carbon monoxide (CO), carbohydrates, volatile organic compounds, long wave UV radiation produces O3
- in absence of sunlight, ozone rapidly depletes in presence of NO_X
- ozone is therefore the main component of the summer smog
- during the day, ozone increases with sunlight and pollutants
- at night, ozone decreases more rapidly over urban areas

keep in mind

Ozone is both foe and friend to man:
exposed to, ozone is an irritating toxic gas but the stratospheric ozone layer absorbs the greater part of UV radiation and protects us from skin cancer

The gas laws

Dalton's law: the pressure exerted by a mixture of gases is the sum of the individual (partial) pressure of each gas in the mixture

$$P = P_1 + P_2 + ... + P_n$$

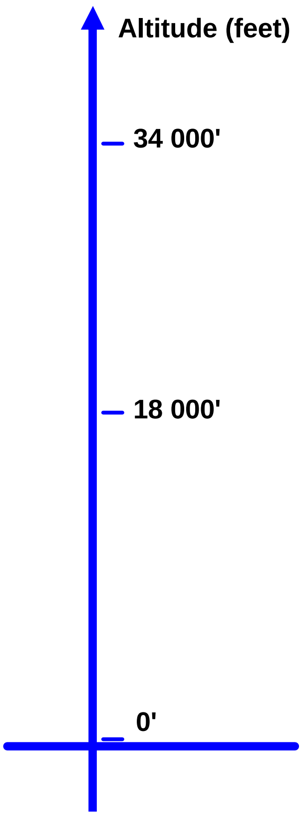
the partial pressure of a gas is proportional to the fractional concentration of the gas in the mixture

$$P_n = P \cdot \frac{V_n}{V} \qquad (V = \text{Volume})$$

Example: hypoxia at higher altitudes

Composition of the air:

21 % O_2
78 % N_2
1 % others (CO_2, noble gases, dust ...)



P = 190 mmHg

P_{O2} = 190 · 21 % » 40 mmHg

P = 380 mmHg

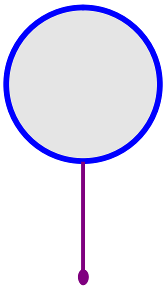
P_{O2} = 380 · 21 % » 80 mmHg

P = 760 mmHg

P_{O2} = 760 · 21 % » 160 mmHg

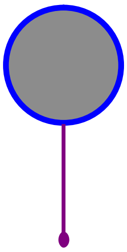
Boyle's law:

The volume of a gas is inversely proportional to its pressure (providing the temperature remains constant)



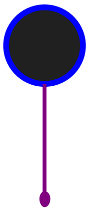
$$P \times V = \text{const.}$$

At 18 000' atmospheric pressure is half the amount of the pressure at sea level. Therefore, the volume of a dry gas in a balloon is doubled compared with the volume at sea level.



$$V_2 = V_1 \frac{P_1}{P_2}$$

Within the body every gas is always saturated with water vapour.
The partial pressure of saturated water vapour at body temperature of 37°C is 47 mmHg.
Therefore the total gas pressure in our body is reduced by the amount of 47 mmHg.



$$V_2 = V_1 \frac{(P_1 - 47)}{(P_2 - 47)}$$

Example: at FL 340, total pressure is 190 mmHg. the volume of a gas saturated with water vapour is

$$V_2 = V_1 \frac{(760 - 47)}{(190 - 47)} = V_1 \cdot 5.027$$

Henry's law: The total quantity of gas dissolved in a liquid is proportional to the partial pressure of the gas in contact with the liquid

$$\frac{P_1}{M_1} = \frac{P_2}{M_2} \qquad (M_{1/2} : \text{amount of gas dissolved})$$

As the partial pressure is doubled, the amount of gas dissolved is also doubled. As the partial pressure is halved, half the amount of the dissolved gas can no longer remain dissolved and vaporizes. Example: Opening a bottle of champagne reduces the partial pressure and therefore carbon dioxide is released.

Climbing from sea level up to 18 000' sets half of the dissolved gases within the body free.

Decompression sickness (Caisson disease)

During rapid decompression vaporized gases form gas bubbles. Depending on the localization of these bubbles, different symptoms can occur:

***Bends*: limb pain, joint pain**

***Chokes*: respiratory disturbances starting with a sense of constriction around the lower chest, soreness beneath the sternum and therefore restricted inhalation**

***Creeps* : Itching, tingling and formication of the skin.**

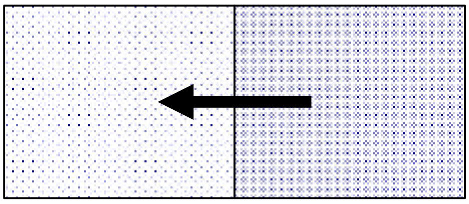
***Neurological disturbances*: dizziness, nausea, blurring of vision, headache.....disorientation, confusion, diminished consciousness, paralysis (due to gas-bubble embolism)**

***Collapse*: general feeling of malaise, pulse weak and slow, cold sweat. Eventually loss of consciousness. Sometimes without any other symptoms (primary collapse)**

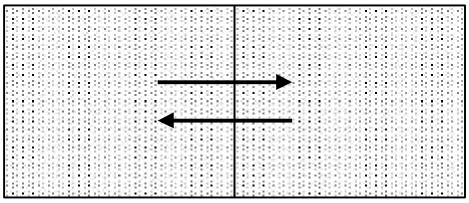
Gas exchange by diffusion:

Adjacent gases of different concentrations mix until the concentration is balanced. Gas molecules move from a region of higher to one of lower concentration.

pO_2: 50 mmHg PO_2: 100 mmHg



pO_2: 75 mmHg



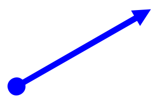
Gas exchange by diffusion is only possible as long as there is a concentration gradient.

Speed, Velocity and Acceleration

Speed describes the rate of movement of a body without specifying the direction of travel.
Speed is defined as the rate of change of distance

$$\text{speed} = \frac{D\text{distance}}{D\text{time}} = \frac{Ds}{Dt}$$

Velocity describes the rate **and** direction of travel of an object. Thus it is a vector, having both **magnitude** and **direction**

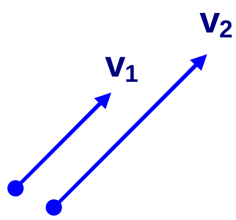


$$v = \frac{Ds}{Dt} \qquad \text{(unit: m/s)}$$

Acceleration describes a change of velocity of an object. It is defined as the rate of change of velocity. It is also a vector, having magnitude and direction

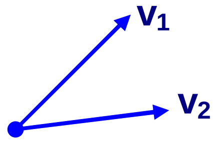
$$a = \frac{Dv}{Dt} \qquad \text{(unit: } m/s^2\text{)}$$

If acceleration results from a change in the rate of movement along a straight line, it is called **linear acceleration**. Thus only the **magnitude** of the velocity changes, the direction remains constant.



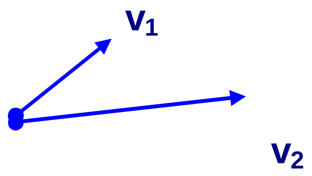
Examples: T/O
launch of spacecraft
apply brakes

If acceleration results from a change in the direction of travel, without a change in speed, it is called **radial acceleration**.



Examples: coordinated turn
centrifuge

If acceleration results from a change in both magnitude and direction of velocity, it is called angular acceleration.



Examples: turn *and* speed increase

turn and speed brakes
rotate during T/O

In aviation, acceleration is frequently expressed as multiples of the acceleration due to gravity, the gravitational constant g = 9.81 m/s^2 (at sea level). The value of an applied acceleration is expressed as G and is given by:

$$G = \frac{\text{applied acceleration}}{g}$$

Acceleration can have a positive or negative value. Negative acceleration is also called deceleration.
To define the orientation of acceleration, a three axis co-ordinate system (x, y, z) is used. The vertical axis (z) is parallel to the length axis of the body (axis of the spine), the first horizontal axis (x) describes acceleration forwards and backwards, while the second horizontal axis (y) describes lateral acceleration.

Weight and Load Factor

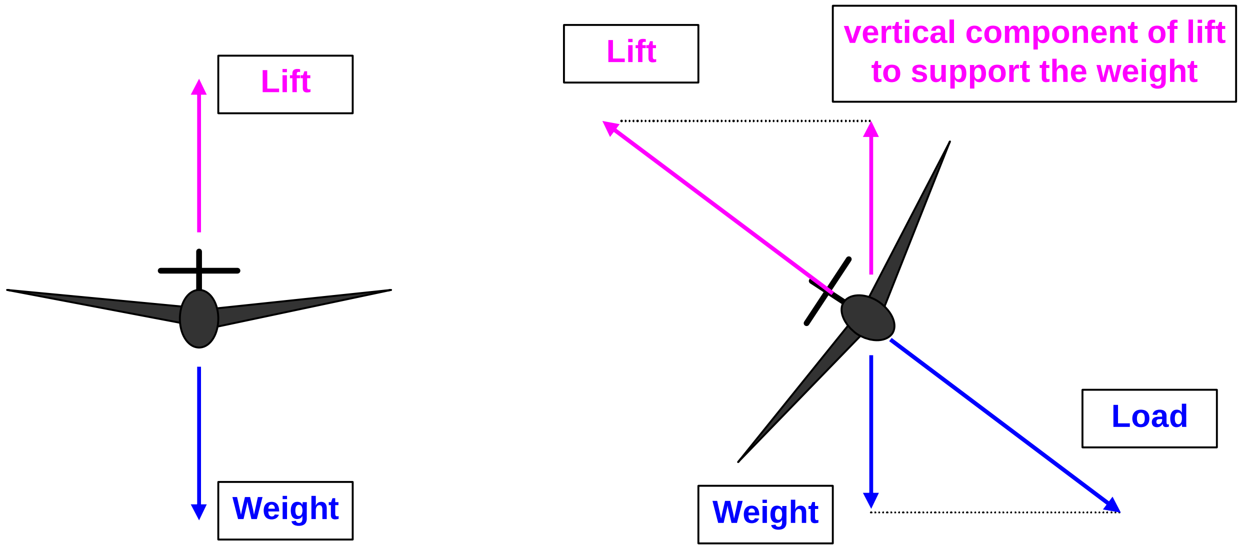
Weight = Mass · Acceleration

Standing on earth, your body mass m is accelerated by the gravity g. The resulting force P = m·g is a vector, pointing to the center of the earth. Since the force P is resisted by the surface of the earth, you actually don't move but feel the force as your body weight.

To keep an airplane in a level flight, the force of lift has to resist the force of gravity. Since the force of gravity is constant for a given airplane and always pointing to the center of the earth, the force of lift has to increase, as soon as the plane is banked. In a 60° banked turn, the load is twice as much as in level flight. Thus, the wings have to produce twice as much lift as in level flight.

The load factor is defined as load divided by the total weight of the airplane.

$$\text{Load factor} = \frac{\text{Load}}{\text{Weight}}$$

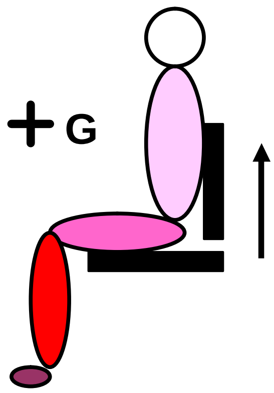


Load factor: 2 G

The pilot experiences the same load factor as his aircraft. In a 60° banked turn, he experiences a G-force of 2 Gs, feeling his "weight" actually doubled. A person on the surface of the moon experiences a weight of 1/6 of the weight on earth.

Effects of acceleration (in civil aviation, we usually only consider acceleration along the z axis: G_Z).

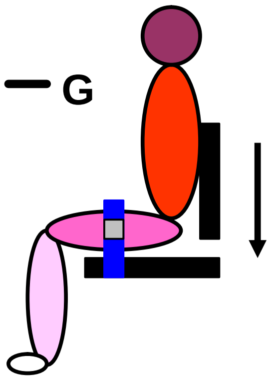
positive acceleration: + G_Z



+ G:
- upward acceleration (headward)
- inertial force acts from head to foot
- body is pressed into the seat
- blood flows to the lower parts of the body
- blood pressure in the brain is low → blackout → unconsciousness

- Example: level off after nose dive, T/O from a carrier

negative acceleration: - G_Z



-G:
- downward acceleration (footward)
- inertial force acts from foot to head
- body is pressed into the shoulder belts
- blood flows to the upper parts of the body
- blood pressure in the brain is high
  - → headache
  - → brain vessels may burst (rupture)
  - → stroke
- edema of the eyelids → red-out
- mental confusion and unconsciousness

- Example: inverse flight
  aerobatics maneuvers

Tolerance range (values for exposure of more than 5 sec)

positive G:	1 – 2 Gs	no problems
	2 – 3 Gs	tunnel vision due to reduced retinal circulation
	3 – 4 Gs	grey-out
	4 – 5 Gs	black-out
	5 – 6 Gs	unconsciousness
negative G:	1 – 2 Gs	tolerable
	2 – 3 Gs	red-out
	> 3 Gs	conjunctival bleeding, loss of consciousness

keep in mind:

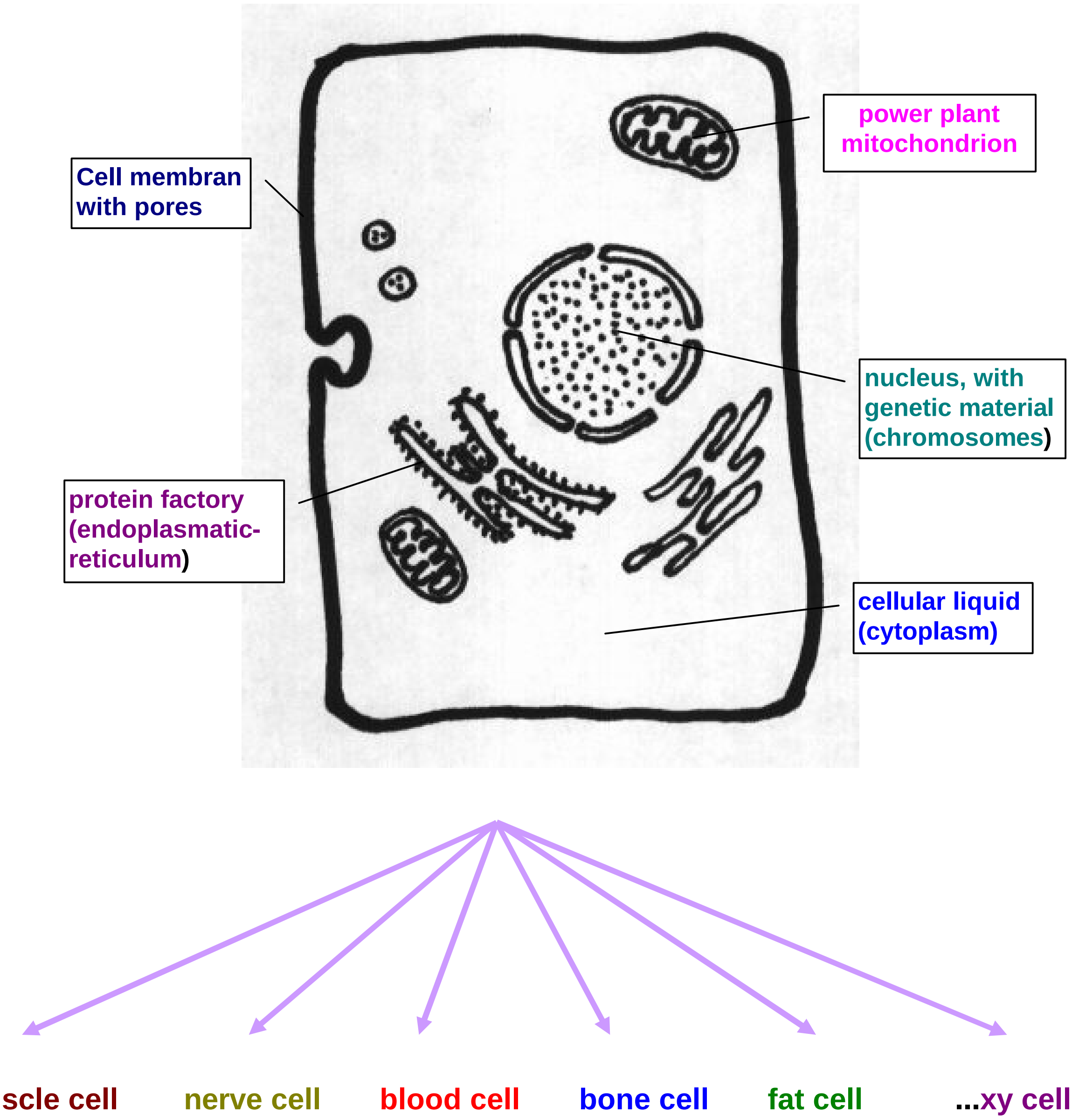
Tolerance of negative acceleration is much lower than that for positive acceleration.

(Aircraft certification:	normal	+ 3.8 / - 1.52 Gs
	utility	+ 4.4 / - 1.72 Gs
	Aerobatics	+ 6 / - 3)

Forward / backward (x-axis) and lateral (y-axis) accelerations are much better tolerated than vertical acceleration. However, in civil aviation they are of low interest.

Cell and Tissue

basic cell organization



Each tissue consists of a lot of specialized cells, all of them are derivatives of the above shown basic structure

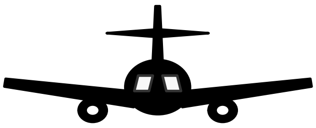
8 sec to impact, ~ 3 km **Closing Speed 720 kts**

4 sec to impact, ~ 1.5 km

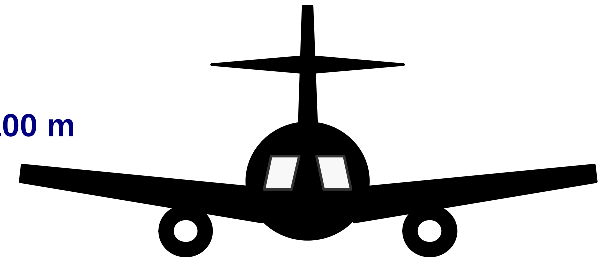
2 sec to impact, ~ 750 m

1 sec to impact, ~ 375 m

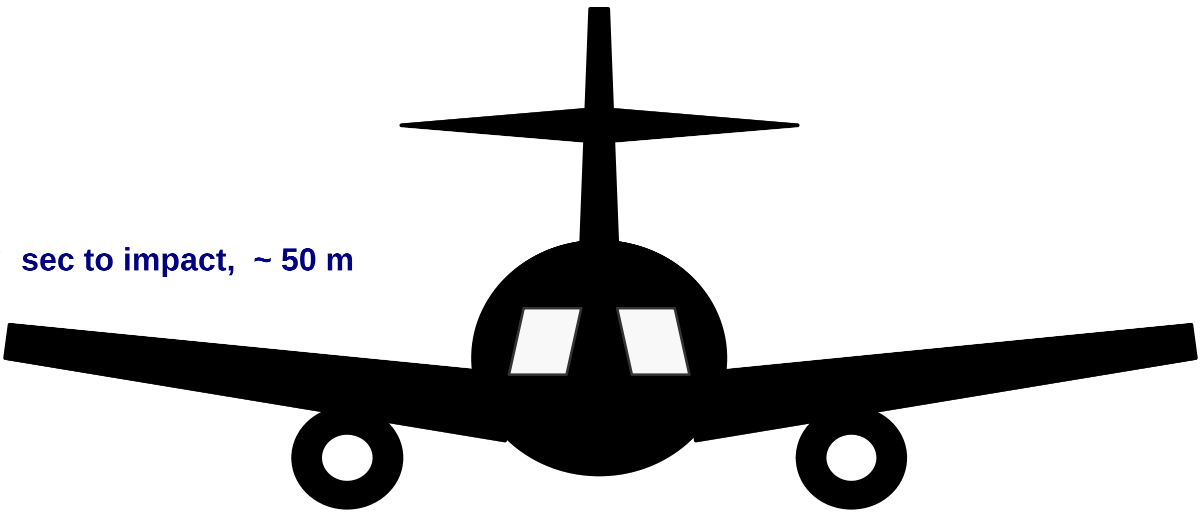
½ sec to impact, ~ 190 m



¼ sec to impact, ~ 100 m



? sec to impact, ~ 50 m



Respiration and circulation

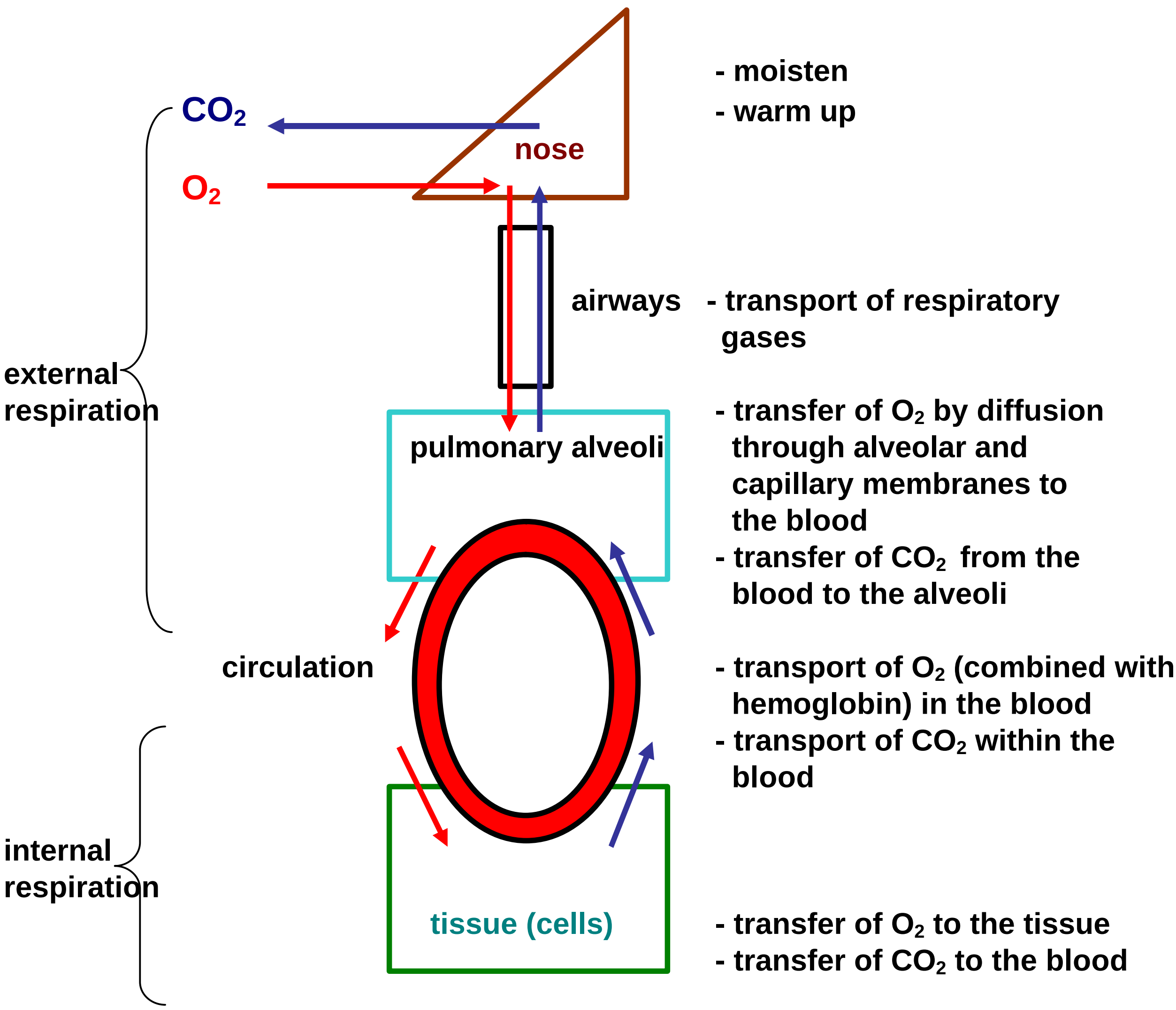
Life means energy and energy is produced in our body by oxidation of energy-rich substances such as sugar, fat, or even protein.
To keep this oxidation going, the tissue needs oxygen. The process by which oxygen is brought into the tissue is called respiration.

Respiration can be divided into external and internal respiration:

external respiration: gas exchange between environment and blood

internal respiration: gas exchange between blood and tissue cells

Diagram of the respiratory process:



The respiratory process

Ventilation

Air is drawn through the conductive airways into the pulmonary alveoli by active inhalation. Airways consist of oral and nasal cavities, throat (pharynx and larynx), trachea and the branches of bronchi and bronchioles. Grouped at the end of the bronchioles, there are small, thin-walled sacs, called alveoli. Alveoli are surrounded by blood capillaries. Healthy young people have a total number of 300....500 millions of alveoli of a diameter of about 0.2mm to form the lung tissue.
Inhaled air is moistened in the airways. In the alveoli, the air is 100% water vapor saturated (partial pressure 47 mmHg at 37°C).

Gas exchange (lung)

The thin walls of alveoli and capillaries allow gases such as oxygen and carbon dioxide to diffuse. According to the concentration gradient, oxygen diffuses from the alveoli to the capillaries while carbon dioxide diffuses from the blood to the alveoli. Oxygen in the capillaries combines with hemoglobin in the red blood cells. Carbon dioxide diffuses from the capillaries to the alveoli. With the next exhalation CO_2 is rejected into the air.

Transportation

Both, oxygen and carbon dioxide are carried by the blood between the lung and the tissue. Oxygen is carried in the red blood cells combined with hemoglobin, while most of the carbon dioxide is carried in solution in the blood plasma.

Gas exchange (tissue)

Since the concentration of oxygen within the tissue is smaller than within the blood, oxygen passes the thin wall of the capillaries and diffuses into the tissue. Carbon dioxide, produced by oxidation in the tissue, diffuses from the tissue cells to the blood, where 95% is dissolved in the plasma (H_2CO_3 = carbonic acid).

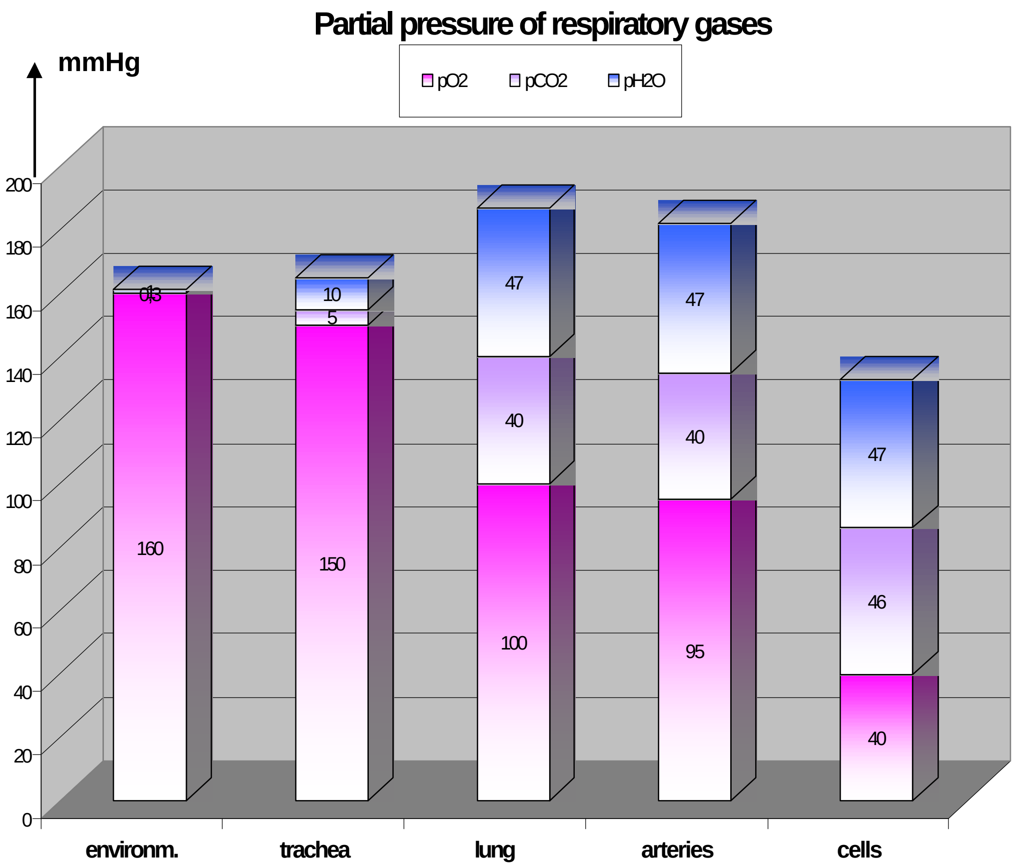
Utilization

Within the tissue cells, oxygen is used to produce the energy needed to sustain life. Carbon dioxide is formed by this oxidation (among other bonds such as water).

Keep in mind

The concentration gradient of the respiratory gases between environment and tissue acts as a motor for the gas exchange.

Partial pressure of respiratory gases between environment and tissue



Pulmonary ventilation

**Ventilation is the gas exchange between the environment and the lungs. Under conditions at rest, healthy people have an average ventilation rate of 16 breaths/min. Respiration thereby is a subconscious process you don't have to care about.
Inhalation is actively accomplished by lowering the diaphragm and elevating the ribs, resulting in a increased thoracic volume and a decreased thoracic pressure. The pressure differential between environment and lung causes the air to rush into the lungs.
Exhalation is a largely passive process due to relaxation of the diaphragm and the respiratory muscles between the ribs.**

Control of pulmonary ventilation

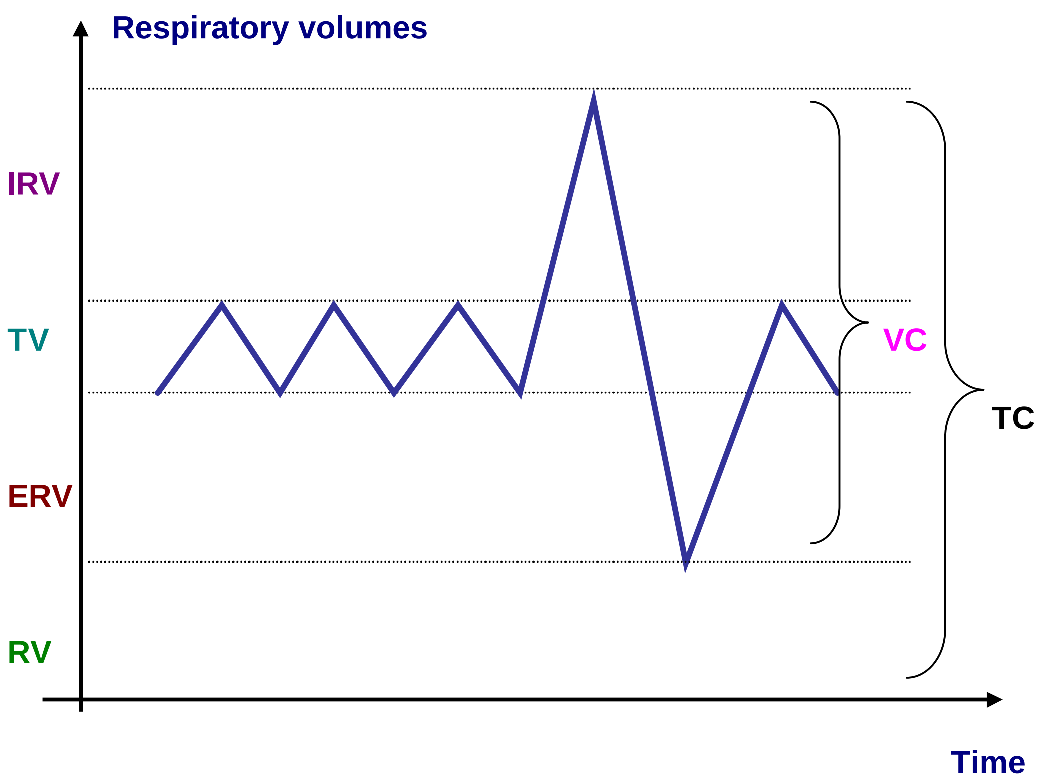
**Oxygen cannot be stored by the body, so we have to breathe from birth to death.
The respiration is controlled by the respiratory control center in the brain stem.
Primarily, the respiratory center is sensitive to the concentration of carbon dioxide CO_2 in the blood. An increase of CO_2 (e.g. during exercise) immediately stimulates ventilation, resulting in a bigger amount of exhaled CO_2. Subjectively, an increase of CO_2 causes a shortness of breath, called dyspnea.
Secondarily, peripheral receptors respond to a lack of oxygen and stimulate ventilation. Subjectively, the lack of oxygen is not perceived, because it doesn't cause any discomfort (no shortness of breath).
Besides the respiratory gases, additional stimuli can increase ventilation such as an increased body temperature, hormones or by will.**

Keep in mind

**increased CO_2 causes shortness of breath,
decreased O_2 remains unnoticed**

Respiratory volumes (young healthy male, 1.7 m tall)

Tidal volume TV	**The volume of air inhaled and exhaled with each normal breath: ˜ 0.5 l (˜ 16 times/minute)**
Inspiratory Reserve volume IRV	**At the end of a quiet inspiration, a further volume of air of ˜ 3.1 l can be inhaled.**
Expiratory Reserve volume ERV	**After a quiet expiration, a further volume of air of ˜ 1.2 l can be expelled.**
Residual volume RV	**After maximum expiration, a considerable amount of air ˜ 1.2 l remains in the lungs.**
Vital capacity VC	**Amount of air the lungs can hold between maximum inspiration and maximum expiration (TV + IRV + ERV) ˜ 4.8 l**
Total capacity TC	**maximum amount of air the lungs can hold (VC + RV) ˜ 6.0 l**



Hyperventilation

Condition in which ventilation is abnormally increased, commonly due to psychological stimuli (anxiety, fear, apprehension, anger, joy) or environmental stress (hypoxia, vibration, noise ...). The increased ventilation causes a loss of carbon dioxide, which shifts the acid-base balance, making it more alkaline.

Carbon dioxide in the blood is present in the form of carbonic acid or bicarbonate:

$$CO_2 + H_2O \text{ ? } H_2CO_3 \text{ ? } H^+ + HCO_3^-$$

During Hyperventilation, too much carbon dioxide is exhaled, causing a reduction in hydrogen ion H^+ thus leading to a rising pH (alkalosis).

Signs and Symptoms of Hyperventilation

objective signs:

- **increased rate and depth of respiration**
- **muscle spasm, twitching and tightness**
- **pallor, cold, clammy skin**
- **generalized muscle cramp (tetany)**
- **unconsciousness**

symptoms perceived by the subject:

- **breathlessness, feelings of suffocation**
- **lightheadedness, dizziness**
- **muscle incoordination**
- **tingling, tickling**
- **blurred vision**

Since Hyperventilation causes shortness of breath and feelings of suffocation, people tend to increase their respiratory rate and depth, causing more and more loss of CO_2 and thus increasing the severity of hyperventilation (forming a vicious circle). Eventually, after becoming unconscious, the breathing rate will be exceedingly low, until the metabolism produces enough CO_2 to resume the acid-base balance.

Treatment: Slowing the breathing rate, talking aloud or back breathing into a paper bag in an early stage of hyperventilation usually restores a proper CO_2-level.

The symptoms of Hyperventilation are easily confused with those of hypoxic hypoxia. However, hypoxia causes cyanosis (bluish skin), flaccid muscle activity and no shortness of breath.

Hypoxia = Shortness of Oxygen

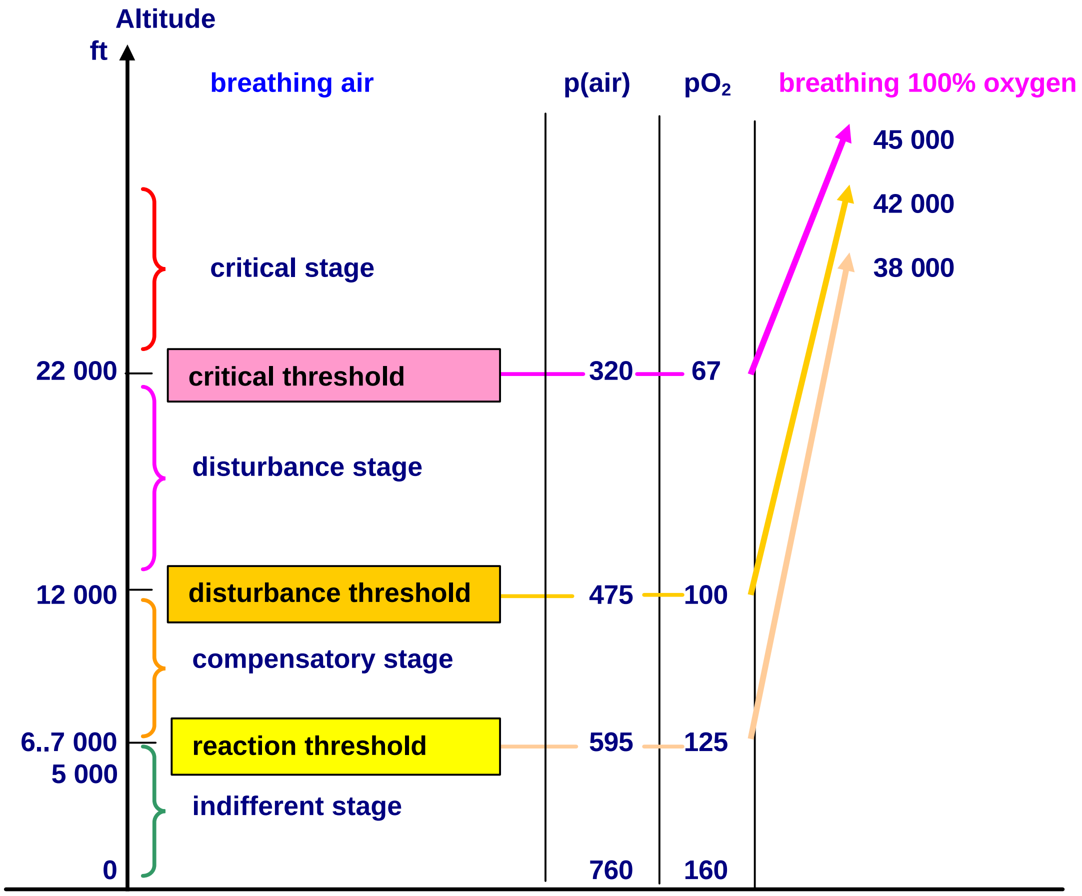
⇨ **lack of oxygen in the tissues**

Causes:

- **hypoxic hypoxia** — **reduced alveolar oxygen exchange** e.g. caused by reduced partial oxygen pressure due to high altitude (Dalton's law) or by respiratory diseases like asthma, pneumonia ...
- **stagnant hypoxia** — **poor circulation of the blood** (reduction of the cardiac output due to heart failure, shock, excessive G forces, positive pressure breathing)
- **hypemic hypoxia** — **reduced oxygen carrying capacity** of the blood = reduced number of healthy red blood cells due to anemia, blood loss or donation, diseases deforming red blood cells. Additionally, hypemic hypoxia can be caused by conditions interfering with the attachment of oxygen to the hemoglobin such as **carbon monoxide poisoning**
- **histotoxic hypoxia** — **Inability of the tissue, to use oxygen**, caused by alcohol, drugs, cyanide...

In aviation, hypoxic hypoxia due to reduced partial oxygen pressure is said to be the most lethal physiological cause of accidents. As you ascend to higher altitudes, there are less oxygen molecules to be attached at the hemoglobin, though the percentage of oxygen in the inspired air remains constant (21%). This leads to an oxygen deficiency in the tissues, causing a disruption of the oxidation process, which impairs cellular function. Most susceptible to oxygen deficiency are nerve cells in the brain, because of their constantly high oxygen demand. The result is an impairment of brain functions, deterioration of performance, reduced vision, and at higher altitudes even unconsciousness and death.
At the beginning, the body has some mechanisms to compensate the effects of hypoxia. As oxygen pressure continues to decrease, compensation mechanisms break down and symptoms arise.

Stages of performance decrements due to hypoxic hypoxia



Symptoms of Hypoxia:

indifferent stage: above 5000 ft	**dark adaptation affected, night vision impaired**
compensatory stage: above 7000 ft	**heart rate ⇧, respiration rate and depth ⇧, blood pressure ⇧, cardiac output ⇧**
disturbance stage: above 12 000 ft	**diffuse symptoms of mental impairment, dizziness, headache, somnolence, drowsiness, air hunger, fatigue, euphoria, hot and cold flashes, tingling and cyanosis (bluish skin), impaired judgement and self-criticism, slow and unreliable thinking, memory failures, poor motor performance, loss of muscle coordination, flaccid muscle action, frequent repetitions of actions narrowing of the visual field, tunnel vision**
critical stage: above 22 000 ft	**mental confusion, total incapacitation loss of consciousness.....death.**

The main problem of experiencing hypoxic hypoxia is, that due to the loss of self criticism, the subject usually is unaware of the deterioration in performance. On the contrary, people think, they are performing very well, meanwhile everything is grossly impaired, objectively. It is this particular effect, that makes hypoxia such a dangerous hazard in aviation.

Keep in mind

The mentioned stages and thresholds go for average young healthy subjects. Elder or sick persons or people with self-imposed stresses such as alcohol, fatigue, medication or poor nutrition are more susceptible to hypoxia.

Most subjects have their own individual symptoms corresponding to the onset of hypoxia (anxiety, dizziness, fatigue, nausea, headache..). These symptoms, once experienced, usually do not vary later. Thus, it is crucial to recognize ones individual symptoms of hypoxia and to take corrective action to obtain supplementary oxygen.

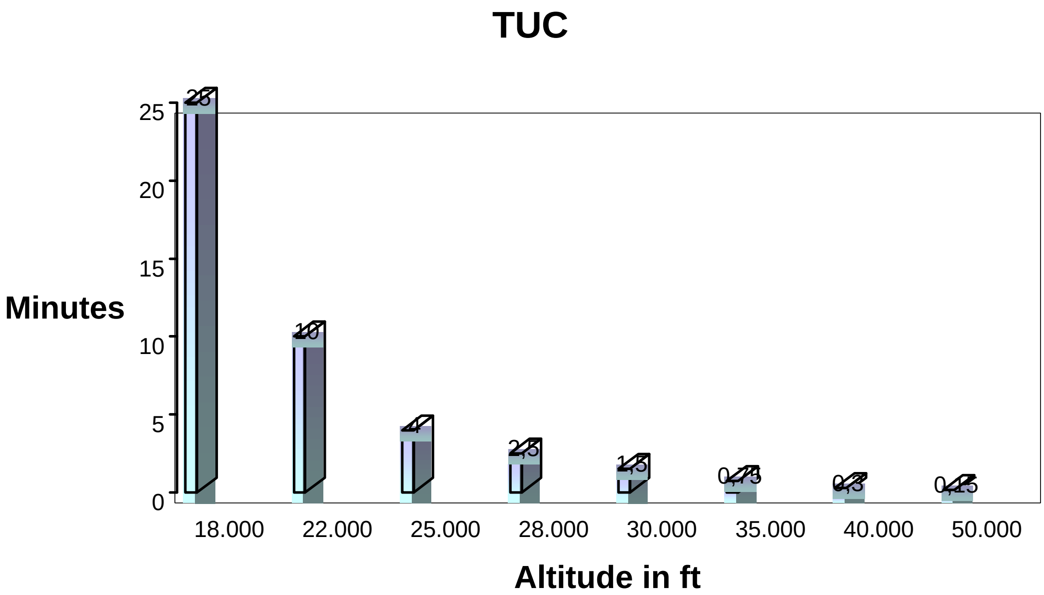
The individual symptoms of hypoxia can easily be experienced at an altitude chamber, which provides a controlled hypobaric environment.

TUC / EPT

Intellectual impairment is an early sign of hypobaric hypoxia. Once it occurs, there is little chance for a safe outcome. The moment a hypoxia takes place, you have to perform the correct actions immediately, otherwise it is too late.
The time, a subject is able to perform adequate flying duties in a hypoxic environment, is called:

> **TUC = time of useful consciousness**
> **or**
> **EPT = effective performance time**

TUC or EPT are highly dependant on altitude as shown below:



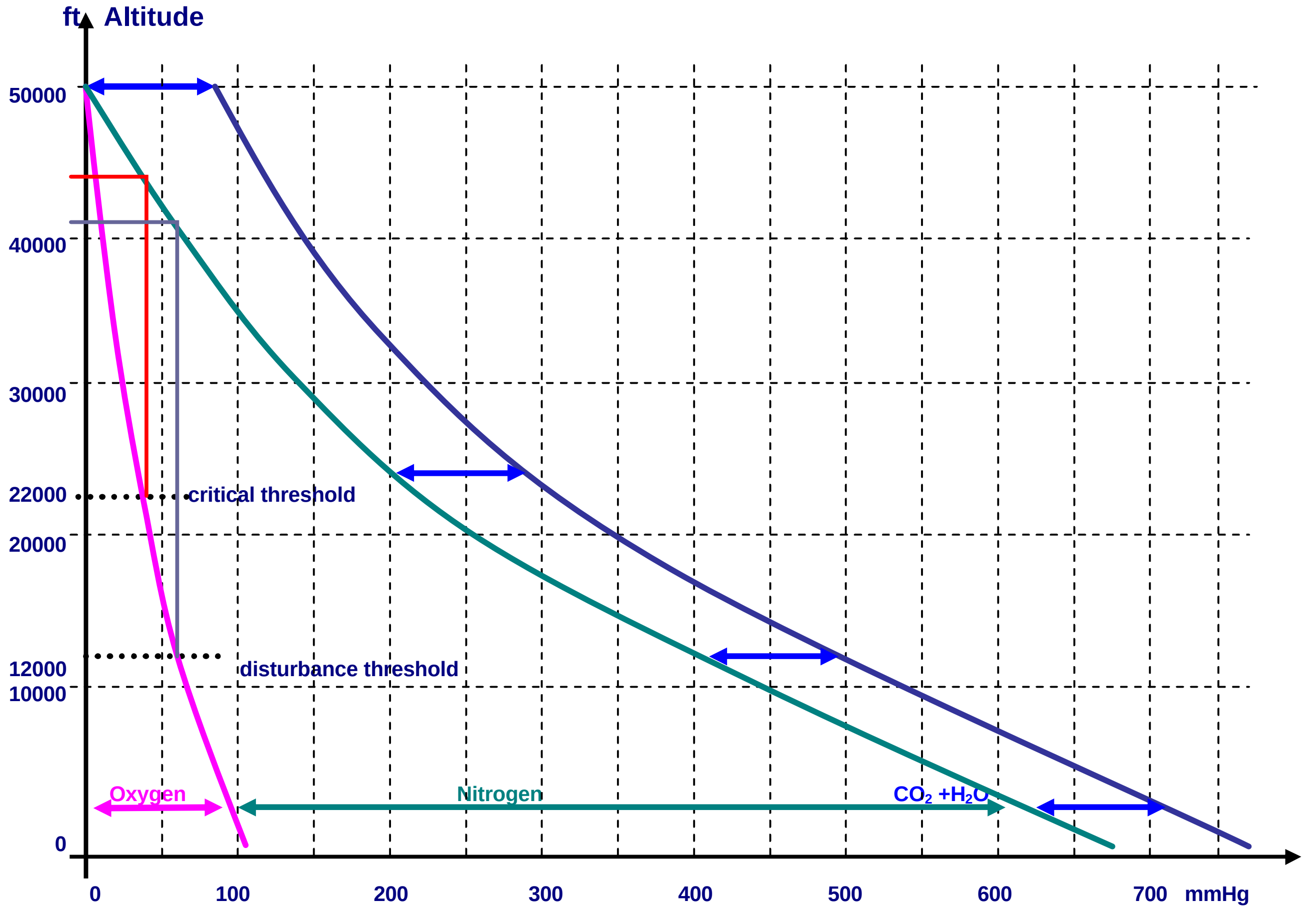
These TUC values apply to young healthy people at rest and under moderate decompression. Fast or even explosive decompression, cuts the times by more than 50%. During explosive decompression at high altitude, more oxygen is exhaled than inhaled due to a negative gradient of partial oxygen pressure (diffusion law)!

There are considerable individual variations in EPT/TUC due to personal fitness, physical exertion and experience. Personal fitness, especially high endurance tolerance rises EPT/TUC, physical exertion and rapid decompression lowers EPT/TUC.

keep in mind

always keep supplementary oxygen ready to use

Partial alveolar oxygen pressure while breathing air or 100% oxygen:



Prevention of hypoxia

The only prevention of hypoxic hypoxia is to ensure, that the individual gets sufficient oxygen. This can be done in different ways:

- **increase of partial oxygen pressure of inhaled air ⇨ O_2 breathing**
- **increase of ambient pressure ⇨ cabin pressurization or**
  ⇨ pressure suits

keep in mind

No one is immune to hypoxia – always anticipate it
do not rely on signs or symptoms,
check the altimeter frequently and
make sure you have supplementary oxygen available

Oxygen breathing

Estimation of oxygen requirements at altitude to maintain sea level conditions:

Altitude	% O_2
sea level	21
5'000 ft	25
10'000 ft	31
15'000 ft	40
20'000 ft	49
25'000 ft	62
30'000 ft	81
34'000 ft	100

Above 34'000 ft, breathing of 100% oxygen no longer guarantees sufficient partial alveolar oxygen pressure. 100% oxygen must be administered along with positive pressure breathing or in combination of pressurization of the ambient air.

Cabin pressurization

The cabin altitude in an aircraft in which crew and passengers breath air should provide a sufficient partial oxygen pressure to guarantee proper performance of the crew and well-being of the passengers. For civil airliners, standard cabin altitude used to be 8'000 ft. Today, a widely accepted cabin altitude, consistent with flight safety, is 5'000 .... 7'000 ft.

Individuals, suffering from cardiorespiratory disease (such as coronary heart disease, asthma, pneumonia ....) may experience problems even at a cabin altitude of 5'000 ft. Sporadic incidents of heart failure during long flights may be induced by mild hypoxia in combination of lack of movement, seated posture, stress and expansion of abdominal gases. High risk passengers should get supplementary oxygen during the whole flight.

Decompression of the pressure cabin

Problem areas

- **physical:**
  - **air blast (raises dust and debris, blows loose articles, furnishings and even people out through the defect)**
  - **mist formed by condensation of water vapor impairs visibility**
  - **noise**

- **physiological**
  - **hypoxic hypoxia**
  - **expansion of entrapped abdominal gases (Boyle's law)**
  - **decompression sickness**
  - **hypothermia (low temperature)**

Treatment of hypoxia

- **100% Oxygen ! , in case of ceased respiration combined with artificial respiration.**
- **recovery occurs within seconds after administering oxygen**

Some subjects experience an increase of the severity of hypoxia symptoms after restoration of normal alveolar oxygen pressure. The so called "oxygen paradox" usually is mild and transient, however, severe forms are possible.

Hypoxia ⇦⇨ Hyperventilation

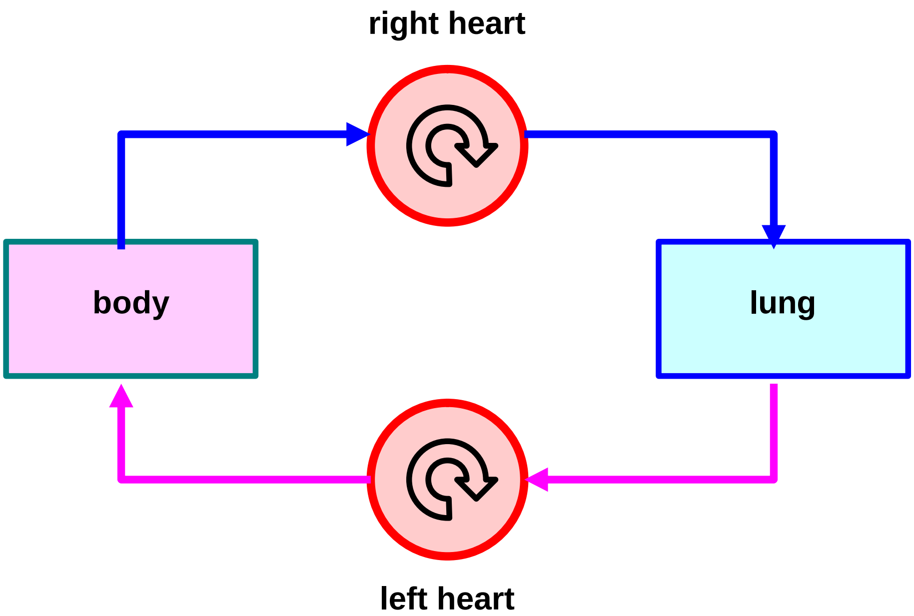
Hypoxia and hyperventilation have similar signs and symptoms. In an emergency, it can be difficult to distinguish. Therefore it is recommended, to treat both, hypoxia and hyperventilation simultaneously:

- **100 % oxygen under pressure**
- **reduce the rate and depth of breathing**
- **check oxygen equipment for proper function**
- **descend to a lower altitude**

Circulation

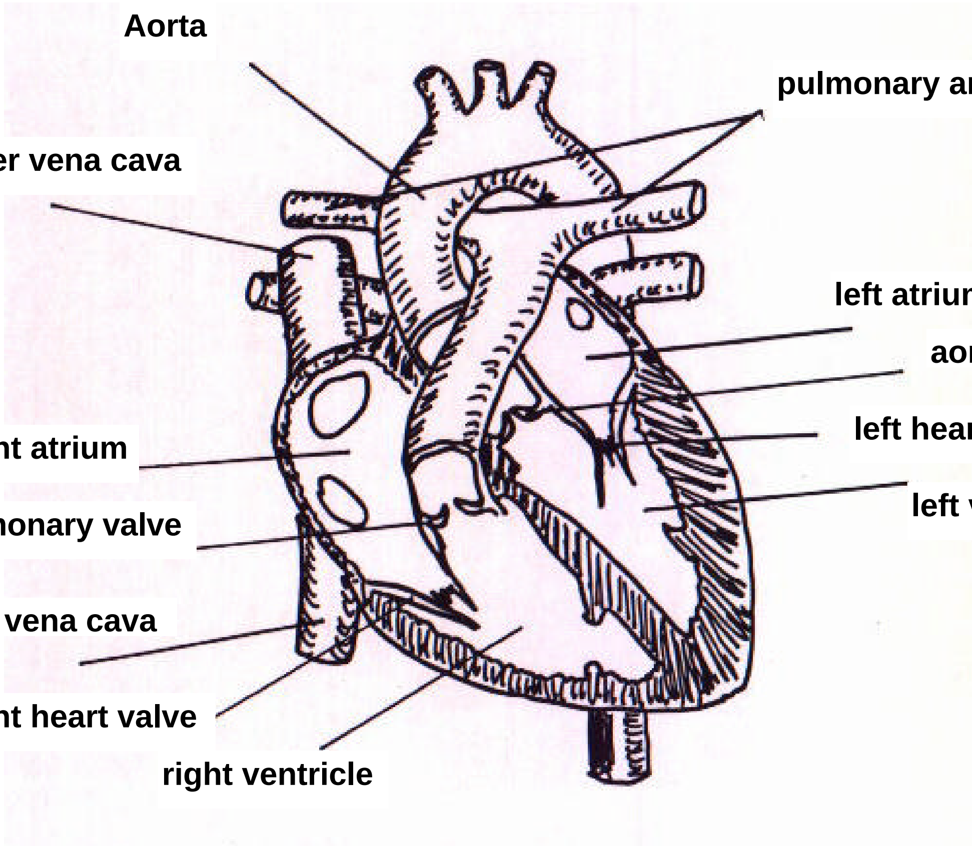
- **Transport of blood to provide the tissue cells with vital substances**
- **consists of**
  - **heart (2 pumps: left heart and right heart)**
  - **blood vessels: arteries, veins and capillaries**
  - **blood: blood plasma, blood cells**
- **control of body temperature**

circulation, basic function:



Heart

- hollow muscle which pumps the blood through the blood vessels by rhythmic contraction
- of about the size of a fist, situated slightly left of the center of the chest between left and right lung
- four chambers (two atriums and two ventricles)
- four valves (one on each side between atrium and ventricle and one at the exit of each ventricle)
- coronary arteries

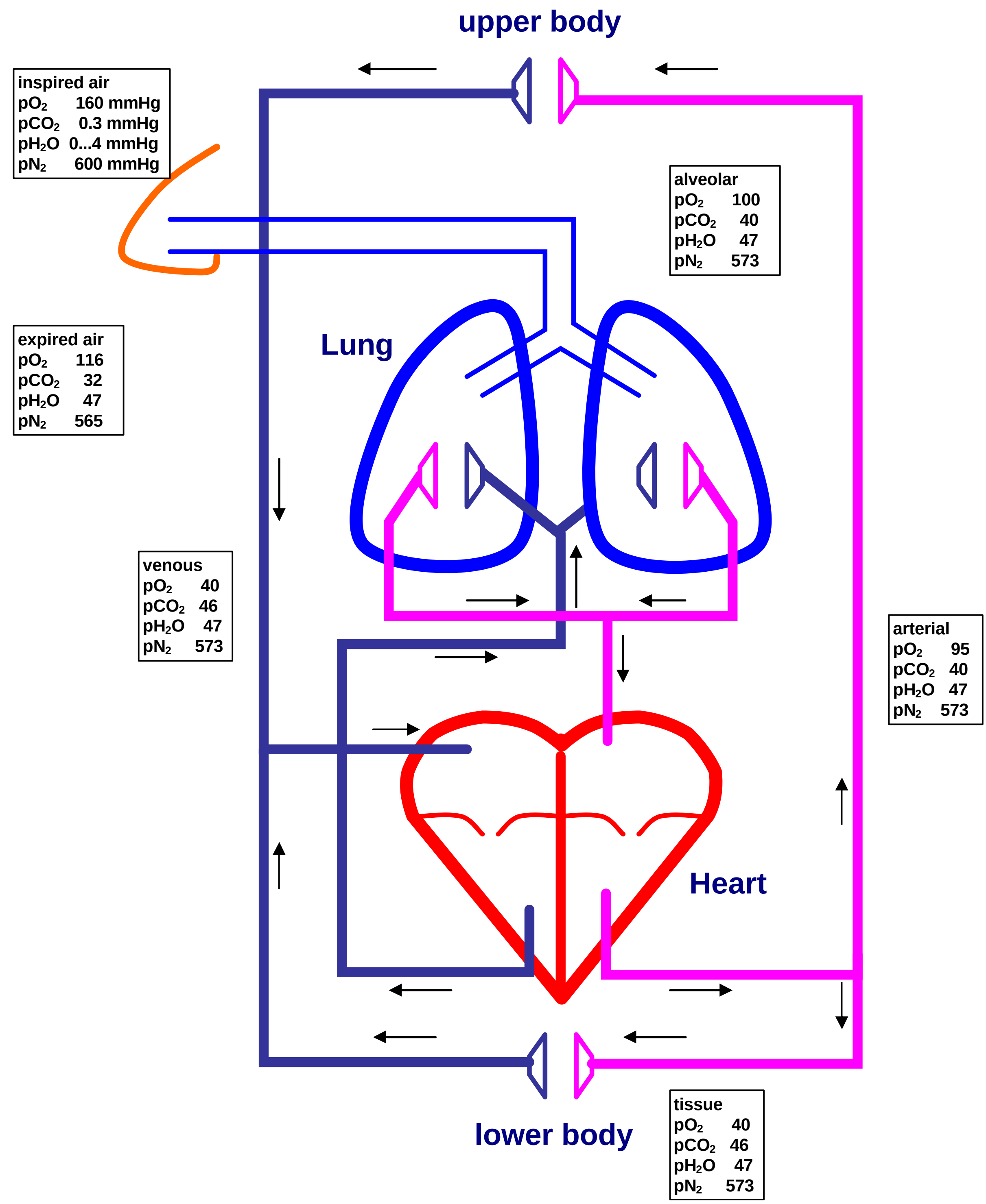


Stroke volume	at rest	~ 70 ml
	during exercise	120....150 ml

Cardiac output	= heart rate x stroke volume	
	at rest	~ 5 l/min
	during exercise	25 ...... 35 l/min

Diagram of the circulation

- low pressure circle: right ventricle – pulmonary artery – Lung capillaries– Pulmonary veins – left atrium: oxygen uptake
- high pressure circle: left ventricle – aorta – arteries – tissue capillaries – veins – right atrium: transport of Oxygen to the tissue



Blood vessels

- Transportation of the blood
- Arteries, heading away from the heart, thick wall (muscle), high pressure, pulse palpable
- Veins, heading to the heart, thin wall (muscle), low pressure, blood flow steady, no pulse palpable
- Capillaries, minute blood vessels, forming a network for the interchange of respiratory gases and various substances between blood and tissue cells
- control of the muscular tone of the blood vessels is guaranteed by the vegetative nervous system (blood pressure, temperature control)

keep in mind

> arterial blood is oxygen enriched
> venous blood is low on oxygen
> pulmonary arteries contain venous blood
> pulmonary veins contain arterial blood

Blood

- 4.5 liters
- 45% blood cells
  - red blood cells (erythrocyte), 5 million / mm^3
    contain the red respiratory pigment hemoglobin which picks up oxygen in the capillaries of the lungs and releases oxygen in the capillaries of the tissue
  - white blood cells (leukocyte), 5....10'000 / mm^3
    protect the body from infectious diseases
  - platelets (thrombocyte), minute disc like bodies that promote blood clotting (coagulation)
- 55 % fluid (blood plasma) containing water, proteins, minerals, various metabolic substances, dissolved gases, hormones ....

The Nervous System NS

The nervous system may be divided into four parts:

- **Brain**
- **Spinal cord**

Central Nervous System CNS

- **Peripheral nerves**
- **Autonomous nervous system**

Peripheral Nervous System PNS

The CNS is responsible for

- **issuing and receiving nerve impulses**
- **analyzing, storing and combining sensory data**
- **generating cognitive processes using retained information from the memory**
- **making decisions under voluntary control**

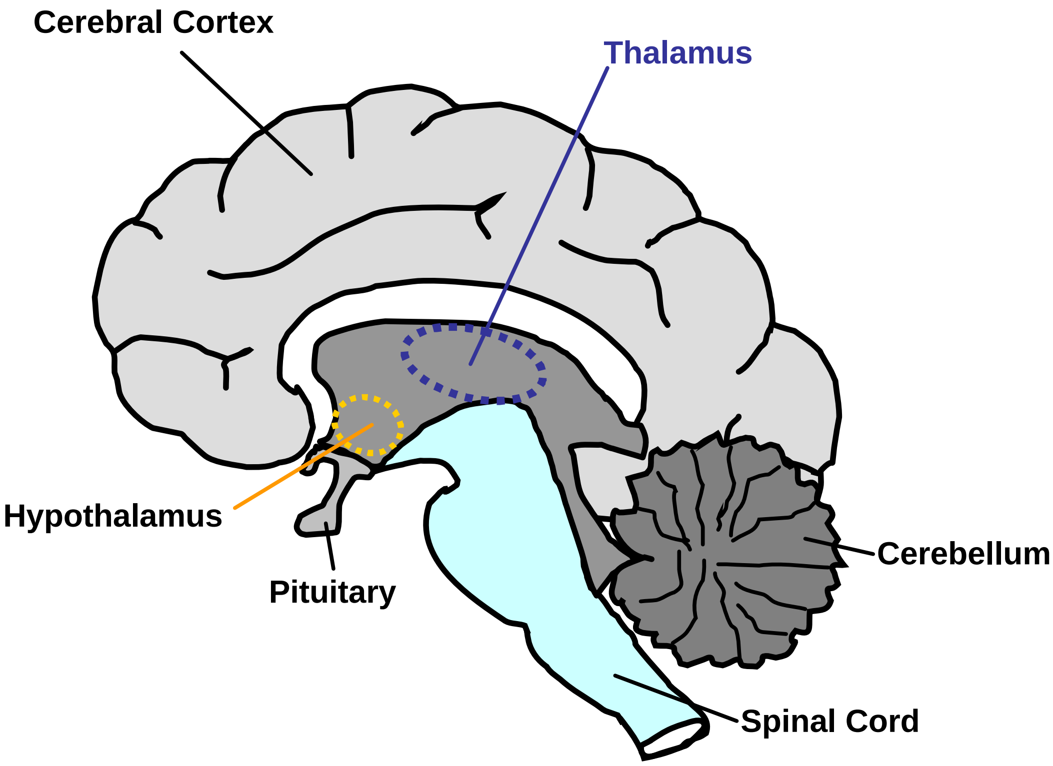
The peripheral nerves are responsible for

- **passing information from the CNS to the organs and muscles (motor nerves)**
- **passing information from the organs and muscles directly to the CNS (sensory nerves)**

The autonomous nervous system (ANS)

- **regulates the operation of the internal organs to support the activity of the body as a whole**
- **is not under voluntary control**

The major parts of the Central Nervous System



The Cerebral Cortex

- **initiates complex mental activity (thinking, remembering, sensory perception....)**
- **controls the various sensory organs**
- **initiates and controls voluntary motor activity**

The Cerebellum

- **controls balance and muscular coordination**

The Thalamus

- **is the major site for the processing of information from the sense organs**

The Hypothalamus (together with the Pituitary Gland)

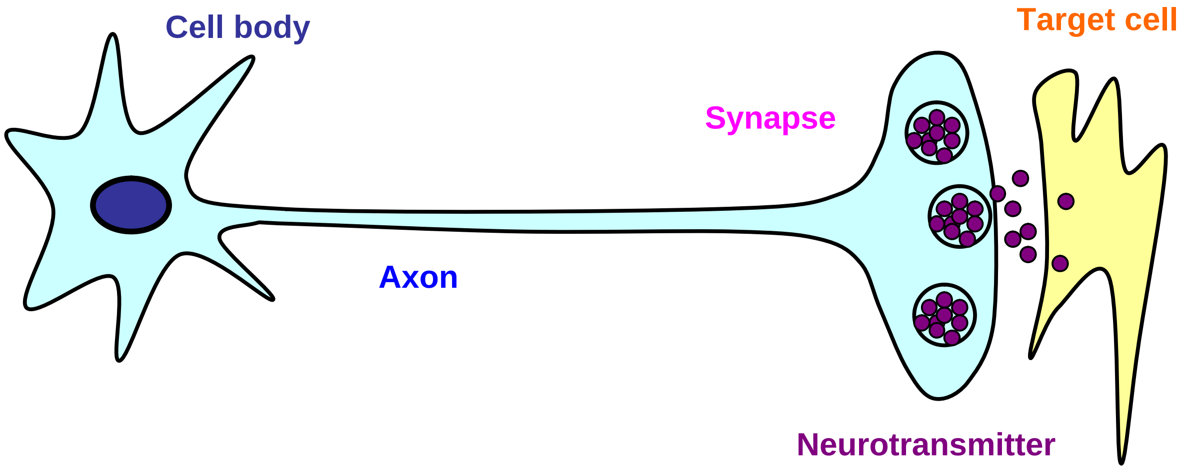
- **regulates of the endocrine system (hormones)**
- **controls several body functions (temperature, metabolism, stress reaction GAS....)**

The Spinal Cord

- **houses the connecting nerves between the CNS and the peripheral nerves (protected in the spinal canal of the vertebral column)**

The Neuron = Nerve Cell

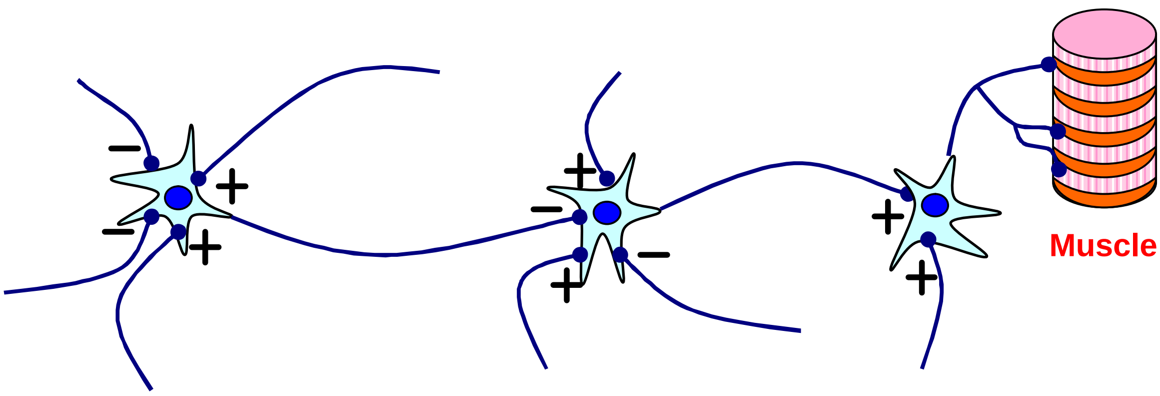
- principal functional unit of the nervous system



The information transmission between neurons and target cells is an electro – chemical phenomenon:

- Electrical signals (action potentials) originated in the cell body pass along the axon and trigger the secretion of neurotransmitter molecules in the synapse

- Neurotransmitter molecules diffuse through the synaptic gap into the target cell where they initiate a specific reaction (new action potential, muscle contraction, endocrine secretion ...)



Neurons with there synapses build up neuronal networks. Synaptic connections can be either activating (+) or inhibiting (–). This allows a very sophisticated control of a specific like a muscle or an endocrine gland.

The Autonomous or Vegetative Nervous System ANS

The ANS is divided into two parts

- The sympathetic nervous system acts in general to prepare the body for activity.
- The parasympathetic nervous system in general promotes restorative functions like relaxation, sleep and digestion.

Sympathetic	Innervation of Organ	Parasympathetic
Dilatation	Eye (pupil constrictor and ciliary body)	Constriction and Accommodation
Heart rate ⇧ Force of contraction ⇧	Heart	Heart rate ⇩
Vasoconstriction →BP ⇧	Blood vessels	Vasodilatation → BP ⇩
Bronchial dilatation	Lungs	Bronchial constriction
Secretion of sweat	Sweat glands	no innervation
Decreased motility Constriction of sphincters	Gastrointestinal tract	Increased motility Relaxation of sphincters
Inhibition of urination	Urinary bladder	Initiation of urination
Increased	Metabolism	no effect
Secretion of stress hormones (adrenaline)	Adrenal gland (medullae)	no innervation

Autonomic nerves maintain a basal level of tonic activity – the tone. In order to modulate the activity of specific tissues, the autonomous tone can be either increased or decreased. (Example: At rest, blood vessels are partially constricted due to a basal sympathetic tone. If the sympathetic tone increases, the blood vessels become more constricted, causing a higher blood pressure and a decreased blood flow).

Many organs receive a dual innervation from sympathetic and parasympathetic nerve fibers. Control of complex functions like body temperature, blood pressure control, sexual functions, gut motility and so on are made possible by multiple interaction of the different parts of the autonomous nervous system. This homeostatic activity of the ANS is controlled by the hypothalamus.

Sense Organs

Definitions:

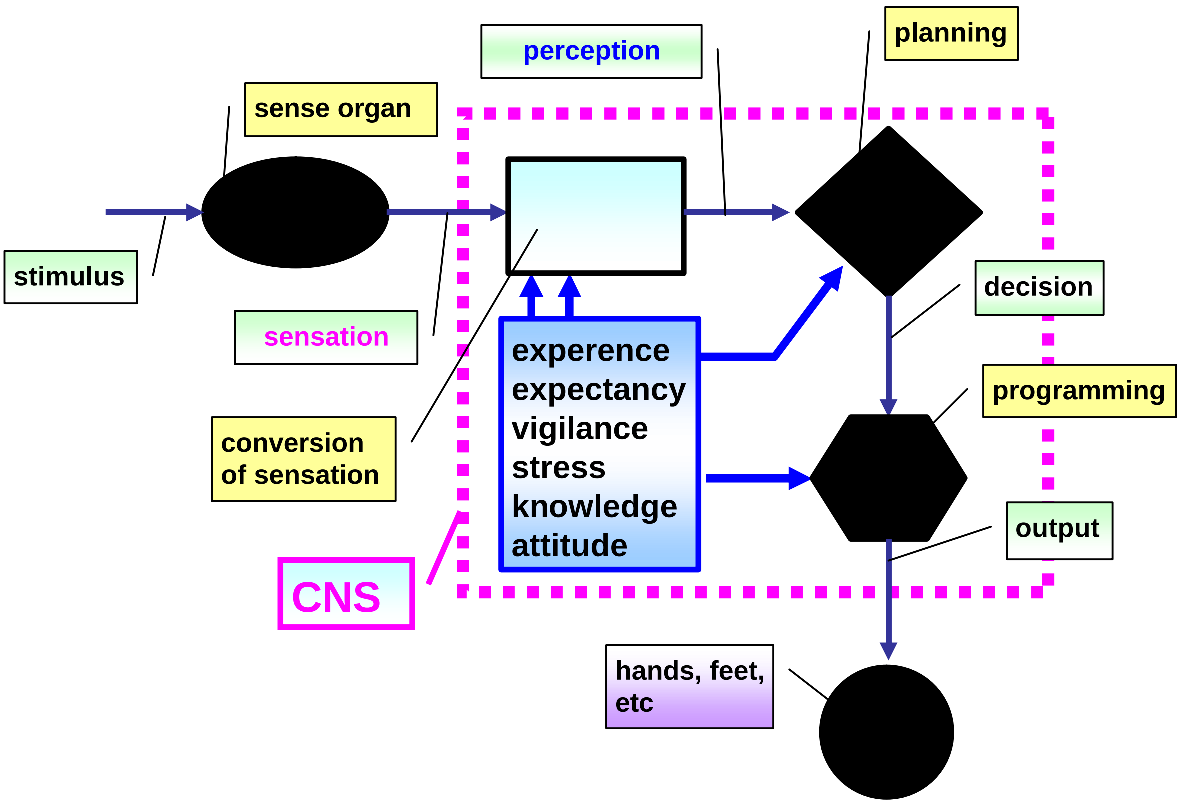
Sense organ: Organ, containing specialized cells which react selectively to particular stimuli from the environment to produce a response called sensation

to produce a sensation, the stimulus has to reach or exceed a minimal intensity called threshold stimulus

Perception: the central nervous system (CNS) converts the sensation into a perception by recognition and interpretation based on memory, experience, expectancy, vigilance, knowledge, attitude, stress...

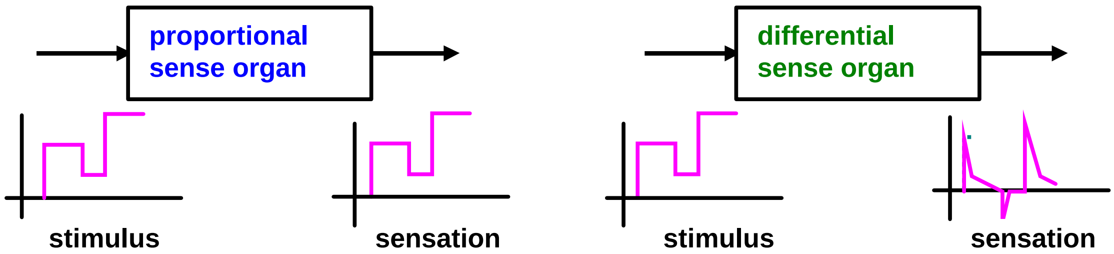
A given sensation, perceived by different people will lead to different perceptions. That's why everybody has his own view of the world

Diagram of sense organ and perception



Proportional versus differential perception

Proportional sense organs create a sensation proportional to the stimulus. A constant stimulus produces a constant sensation
Examples: eyes, hearing.
Differential sense organs react to the change of a stimulus. A constant stimulus produces a fading sensation.
Examples: semicircular canals of the labyrinth.



Perception also can be differential, even if the sense organ works proportional. Sitting on a chair without moving, lets us gradually adapt to the sensation of the skin receptors (touch and pressure) until eventually, we're no longer aware of being seated. Moving a little bit, immediately reactivates the perception of seated. Hearing is another example of differential perception. After a short time in cruise flight, pilots adapt to the noise of the power plant where a sudden change in engine noise, immediately is perceived.

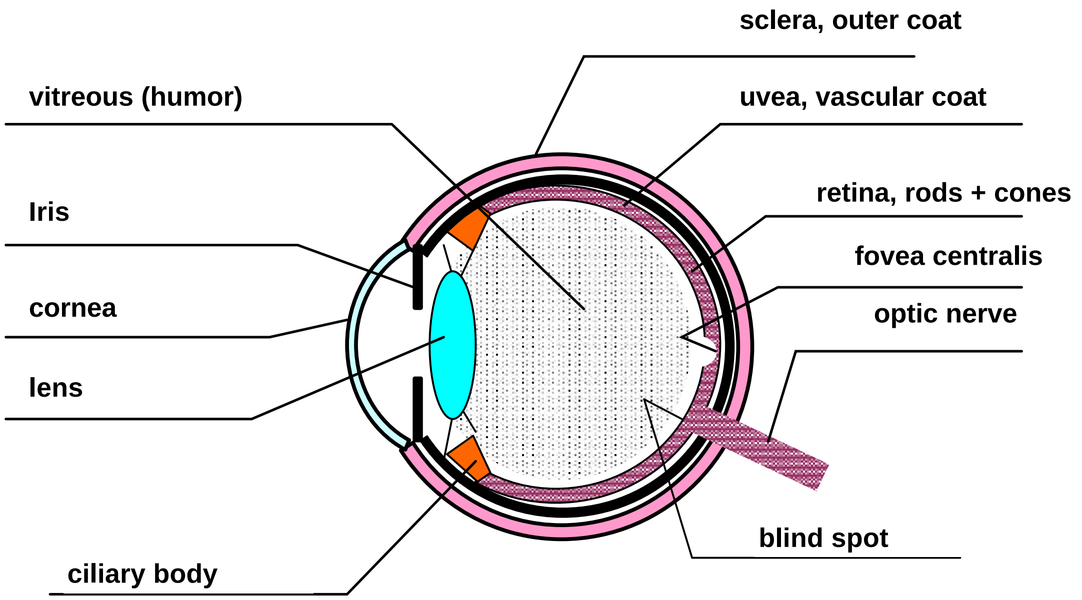
Sense organs, receptor cells and stimuli:

eye (vision)	rods and cones of the retina	light
inner ear (hearing)	nerve endings of the cochlea (corti organ)	sound
inner ear (balance)	receptors of the otolith organs (utr./sac.) receptors of the semicircular canals	linear acceler. angular accel.
skin	mechano-receptors (touch/pressure/pain) thermal receptors for temperature	mechanic force heat / cold
joint, muscle, ligament, tendon	kinaesthetic receptors signaling the relationship between different body parts	g-force, movement
nose	olfactory nerve endings	smell
tongue	nerve endings of the tongue	taste

The eyes, sense organ of vision

- recognizing of structures and contours, sensing light intensity and colors, providing stereoscopic vision.

Anatomy:



The eyeball is about 2.5 cm in diameter. It is well protected by bones, except at the front. The composition consists of three coats (sclera, uvea, retina), the optic system (lens, vitreous humor)

Sclera: tough white fibrous outer envelope of the eye, provides protection against damage. At the front it is transparent and called cornea

Cornea: convex, transparent front part of the sclera to admit light

Uvea: vascular middle layer, also called choroid, constituting at the front the iris and ciliary body

Retina: inner layer, containing the light sensitive cells (rods and cones). In the center of the retina is a yellowish area, the macula lutea, containing the fovea centralis, where perception is most acute

Optic nerve: bundle of nerve fibers, connecting the sense cells (rods and cones) to the brain. At the area, where the optic nerve emerges from the eyeball, there are no rods or cones, thus leaving a light insensitive region, the blind spot.

Vitreous: clear gelatinous (jelly) substance that fills the eyeball between retina and lens to stabilize the shape

Pupil: opening in the center of the iris

Optic system of the eye

- 2 refracting structures: Cornea and lens

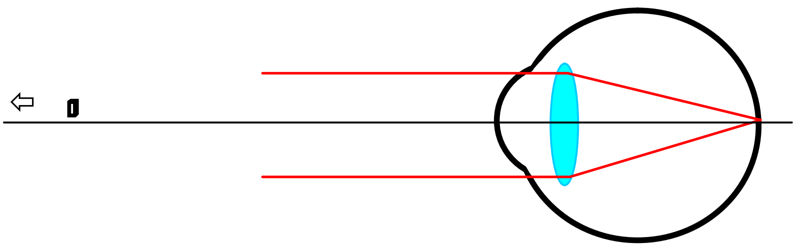
  Cornea fixed refraction of ~ 43 diopters (D)
  (1 D = 1/focal length, measured in meters)

  Lens variable refraction of 16......20....30 diopters

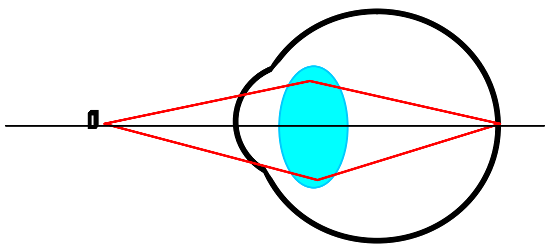
- Accommodation

  automatic adjustment in the focal length of the lens, according to the distances of an object, to permit retinal focus

  object far away: lens ~ flat, refraction low

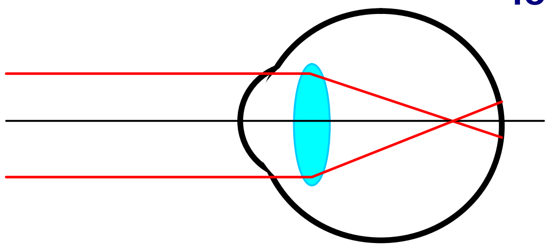


  object nearby: lens thick, refraction high

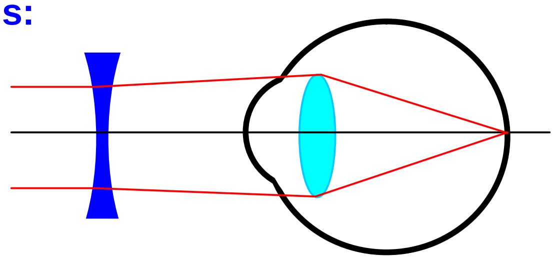


Visual defects, refractive errors

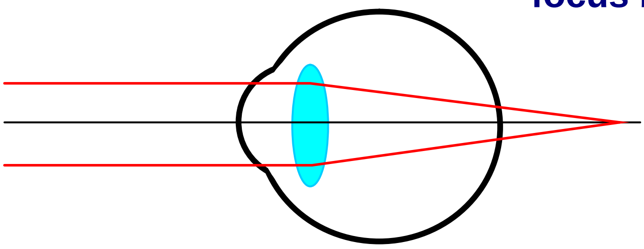
- **Shortsightedness (myopia):** eyeball too long for refractive power
  focus lies in front of retina (at rest)



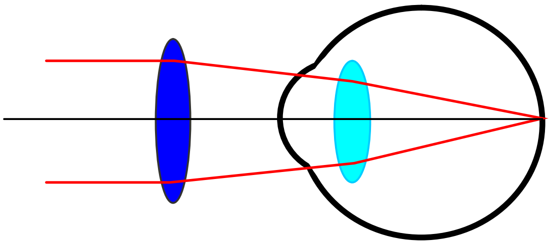
correction: concave lens:



- **Farsightedness (hyperopia):** eyeball too short for refraction
  focus behind retina (at rest)

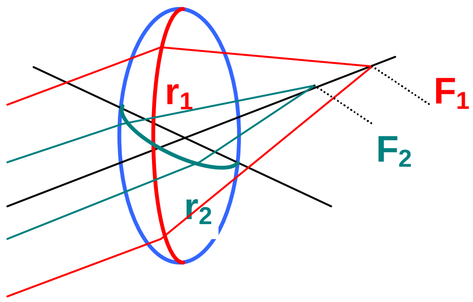


correction: convex lens:

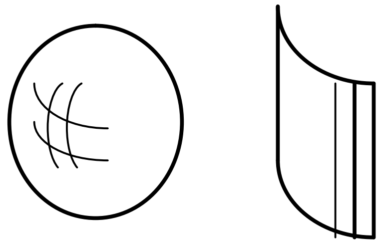


- **Presbyopia:** **with age, the lens loses its elasticity and is no longer able to assume a high convexity, resulting in a progressive inability to focus on nearby objects.**
  At an age of 45 years the average refractive power of the lens is ~ 3 D, corresponding to a focus distance of ~ 30 cm. At this time people need convex lenses of gradually increased power to focus on nearby objects.
  Hypermetropes start earlier, myopes start later with presbyopia.

- **Astigmatism: the refractive power is unequal in different meridians, therefore producing different focuses, resulting in a blurred vision**



correction: combination of spherical and cylindrical lenses



The retina and its sense cells

The retina is a transparent layer housing the light sensitive receptors and the nerve fibers which connect the receptors to the brain.

Cones: responsible for daylight vision, most densely concentrated in the fovea centralis creating the area of greatest visual acuity

responsible for color vision (red- / green- / blue sensitive cones)

~ 5 million of cones

one-to-one connection, each cone is connected to a single optic nerve fiber leading to the brain, providing greatest discrimination (greatest visual acuity)

Rods: responsible for dim and night vision

highly light sensitive after dark adaptation

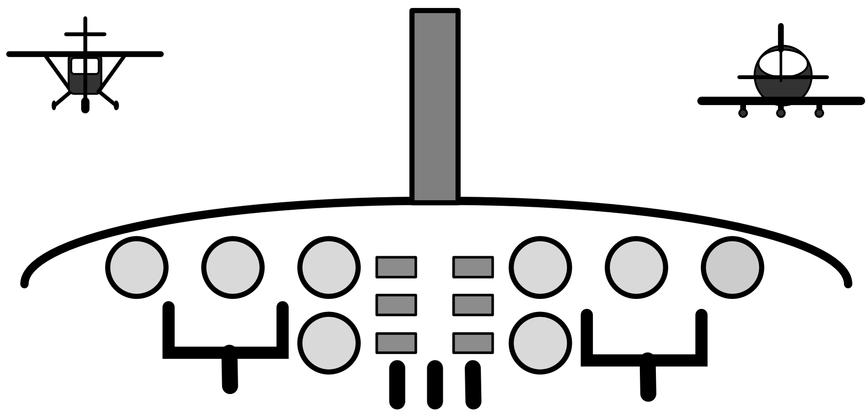
distributed all over the retina except at the fovea

responsible for peripheral vision

~ 100 million of rods

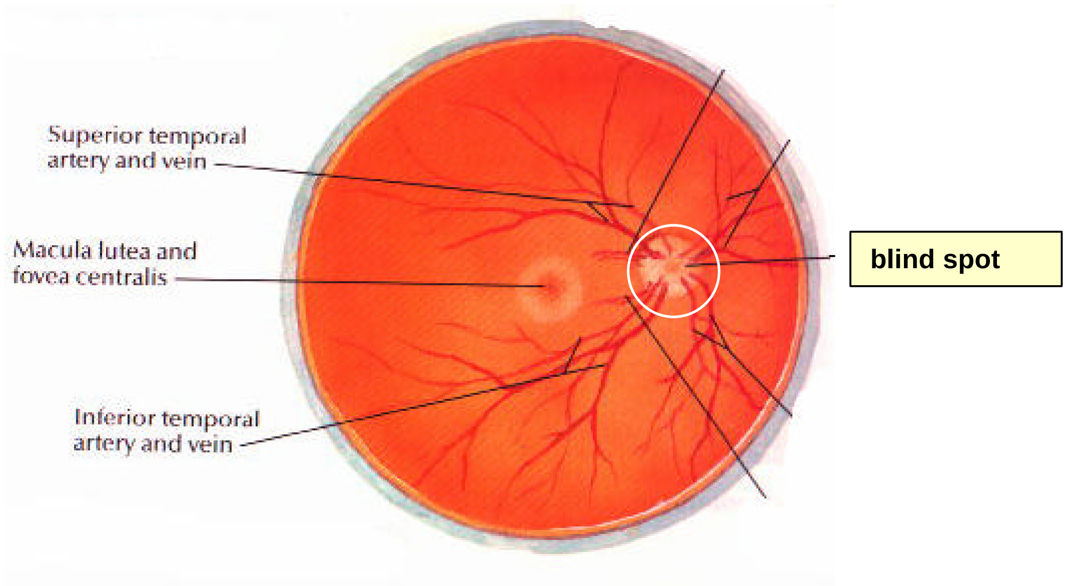
large groups of rods are connected to the brain by a single optic nerve fiber, thus providing excellent light sensitivity and also excellent sensitivity to motion, but bad ability to discriminate.

Blind spot: At the area, where the optic nerve emerges from the eyeball, there are no rods or cones, thus leaving a light insensitive region, ~ 16° lateral.

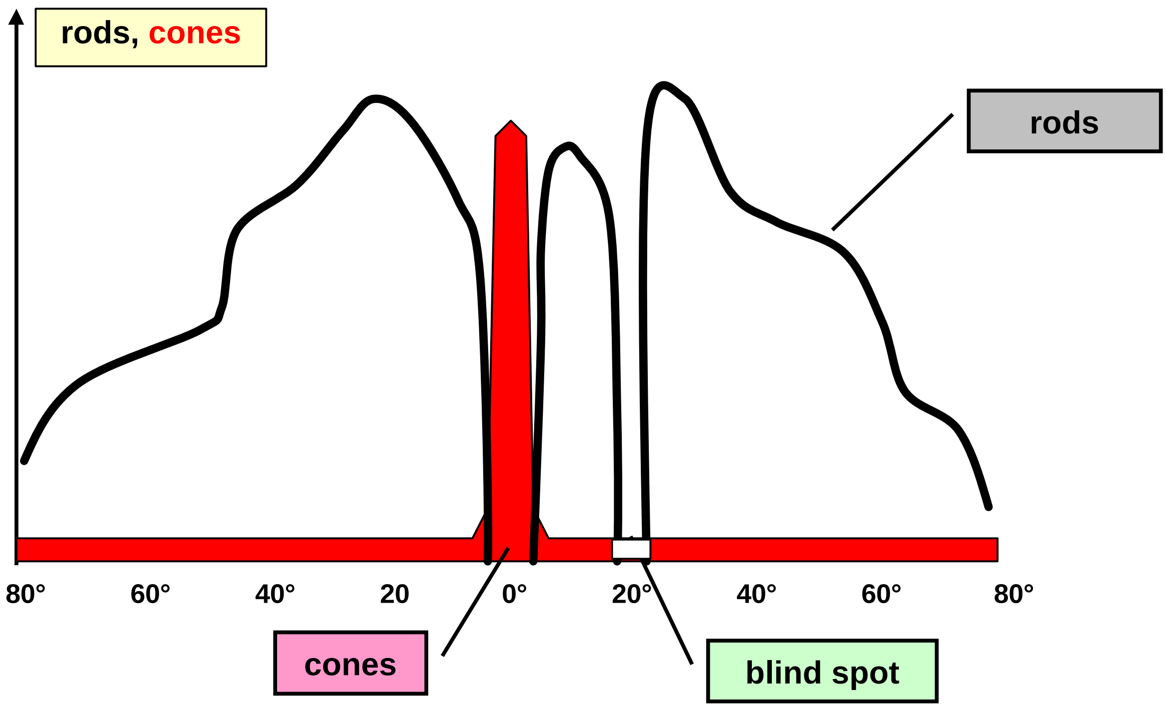


Blind spot: close your left eye and fixate the left aircraft by your right eye moving the page slowly back and forth until the right aircraft disappears

Retina:



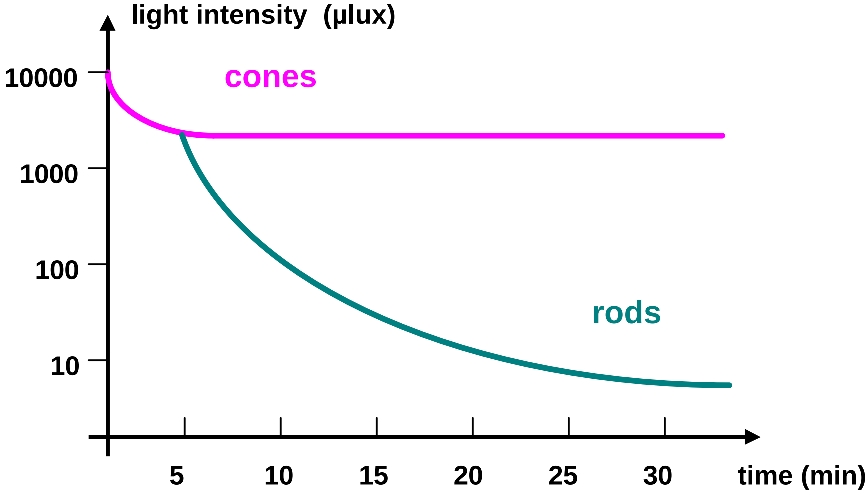
Distribution of rods and cones in the retina:



Visual field: space within which objects are visible to the immobile eye
~ 100° lateral
upward limited by the eyebrow
medial limited by the nose
downward limited by the cheekbone

Dim vision, dark adaptation:

- cones adapt fast but poor
- rods adapt slowly but well



Due to the poor dark adaptation of the cones, there is no color vision at dusk and the fovea centralis is no longer providing a high visual acuity, leaving another "blind spot", the so called central scotoma. To detect objects in dim light, it is obviously necessary to look off-center.

Rods and cones have different spectral sensitivity:

- rods are maximally sensitive to blue-green light of ~ 500 nm
- cones are maximally sensitive to yellow-green light of ~ 560 nm.

Limiting factors for dim vision:

- Hypoxia (above ~ 5000 ft)
- Nicotine (due to toxicity to the nerve cells)
- bright light (e.g. landing lights while waiting before line up)

keep in mind

no nicotine before a night flight

Color sense

3 different classes of cones with different absorption peaks:

- **564 nm red**
- **534 nm green**
- **420 nm blue**

A combination of the three frequencies in appropriate saturation is perceived as white light. By varying the saturation, any desired color can be matched.

Defective color vision:

- **monochromats:** = achromates: no color sensation (~ no cones) completely color blind (1 of 30'000 people). These people have also reduced visual acuity
- **dichromats:** only 2 types of cones
  - **protanopes: no red sensitivity (1 of 100)**
  - **deuteranopes: red an green in the same cone leading to red-green confusion (1 of 100)**
  - **tritanopes: no blue sensitivity (1 of 65'000)**
- **anomalous trichromats: 3 types of cones but poor working:**
  - **protanomalous: require more red stimulation (1 of 100)**
  - **deuteranomalous: require more green stimulation to avoid confusion red-green (1 of 20)!**
  - **tritanomalous: require more blue stimulation (1 of 4'000)**

Defective color vision is inherited as X - chromosome - linked recessive trait (women need two altered X-chromosomes to show the defect).
Thus, many more males show the defect than females, but a father never transmits it to his sons. All daughters of a color blind father have a chance of 50% to transmit the trait to their sons.

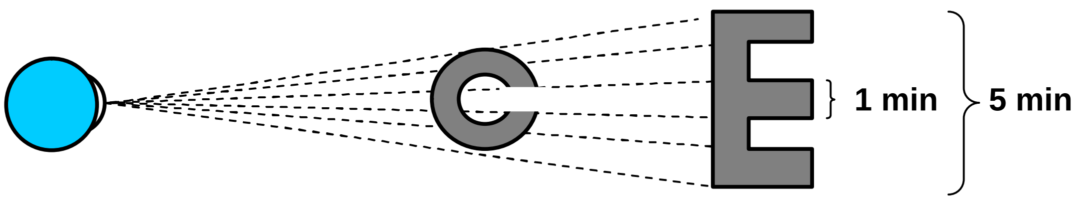
Visual acuity = sharpness of vision

Ability of the eye to perceive shape and details of objects. Visual acuity is measured as the visual angle needed to discriminate two neighboring points. This angle is given by the architecture and the dimensions of the cones at the fovea centralis and is

$\sphericalangle$ = 1 minute of arc

At a distance of 5 m, two points can be discriminated if the respective distance is 1.5 mm
The above visual acuity is defined as 1.0 (USA :20/20, UK: 6/6) and represents the average eye. Young healthy people may have a better visual acuity of 1.5 ... 2.0

Examination of the visual acuity is made by letter test charts, where one bar of a letter equates to 1 minute of arc:

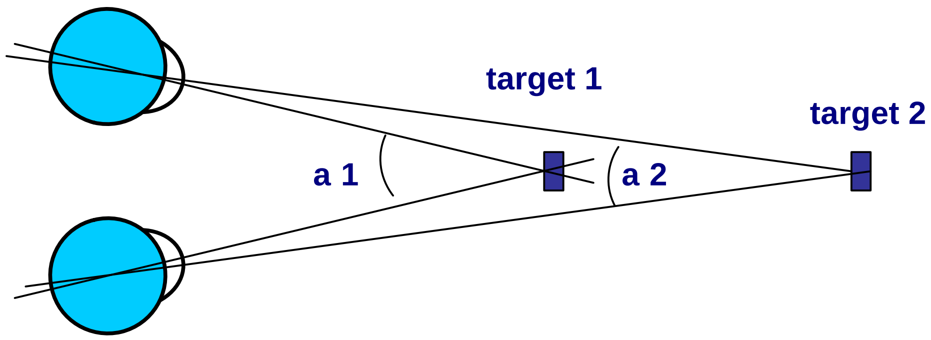


Dynamic visual acuity

If an object moves across the visual field, the eye can track it up to an angular velocity of ~ 30 °/sec without loss of visual acuity. Faster movements result in a rapid decrease of the visual acuity.

Depth perception – binocular versus monocular vision

Focusing a distant target, the eye muscles start moving the eyeball until the two images perfectly match. The angle between the two eye axes is a measure for the distance.



The angle a is the binocular parallax for a given target

Due to the distance between the eyes, the retinal images of the two eyes always differ a little bit. This difference allows us to construct a stereoscopic image

Monocular cues for depth appreciation

- **Parallax:** head movements let targets at different distances change its respective position: a nearer target moves in reverse direction to the head movement
- **Relative size:** the perceived size provides information about the distance
- **Overlapping:** objects that overlap others are closer
- **Perspective:** converging parallel lines (RWY, highways) indicate the depth
- **Color:** objects at greater distance appear bluer due to light scattering

Image processing and reaction time

Time needed for image processing

sensation at the retina	0.1 sec	
focusing	0.3 sec	
recognition and perception	0.7 sec	total 1.1 sec

Time needed for decision and reaction

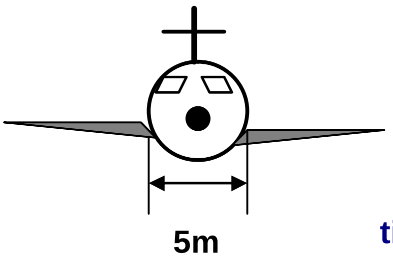
decision	2.0 sec	
motor action	0.4 sec	
course change of aircraft	2.0 sec	total time elapsed 5.5 sec

At a aircraft speed of 360 kts the corresponding distance covered in 5.5 seconds is

0.55 NM ? 1 km

Big problems occur, if two aircraft approach each other head-on. Because of the minimal relative lateral motion, the approaching aircraft is difficult to detect but their is little time to react.

head-on course:



limit of perception (visual ac. 1.0)	9 NM
closing speed	720 kts
time between 1st possible perception and impact	45 sec
total elapsed time to react	5.5 sec
time reserve	39.5 sec
time reserve, perception at double size	17 sec
perception at 3 x size	9.5 sec
perception at 4 x size	6.75 sec

Eye movements

We distinguish two fundamental types of movement:

- **smooth movements to pursuit an object, driven by the vestibular system. These movements serve to stabilize the retinal image during head movements up to a angular speed of about 60°/sec.**
- **saccadic movements (rapid, jerky movements). These movements serve to acquire a target to move it into focal vision or to catch up to a target moving faster than 60°/sec.**

Visual modes

Due to the different receptors of the central and the peripheral part of the retina, we distinguish between two different modes of visual signal processing:

focal mode:

- **used for object recognition and identification**
- **requires high resolution and high intensity of light**
- **best represented in the central visual field (fovea centralis, cones)**
- **usually well aware in consciousness, much attention needed**

ambient mode:

- **used to determine our orientation to surroundings**
- **mediated by stimulation of the peripheral visual field (rods)**
- **low image quality and low light intensity needed**
- **conscious awareness low or frequently completely absent, little attention needed**
- **closely related to vestibular and somato-sensory receptors signaling body orientation and body movement**

In VMC, spatial orientation relies on the outside visual cues and therefore the pilot uses ambient vision. This requires little attention and is very similar to orientation in everyday life. Ambient vision also is highly independent of focal vision, which allows, to fully occupy focal vision, e.g. with the task of reading, while still getting sufficient orientation cues with ambient vision to walk or ride a bike.

In IMC, the pilot controls aircraft orientation by scanning the instruments which needs focal vision, demanding much more attention. Though focal vision provides high quality images, it is less sensitive to movements than ambient vision. Therefore scanning the artificial horizon becomes a very demanding task which has to be learned and trained again and again.

keep in mind

Orientation in IMC absorbs attention due to focal vision

The ear ⇨ hearing and balance (equilibrium)

Anatomy:

outer ear: ⇨ auricle or pinna for localization of a sound
⇨ auditory canal ⇨ transmission of sound

eardrum = tympanic membrane: separates the outer from the middle ear

middle ear: ⇨ 3 ossicles: hammer (malleus), anvil (incus) and stirrup bone (stapes)
⇨ aero-hydraulic transducer, converts the sound wave of the eardrum (air) into a sound wave of the oval window (fluid in the inner ear)
⇨ vented to atmosphere via a tube (Eustachian tube), which connects the middle ear to the pharynx allowing equalization of the air pressure

oval window: separates the middle ear from the inner ear

inner ear: ⇨ complex system of canals filled with fluid (endolymph), housing
⇨ cochlea: a snail shaped cavity, containing the sense cells of hearing
⇨ 2 otolith organs (linear acceleration)
⇨ 3 semicircular canals (angular acceleration)

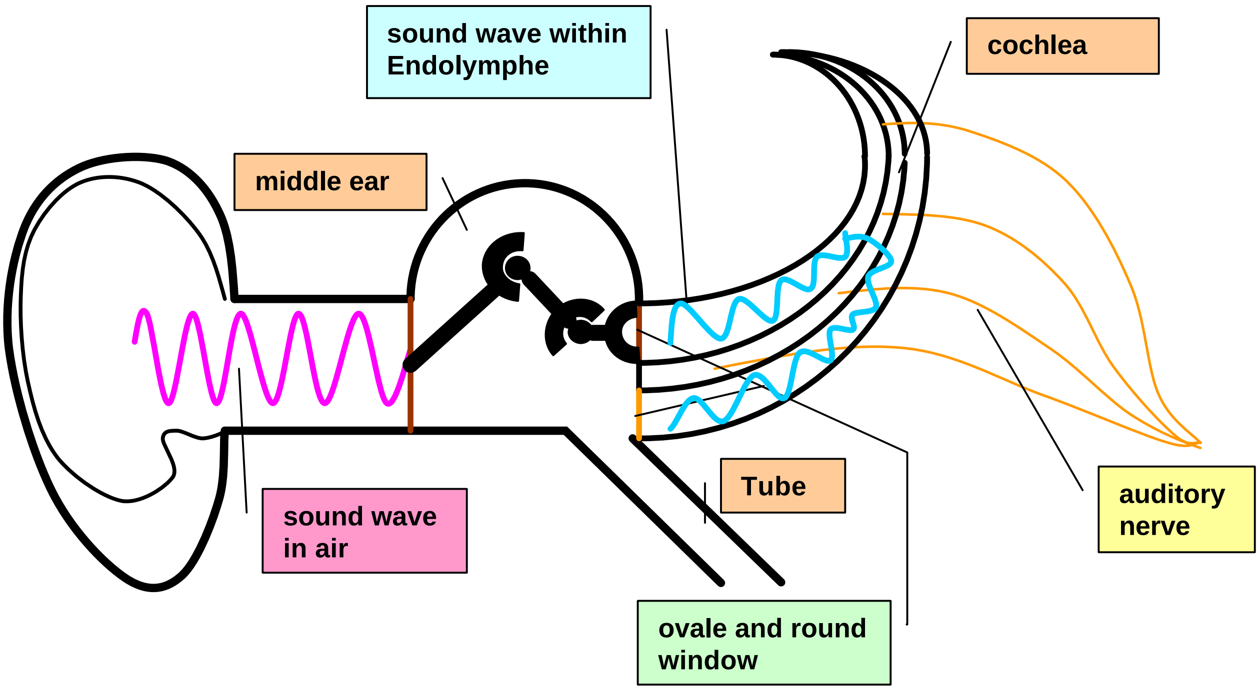
Equalizing pressure

The middle ear constantly uses air. Without replacement of the air, the pressure within the middle ear drops, causing the eardrum to deform which leads to an impaired function of this sound membrane. Under normal circumstances, the air periodically is replaced through the Eustachian tube (yawning, swallowing, working the lower jaw).

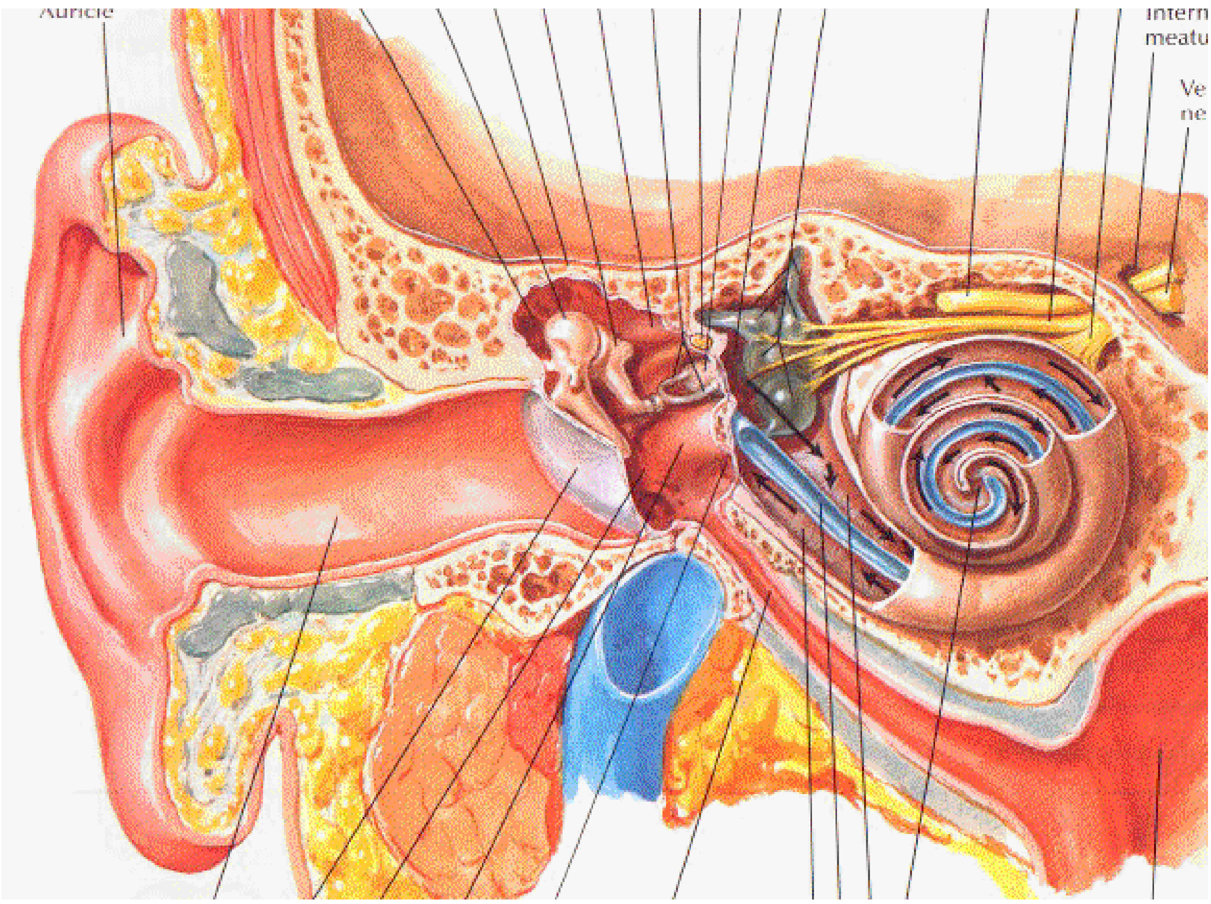
During a cold or a flu, the mucous wall of the Eustachian tube is swollen and doesn't allow air to pass. This causes an impaired hearing, especially for higher frequencies. Rising the oral pressure by means of a forced exhalation with a closed mouth and nose, sometimes opens the Eustachian tube and lets equalize the pressure (Valsalva maneuver).

As the pressure decreases during climb, air easily passes through the tube to the throat. During descent, the Eustachian tube tends to remain closed, especially with a cold or flue, causing severe pain.

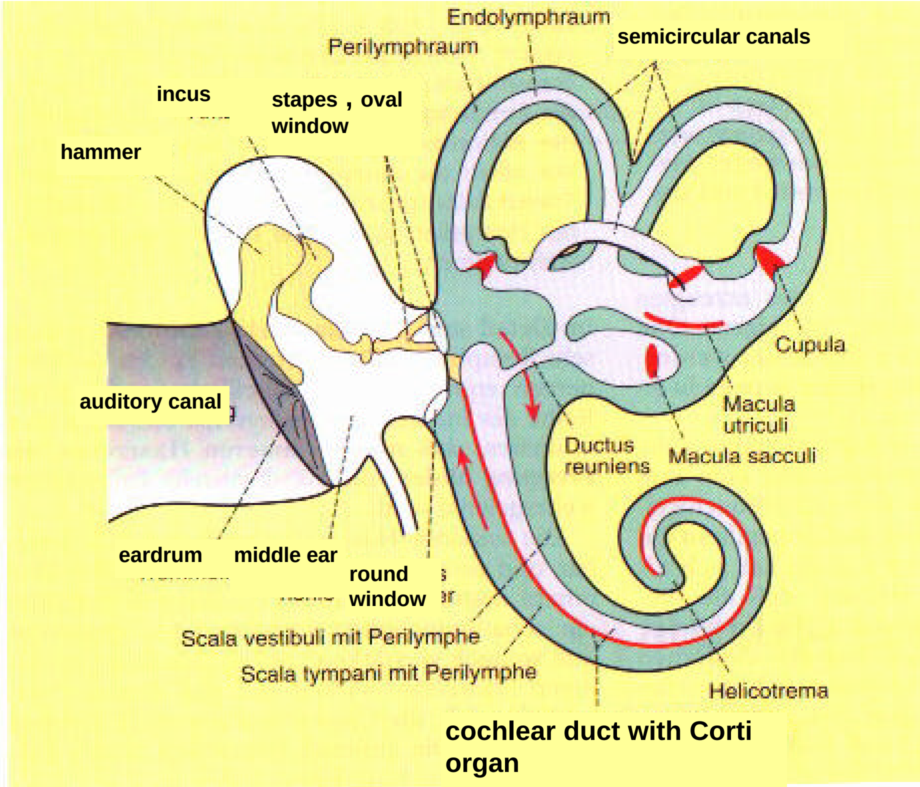
Functional diagram of hearing



Anatomy:

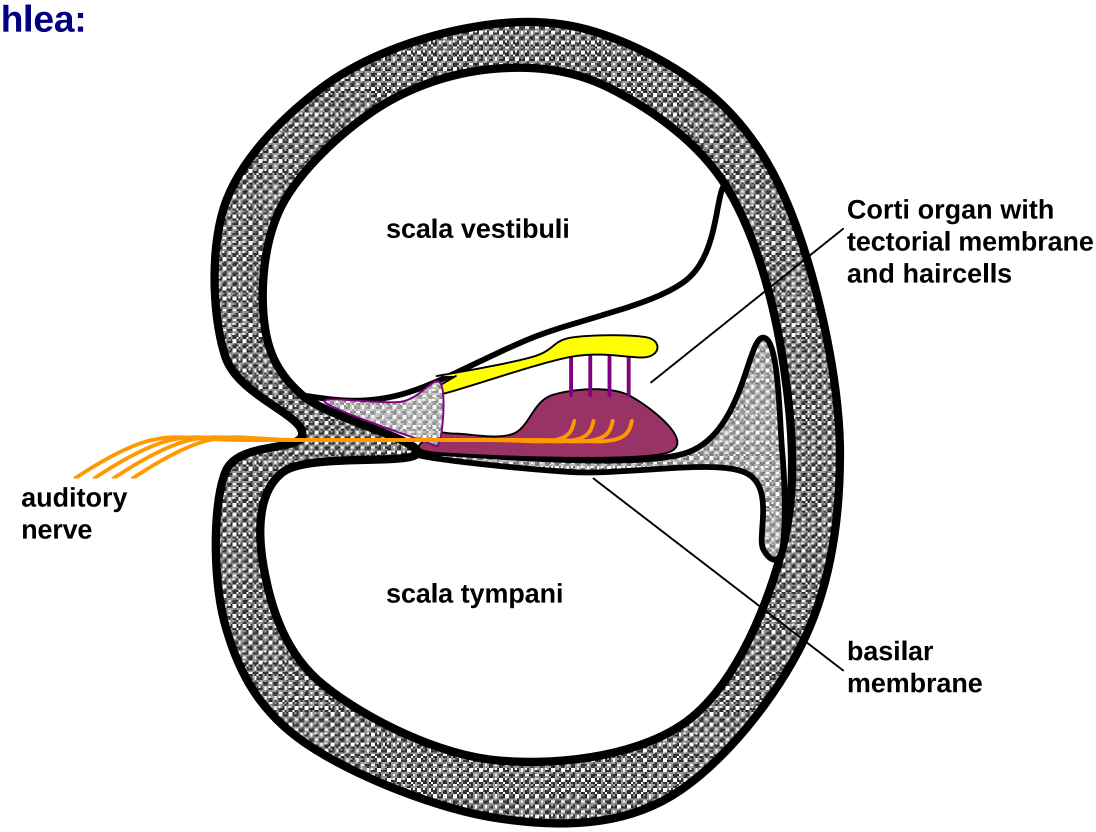


Cochlea and semicircular canals

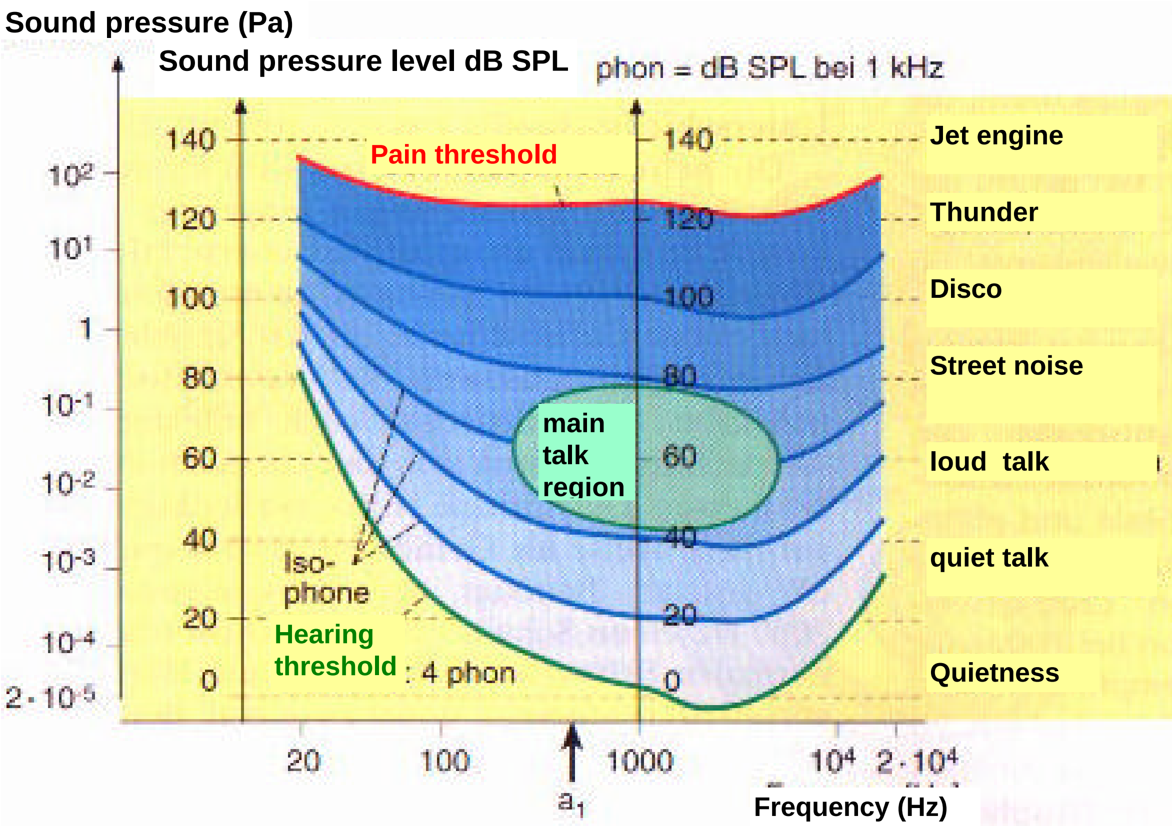


(picture from Golenhofen: Physiologie, Urban & Schwarzenberg 1997)

cross section of the cochlea:



Sound pressure level



Hearing disorders

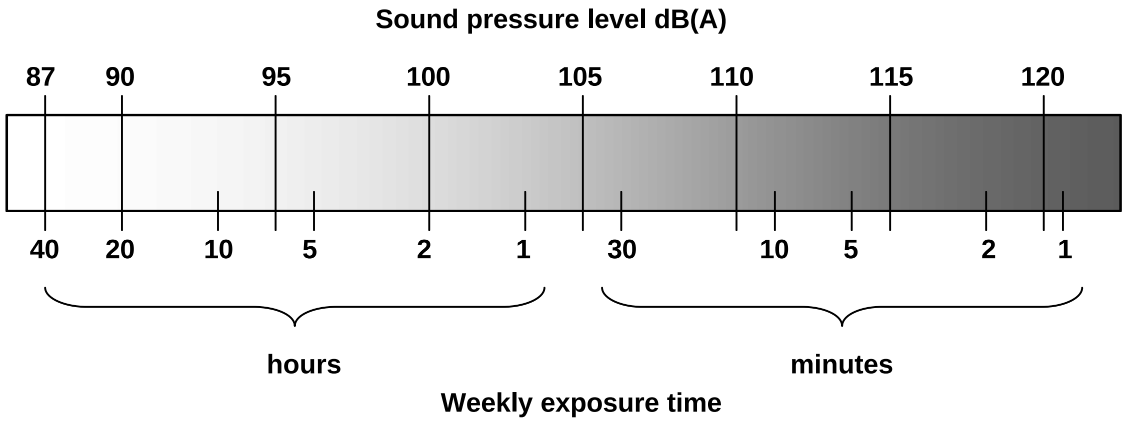
main causes:

- **conductive deafness**
  Impairment of the sound transmission system in the middle ear (due to ear wax, failure of the eardrum, poor mobility of the ear ossicles ...)

- **noise induced hearing loss (NIHL):**
  Continued exposure to sound pressure levels above 85 dB for more than 8 hours can impair hearing, causing symptoms like
  - **tinnitus (ringing or whistling in the ears)**
  - **reduced sensitivity to sound (temporary threshold shift)**
  - **partial deafness**
  - **permanent deafness (permanent threshold shift)**

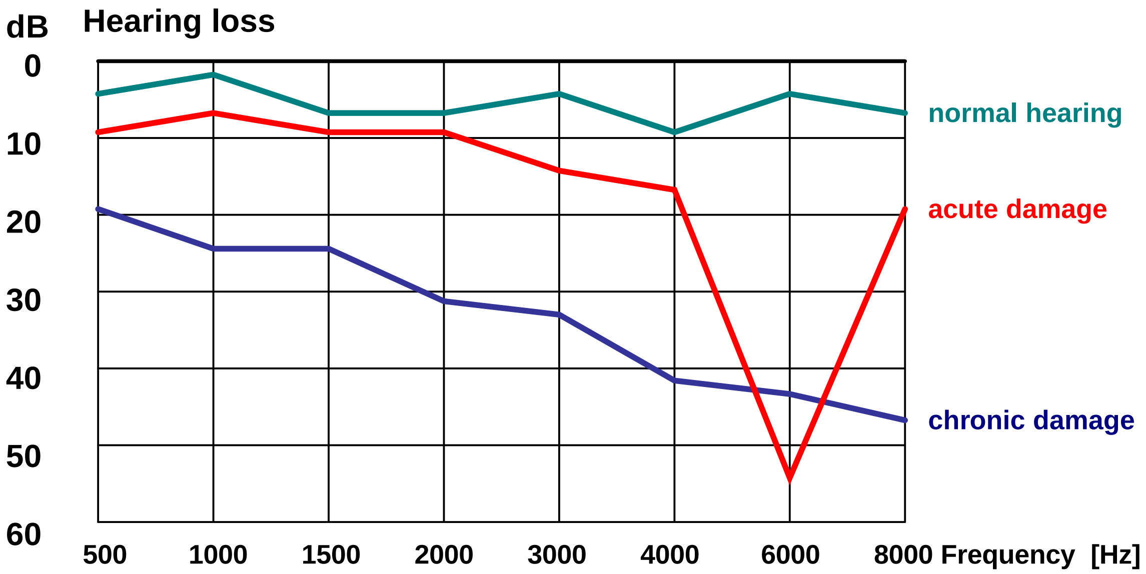
- **Presbyacusis: gradual loss of high frequency sensitivity with aging.**

NIHL is highly dependant from exposure time and sound pressure level (SPL). The weekly acceptable elapsed SPL can be estimated by the following diagram (referring to music sound, Cercle Bruit Suisse 1998):



Individuals vary greatly in their susceptibility to hearing damage. But, once harmed, hearing is more susceptible than before!

Typical audiograms of hearing loss:



Protection to prevent hearing loss ⇨ ear defenders:

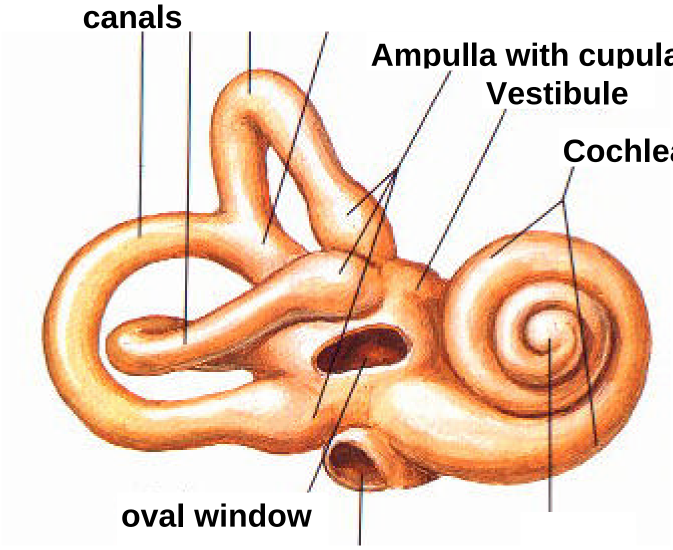
- **ear plugs (sound absorbent material, small, attenuation ~20 dB**
- **ear muffs (close fitted cups, attenuation up to 40 dB)**
- **active noise canceling headset**

keep in mind

always use ear defenders in noisy environment

Vestibular apparatus – organ of equilibrium

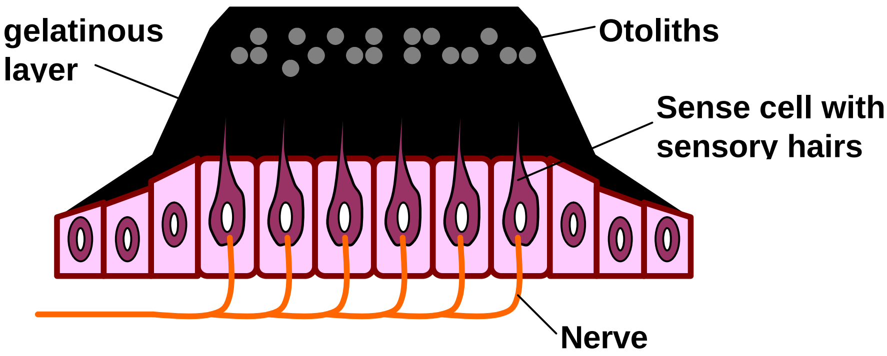
- ~ the size of a pea, firmly embedded in the hardest bone of the skull (petrous temporal bone)
- membranous labyrinth, filled with endolymph (a watery fluid), surrounded by perilymph (between membrane and bone)
- connected to the cochlea
- divided into two parts
  - sac-like utricle and saccule, housing the otolith organs which detect ⇨ linear acceleration
  - the 3 semicircular canals containing the receptor cells for ⇨ angular acceleration



the membranous labyrinth

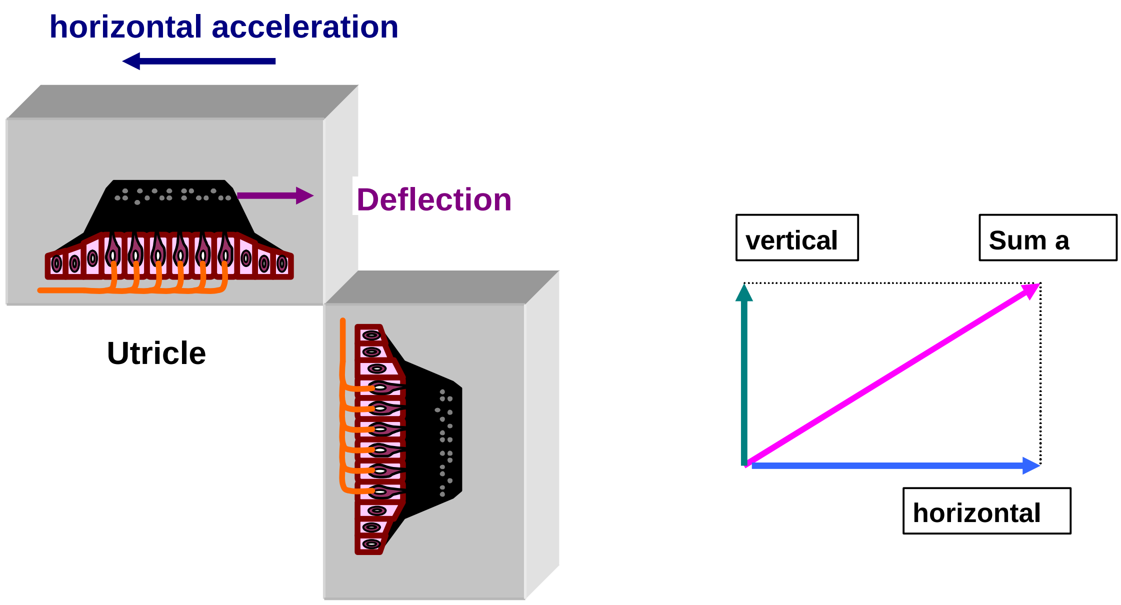
Otolith organs:

Endolymph filled sacs, containing the macula, special areas of sensory cells with hair-like projections, covered with a gelatinous layer invested with small calcium carbonate crystals (otoliths). If the macula is accelerated, due to inertia, the gelatinous layer is deflected, bending the hair-like projections, which triggers the nerve signal of the sensory cells



Macula

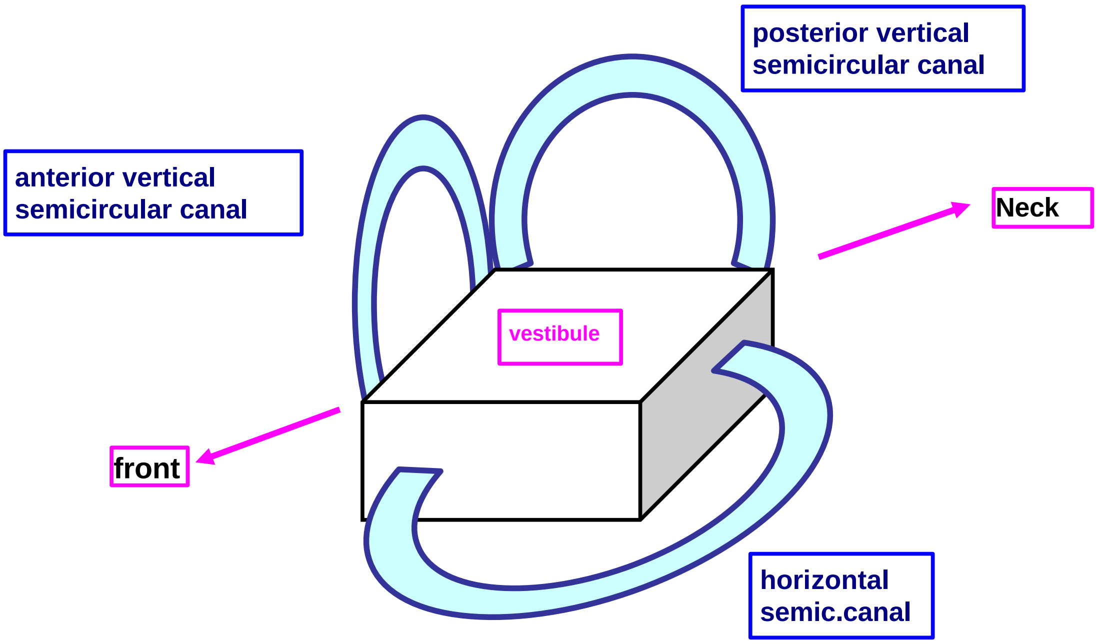
Any linear acceleration can be divided into a horizontal (utricle) and a vertical (saccule) vector. The brain calculates the sum vector which provides the perception of the original acceleration.



Semicircular canals ⇨ angular acceleration

- a horizontal semicircular canal
- an anterior vertical semicircular canal
- a posterior vertical semicircular canal

The three semicircular canals form a system in the three planes, each canal being perpendicular to the others. Thus any acceleration can be perceived.



Sensory threshold for angular acceleration:

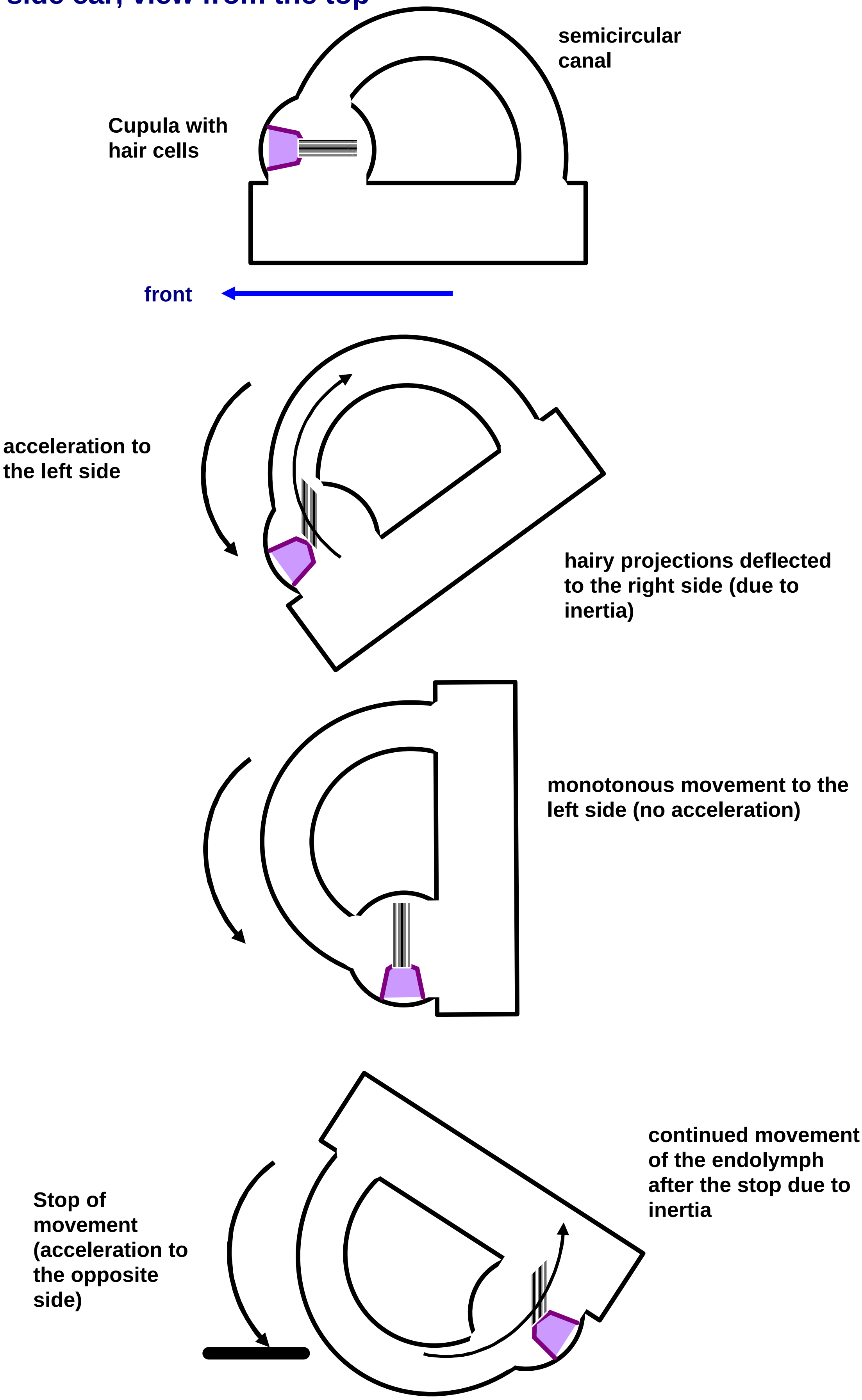
~ 1 ° / sec^2

slower accelerations are not perceived

keep in mind

Otolith organs and semicircular canals perceive accelerations, monotonous (steady state) movements are not recognized.

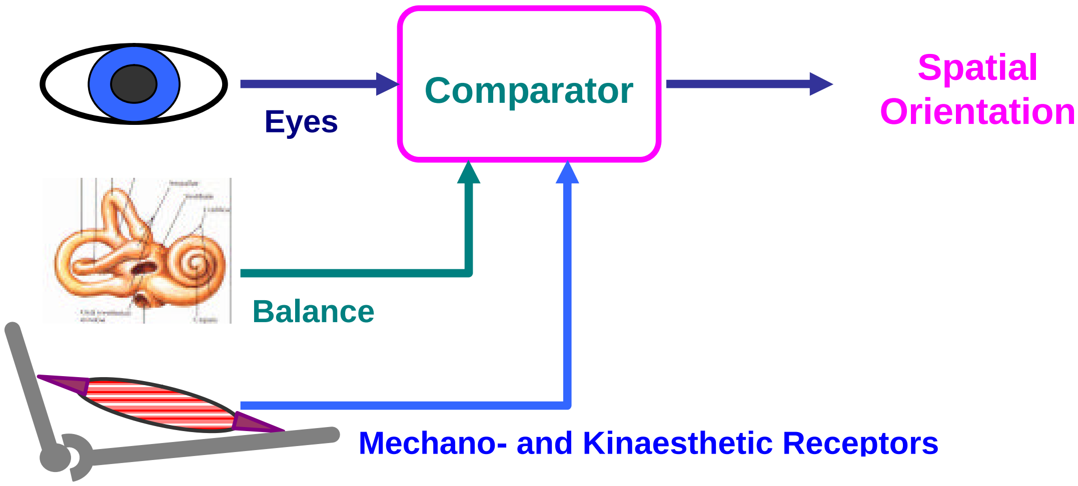
right side ear, view from the top



Spatial Orientation

⇨ **complex interaction of multiple sensory inputs:**

- **cones and rods of the retina**
- **sensory cells of the otolith organs and the semicircular canals**
- **kinesthetic receptors of skin, joints, muscles, tendons, ligaments and supporting tissue**



Primary sense organ to guarantee spatial orientation

- **Eyes (continuous = proportional perception)**

Backup system and support

- **Balance (otolith organs and semicircular canals, differential perception!)**
- **Mechano- and kinaesthetic receptors**

There is no doubt, that the visual system is of prime importance in spatial orientation due to its continuous, proportional perception. The other available sensory cells provide supporting cues for cross-checking. These perceptions are quite reliable, as long as we stay or move on earth. However, in the flying environment, their differential operation can contribute to spatial disorientation.

Attention Resources and Visual Mode

In everyday life, ambient vision is responsible for guaranteeing orientation, using little attention. VMC is very similar to everyday life, as long as we actually look out of the window.

In IMC, where the peripheral cues of the retina no longer contribute to orientation, problems can be expected. Though it is still the visual system that provides spatial orientation, we now use focal vision for scanning the instruments, absorbing a great amount of attention.

In everyday life, the sensory inputs of the different sense organs usually match, which guarantees a correct perception of the spatial orientation. Under special conditions, especially in the flying environment, the sensations of the different sense organs mismatch, resulting in an incorrect perception of the spatial orientation, a situation called illusion. According to the primarily responsible sense organ, we distinguish visual from vestibular illusions.

Spatial disorientation can occur if either

- erroneous sensory information is transmitted to the brain (input error: false external cues, malfunctioning instruments, impaired vision, G-excess, ...)

or

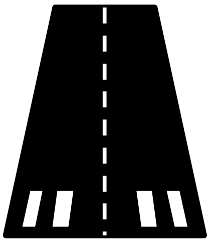
- correct sensations are erroneously perceived by the brain (central error: focusing of attention, inaccurate expectancy, stress, ...)

Visual Illusions = optical Illusions

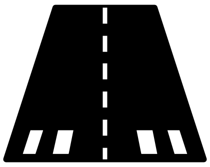
- ### geometric perspective illusion

  During flight training we get accustomed to the size and shape of the runway and the changing perspective as the aircraft approaches on a typical glide path. An approach on a unfamiliar airport can cause typical illusions, as we apply our common retinal runway image to the unfamiliar runway

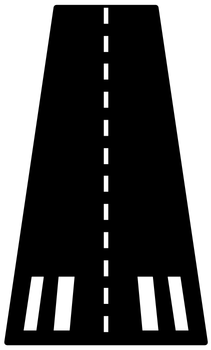
  - **Runway slope**



horizontal RWY
Approach correct

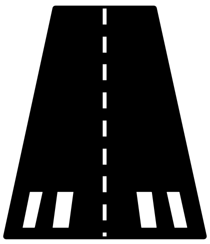


downsloping RWY
Approach too high

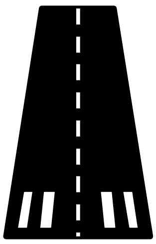


upsloping RWY
Approach too low

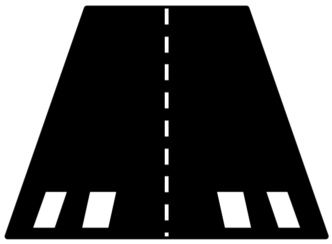
  - **Runway width**



accustomed RWY
Approach correct



narrower RWY
Approach too low



RWY wider
Approach too high

- ### Empty field myopia

  Tendency for the eye to focus at a distance of about one meter when looking at a visually non stimulated field. This accommodation makes perception of a distant object very unlikely.

- ### Flicker Vertigo

  The disruptive, annoying psychological effect of cyclic visual stimulation of ~ 10...15 cycles per second (created by helicopter rotors or idling propellers)

- ## false horizon illusion

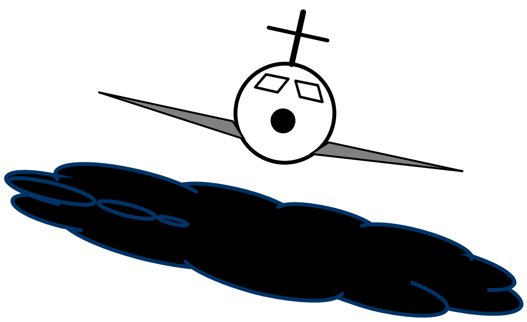
Misinterpretation of sloping ambient cues as horizon, leading to a dangerous attitude, as the pilot attempts to align the aircraft with the misperceived horizon. Common examples are:

sloping cloud decks

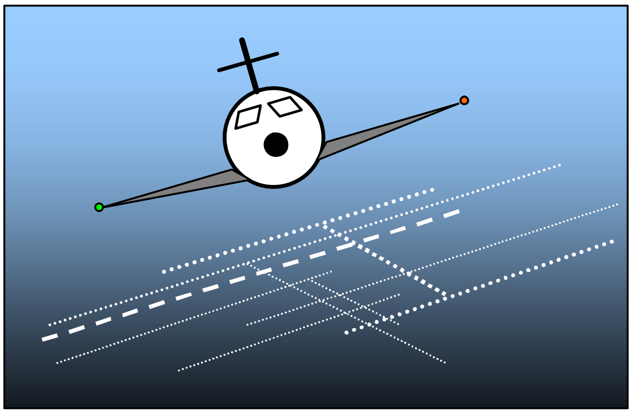
lights of a city at night (especially cities built on sloping terrain)

shore lines

isolated ground lights appearing as stars (boats on dark water, houses on an unlighted terrain)



sloping cloud deck



lights of a city, built on sloping terrain

keep in mind

always check the instruments while flying at night or on top of clouds

- ## Autokinesis

A small, dim light seen against a dark background seems to move after 6 to 12 seconds of fixating on the light. Autokinesis can cause the pilot to mistake a stationary ground light or a star for an other aircraft and then try to intercept or join up with it

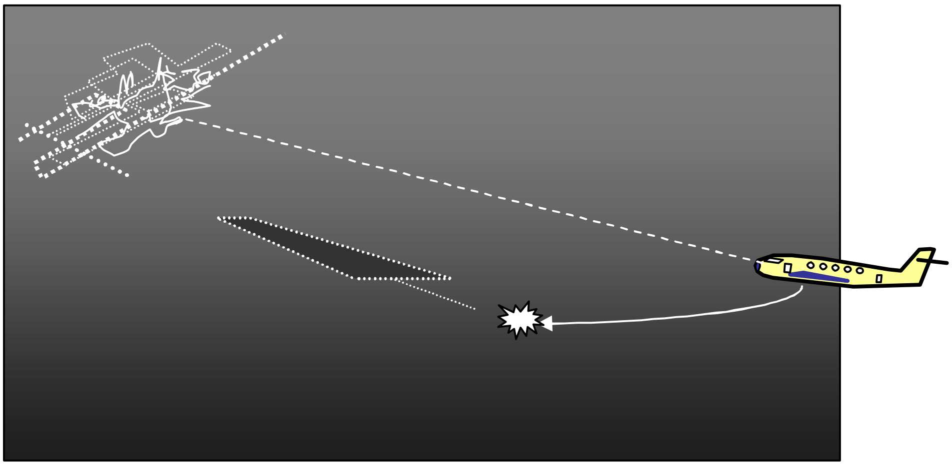
- ## Modification of aerial perspective

Atmospheric conditions (fog, haze, rain, snow, smoke) reduce the brightness of lights. Under such conditions, lighted structures such as runways, aircraft, highways..., therefore, appear farther away then in clear air. A preceding aircraft flying into a shallow fog or haze can appear to move away (a problem especially occurring in formation flight).

- ## Black-hole and whiteout approach

Absent ambient cues as experienced during an approach on a dark night over water or over featureless terrain to a runway beyond which the horizon is indiscernible, can create considerable difficulty for the pilot. When only the runway lights are visible, the pilot tends to feel, that the aircraft is stable and positioned appropriately, but that the runway is moving or remaining mispositioned.

A black-hole approach is particularly dangerous if it is combined with the distant lights of a city on rising terrain in the background. The pilot tends to misinterpret the city on a flat terrain and adjusts the glide slope with the lights of the city, resulting in an approach far too short of the runway.



Black-hole approach

Identical problems can occur, when an approach is made over snow covered ground merging with a white overcast or in blowing snow conditions. Both cases are called whiteout and occur under visual rather than instrument conditions. Even if visibility is unlimited in the first example, orientation can be very difficult. The second example often occurs when helicopters create blowing snow conditions during landing

keep in mind

during black-hole or whiteout approaches, always keep a close eye on the instruments

Vection Illusions = Visual Illusions of motion

Looking at a moving external object can create the illusion, that the person moves while the object seems to be stable. This type of illusion is very common in everyday traffic and often responsible for "fender benders". Some people distinguish circular vection (erroneous perception of rotation) from linear vection (erroneous perception of linear movement). Vection illusions are used to create the perception of flying in full motion flight simulators.

Kinesthetic Illusions

Erroneous perception of somatosensory stimuli to the ligaments, muscles or joints of the body

- ### G-Adaptation Illusion

The perception that motion has ceased after continued exposure to sustained velocity (because of the differential character of most sensory receptors). For example, movement in an elevator is only perceived at the beginning and end of the ascent or descent.

- ### G-Differential Illusion

The perception of aircraft attitude based on "seat of the pants" sensations. For example, without other sensory inputs, a 30-deg-bank level turn gives the same "seat of the pants" sensation as a 60-deg bank turn

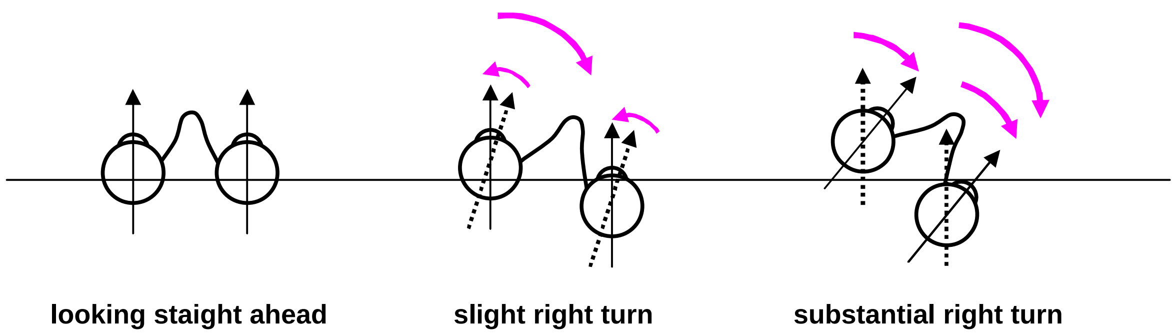
Vestibular Illusions = Illusions of the sense of equilibrium

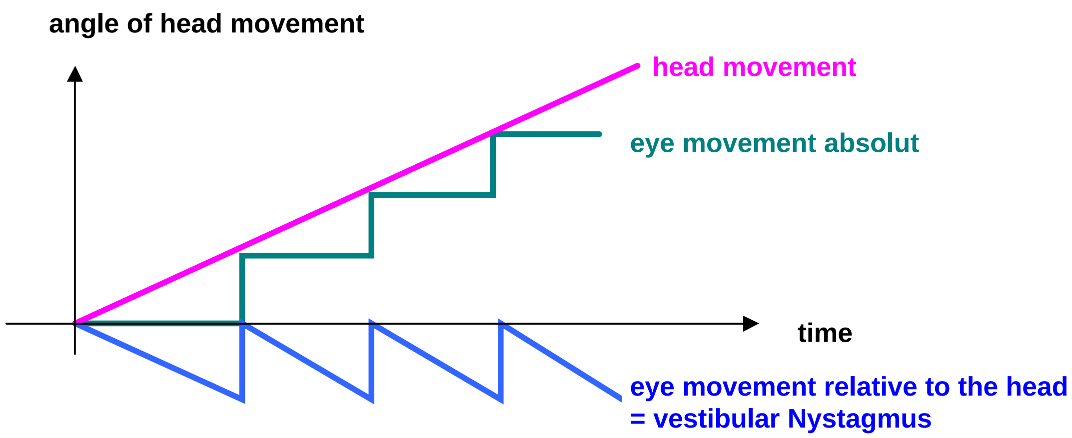
The main function of the vestibular apparatus is to maintain equilibrium. Usually, this task is achieved automatically without willed control.

An important part of the maintenance of equilibrium is to stabilize the retinal image of the outside world when the head moves. This vestibular reflex controls the eye muscles in a way, that any small movement of the head causes a compensatory movement of the eye in the opposite direction. Without this vestibular stabilization, humans would not be able to see clearly or resolve fine visual detail when walking around, running or exposed to vibration or turbulence.

Nystagmus

When the head is turned, the eyes move reflexively in the opposite direction. After a deviation of about 10° from their initial position, the eyes quickly flick in the direction of the head movement and start another compensatory movement. The result is the characteristic vestibular Nystagmus, an eye movement containing of a slow movement opposite to the direction of the head movement and a fast movement in the direction.





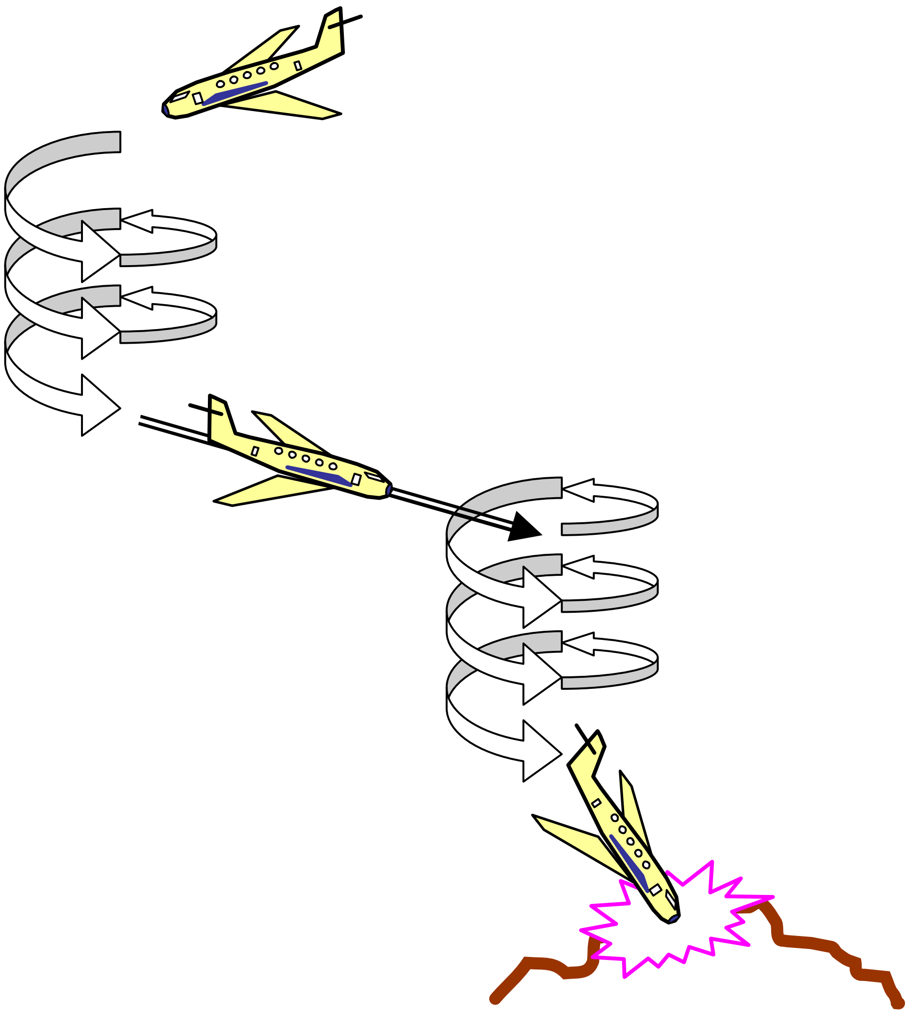
Examples of vestibular illusions:

- ### Somatogyral illusions:

  An erroneous perception of rotation (or that rotation has ceased). Somatogyral illusions result from the inability of the semicircular canals to accurately register a prolonged rotation due to the differential perception of the semicircular ducts.

  - ### Graveyard spin / graveyard spiral

    After several turns of a spin, the perception of spinning is gradually lost. When the pilot tries to stop the spin, she/he experiences the perception of spinning in the opposite direction. The correction of this resulting somatogyral illusion makes the pilot to reenter the original spin.



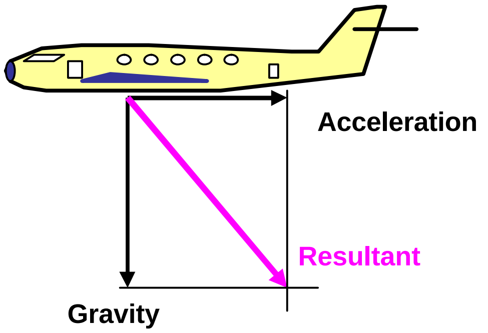
- ## Oculogyral illusions:

When a prolonged turn stops, the nystagmic eye movements cause a movement of the perceived visual scene. The visual scene seems to turn around in the direction of the original turn. Without well defined external visual cues, this illusion may persist for many seconds or even minutes.

Oversimplified one could say that the oculogyral illusion is the visual correlate of the somatogyral illusion

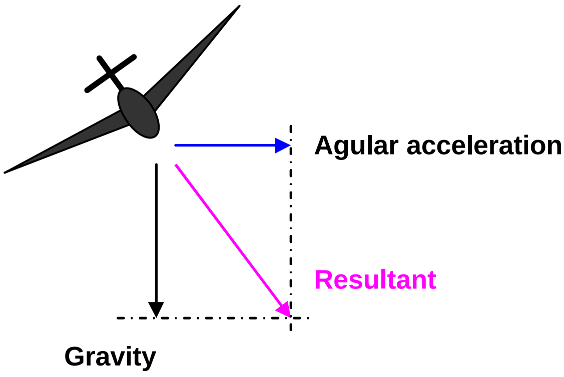
- ## Somatogravic illusions:

A false perception of body tilt that results from perceiving the direction of a nonvertical gravitoinertial force as vertical. Gravity is a linear acceleration and we are used to perceiving gravity as vertical. If an additional linear acceleration is applied, pilots tend to misinterpret the resultant vector as vertical acceleration.



A well known example of somatogravic illusion is the perception of pitching up after taking off into conditions of reduced visibility or into clear sky (take off from a carrier)

Somatogravic illusions also can occur in a turn and lead to a false perception of attitude. E.g. in a coordinated turn, the pilots equates the resultant force (gravity and radial acceleration of the turn) with the vertical and, therefore, has no perception of the bank attitude.

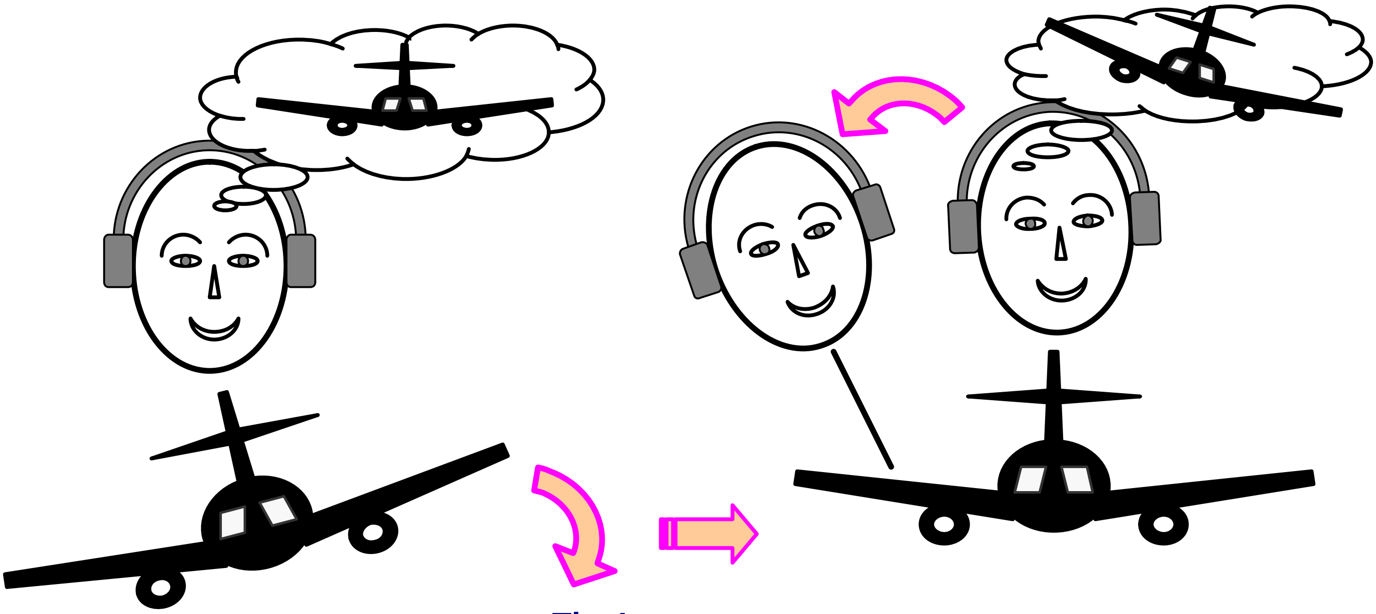


- ## Oculogravic Illusions:

Visual correlate of the somatogravic illusion. E.g. if speed brakes are applied, pilots can perceive a nose down attitude as somatogravic illusion. The corresponding oculogravic illusion is the perception of the instrument panel moving downward.

- ## The leans

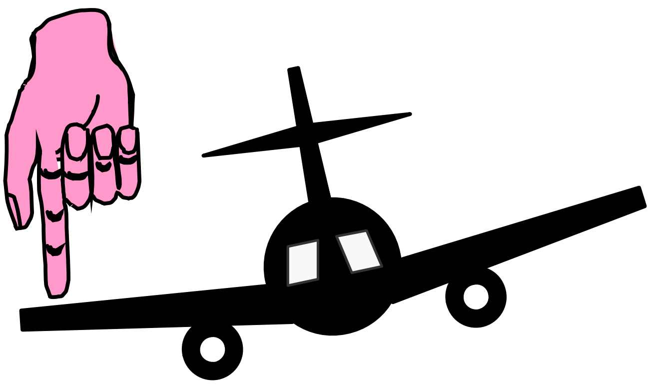
The most common vestibular illusion is the leans, a false perception of roll attitude. Pilots experience the leans after recovery from a subthreshold angular acceleration (undetected by the semicircular ducts) followed by a more abruptly (transthreshold) correction maneuver. Due to the un-perceived subthreshold banking, the pilot has the illusion to be in level flight. After the well perceived correction maneuver, she/he perceives a change in roll attitude, resulting in an erroneous perception of banking away from the level attitude. In an attempt to align head and trunk to his perceived vertical, the pilot leans to the side of the initial bank.



The Leans

- ## Giant hand illusion:

The erroneous perception, that controls will not respond properly to inputs because every time the pilot tries to bring the aircraft to the desired attitude, it seems actively to resist the pilots effort and fly back to another, more stable attitude. The pilot may feel a force, like a giant hand, trying to push one wing down and hold it there.

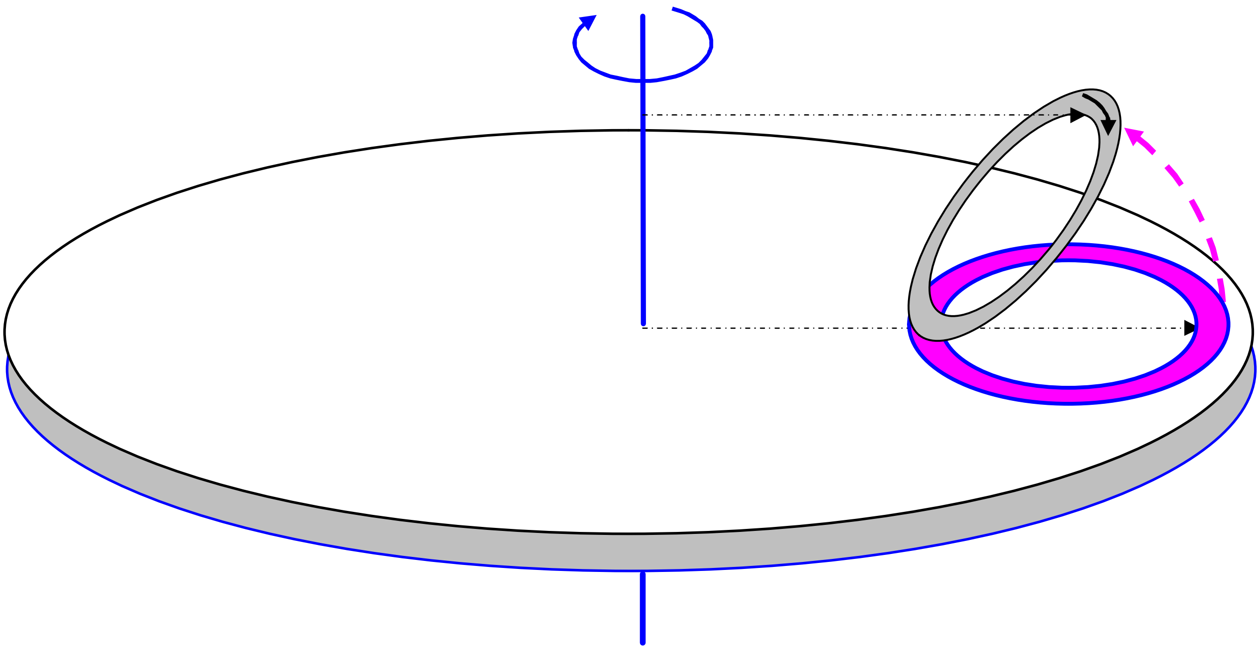


- ## Corriolis Illusion

After a prolonged rotation of a semicircular canal in its plane, the endolymphe doesn't move relative to the head, the cupula is in its resting position and therefore no acceleration is perceived. If the pilot then moves her / his head out of the plane, the endolymphe starts moving, due to a change of the radius, causing a sensation of angular acceleration in the original plane.

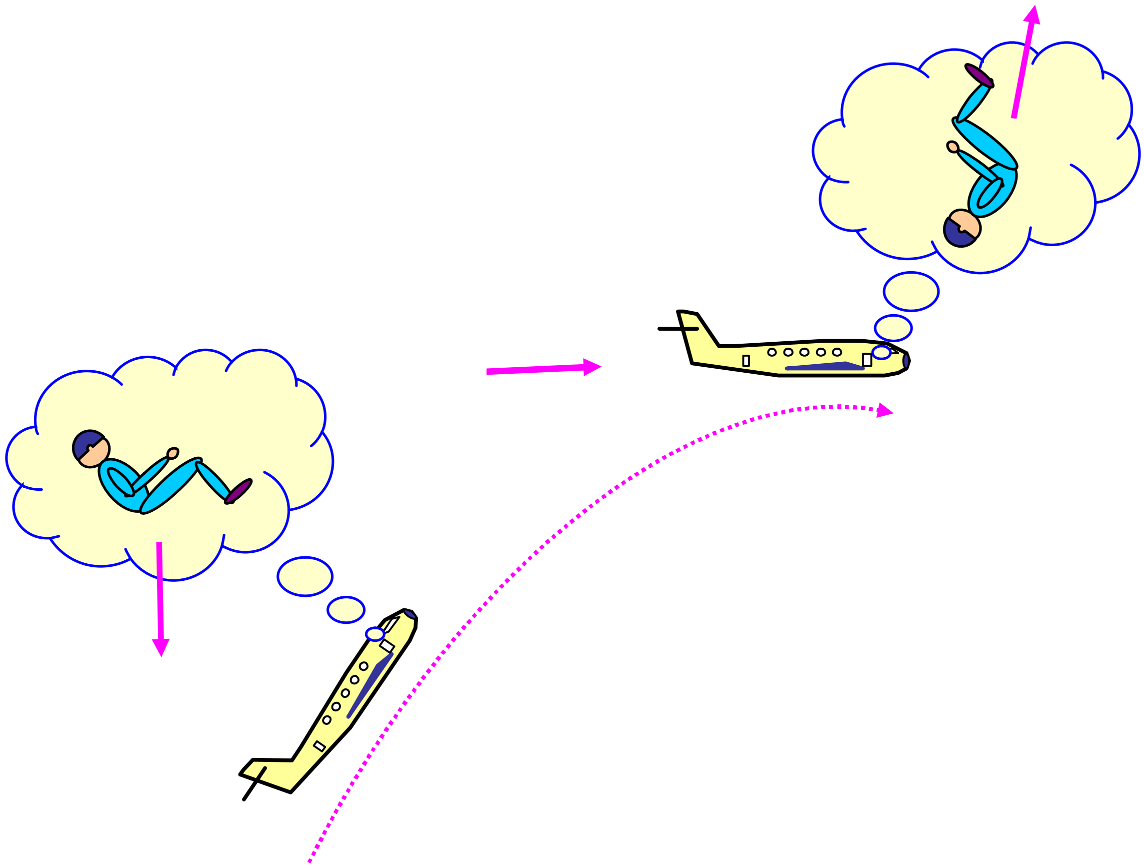
Since the perceived angular acceleration starts a nystagmus to synchronize the eye movement with the (erroneously) perceived head movement, the result is a vertigo.

Common examples are lowering the head in a prolonged turn, turning the head to look out for traffic during prolonged level off....



- ## Elevator or inversion illusion

An erroneous sensation of pitch-up after level off from a steep climb or when in turbulence. The inversion illusion is a type of somatogravic illusion which occurs during a level off after a steep climb.The gravity and the inertial force due to the deceleration combine to a gravitoinertial force vector, which rotates backwards, giving the pilot the illusion to be upside down in the air.



Inversion illusion

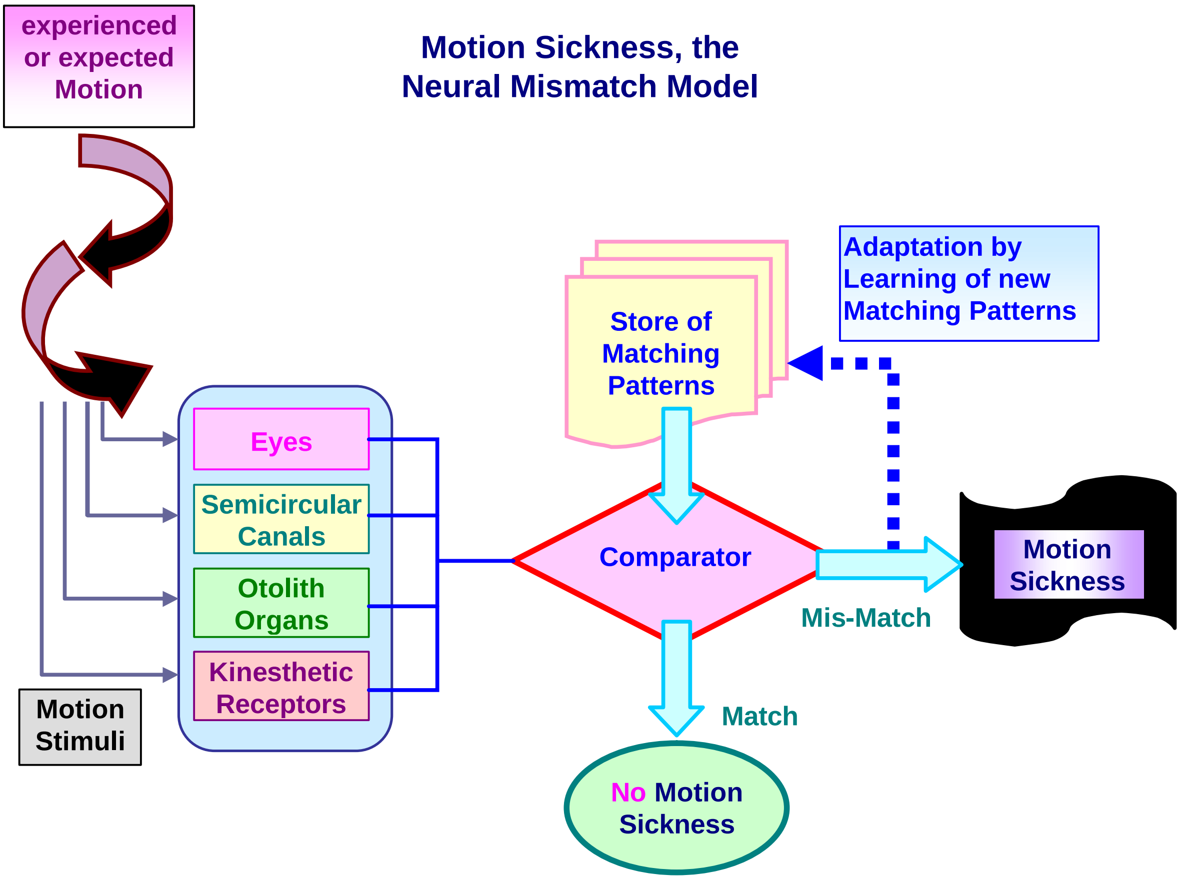
Motion Sickness

Orientation in everyday life is guaranteed by the visual stimuli supported by vestibular and kinesthetic information. In the natural environment, that is when sitting, standing, moving around on the ground or even jumping, the visual and the vestibular / kinesthetic perception match. Within the flying environment, we experience a lot of situations, where visual and vestibular / kinesthetic perception don't match, often due to the differential perception of the angular motion or the differential mode of skin, muscle and joint receptors. The resulting mismatch creates vestibular illusions and can lead to motion sickness.

According to continued experience, the nervous system seems to form a model of matching visual, vestibular and kinesthetic stimuli, associated with body movement. To experience motion sickness, there must be not only a conflict between the sensory stimuli, but between expected and actually perceived sensation.

Unfamiliar motions, producing conflicting sensory stimuli, for which no matching pattern exists, are therefore prone to cause motion sickness.

Repeated exposure to the same unfamiliar motion stimulates adaptation of the store of matching patterns.



Depending on the environment, motion sickness can occur as air sickness, sea sickness, car sickness, simulator sickness, space sickness...

Signs and Symptoms of Motion Sickness

cardinal symptom:	**nausea**
cardinal signs:	**pallor, cold sweating, vomiting**
early symptoms:	**stomach awareness (discomfort), sighing and yawning, increased salivation, drowsiness.**

Typical situations, where motion sickness is common:

- **Reading during a car ride or on a ship**
- **Flying in turbulent IMC**
- **Head movements during a prolonged turn**

Factors influencing susceptibility to motion sickness

- **Alcohol**
- **Medication**
- **Anxiety, apprehension**
- **Shortness of sleep**
- **Infectious diseases, fever, ...**

Prevention of Motion Sickness

- **reducing head movements to an absolute minimum**
- **fixing distant stable visual cues (in VMC)**
- **sitting near the center of gravity of the aircraft**
- **venting fresh air**
- **concentrate attention and mental force on some task**
- **eating small meals (low fat and low protein), drinking cold water**
- **drugs against motion sickness (passengers only!)**

keep in mind

**Motion sickness is a normal reaction,
only subjects without a functioning vestibular system don't suffer from motion sickness**

Pressure change and body cavities

A change of environmental pressure as during climb, descent or sudden loss of cabin pressure has considerable effects on gas-filled cavities within the body. The effects depend on whether the cavity is open, semi-closed or closed.

Open cavities:

Nose, outer ear

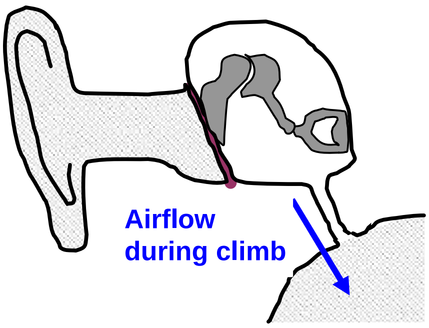
Pressure equalization immediately

Semi-closed cavities:

Middle ear, paranasal sinuses

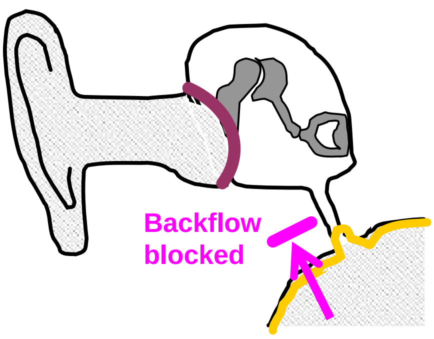
One-way valve mechanism, allows air to escape during pressure decrease, while the back flow of air during descent is partially or completely blocked

Middle ear:



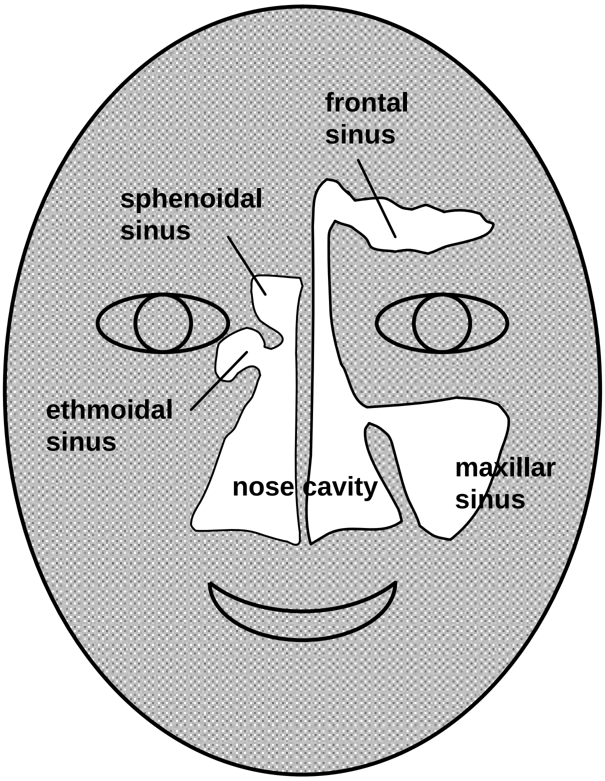
During climb, air escapes along the Eustachien tube into the throat.

During descent, air flows back into the middle ear every time the Eustachien tube opens, which usually occurs when swallowing, yawning or moving the jaw or by the Valsalva maneuver.



Having a cold or a flu, the mucous membranes of the throat and tube are swollen and obstructed with mucus, thus preventing the pressure equalization. Due to the higher ambient pressure, the eardrum is pushed into the middle ear, causing severe pain, partial hearing loss and even vertigo.

Paranasal sinuses:



Frontal, maxillary, sphenoidal and ethmoidal sinus at both sides

In a healthy subject, air communicates easily between the sinuses and the nose. If the mucous membranes become inflamed and edematous, as during a cold or flu, the connecting openings get obstructed, thus preventing pressure equalization.

Due to the one-way valve mechanism, the back-flow of air during descent is particularly susceptible to obstruction. The pressure gradient causes severe pain, sometimes even bleeding into the sinus (hemorrhage, barosinusitis).

Lungs:

Pressure change usually does not affect the ventilation of the lungs, because the airways are wide open, providing rapid airflow for pressure equalization

Only during explosive decompression or in a subject suffering from an airway disease like asthma, problems may occur

Closed cavities:

Alimentary tract:

Stomach and intestines contain gas bubbles (swallowed air, gas forming food, carbonated drinks).

During climb, the gas bubbles expand and may cause abdominal discomfort and pain. Under normal conditions, the gas escapes through natural pathways (oral or anal). Severe problems only occur during rapid decompression.

To prevent abdominal problems avoid gas forming food (beans, peas, cauliflower, cabbage, whole grain food) and carbonated drinks!

Teeth:

Trapped air under a filling of a tooth or air produced by bacteria in an apical tooth abscess may cause severe pain when expanding during a climb. This symptom is called barodontalgia or aerodontalgia.

Keep in mind

> middle ear and paranasal sinuses are susceptible to descent
> intestinal gases or trapped air in a tooth are susceptible to climb

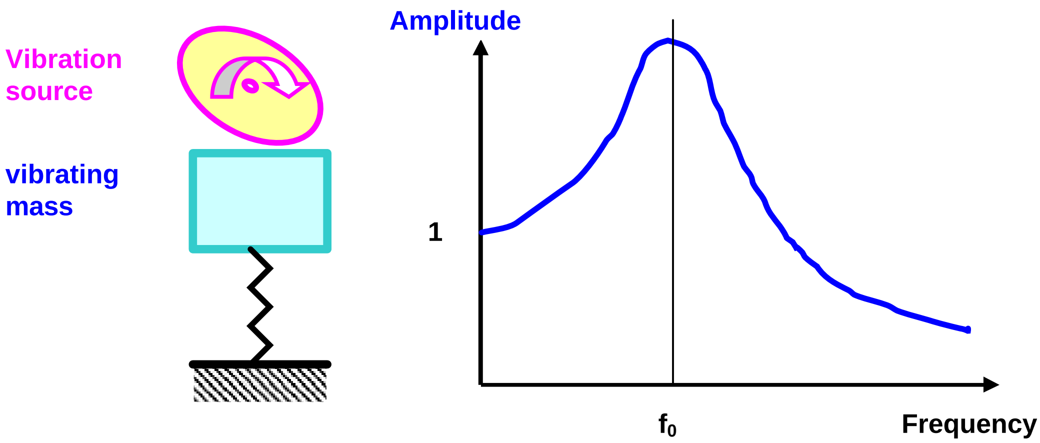
Vibration

Vibration is a very common phenomenon: Any motion that repeatedly alternates in direction constitutes vibration.

natural vibrations:	**ocean waves**
	movement of leafs in the wind
	sand dunes
	tidal motion
man-made vibrations:	**movement of a piston in an engine**
	rotation of a propeller
	sound of piano
	movement of wings through turbulent air
forced vibration:	**vibration of a mass through direct contact with a vibrating media**

Resonant frequency of forced vibration

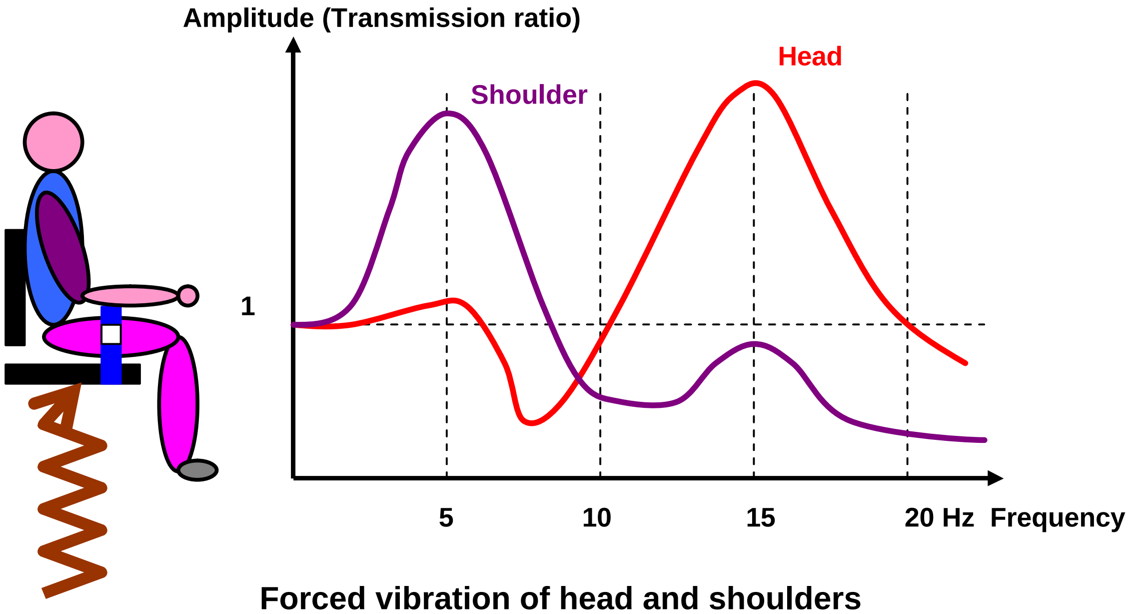
The vibration amplitude of a mass depends on the frequency of the vibrating media. At very low frequencies, the mass movement is equal to the movement of the vibration source. As the vibration frequency increases, the amplitude also increases until it reaches a peak at the resonant frequency f_0 of the mass. Further increase in vibration frequency causes a decrease of the vibration amplitude.



Forced vibration

Forced body vibration

Am complex mass like the body has plenty of different resonant frequencies. In aviation, forced vibration of the head and the shoulders are of practical interest.



Forced vibration of head and shoulders

Vibration sources in aviation

- inner sources: engine, air condition, electric motors, ...
- outer sources: turbulent air, runway surface, ...

Power source vibration frequency

⇨ depends on the rotational speed of the power source:

- piston engine:	3600 rpm	⇨	60 Hz
- rotor of helicopter:	240 rpm	⇨	4 Hz
- single-stage turbine:	8000 rpm	⇨	130 Hz
- dual-stage turbine:	14000 rpm	⇨	230 Hz

Physiological and psychological effect of vibration

Vibration at a frequency within the audible spectrum is perceived as sound. In the low sonic and subsonic frequencies it may cause hazardous physiological and psychological effects:

• **Cardiovascular system**	**heart rate ⇧, blood pressure ⇧**
• **Respiration**	**respiration rate ⇧** **(increased muscle activity causes an increase of CO_2 production)**
• **Neuromuscular**	**vibration of a skeletal muscle causes reflexive contractions and the erroneous perception of increased muscle stretch**
• **Vision**	**visual acuity ⇩ at frequencies > 1Hz**
• **Vegetative control**	**motion sickness ⇧ at 0.2 .....0.8 Hz**
• **Psychological effect**	**fatigue ⇧, stress ⇧**

Human tolerance to vibration:

maximum sensitivity	**Gz**	**4 .... 8 Hz**
	Gx/y	**1 .... 2 Hz**

Body Weight

Body Mass Index BMI:

$$BMI = \frac{\text{Body Weight in [kg]}}{\{\text{ Height in [m] }\}^2}$$

Example: 70 kg, 174cm : BMI = 70 / $\{1.74\}^2$ = 23.12

BMI Range for ♂ ♀

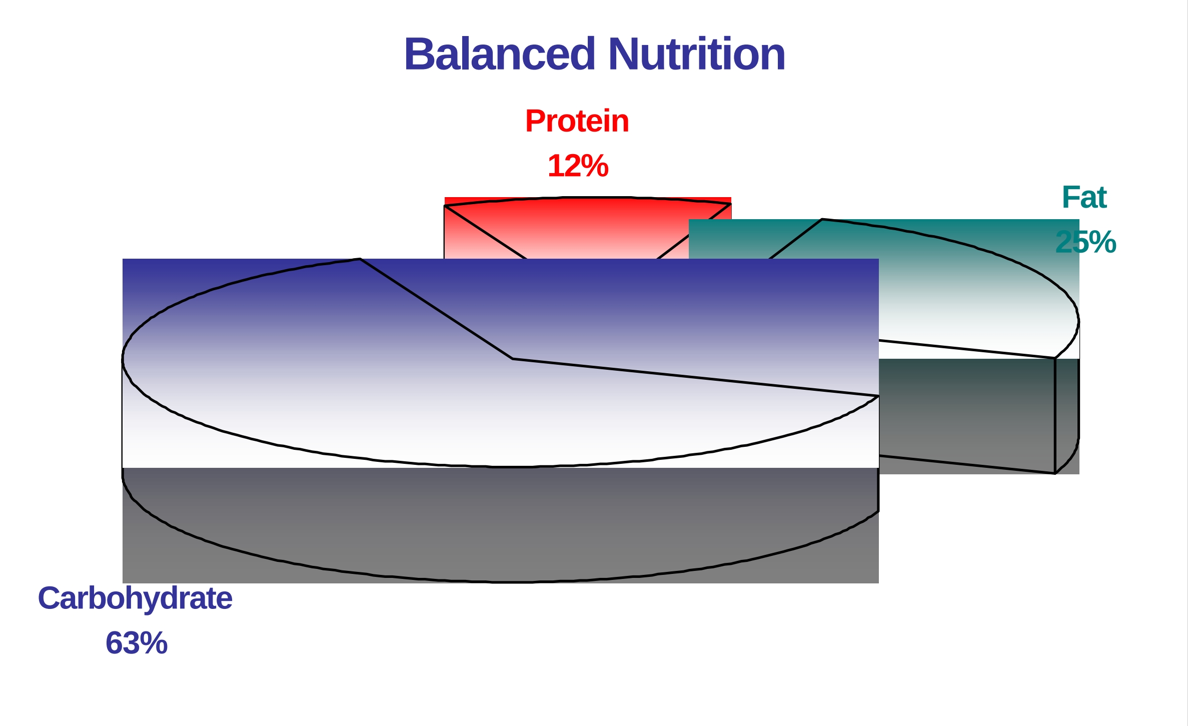
	♂	♀	
BMI	< 19	< 20	⇨ underweight
	19 – 24	20 – 25	⇨ normal range
	24 – 30	25 – 30	⇨ moderately overweight
	> 30	> 30	⇨ obesity

Energy required per day:

Basic metabolism: 25 kcal (~100 kJoule) per kg normal weight
add 30 % for sedentary working
50 % for moderate working
100 … 200 % for heavy working

Balanced Nutrition

- **Energy providing food components:** **Carbohydrate**
  Fat
  Protein



Situation in Switzerland today:	**Carbohydrate**	**40 %**
	Fat	**35 %**
	Protein	**15 %**
	Alcohol	**10 %**

Recommended distribution of the food intake:	**breakfast**	**30%**
	snack	**10 %**
	lunch	**30 %**
	snack	**10 %**
	dinner	**20 %**

- **Low energy but essential food components**
  - **Minerals:** Sodium (Na)
    Potassium (K)
    Calcium (Ca)
    Magnesium (Mg)
    Phosphate (P)
  - **Trace elements:** Iron (Fe), Copper (Cu), Iodine (I), Fluorine (Fl), Sulfur (S), Zinc (Zn), Selenium (Se), Cobalt (Co), ...
  - **Vitamins:** A, B_1, B_2, B_6, B_{12}, C, D, E, K, Biotin, Niacin, Thiamine Panthothenic acid, Folic acid, ...

- **Fiber**

  Fiber (Cellulose) is an indigestible part of whole grain cereals, fruit and vegetables. Fiber stores water and therefore leads to bulky soft stools which are expelled (transported) by the colon with low effort. Fiber only acts in the presence of water.

  Although fiber is not digested, it is an essential part of the food because it regulates the transportation within the colon.

The essential nutrients are provided by a balanced low fat diet containing

- Cereals (bread, pasta, rice, ...) ⇨ carbohydrate, protein, fiber, minerals, vitamins, trace elements, ...
- Fruit and vegetables ⇨ carbohydrate, protein, fiber, minerals, vitamins, trace elements, ...
- Dairy products (low fat or skimmed milk) ⇨ protein, fat, carbohydrate, minerals, vitamins, ...
- Pulses (beans, peas ...) and nuts ⇨ protein, fat, minerals, vitamins, trace elements, ...
- Small amount of meat , fish and egg ⇨ protein, fat, minerals, vitamins, ...

Water

Water exchange in 24 hours at rest:

Water intake	2200 ml	Water excretion	2200 ml
Food	900 ml	Urine and stool	1500 ml
Beverages	1300 ml	Perspiration and respiration	700 ml

During exercise fluid loss through sweating and respiration can dramatically increase and reach values up to ~1 liter per hour. To maintain a balanced water exchange, it can therefore be useful to rely on the amount of urine excreted per day:

The daily water intake should result in production of about 1500 ml of urine per day

In a dry atmosphere, like in the cockpit of an airliner, fluid loss through perspiration and respiration can be up to 250 ml per hour. Since there is no loss of salt through respiration, people don't get thirsty. To guarantee a balanced water exchange, it is advisable to drink an additional amount of 250 ml water per hour during a long haul flight.

Water loss and decrease of performance

If the body looses water due to increased perspiration or respiration in a dry atmosphere, physical and mental performance dramatically decreases:

Water loss in % of body weight	Decrease of Performance (mental and physical)
2 %	10 %
4 %	40 %

This "drying out" of the body is often accompanied by a headache.

Example: A pilot of 75 kg body weight doesn't drink any additional water during a 12 hour flight from Zurich to San Francisco. Due to perspiration and respiration he or she loses 12 x 250 ml = 3 liters of water which is 4 % of the body weight. At the time of the approach and landing, a performance decrease of 40 % has to be expected.

Cardio – Vascular Diseases

Basic Problem:

- damage on the wall of a blood vessel, especially arteries
- blood clotting / aggregation of thrombocytes
- deposits of fat and chalk in the damaged wall of the artery

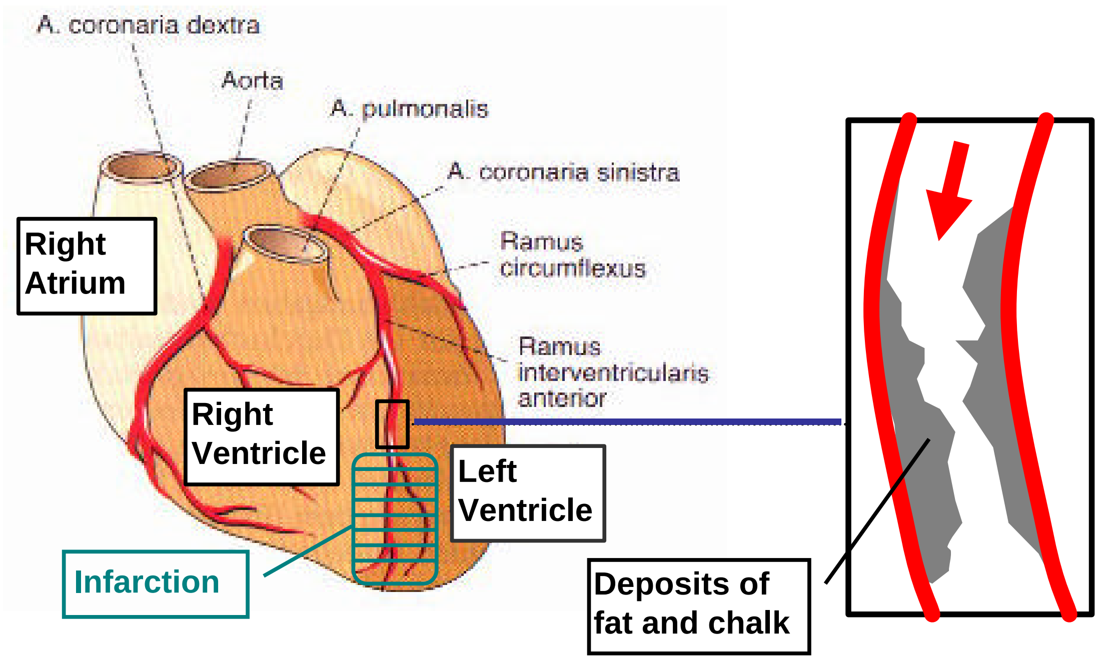
⇨ Arteries become narrower and stiffer = Arteriosclerosis = Atherosclerosis

Resulting illnesses:

- **Coronary heart disease**

⇨Angina pectoris: severe but reversible chest pain on exertion due to a partially blocked coronary artery. The pain concentrates over the central and left part of the chest and typically radiates towards the left arm, sometimes also towards the jaw. After a couple of minutes of rest, the pain usually calms down.

⇨ Heart attack: severe pain deep inside the chest, feels like a squeezing or crushing of the thorax, due to a total (or nearly total) block of a coronary artery. The pain persists for hours and doesn't calm down after rest



- **Cerebral sclerosis = sclerosis of the arteries in the brain**

  ⇨ **Stroke:** **Dysfunction of the brain due to**
  - **a blocked brain artery (ischemic stroke) or due to**
  - **a ruptured brain artery (hemorrhagic stroke)**

- **Peripheral vascular disease**

  ⇨ **"smokers leg":** **Malperfusion of the muscles in the legs due to an obstruction of a leg artery, typically causing pain in the leg which begins on exertion and disappears after a few minutes of rest (intermittent claudication).**

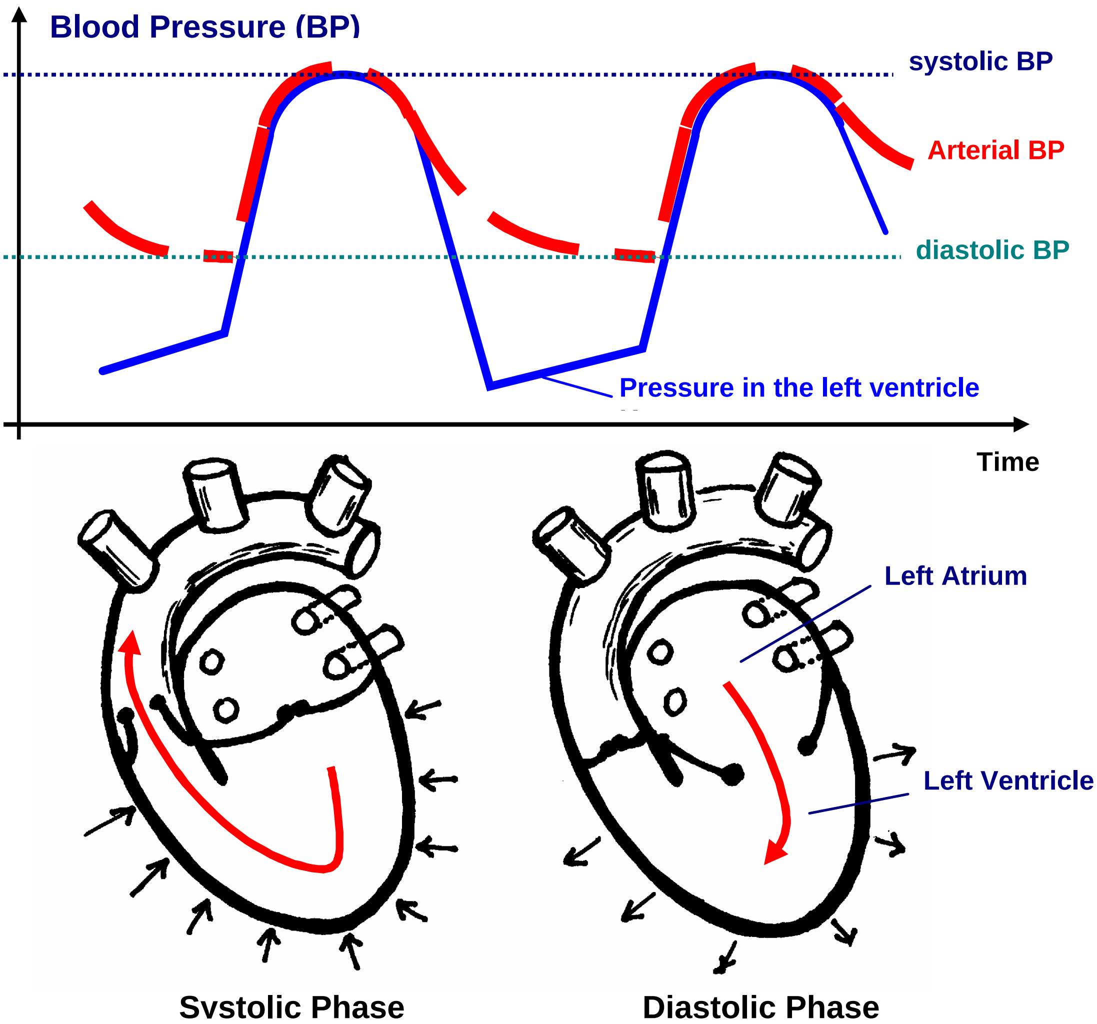
Risk factors for Cardio Vascular Diseases

- **non controllable:**
  - **Family history (hereditary factors)**
  - **Sex**
  - **Age**
  - **Race**
  - **Congenital heart disease or infectious diseases**

- **controllable**
  - **High arterial blood pressure (Hypertension)**
  - **Smoking**
  - **High cholesterol**
  - **Chronic distress**
  - **Obesity**
  - **Diabetes mellitus**
  - **Lack of exercise**

Arterial Blood Pressure, Hypertension and Hypotension

Due to the contraction and relaxation of the heart muscle, the blood pressure in the arteries is rhythmically changing:



Normal values:

systolic blood pressure = 140 mmHg
diastolic blood pressure = 90 mmHg

High Blood Pressure = Hypertension

About 20 % of the western adult population has a high blood pressure with one or both of systolic and diastolic blood pressure above normal values. There is a suspicion that the western way of life with stress, too much and unhealthy eating, overweight, lack of exercise or high alcohol intake is closely related to the development of high blood pressure. Although the specific causes are not known today.
Contrary to popular belief, high blood pressure rarely triggers any symptoms. Only if the pressure is very high, people may have a headache early in the morning which calms down with getting up and moving.

Keep in mind:

> **Hypertension is diagnosed by checking the blood pressure rather than by perceived symptoms**

Treatment

- regular exercise
- healthy diet (low fat and low salt)
- medication

Low Blood Pressure = Hypotension

The blood pressure is considered low, if people suffer dizziness, light-headedness or feel faint when getting up rapidly. This is also called postural hypotension. Symptoms are due to a malperfusion of the brain arteries and usually occur, if the systolic pressure is < 90 mmHg. However, there is a large variation of the critical lower value and therefore no lower limits for the blood pressure are defined.
Commonly, hypotension is caused by a delayed reaction of the vegetative (autonomous) nervous system which controls the blood pressure.

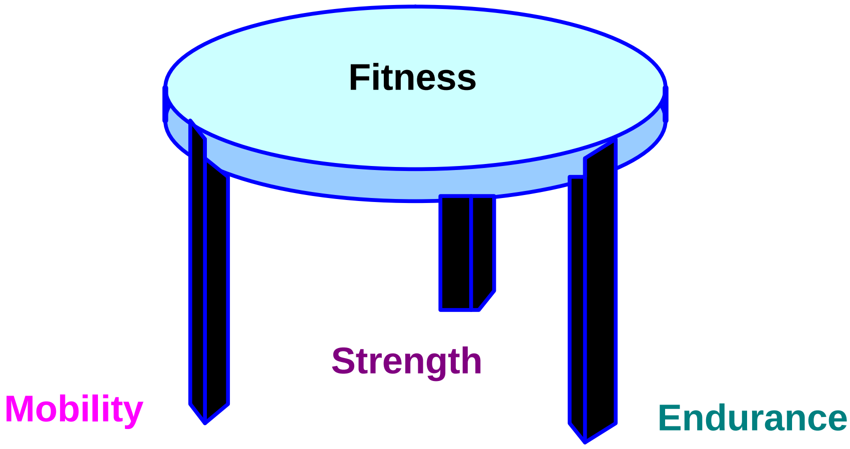
Treatment

- regular exercise
- increase of water intake
- (medication, usually not recommended)

Physical Fitness

Physical fitness is made up of the following three basic constitutional factors of the body:

- **Endurance of the muscles and the cardiovascular system**
- **Mobility of the muscles**
- **Strength of the muscles**



To maintain physical fitness, each of the three constitutional factors must be trained regularly. However, especially for younger people, the most important training is aerobic exercise to improve the endurance.

General recommendation for aerobic training:

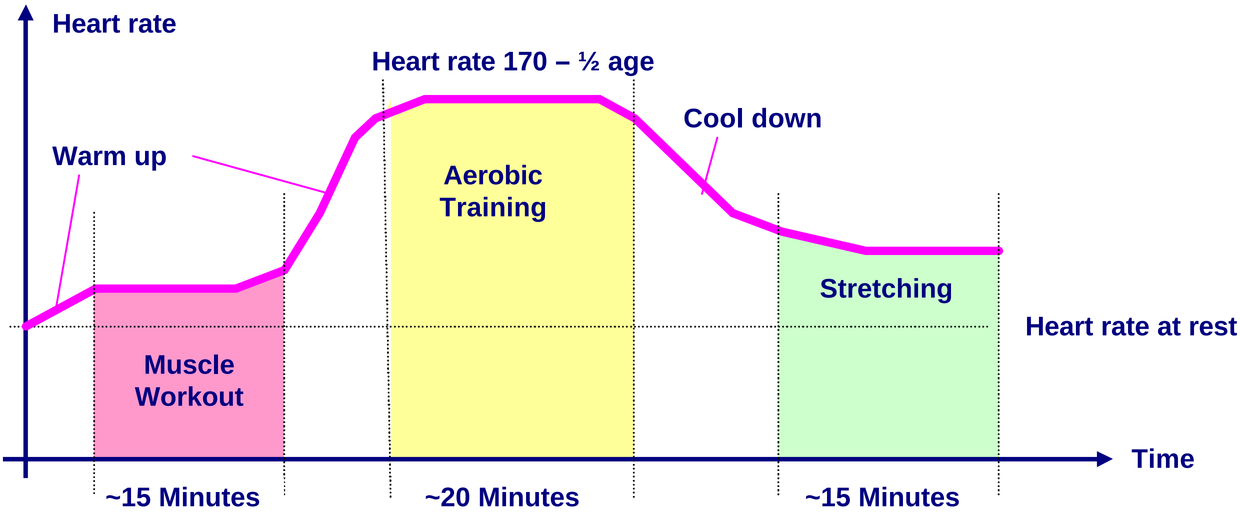
**3 times a week, for at least 20 minutes
at a heart rate of 170 – ½ age**

Aerobic training is a question of how to do it rather than what to do, as long as more than 30 % of the body muscles are working. Basic aerobic exercises are: Jogging, walking, cycling, swimming, Nordic skiing, aerobics, rope jumping, dancing, inline skating and a lot more.
Aerobic exercise means that your muscles get enough oxygen to produce energy by burning glucose, fat, or protein. Thus, only a little lactic acid is produced and your workout feels great. The moment your training gets too hard, you get an oxygen deficiency in your muscles, resulting in a dramatically increased lactic acid. This condition immediately lets you feel exhausted with sore muscles, a situation athletes call "hitting the wall".

To maintain a balanced fitness, you should complete the endurance training by

- **stretching to gain mobility of the muscles**
- **workout the muscles to gain strength**

A typical training session looks like the following graph:



Average energy requirements for aerobic training:

Jogging	9 km/h	10 kcal/min
	12 km/h	11.4 kcal/min
	15 km/h	13.1 kcal/min
Cycling	10 km/h	2.8 kcal/min
	15 km/h	4.8 kcal/min
	20 km/h	7.8 kcal/min
Walking	4.8 km/h	2.8 kcal/min
	6 km/h	4.4 kcal/min
	7.2 km/h	7.8 kcal/min
Swimming (Breast stroke)	20 m/min	4.5 kcal/min
	28 m/min	6.9 kcal/min
	36 m/min	10.0 kcal/min
Crawl	40 m/min	11 kcal/min
	50 m/min	14 kcal/min

Benefit of Aerobic Training ⇧

- Heart rate at rest ⇩
- Stroke volume and cardiac output (per minute) ⇧
- Blood pressure is stabilized : high pressure ⇩, low pressure ⇧
- Cholesterol profile is improved (HDL ⇧, LDL ⇩)
- Body weight is optimized
- Tolerance to stress ⇧
- General mood ⇧
- Sleep ⇧
- Depression and anxiety ⇩

Keep in mind

Aerobic training lowers the risk of developing a cardio – vascular disease

General rule about fitness

Any fitness you might have at a time, will gradually decrease, if you don't train it. So the best time to start your exercise program is right now, according to the idiom:

Your body ? use it - or loose it !!

Tobacco

Toxic substances in the cigarette smoke:

- **Nicotine:** Neurotoxic and addictive substance.
  Increases the tendency of the thrombocytes to clot.
  Narrows arterial blood vessels by chronic muscle contraction.
  Increases heart rate and blood pressure.
  Induces stomach or duodenal ulcer.
  …..

- **Carbon monoxide (CO)**
  Supersedes Oxygen at the surface of hemoglobin, causing a hypemic hypoxia. (< 200 molecules of oxygen are needed to replace one molecule of carbon monoxide at the surface of the hemoglobin molecule).

- **Cancer inducing substances (carcinogens) and tar**
  Hundreds of different components including tar, may cause lung cancer and cancer of the larynx.

  Tar and dirt damage the lining of the bronchi, causing slower transportation of the mucus and leading to chronic bronchitis.

Other substances induce depletion of the tiny walls between two alveoli, leading not only to bigger alveoli but also to a reduction of the gas exchange surface area (a situation called emphysema).

> **25 % of all smokers will die from a disease caused by smoking such as coronary heart disease, stroke, obstruction in the peripheral arteries of the legs, chronic bronchitis or lung cancer.**

Smoking and Flying

Besides the harmful effects on the respiratory and cardiovascular system, smoking directly affects flight safety through

- **Increased susceptibility to hypoxia (CO)**
- **Impairment of night vision (toxicity of nicotine)**
- **Reduced tolerance to G - forces**

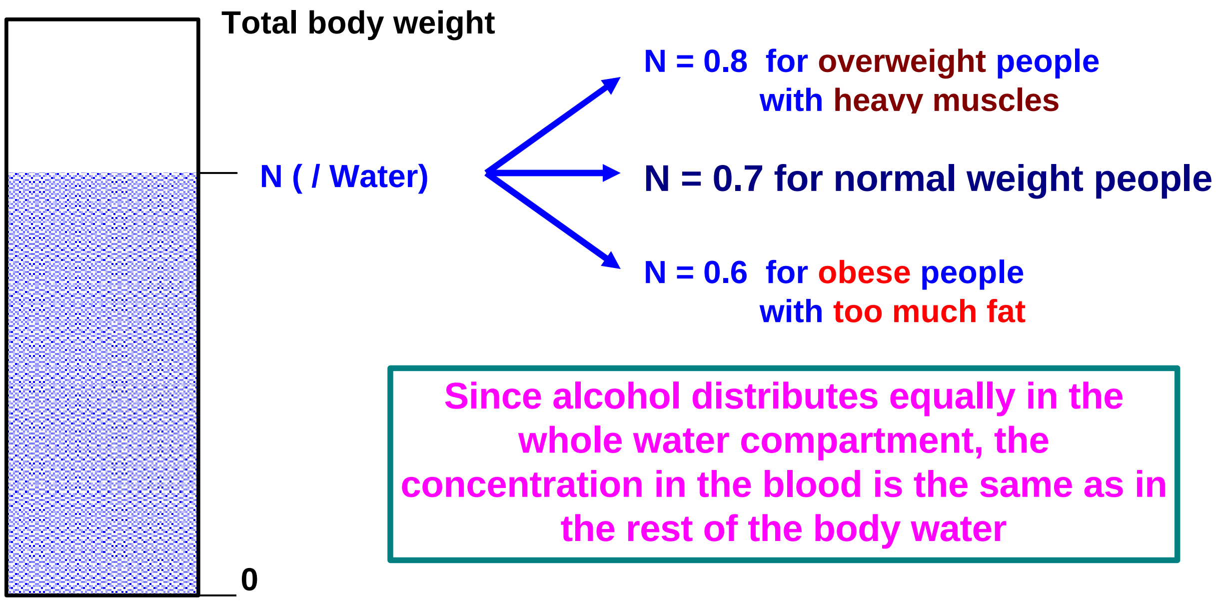
Alcohol

Alcohol is a carbohydrate (C_2H_5OH), contributing

7.2 kcal / g (= ~30 kJoule / g)

to the oxidation process in the body.

Alcohol passes very quickly by diffusion into the blood (a few % through the mucous membrane of the mouth, 20% through the stomach, the largest part through the mucous membrane of the small intestine) and distributes through the entire body water:



Since alcohol distributes equally in the whole water compartment, the concentration in the blood is the same as in the rest of the body water

Alcohol concentration in the blood (alcohol level) C:

$$C = \frac{\text{Alcohol intake in [g]}}{\text{Body weight in [kg]} \cdot N} = [\text{‰}]$$

Standard drinks (units):

- 1 dl of wine (12%) = 12 g of alcohol
- 3 dl of beer (4%) = 12 g of alcohol
- 0.3 dl of spirits (40%) = 12 g of alcohol

Removal of alcohol is only a function of the time:

0.1 ‰ per hour for all subjects

Example: **A pilot (70kg, 175cm) takes 5 dl of wine (12%) at 11 p.m.
What is the blood alcohol level he can expect to have at 6 a.m.?
(C= 60g / 70kg . 0.7 = 1.2 ‰ ; after 7 hours C= 0.5 ‰ !!)**

Keep in mind

The blood alcohol level depends on the intake of alcohol and the body weight, the elimination of alcohol only depends on the time

Effects of Alcohol

Alcohol acts as a depressant on the central nervous system. Small amounts of alcohol start inhibiting higher functions of the brain, causing

- **slower thinking**
- **dulling of judgment**
- **decreased attention span**
- **lessened sense of responsibility, combined with euphoria**
- **decrease of memory and reasoning**
- **increase of the frequency of errors**
- **decreased social inhibition**
- **fatigue**

Shy people become more extraverted, anxious people more relaxed and tongue-tied subjects more eloquent.

Increased amount of alcohol also affects other functions of the brain and the whole body:

- **< 0.1 ‰ interference with the brain's ability to use oxygen**
- **< 0.3 ‰ disturbance of color vision**
- **< 0.5 ‰ inability to perform a tracking task (shooting an ILS)**
- **< 1.5 ‰ loss of self control, nausea, vomiting**
- **< 2.0 ‰ double vision, slurred speech, staggering, memory loss**

<< ⇨ oblivion, sleepiness, coma, ….. death

Subjects suffering from insomnia tend to fall asleep sooner after one or two units of alcohol. However, under the influence of alcohol, the sleep pattern changes and the sleep may be not as refreshing as without alcohol.

Keep in mind

The effect of alcohol increases with altitude because alcohol interferes with the brain's ability to use oxygen (histotoxic hypoxia)

After heavy drinking many people suffer hangover symptoms such as nausea, headache, lack of concentration, fatigue…. . In this case two or three days can be needed to cleanse the body of the toxic effects of alcohol and to restore a proper metabolism.

General rule concerning alcohol

No alcohol in the system when you fly!
(12) …. 24 hours from the bottle to the throttle!

Alcoholism

WHO's definition:

- A subject is considered an alcoholic, when the excessive use of alcohol repeatedly damages the person's physical, mental or social life

Chronic alcohol abuse is associated with

- Poor nutrition (alcohol reduces appetite)
- Lack of vitamins, shortness of protein
- Congestive heart disease (alcohol induced damage of the heart muscle)
- Liver disease (cirrhosis)
- Chronic pancreatitis
- Brain deterioration with loss of memory and emotional disorders (Korsakow's disease)
- Loss of social relationships, isolation

The current WHO's recommendations of maximum alcohol intake
for men are 28 units a week
and
for women 21 units a week

(The consumption of alcohol is measured in units:

1 unit	=	1 dl of wine	~ 12 g of alcohol
		3 dl of beer	~ 12 g of alcohol
		0.3 dl of spirits	~ 12 g of alcohol)

Drugs and Self Medication

There are two things you always should consider before flying while using a drug;

1. what is the condition you are treating?
2. what are the possible side effects of that drug used to treat the condition?

Since side effects in your particular and specific case are not predictable, never use any drug for first time while flying

Depressants

Depressants reduce many of the body's functions like reaction response time, muscle activity, mental processing, vigilance, blood pressure, ... Typical representatives are tranquilizers (Valium®, ...), medication against motion sickness, stomach medication, antihistamines, alcohol.

Some depressants are also used during diagnostic procedures (gastroscopy, colonoscopy, bronchoscopy, ...) and may have side effects which can impair the ability to fly for up to 48 hours!!

Stimulants

Stimulants excite the CNS, producing an increase in alertness and activity while suppressing appetite. Dangerous side effects are common and include anxiety, nervousness, drastic mood swings, psychotic reactions, unreliable thinking and judgment, impaired self criticism and sleep disorders.

Typical representatives are amphetamines, caffeine, nicotine, ...

Hypnotic drugs = medication against insomnia

**Severe insomnia is a condition which impairs your ability to fly and must carefully be evaluated (depression) and adequately treated.
Usual hypnotics are not allowed for pilots, due to their hangover symptoms which impair the ability to fly the next day.
For occasional use some ultra short acting hypnotics like midazolam (Dormicum®) may be helpful and can be taken up to at least 8 hours before work starts (you have to inform your physician).
Within a couple of weeks of regular use, people can get used to hypnotic drugs, which results in a decreased hypnotic effect combined with an increased rate of side effects.**

Cold or flu medication

Drugs against the flu or a cold are usually combinations of pain killers and substances which decongest the mucous membrane of the respiratory tract. Common side effects are fatigue, reduced vigilance, unreliable judgment and poor motor action. These drugs are not allowed while flying.
Some locally acting nose drops would be allowed while flying, however, due to the effects of pressure change, you should not fly when you have a cold or the flu.

Anesthetics

Anesthetics are drugs which deaden pain or cause a loss of consciousness. They are used for surgical or dental treatments.
Local anesthetics used for dental applications or minor surgery wear off within a relatively short time. Nevertheless, if you have to undergo dental or surgical treatments, always inform your dentist or physician that you are a pilot.

Pain killers

Pain killers are drugs containing substances which reduce inflammation processes and therefore reduce pain. The most common representatives are acetylsalicylic acid (Aspirin®), acetaminophen (Tylenol®, Panadol®) and ibuprofen (Brufen®, Advil®). These drugs have few side effects when taken in the corrects dosage over o short period and usually don't affect the pilot's ability to fly. However, some people are allergic to certain substances or may suffer from stomach irritation, so never use it for the first time while flying and always inform your physician.
Other analgesics (pain killers), especially prescription drugs are not allowed while flying because of hazardous side effects like dizziness, headache, nausea, vision problems, mental confusion, ...)

Antihistamines

These drugs are used to treat allergies like hay fever, allergic asthma or an urticaria (allergic skin rash). Most antihistamines cause fatigue, although some never substances don't have this side effect and may be taken while flying under the supervision of your physician.

OTC drugs

Drugs you can get without a prescription are called OTC drugs (Over The Counter). Since you never know, if you may experience hazardous side effects, never take any medication for the first time while flying.

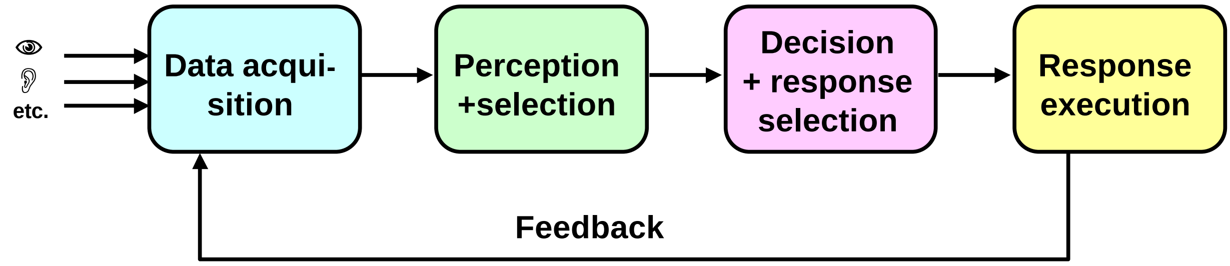
General rule concerning medication

If a pilot is so unwell that he or she requires any medication then he or she should consider him/herself unfit to fly

Self Assessing Fitness for Flight: I'M SAFE

I	**Illness**	**Do I have any symptoms?**
M	**Medication**	**Have I taken any prescription or OTC drugs?**
S	**Stress**	**Do I have substantial stress caused by physiological health disorders, family discord, job related or financial problems?**
A	**Alcohol**	**Have I been drinking within the last 24 hours?**
F	**Fatigue**	**Am I tired and not adequately rested?**
E	**Eating**	**Am I adequately nourished?**

The Information Process



Data acquisition

Continuous gathering of data by scanning available sensory signals from the

- **eyes (cones and rods)**
- **ears (cochlea, otolith organs and semicircular canals)**
- **mechano- and thermal receptors of the skin**
- **kinesthetic receptors of muscles, joints, ligaments, tendons**
- **nose**
- **tongue**

The data are stored for a very brief period in a sensory store for each sensory modality and sum up to a high amount of information, which is impossible to be processed simultaneously.

Thus, further processing requires selection of particular data, while the bigger part of the available data is neglected and lost.

- **large amount of data**
- **short storage time of 2..3 seconds**
- **no attention resources absorbed**

Perception and selection

Recognition by comparison of sensory signals with stored patterns.

- ⇨ transformation of the sensory signal into a **meaningful** information
- ⇨ based on memory, experience, expectancy, attention, vigilance, attitude, knowledge, stress, ...

- large amount of attention resources absorbed
- loss of considerable amount of unrecognized data

Decision and response selection

Decision what to do with recognized data by judgment of data significance, generating options, risk analysis and finally choosing an intention

- large amount of attention resources absorbed
- firmly dependent on experience

⇨ **Decision making**

Response execution

Translation of the intention into a coordinated sequence of (most often prefabricated) motor commands (skills).

- small amount of attention resources absorbed
- highly susceptible to initiation slips (stress!)
- supervision needed

Feed back

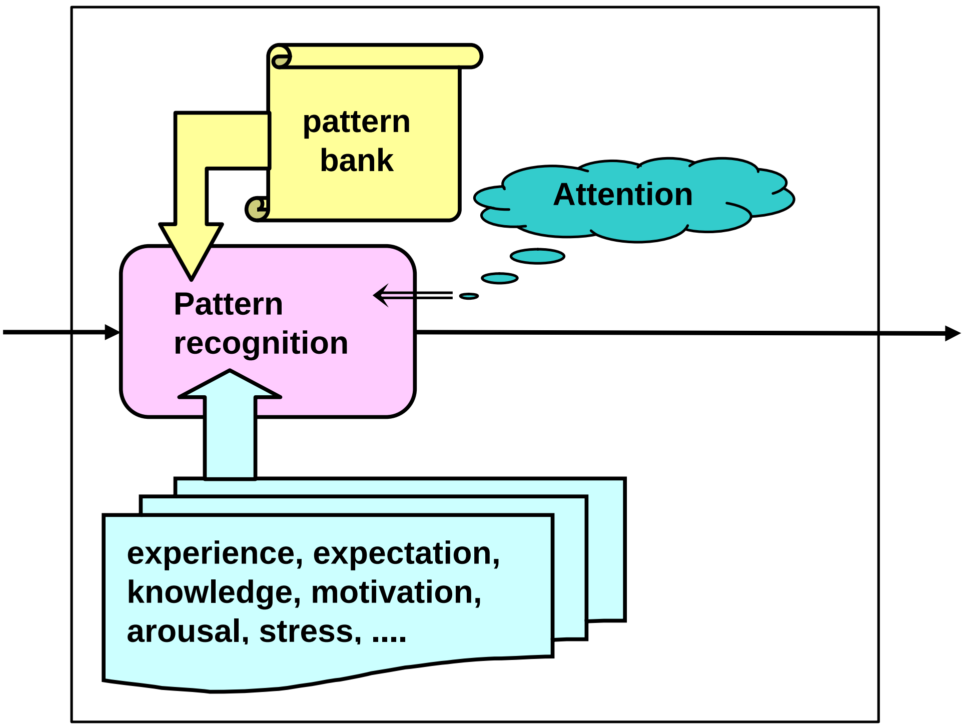
The executed response, by way of the feedback loop, modifies the inputs to the sensory stores. The modified inputs are used to select the next response.

Perception

Association of meaning to the "booming buzzing confusion" of physical stimuli in the sensory stores, by comparison of input data with a stored pattern bank, based on

- **memory**
- **experience**
- **expectancy**
- **wishes and desire**
- **vigilance**
- **attitude**
- **knowledge**
- **stress**
- **....**

Example: **Perception transforms the marks on this page into meaningful (semantic) elements like words, graphic elements, ideas.**



Perception

Perception absorbs a large amount of attention resources.

Due to the limited attention, a considerable amount of unrecognized data is lost in this stage of information processing.

Filters of Perception

In everyday life, perception depends on applied perception filters like

- selecting particular information sources (newspapers, TV, radio, meetings ....)
- focusing of attention
- limited performance of sense organs
- personal point and time of view
- experience
- culture

Subjectivity of Perception

since every individual has a particular own pattern bank, adds personal experience, knowledge, attitude, combined with particular today attention, vigilance, stress, whishes and desire, it is evident that

> **Perception always remains subjective,**
> **an objective perception does not exist**

Bottom-up processing

Perception driven by

- step by step combination of separate input elements (synthesis)

  ⇨ **no particular result expected**

Top-down processing

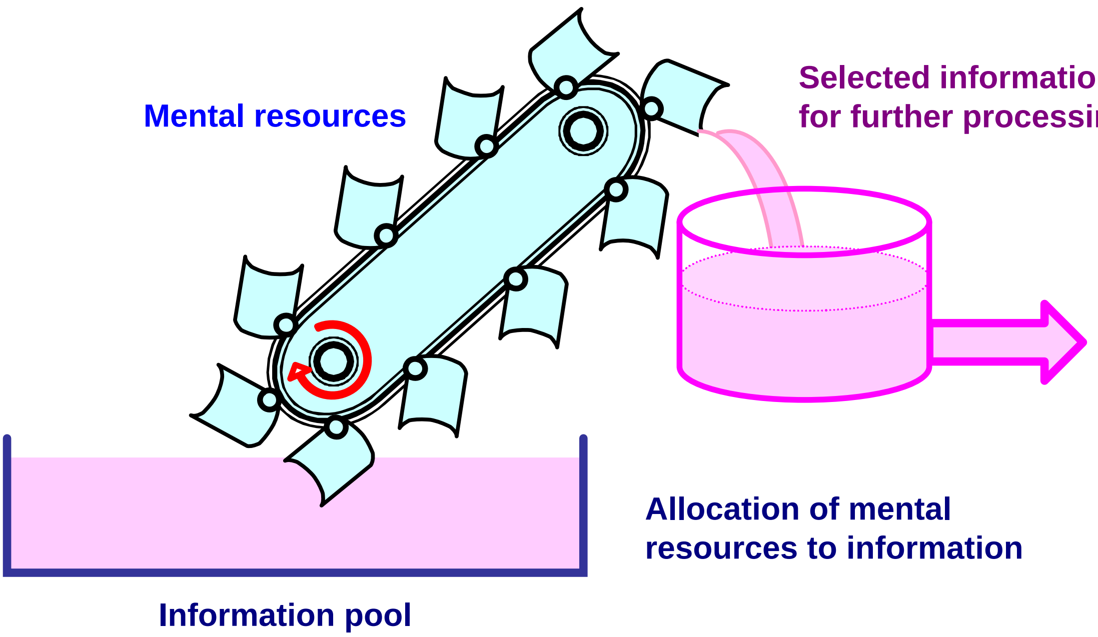
Perception driven by

- a hypothesis concerning the nature of the incoming data

  ⇨ **incoming data are checked whether they match an assumed result (analysis)**

Attention

- **Allocation of mental resources to particular information sources or activities. Allocation of attention selects the information for further processing. Mental resources are limited.**
- **To accomplish a task deliberately and consciously, it is compulsory to pay attention to it**



Since mental resources are limited, attention is the bottle neck of conscious information processing.

Attention is a limited resource

Selective attention

Assumption: At a given time, we can willingly pay attention to exclusively one thing.

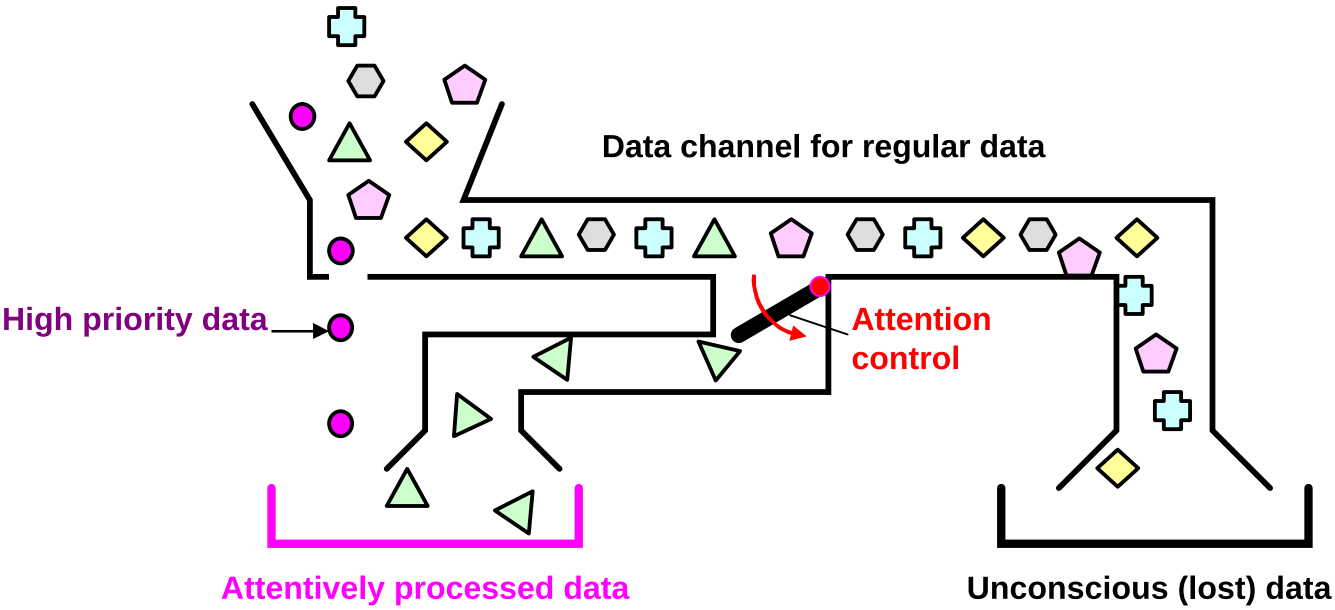
Example: **Cherry's shadowing task (1953):**
Subjects had to repeat aloud ("shadow") the information presented to the right ear. From the unattended message presented to the left ear, only gross physical characteristics (e.g. female or male speaker?) could be extracted.

Cocktail party phenomenon

In a group of people you can listen to one conversation, while filtering out other conversations around you. Attention control selects the person to listen to and you can hear that person very well due to selective attention. At this time, you actually don't hear the other conversations.

Focused attention

Selective attention allows concentration on one particular conversation in a cocktail party. However, if e.g. your name is mentioned in one of the other conversations, you will probably become aware of it and divert your attention to that conversation. This indicates, that your channel for conscious information processing may have a continuous additional capacity for processing important information.



Focused attention is also selective, however, the mental resources are not willingly allocated but imposed by environmental stimuli.

Synonyms for focused attention:

- **captured attention**
- **trapped attention**
- **to be in a set**

Divided attention

In aviation it is seldom appropriate to devote attention to a single task. Usually, pilots have to perform more than one activity at a time.

- **Sharing of attentional resources between two or more information sources is possible as long as**
  - **the total demand for resources does not exceed the total capacity of mental (cognitive) resources.**

Broadbent's model:

- **single central processing channel (bottleneck)**
- **multi-task performance by time sharing (alternating attention)**

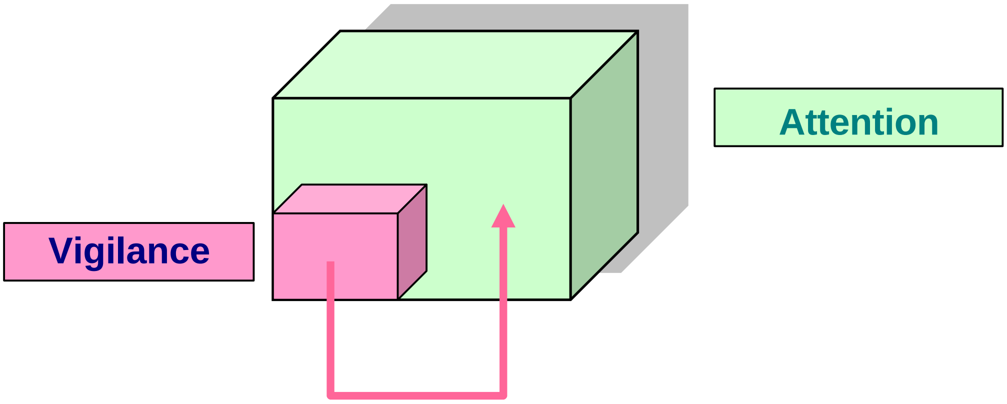
Kahneman's model:

- **flexible general purpose resources that can be allocated simultaneously to any task (genuine multitasking)**
- **the volume of devoted resources (workload) must not exceed the total capacity of mental (cognitive) resources**

Vigilance and mental workload

Vigilance

- autonomous, independent part of attention (mental resources)
- checks periodically the allocation of the remaining attention



To act safe as a pilot, it is crucial to reserve a minimal part of mental resources for vigilance

Hypovigilance, hypervigilance and performance

Hypovigilance:

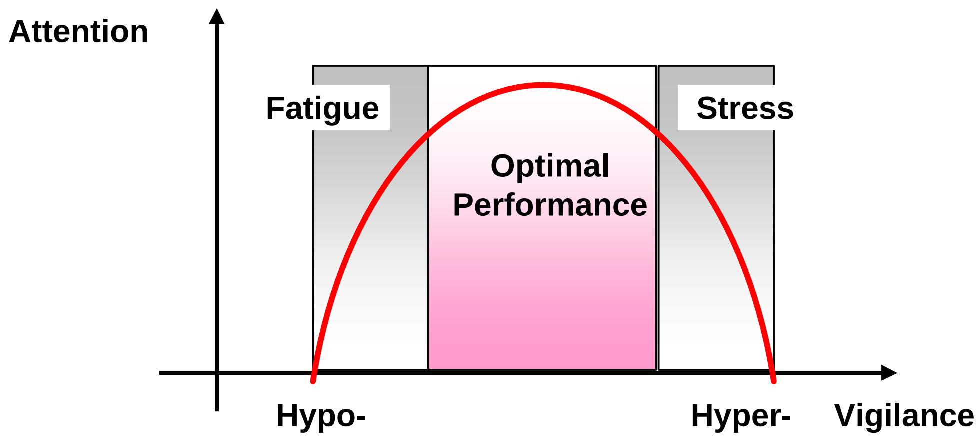
- vigilance low, fatigue, boredom, low workload

  ⇨ performance poor

Hypervigilance:

- vigilance high, stress, nervousness, workload high

⇨ performance poor



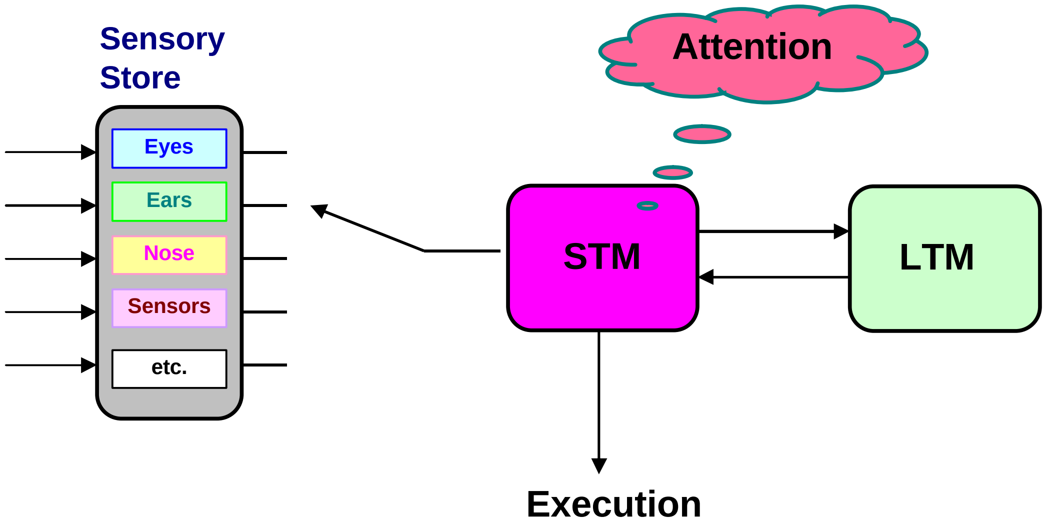
Example: 1972 Lockheed 1011 Tri-Star Eastern Airlines Approach to Miami

Factors to forestall Hypovigilance during flight

- obtain adequate sleep before any flight
- take regular meals with a healthy diet
- drink enough beverages
- maintain physical and psychological fitness
- take care that the seat is correctly adjusted to provide optimal comfort
- keep activities on your home time during short stopovers after crossing of time zones
- do not take sedative medication or alcohol to overcome jet lag insomnia

Memory

- sensory memory = sensory store
- short term memory (STM)
- long term memory (LTM)
    - motor memory (skills)



Sensory store

- stores sensory signals from the sense organs for a very short time
- rapid decay of information after 1....2 seconds
- acts as a temporary buffer for sensory signals
- each sense organ has its own buffer
- high storage capacity
- susceptible to disruption and masking
- selection of interesting data by allocation of attention

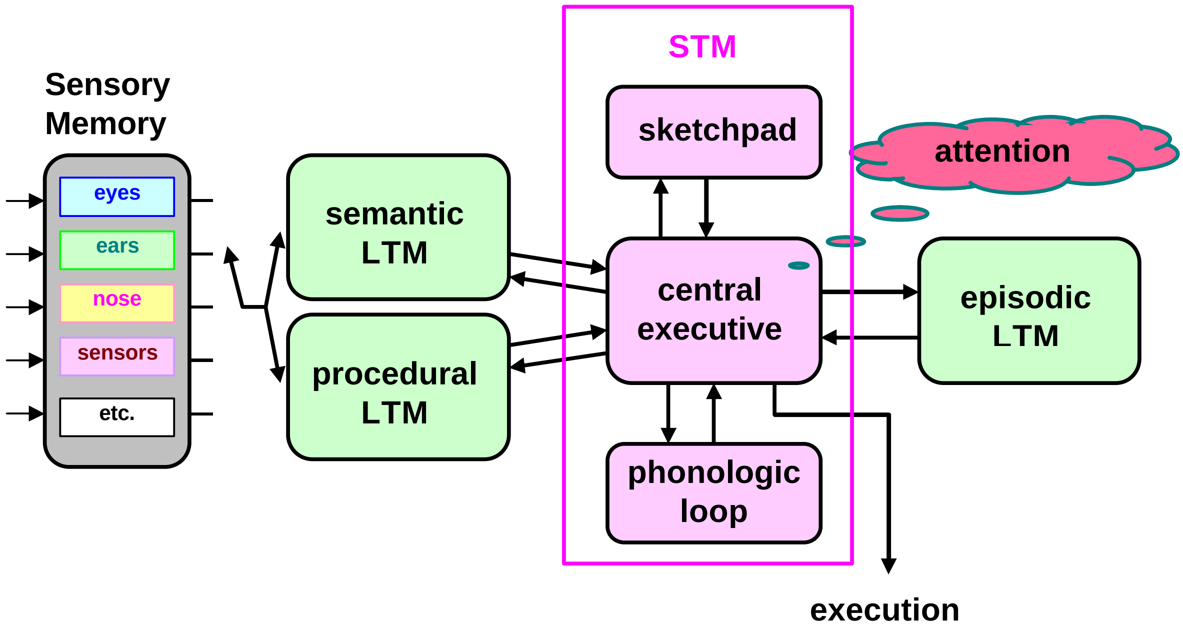
Short-term memory, working memory (STM)

- retention of selected information for a short period of a few seconds (10...20...(30) seconds)
- used to retrieve and store information relevant to our plan of action
- limited capacity to 7 ± 2 items
- short access time of ~ 2 seconds
- improved capacity by chunking of items (separating into meaningful segments, each of which acts as a single item)
- main difficulty: fragility, susceptible to interference and noise, information is volatile
- repetitive rehearsal prevents from loss of information

Long-term memory (LTM)

- permanent storage of information
- size nearly unlimited
- separate systems for information about
  - meanings of words, rules and facts (semantic memory)
  - encountered specific incidents (episodic memory)
  - operational programs for skill execution (procedural memory or motor memory)
- long access time if the stored information isn't used recently
- reduced access time by pre activation of information to be used such as by briefings, preflight preparation etc.

Newer memory model (Baddeley)



STM: central executive and two slave systems

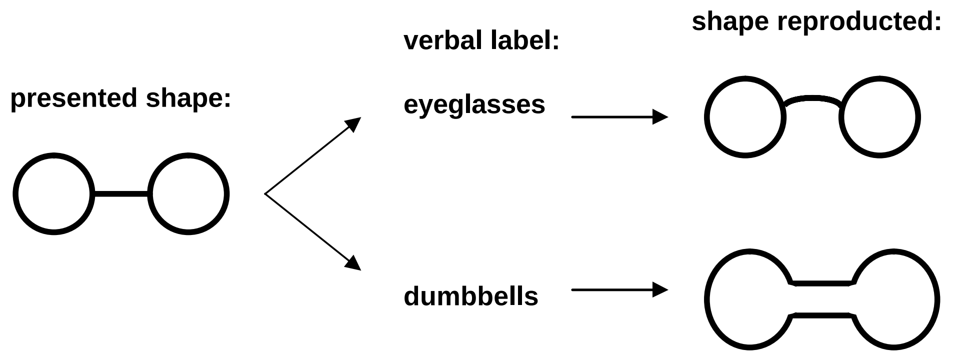
- central executive: limited capacity attentional system that controls and coordinates the activity to cope with the plan of action. Highly automated tasks use fewer attention resources.
- sketchpad: buffer for visuo-spatial information, which can be processed independandly
- phonologic loop: buffer of 2..3 seconds of verbal information, plays a important role in the perception of speech and is used for repetitive rehearsal

All the mentioned memory parts are functional units and no anatomical correlate is known so far.

Memory of incidents / events

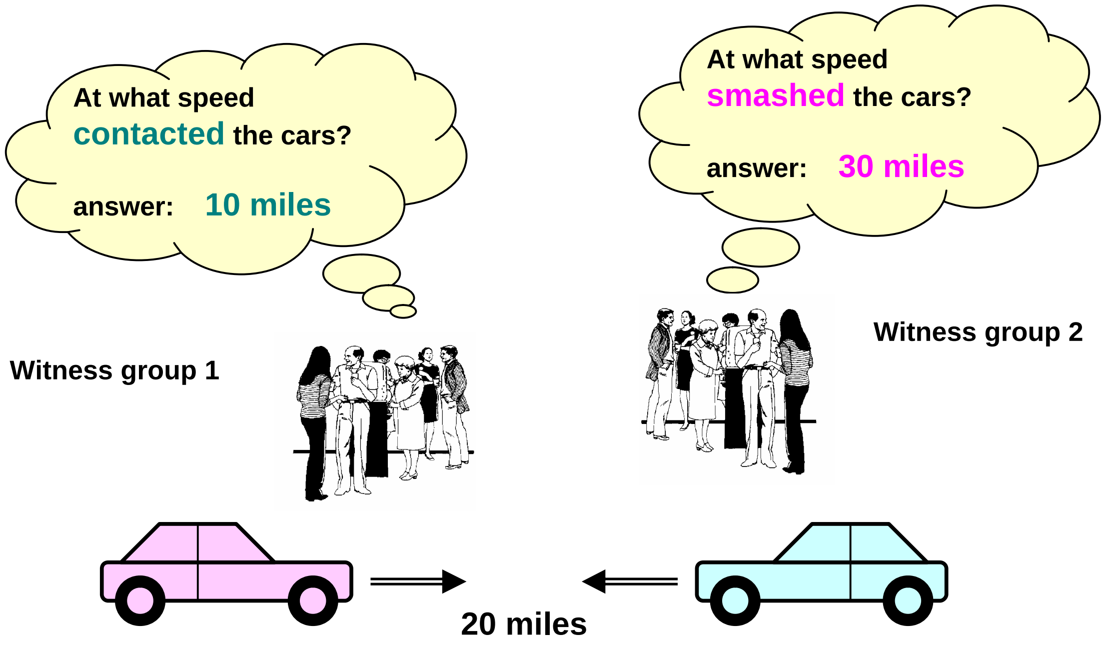
affected by several factors

- **emotional state: poor immediate recall of unpleasant stimuli**
- **trauma / shock: information may be permanently lost**
- **subjective initial interpretation:**



- **distortion during recall by the kind of questions**

subjects witnessing an car accident movie had to estimate the speed at which the cars collided. Results were influenced by the verb used in the question: smashed produced the highest estimate of speed, contacted produced the lowest.



Learning and response selection

Learning

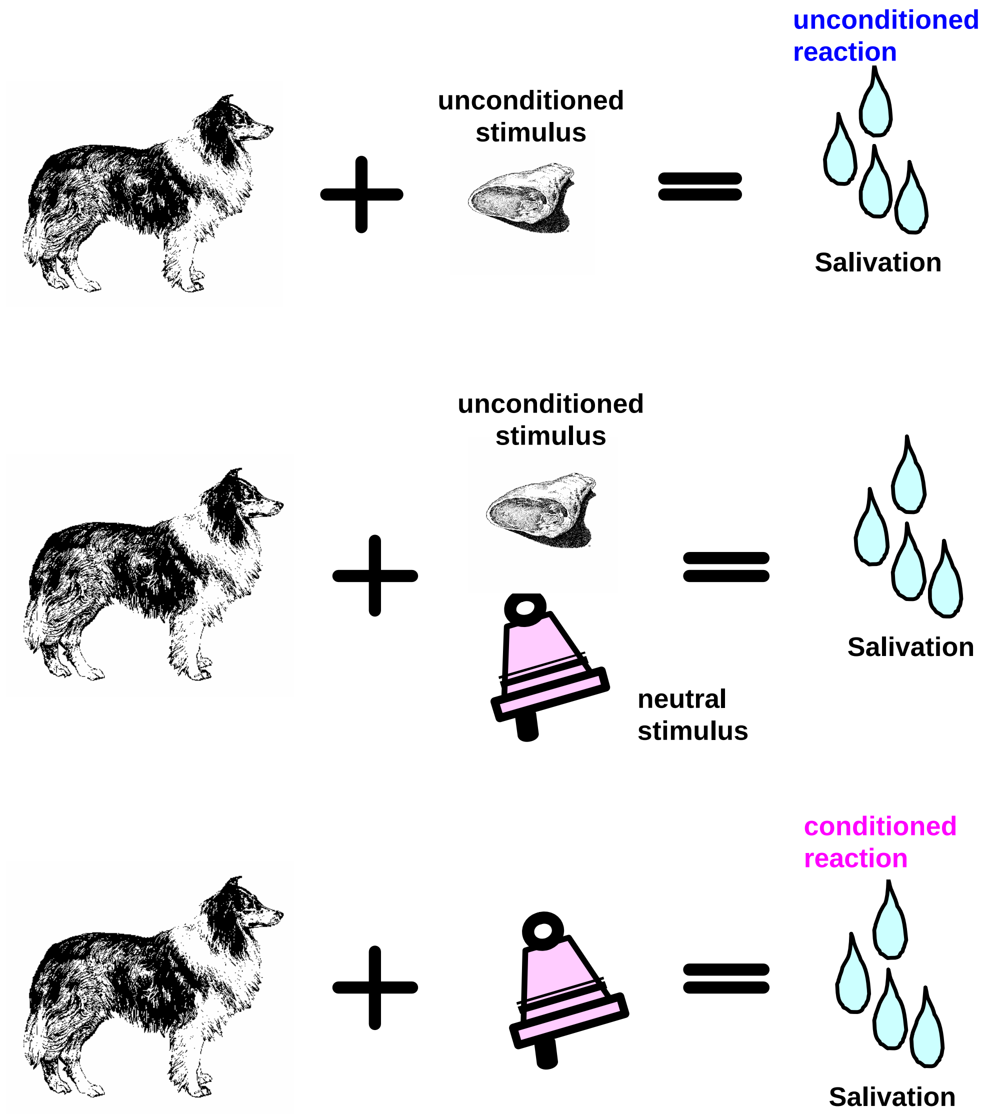
- Acquisition of a new possibility to behave
- permanent change in the CNS due to experience or practice

Maturation

- change in the CNS due to genetically determined growth processes
- fundamental condition for subsequent learning

Paradigms of learning

- classical conditioning



- **Instrumental conditioning**

  learning by success

  - **either by a positive reinforcement**

    or

  - **by avoidance of a negative reinforcer**

- **Learning by insight**

  solutions obtained by trial and error based on previously learned habits and under the influence of reinforcement.

- **Learning by observation of a role model and imitation**

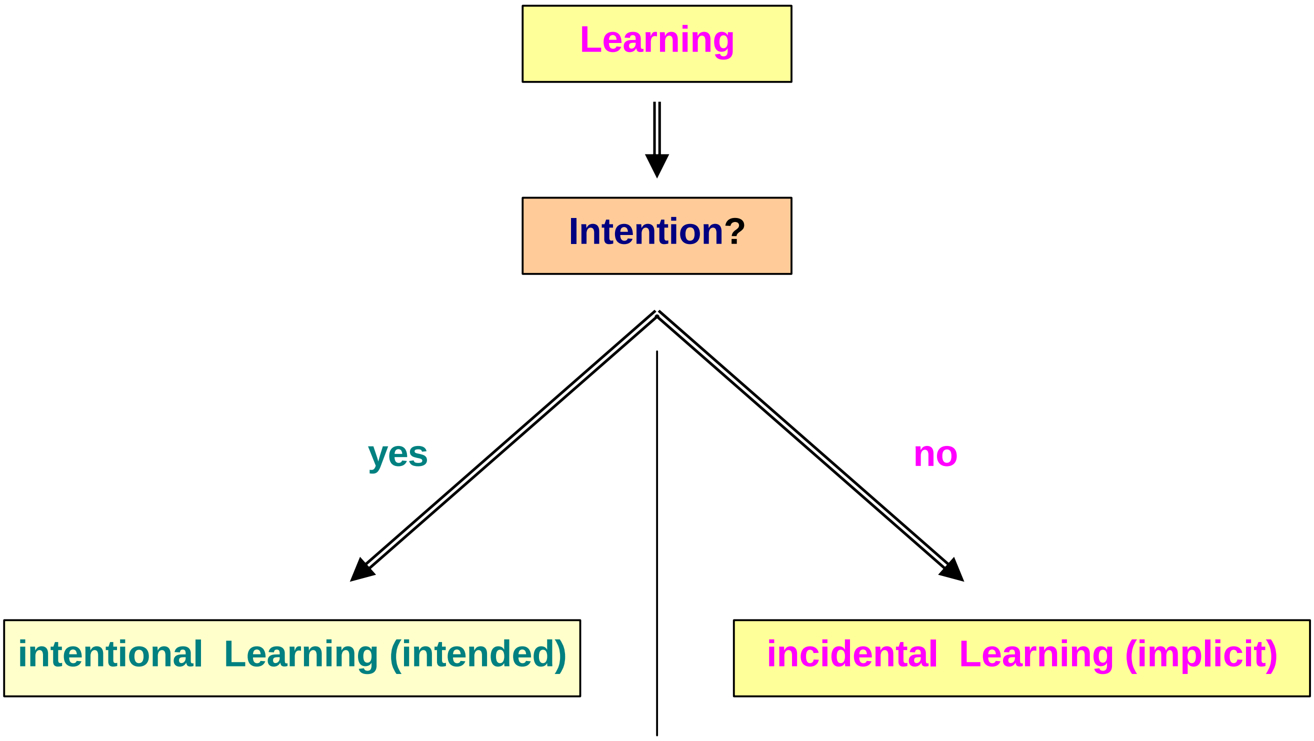
  important particularly in the social environment

- **Implicit learning of rules (without concern, unaware)**

  plays a major role in learning a language

crucial factors in human learning are
motivation of the trainee and
reinforcement of correct responses

Division of learning



intentional learning absorbs attention resources, incidental learning is unaware and doesn't use attention

Procedural learning = implicit learning

- ⇨ incidental acquisition of a new behavior
- ⇨ learned information remains unaware and
- ⇨ is stored in the procedural long-term memory

Declarative learning = explicit

- ⇨ intentional acquisition of facts and events
- ⇨ information is stored in
  - ⇨ the semantic long-term memory (facts)
  - ⇨ the episodic long-term memory (events)

The J. Rasmussen's model for activity control

- **skill based behavior** automatic (reflex) motor action
  controlled by the motor memory
  once initiated, few attention resources absorbed

  ➔ condition for multitasking

  Risk: skills are highly susceptible to initiation slips ⇨ error of routine
  ⇨ environmental capture

- **rule based behavior** association of a current analyzed state with a suitable task based on stored rules
  big amount of attention resources used

  ➔ procedures

  Risk: lack of technical know how, procedures are susceptible to mistakes (faults)

- **knowledge based behavior**
  creative decision on which task to do in a complete new and unknown situation
  based on knowledge, experience, planning and evaluation
  extremely costly for attention resources

  ➔ decision making

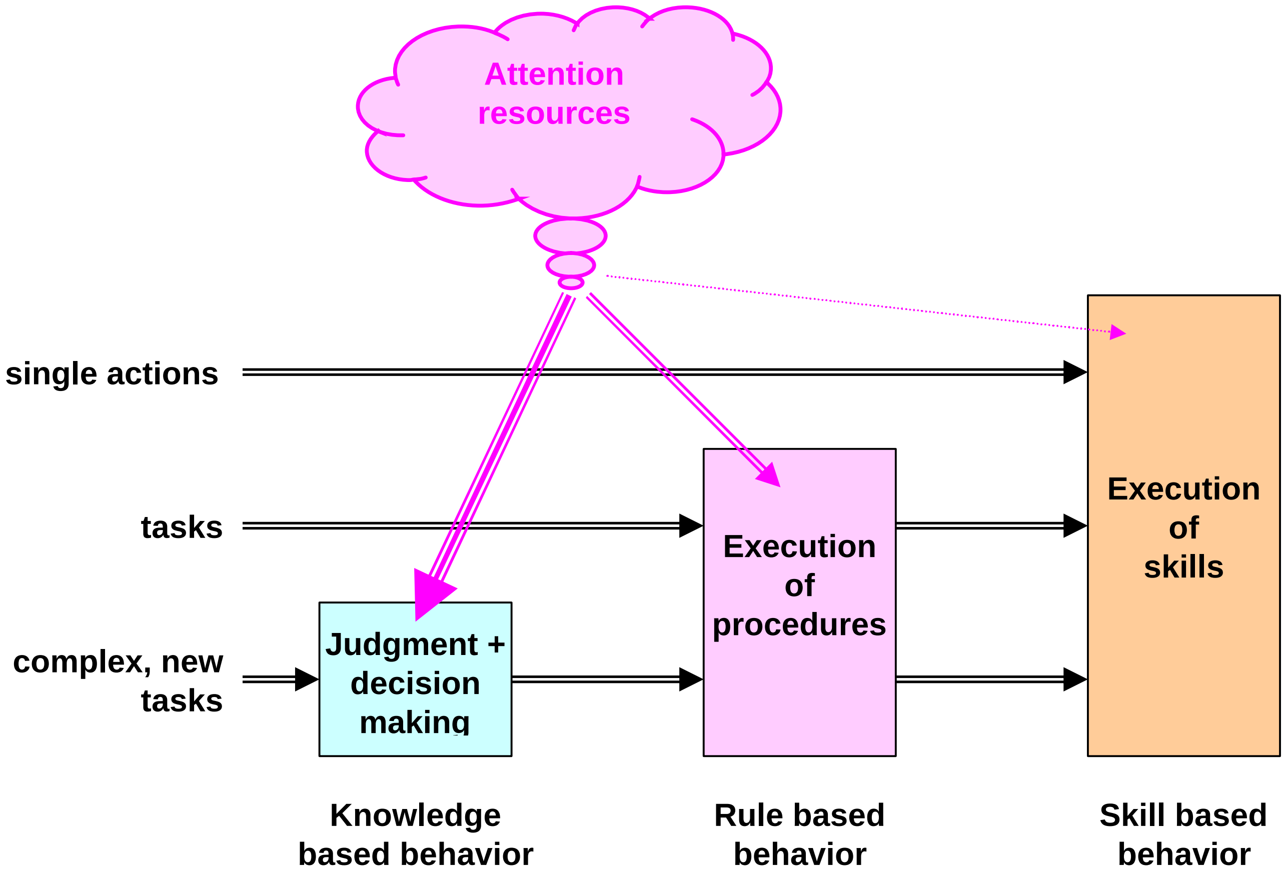
  Risk: uncertain results, extremely slow and thus susceptible to capturing of attention

" The fact, that the pilot is able to evaluate evidence and come to conclusions will, in future, be the only reason for keeping him on the flight deck"

"Human Factors for Pilots"

Complex behavior like flying

- combination of skill based, rule based and knowledge based behavior



During normal operation, most of the tasks should be executed by skill based behavior. As soon as there are no suitable skills to solve a given task, transition to rule based behavior is appropriate. At the moment the known rules are unsuitable for the given task, transition to knowledge based behavior is appropriate.

Since knowledge based behavior absorbs an extra large amount of attention resources, transition back to rule based or even skill based behavior as soon as possible, is a crucial factor to maintain an effective workload management.

Learning stages of skill acquisition

- **cognitive stage**
    - **familiarization with every single aspect of a task**
    - **single aspects are recognized and step by step exercised**

- **associative stage**
    - **integration of the single aspects to form the whole task**
    - **initially by intentional triggering of each single aspect at the right time**
    - **with growing expertise, each aspect is triggered by the previous, conscious control shifts to supervision**

- **automatic or autonomous stage**
    - **by continued repetition the task becomes more and more effective, needs less supervision by mental resources until it is fully automated and reflex**
    - **meanwhile it becomes more and more difficult to describe the execution of the task verbally, due to its automatic character with the information stored in the (unaware) procedural long-term memory.**

Motivation and drives

- **Motivation**

  ⇨ mental or psychological force that causes human subjects to behave in a certain way and to pursue particular goals

  ⇨ anatomically localized in the brain (Hypothalamus)

  ⇨ influences the threshold stimulus to perform actions

  ⇨ determines why a particular action is performed

  ⇨ closely related to human needs and drives but also dependant on the desire for personal comfort

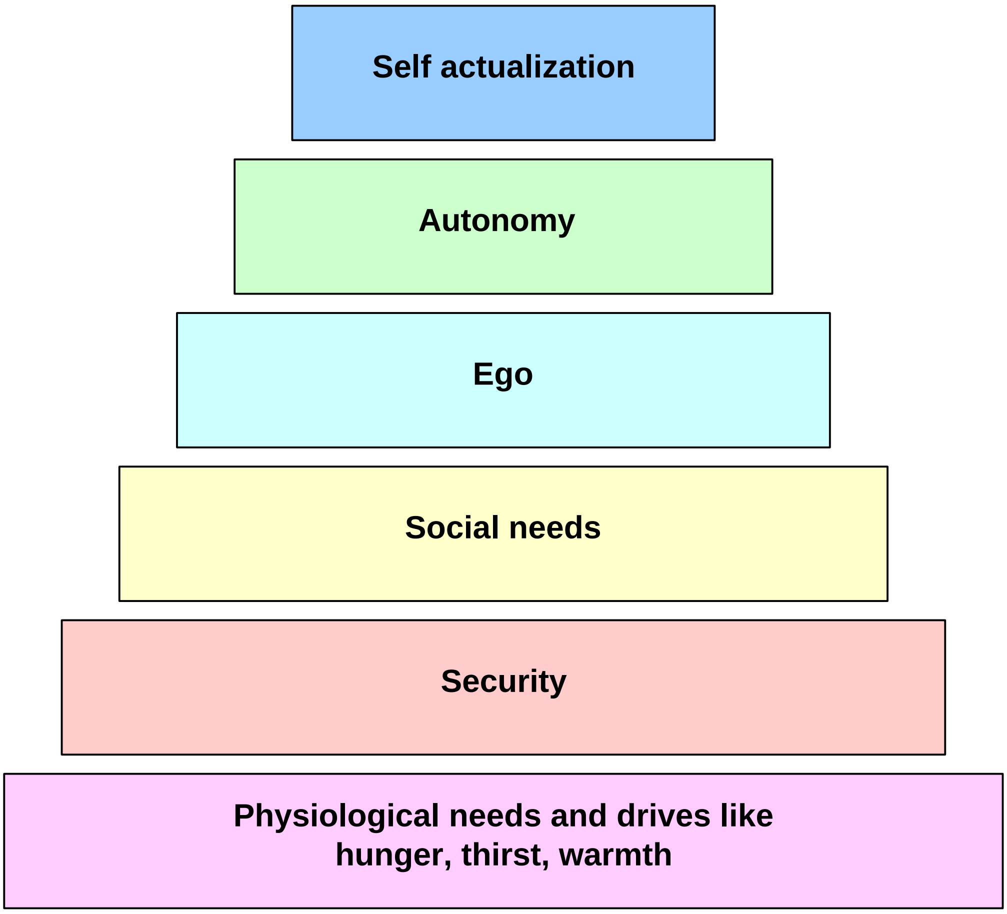
- **Human needs, drives**

  ⇨ **strong individual forces that, under certain circumstances, compel subjects to act in a particular way**

  - **homeostatic drives provide balancing of the system**
    - ⇨ **hunger**
    - ⇨ **thirst**
    - ⇨ **temperature control**

  - **non-homeostatic drives provide survival of the subject**
    - ⇨ **sexuality**
    - ⇨ **drive to survive**
    - ⇨ **fight or flight**

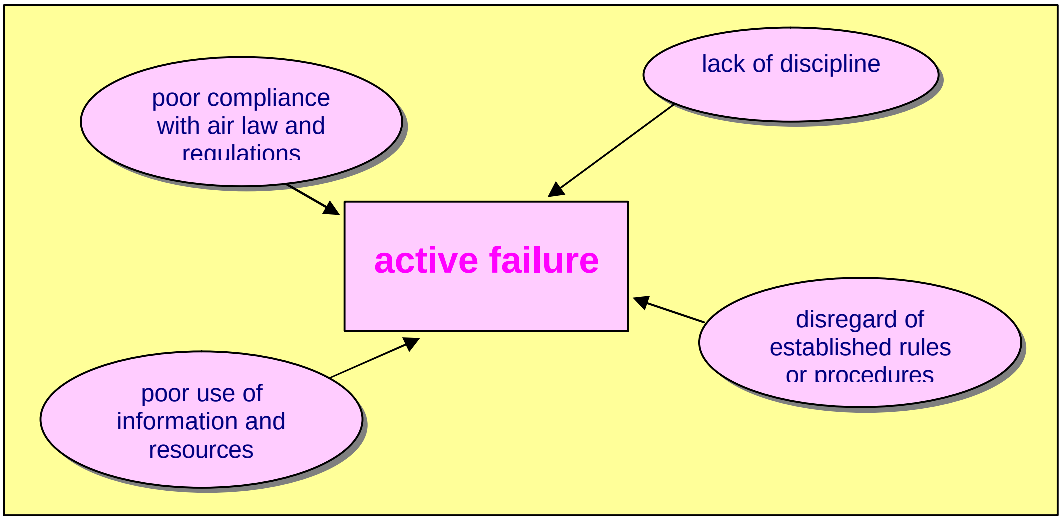
Hierarchy of needs – Maslow's pyramid

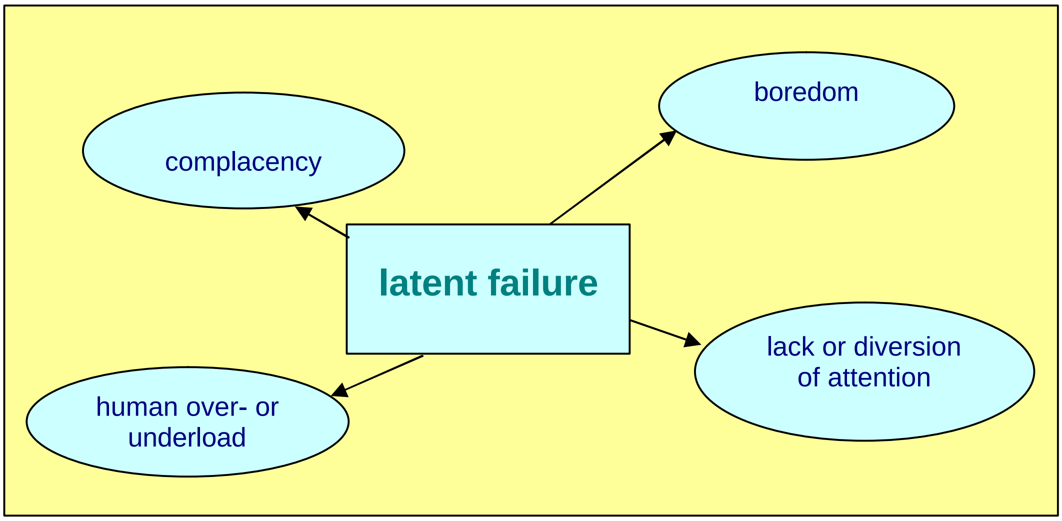


Human Error

Cicero: "it is the nature of man to err"

- Error types
  - active failure ➔ false action
  - latent failure ➔ omission of an action





Basic Error Classification

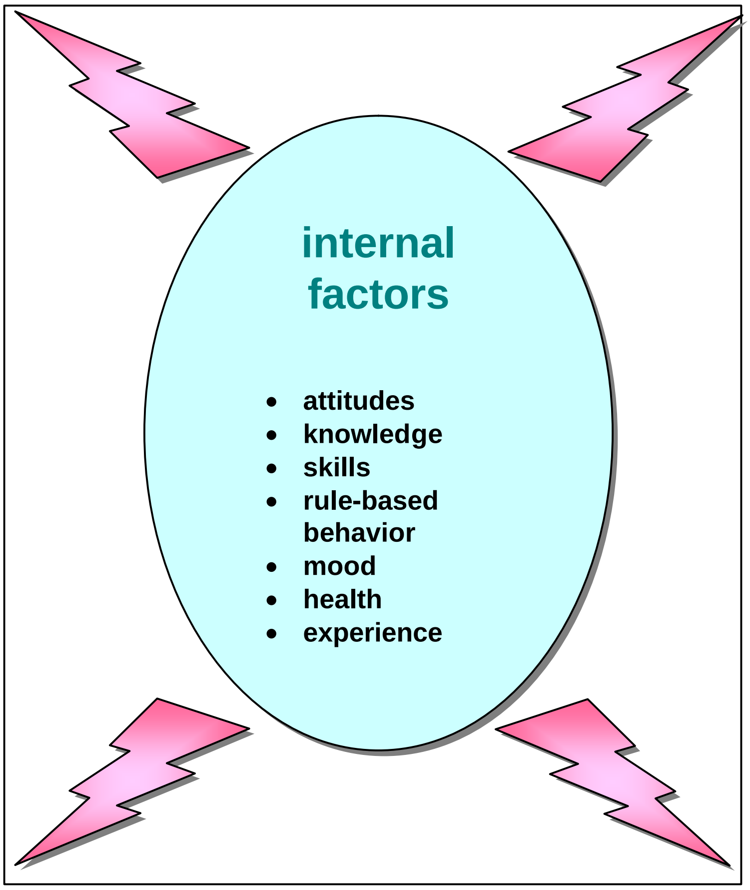
Slips ↔ **Mistakes**

incorrect or inadvertent action (skills)

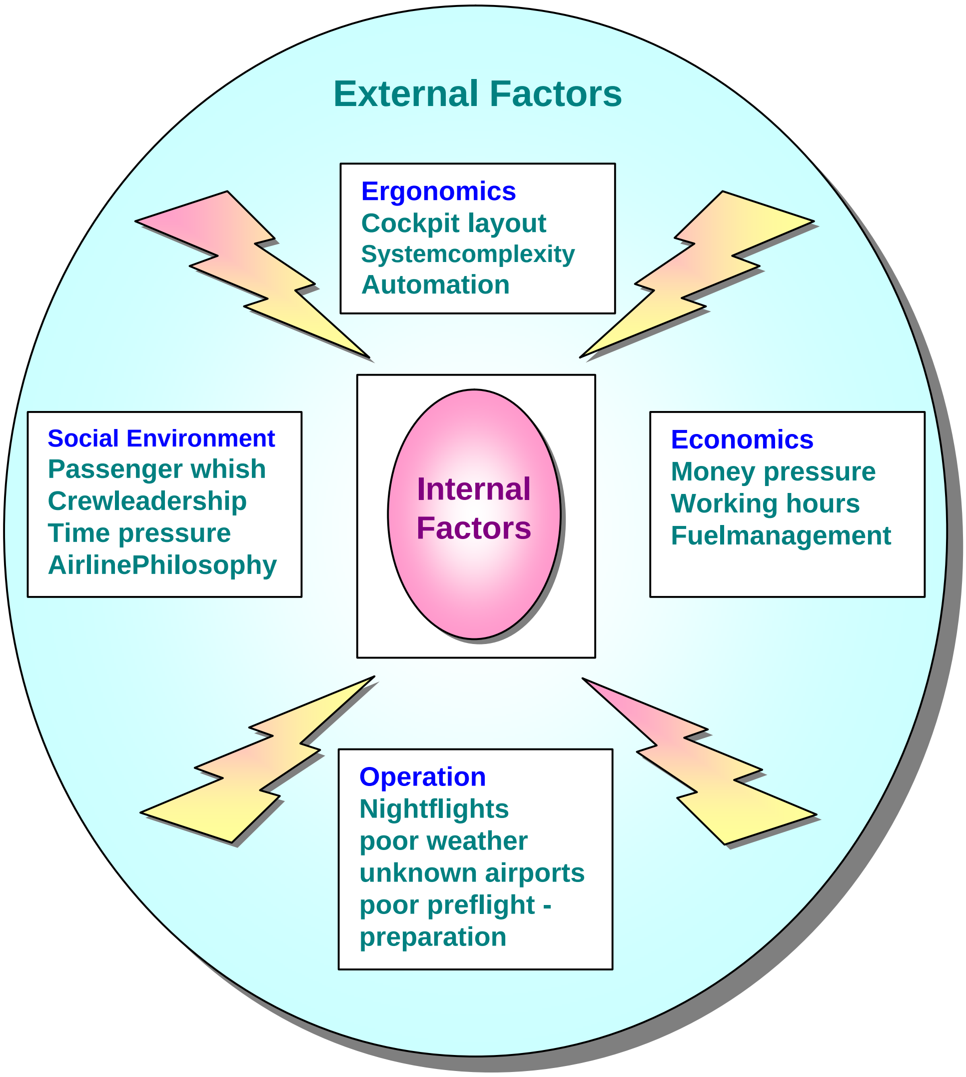
error of intention, understanding or knowledge

Factors in error generation

- Internal factors



- External factors



Pilot Judgment

- **Mental process that we use in making decisions**

  - **perceptual judgment (based on perception)**

    Few attention resources absorbed, relatively easy to learn and to perform, if the pilot is aware of a possible illusions and anomalities

    Example: judgment of distance, closure rate, speed, altitude

  - **cognitive judgment (based on evaluation)**

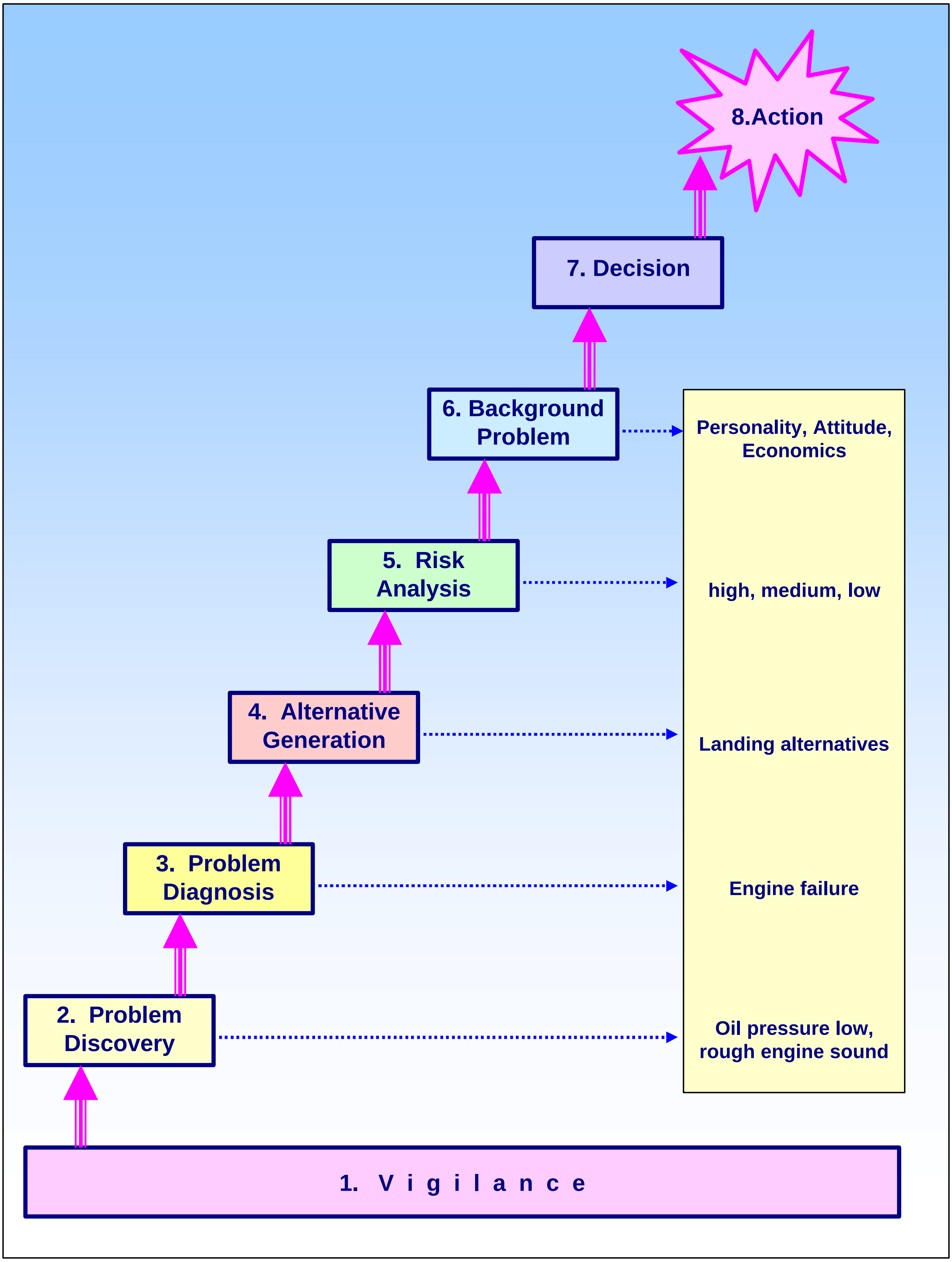
    Large amount of attention resources absorbed, usually more than two alternative, risks associated with each alternative are harder to assess, grossly influenced by non-flight factors like stress, fatigue, social and economical factors

The transition from perceptual to cognitive judgment depends on the level of proficiency. Being a beginner, most decisions are made by cognitive judgment, while the highly experienced professional pilot makes most of his decisions by perceptual judgment nearly automatically.

Keep in mind

Judgment Training should help you move from cognitive to perceptual judgment

Eight Step Model of Judgment and Decision Making



Good judgment can be learned

DECIDE Model

D	–	**D**etect:	**the fact that a *change* has occurred that requires attention**
E	–	**E**stimate:	**the *significance* of the changes to the flight**
C	–	**C**hoose:	**a *safe outcome* for the flight**
I	–	**I**dentify:	***plausible actions and their risks* to control the change**
D	–	**D**o:	**the best option**
E	–	**E**valuate:	**the *effect of the action* on the change and on the progress of the flight**

Keep in mind

DECIDE is the Checklist of Decision Making

Biases in Human Decision Making (Dedale 1994: Briefings)

- **Bias in selecting data**

  Preferences lead to a strong tendency to select a restricted range of facts and information.

- **Bias due to habits**

  There is a tendency the most familiar solution even if it is not optimal for the given situation.

- **Confirmation bias**

  We look first for confirming information which supports our decision rather than for information which would contradict it.

- **Bias due to group pressure**

  Tendency to go for a majority decision.

- **Bias in evaluating the frequency of serious events**

  The risk of occurrence is almost always under or overestimated because it is based only on personal experience

Factors affecting a pilots decision

- **Know how**

  Knowledge of systems and procedures and human factors

- **Access to information**

  Do you know where to get the necessary information?, do you know the key function of human support and interfaces.

- **Risk management strategy**

  What is your degree of commitment?, are you more hesitating, reluctant or more radical in making decisions?

- **Personality**

  Personality traits, attitudes and group interactions

CRM, Crew Resource Management

Definition (ICAO):

- Effective use of all resources available (equipment, procedures, staff) to ensure flight safety and efficiency.

~70 % of incidents / accidents are related to a malfunction in the crew, such as

- leadership problems
- inappropriate intra- crew communication
- uncoordinated crew action
- inappropriate situational awareness and poor decision making
- overconfidence in the system and man

Safety Awareness

To err is human, thus there is no absolute safety

To improve safety, the system must guarantee two properties:

error tolerance: actions known as error prone must not be critical, but at least double checked

error visibility: error caused dangerous situations must be clearly visible to the operators (pilots)

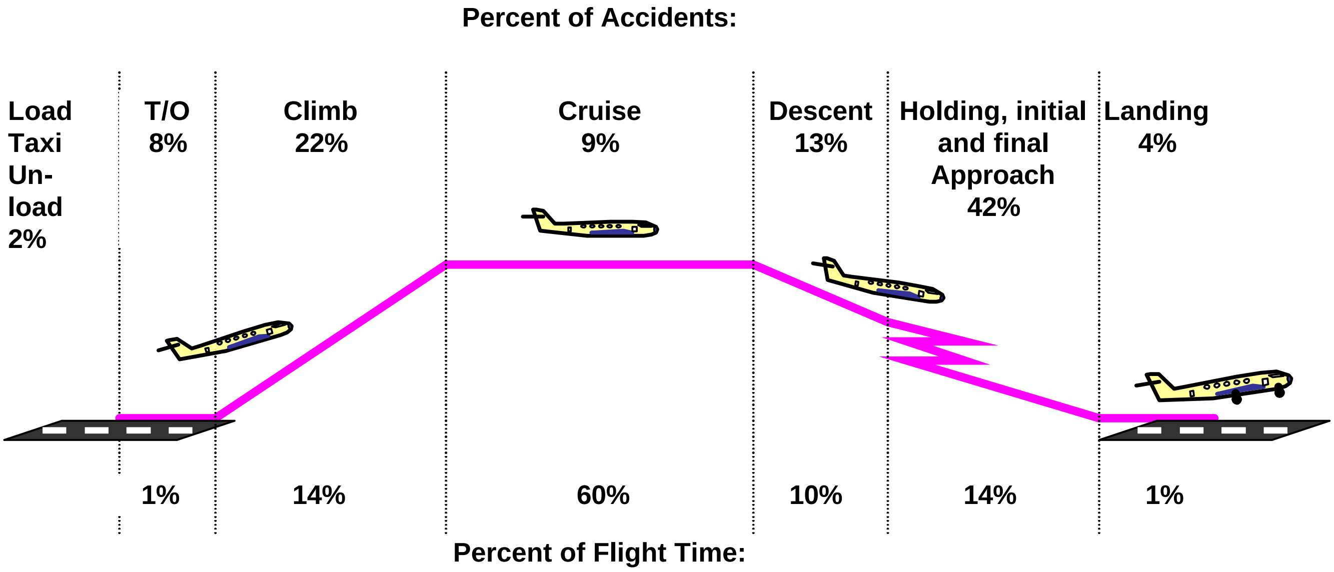
To maintain safety awareness, we have at least to guarantee

- risk area awareness
- awareness of the susceptibility to errors (internal, external)
- situational awareness

- **Risk area awareness, risk assessment**

Different phases of flight have their different risk:

(Air carrier accidents 1959-1983, world-wide jet fleet, all operations, average flight duration 1.6 hours, Boeing, 1985)



- **Susceptibility to errors**
  - **internal risks ⇨ risks caused by pilots actions, depending on**
    - **insufficient know how, poor skill performance**
    - **unexpected events**
    - **high workload, stress, fatigue**
    - **poor preplanning ....**
  - **external errors ⇨ errors caused by conditions beyond the pilots control, such as**
    - **hazardous weather**
    - **heavy traffic**
    - **defective equipment**
    - **poor ATC performance ....**

- ## Situational awareness

Situational awareness covers at least five different areas:

1. Status information

physical state or condition of the airplane like speed, attitude, altitude, heading, power setting, flaps and spoiler setting, fuel state, position of the landing gear, communication and navigation settings .....

2. Position information

position in respect to flight plan to any natural or man made obstruction or to other flying objects

3. External environment information

present and future weather, details of the aviation structure like airports, runways, taxiways, navigation aids, radio facilities, ATC systems, fueling facilities .....

4. Time information

actual time in comparison with the flight plan, next EET, expected arrival time at destination, time available for holding, diversion, time limit for the fuel available, time until weather changes ....

5. Social environment information

state of the other crew members (cockpit, cabin), the passengers and even cargo ....

Keep in mind

You are fully situational aware, if perception matches reality

Crew Coordination, the Multi- Crew Concept

Crew coordination deals with the interaction of the different crew members in a multi crew cockpit. The action of the crew members is harmoniously adjusted so that their combined effect is greater than the sum of the individual effects.

Most airliners today are operated by a two man cockpit:

- **Pilot in command (PIC, Captain) and Co-Pilot (First Officer, FO)**

To distinguish the different functions in a coordinated cockpit, the terms PF and PNF are used:

PF = Pilot Flying (PIC or FO)

PNF = Pilot Not Flying (PIC or FO)

Types of crew coordination:

- **Duplication of actions (redundant actions). PF and PNF carry out strictly the same actions**

- **Crew Cooperation. The actions of the PF and PNF are somewhat different, but synchronized, designed to gain synergy and manage crew resources. Synchronization is both, cognitive and temporal:**

  - **Cognitive synchronization**

    Briefings, compulsory announcements, use of checklists, mutual supervision etc. develop and maintain a common image of the present situation and allow to monitor changes and to follow the sequence of further actions

  - **Temporal synchronization**

    is used to trigger simultaneous or successive actions or to ensure that prerequisites for actions are satisfied

- **Co-action requires less precise coordination. Participants work side by side on the same general task but are relatively independent in pursuing their actions. This kind of coordination is typical for the co-work of cabin crew and cockpit crew**

Challenge- Response- Method

Crew cooperation method when going through checklists:

Pilot 1 **reads the checklist item loud: "Flaps ..."**

Pilot 2 **completes the task and repeats the instruction verbally: "...... set for approach."**

Both crew members are directly involved in the checklist process

⇨**enhanced communication**

⇨**enhanced safety**

Crew Cooperation is more than Technical Skills

⇨**Coordinated interaction of crew members designed to develop synergy.**

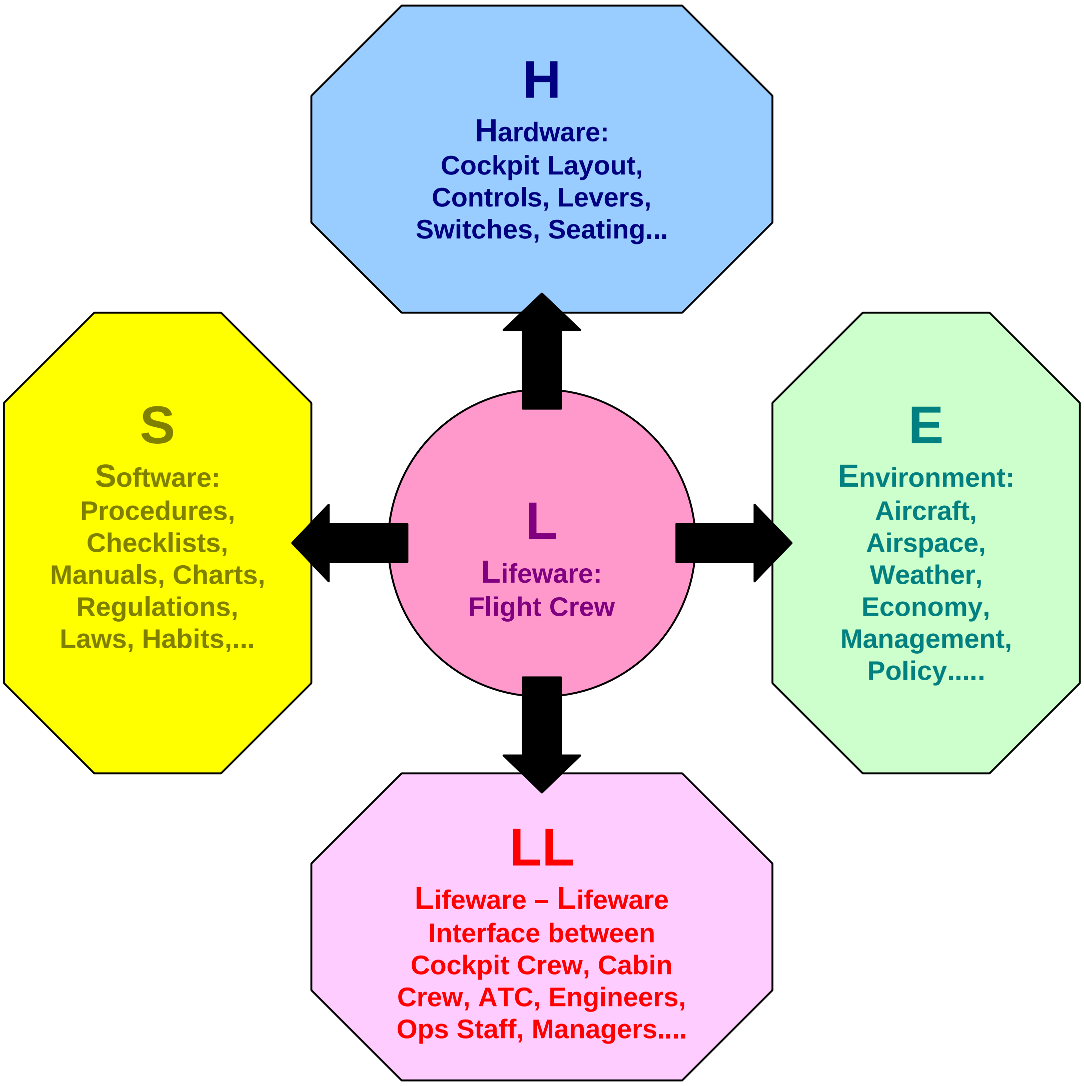
Synergy means, the combined effect of the crew members actions is greater than the sum of their individual effects.

CRM Training programs deal primarily with Crew cooperation topics. Trainees learn, that a cooperating crew is much more than just a collection of technically competent individuals.

The emphasis of CRM is on the development of non-technical skills and knowledge about topics like

- **Interfaces according to the SHELL model**
- **Personality attitude and motivation**
- **Group interactions and group thinking**
- **Leadership, followership and authority**
- **Status and role**
- **Communication, listening and advocacy**
- **Mutual supervision**
- **Conflicts and conflict resolution**
- **Dealing with criticism**
- **Dealing with different cultures, different languages**

The SHELL Model



The cooperating cockpit crew is the central function in the model which makes the judgements and decisions to bring all the other factors into a harmonious and safe working whole.

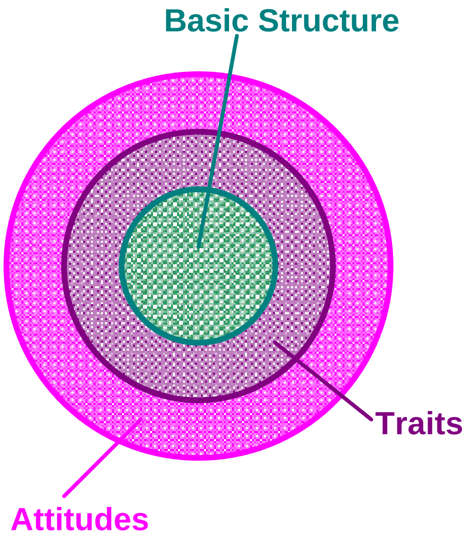
Therefore, a lot of typical problems may occur:

- **Information transfer problems (communication breakdown, misunderstandings, insufficient recall of operational and ATC procedures)**
- **Language or cultural difficulties when operating internationally**
- **Mis-read checklists, misinterpreted instrument indications**
- **Incorrect operation of system controls, incorrect computer programming**
- **Task saturation, causing the human mind to tune out, ignoring vital information**
- **Fatigue and subtle incapacitation**
- **Bad habits, developed during training or afterwards, hazardous attitudes**
- **Poor coping with stress, leading to confusion and in turn causing deterioration of the cognitive process, judgment and psychomotor ability**

Personality and Attitude

Personality describes a pattern of characteristics and behavior which allows us to master our life.

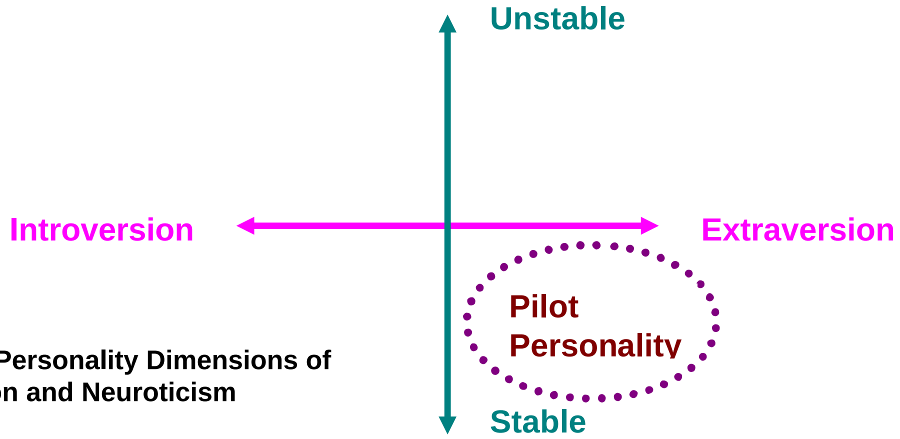
Deep in the core of the personality we find the basic mental, social and emotional structure we are born with or develop in the first few months.



Over the years of development, each of us develops strategies to best accomplish our goals of dealing with life and the persons around us. These so called personality traits are well establishes by the age of six and become deeply ingrained. Traits are difficult to change and may be modified only through considerable efforts of psychotherapy.

From an outside view, basic structure and personality traits are barely visible. Both are covered by a set of less deeply internalized components of the personality, called attitudes. Attitudes are subject to change fairly easily, especially under pressure. They are constantly bombarded by people like teachers, salesman, bosses, advertisers, friends, who try to change some of our attitudes.

Over the years, many researchers have presented models to describe the personality types. Among those we find Eysenck's personality dimensions based on Jung's terms of Introversion – Extraversion on one dimension and the ability to bind anxiety (neuroticism) on the other dimension:



Eysenck's Personality Dimensions of Extraversion and Neuroticism

Correlation of a given subject to Eysenck's personality inventory is made by analysis of a set of personality factors. This factor analysis reduces a table of interrelations between items to a small number of factors.

A well known contemporary factor analysis is Catell's, which describes 16 different factors:

Factor	Low score	1........10	High score
Warmth	reserved	------------	outgoing
Intelligence	dull	------------	bright
Ego strength	unstable	------------	stable
Dominance	submissive	------------	assertive
Impulsivity	sober	------------	impulsive
Group conformity	expedient	------------	conscientious
Boldness	shy	------------	bold
Emotional sensitivity	unsentimental	------------	sensitive
Suspiciousness	trusting	------------	suspicious
Imaginativeness	practical	------------	imaginative
Shrewdness	forthright	------------	shrewd
Guilt proneness	self-assured	------------	apprehensive
Radicalism	conservative	------------	radical
Self-sufficiency	group dependant	------------	self-sufficient
Ability to bind anxiety	uncontrolled	------------	controlled
Free-floating anxiety	relaxed	------------	tense

Personality profile according to Catell's personality factors

Pilot Personality

It is evident that the personality of the average pilot is distinct from that of the general population. In the framework of Eysenck's dimensions of personality, pilots tend to present as

- **considerably more stable**

  and

- **somewhat more extraverted**

than the general population

However, much more important than basic structure and traits are the attitudes of a pilot. Of special interest are attitudes which imply an error proneness, the so called

Hazardous Attitudes

Hazardous Attitudes

Six hazardous attitudes have been identified that help to explain much of the irrational behavior one can read in the accident reports:

Anti- Authority: **These people do not like anyone telling them what to do. They disregard regulations and required procedures.**

They say: **"You can't tell me what to do"**

Antidote: **"Follow the rules, they are usually right"**

Impulsivity: **These people frequently feel the need to do something, anything, immediately, right now.**

They say: **"Do something – NOW!"**

Antidote: **"Think first, judge carefully, than decide!"**

Invulnerability: **These people believe that accidents always happen to others and never to them.**

They say: **"It won't happen to me!"**

Antidote: **"Be careful, it could happen to you!"**

Machoism: **These people attempt to prove that they are better than anyone else and exceed either their own or the aircraft's performance. Though it is thought to be a male attitude, woman are equally susceptible**

They say: **"I'll show you, I can do it!"**

Antidote: **"Flying is about safety and there is no place for showing off "**

Resignation: These people do not see themselves as making a great deal of difference in what happens to them. They are likely to go along with fairly unreasonable requests just to be "a nice guy"

They say: "What's the use"

Antidote: "You can make a difference!"

Complacency: These people tend to think that they are actually not needed in the cockpit because automation does it all.

They say: "Everything works perfect, no need to check"

Antidote: "Checking and cross-checking is better!"

The awareness of the hazardous attitudes, which are found to some extent in everyone, will help you to develop a more positive and rational approach toward your flying decisions.

Groups, Group Performance and Interactions

All of us belong to groups of different kind, whether we wish to or not. Primary groups are those, we are born in, like

Family, sex, religion, race, skin color, ...

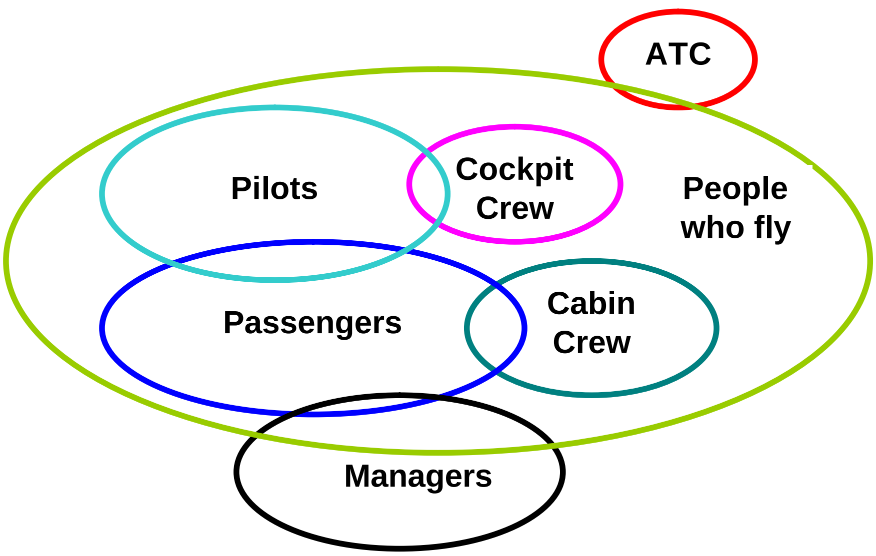
Secondary groups are groups we belong to because of a particular decision:

Profession, hobbies, sports, political party, leisure time, ...

As soon as two or more people form a group, they develop relationships which lead to a change in their behavior.

Social psychology is the study of how people behave in groups, and of how their judgment, attitude, opinions and behavior are influenced by others.

Typical groups in aviation:



Groups tend to create their own, new identity, which is often remarkably different from the identity of the members of the group.

Keep in mind

The group identity is different from the identity of the members of the group

Group Interactions

Human factors which play a crucial role in group interactions are listed below:

Conformity

- **Obedience**
- **Going along with other peoples mind rather than one's own**
- **Excessive desire to please**

  Example: Solomon Asch Test: A group of subjects (all but one of them where accomplices of the experimenter) was shown a line drawn on a card and asked to match the length of the line with one of three test lines. The correct answer was obvious, and the experiment started with all subjects giving the correct response. While progressing, the accomplices began to give incorrect judgments, and most of the test subjects agreed with the clearly wrong judgment on at least some occasions.

Compliance

- **Willingness to accept a meaning or to comply with a request**

  Example 1: Foot in the door technique: If a large and unreasonable request is made, a compliant response is more likely if it has been preceded by an accepted smaller, more reasonable, but similar request.

  Paradoxically, a compliant response is also more likely, if the request has been preceded by an obviously outrageous request which has not been complied with (Door in the face technique)

Status and Role

- **Status reflects the position of a subject in relation to other subjects e.g. Captain, Copilot, Chief instructor, Maitre de cabin, ...**
- **Role is a set of cultural models associated with a given status. The role describes attitude, behavior and values other subjects expect from the person having a particular status**
- **A given person can have several different status which can lead to a mismatch between the different roles**
- **Higher status implies higher prestige and obedience is more likely to subjects of a higher status.**

Risky Shift

- **Distortion of risk awareness: Groups tend to take larger risks than the individuals would do.**

Keep in mind

> **There are old pilots and there are bold pilots,**
> **but there are no old bold pilots**

Authority and Obedience

- **Humans tend to give away their responsibility to subjects of suggested higher authority. Afterwards they sometimes show a blind obedience to the high authority person.**

  Example: Milgram's Memory Experiment about learning by punishment:
  As a teacher, a test person had to punish a learner by administration of progressively more severe electric shocks if he failed in memorizing lists of words. The learner who, in fact, was an actor, cried out and complained of a heart condition as the teacher administered increasingly severe '"shocks". Even though many of the teachers demonstrated acute anxiety they continued to administer shocks.

Group Duration

- **Modern civil air crew may never have flown together or never even have met before they are required to function as a working unit.**

  Obviously the roles of each crew member must be defined closely so that a given first officer can perform in exactly the same way regardless of the captain he finds himself with and vice versa. The so called Standard Operating Procedures are of paramount importance

- **Military crew often are constituted and each crew member will be very familiar with each other's way of working. This may lead to departing from standard operating procedures and failing to carry out proper checks.**

Leadership

The secret of successful leadership is to concentrate

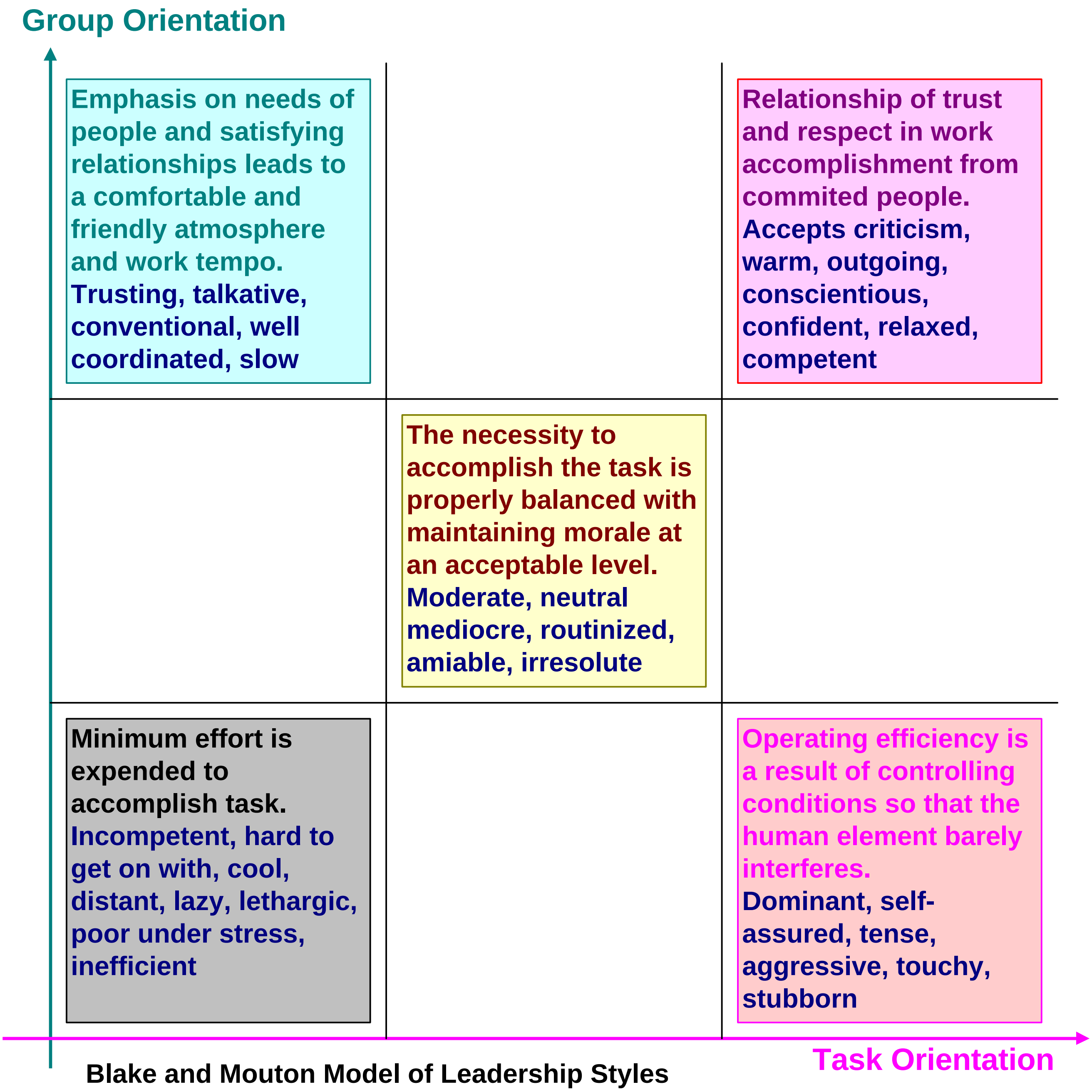
- **on the task which has to be performed**

  and

- **on the relationship within the group**

  at the same time

This leads to a two-dimension model of leadership styles, (Blake and Mouton, 1978):



Blake and Mouton Model of Leadership Styles

Attributes of a perfect Leader (acc. to Stanley R. Trollip and Richard S. Jensen)

- **Competence**

  Knowledge and experience are basic for a successful judgment and decision making. Pilot skills must be exemplary and should inspire the confidence of other Crew members. Other subjects can sense competence, and the competent pilot will frequently be given preferential treatment by ATC or line personnnel.

- **Communication Skills**

  Leaders have a wide-ranging and adaptive vocabulary which allows them to communicate with a broad variety of group members.

- **Listening Skills**

  Leaders have the ability to listen actively and to ask questions until everything is clear. Leaders interpret and evaluate what they hear and do not permit personal ideas or prejudices to distort what a person says.

- **Well considered judgment and favorable decision making**

  Leaders base their judgment and decision making on the sum of information available. Making an extra effort to seek out additional information may place a new perspective upon a situation.

- **Decisiveness**

  Leaders conclusively carry out decisions once they are made. They view decisiveness as essential for unity of action. Followers will usually accept everything but excessive timidity.

- **Perseverance**

  Leaders steadily persist in adhering a course of action. They stick to tasks and see them through to completion, regardless of difficulties. Leaders are optimistic and confident that they can find solutions to problems. They may even be a little bit stubborn when they are convinced of the correctness of a decision.

- **Sense of Responsibility**

  Leaders place responsibility above personal desires. Group concern is more important than personal concern.

- **Emotional Stability**

  Leaders exercise self-control if they expect to control others, and they must maintain control in the most trying situations.

- **Self- Esteem and Self- Respect**

  Leaders must have a positive self-image

- **Enthusiasm**

  Leaders must be enthusiastic in all the tasks which comprise the mission at hand. Followers will automatically give themselves and take pride in their work when they know their leader is involved an committed.

- **Reliability in Ethics and Moral Values**

  Ethics play a key role in leadership because they are the basis of all group interaction and decision making. Leaders must maintain high standards of personal conduct and adhere to those standards in all situations so that followers can rely on the leader's actions. Leaders should not misuse their position for personal and special privileges.

- **Recognition**

  Leaders recognize the accomplishments of their people. "The deepest principle in human nature is to be appreciated" (William James). Leaders are aware of the people surrounding them. They know their names, home towns, family situations and so on. Leaders care about their people.

- **Sensitivity**

  Leaders must be aware of their own psychological and physiological states as well as of the states of other group members. Leaders must also be sensitive to the impact they have on others.

- **Humor**

  Leaders set the tone in the cockpit, therefore they should have a sense of humor. Humor is a positive and welcome contribution to an efficient and effective cockpit.

- **Stamina**

  Leaders have a high level of physical and mental stamina. They always seem at the ready and require only normal periods of rest. They know how to pace themselves well and maintain themselves in good physical condition.

- **Flexibility to adapt the Leadership Style**

  Leaders understand that no two people or situations are ever exactly alike. Leaders adapt their styles to the particular person or problem at hand.

Leadership Styles

Effective leaders adapt their styles to particular circumstances and persons. They may show

- **Firmness**
  ⇨ to establish "who is who" and to take back control and in case of urgent decisions

- **Flexibility and Friendliness**
  ⇨ to communicate, collect ideas; appropriate during cruise flight.

- **Federal or Chairman style**
  ⇨ to encourage members to give their best in difficult situations.

Crew Leadership, Crew Followership

The Leader should

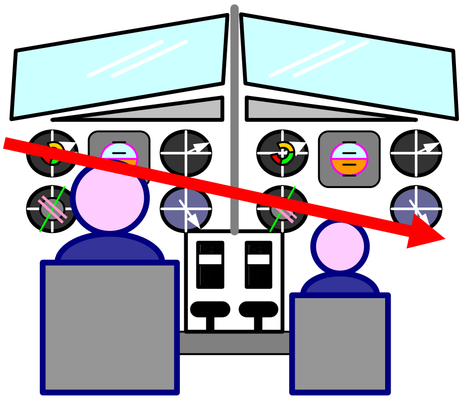
- **first listen and withhold his opinion to encourage followers to express themselves without feeling biased,**
- **ask the followers opinion and encourage them to express doubts,**
- **make sure, potential problems are recognized and not covered up**
- **make decisions and inform the followers to guarantee support of the plan of action.**

The Follower should

- **accept the authority of the leader,**
- **voice his or her opinion in a respectful yet confident manner,**
- **express concern or doubts regarding practices which look unsafe, without fear of looking stupid in the eyes of the leader,**
- **remain objective and leave personal and egoistic belongings behind,**
- **help to maintain a warm, open and animated atmosphere in the cockpit to support maximum synergy.**

Cockpit Authority Gradient

- ## Autocratic Cockpit

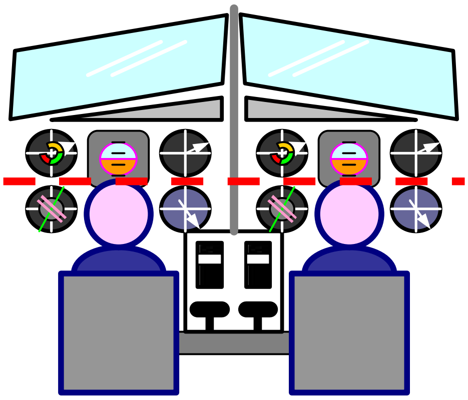


Gradient too sharp and synergy poor
Leader is authoritarian an segregated from the group. He imposes objectives and resources and doesn't give information. There is no teaching. Only at the end of the operation does he make general comments.

Causes:
- **excessive difference in seniority or proficiency**
- **Captain with a very strong personality and Copilot with a weak personality**
- **Captain lacking of self-confidence and using his authority to conceal it**

Crew reaction:
- **aggressivity which increases the tension in the cockpit**
- **apparent submission and withdrawal ("I'm saying nothing more!")**
- **"scapegoat effect" : unexpressed aggression is turned against a third person (cabin crew, ATC, ...)**
- **unexpressed aggression is locked in the memory, absorbs attention resources and therefore reduces tolerance to stress.**

- ## "Laisser- faire" cockpit

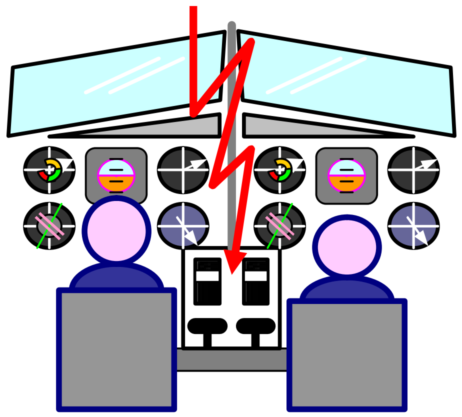


There is no Authority at all.
The Captain doesn't make decisions. He is a member of the group, maintains a good, amiable atmosphere but makes no judgment or assessment. Very little of the communication is about the task. Cockpit synergy is very poor

Causes:
- **Captain with excessive desire to please**
- **Captain having a leadership which is not recognized by other crew members**

Crew reaction:
- **The power vacuum always will be filled in by another crew member who will take over**

- **Self- centered Cockpit**



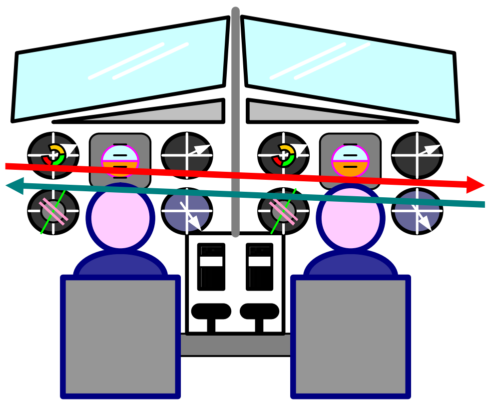
Each crew member keeps himself to himself, taking no interest in what the others are doing. The Captain is convinced, that he has no need of other crew members. He ignores their plan of action without realizing that they don't know what he is doing.
There is barely any teaching, no synergy, little communication and limited number of cross-checks
Causes:

- **encouraged by glass cockpits, which offer individuals independent access to FMS and AP functions and lead to a "two-parallel one-man-cockpit"**
- **Captain with a self-centered childish personality**

Crew reaction:

- **overconfidence if other crew members have weak personality.**
- **withdrawal, if other crew members have a stronger personality which results in a self-centered behavior of the other crew members themselves.**

- **Synergistic Cockpit**



The slope of the authority gradient depends on the context: It must initially slope sharply to "set the scene", decrease during cruise and again increase if there are problems.
The Captain creates plans of actions jointly with his crew. He accepts criticism and, possibly will change his mind.
He collects all information available before taking a decision. He anticipates and allows others to work and participate.
He is a friendly leader who attempts to relax the group.

The captain creates an atmosphere that encourages exchange, brakes down barriers and supports synergy. His decisions are based on facts rather than on personal prejudice. He takes the decisions himself but then informs other crew members to guarantee they support the plan.

Causes:

- **Captain and crew members follow the rules of leadership and followership**

Crew reaction:

- **Crew members feel as valuable members of the group, take their responsibility and give their best**

Communication

Definition:

- Exchange of messages, expressed as codes, such as
  - speech
  - writing
  - gestures, posture
  - glances, mimes
  - intonation
  - .....

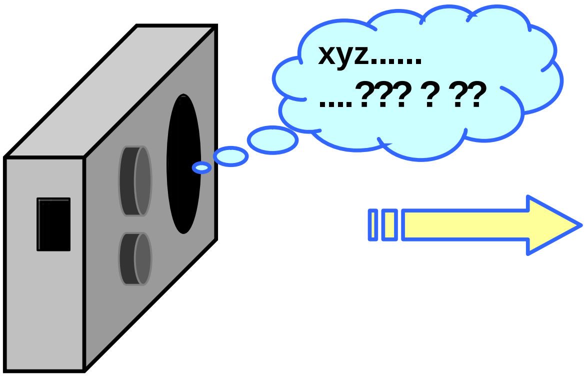
speech, writing: verbal communication

gestures, posture, glances, mimes, intonation, ...: non-verbal communication

- **One- Way- Communication:**

  Information flow unidirectional:

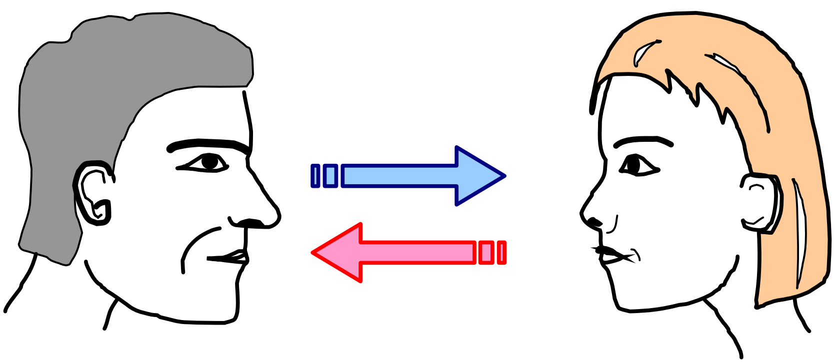
  Example: TV, broadcasting, newspapers, transmission blind .....



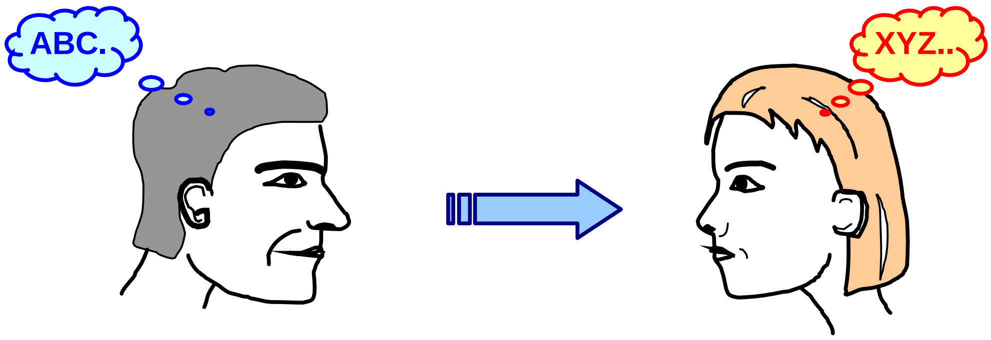
- **Two- Way Communication:**

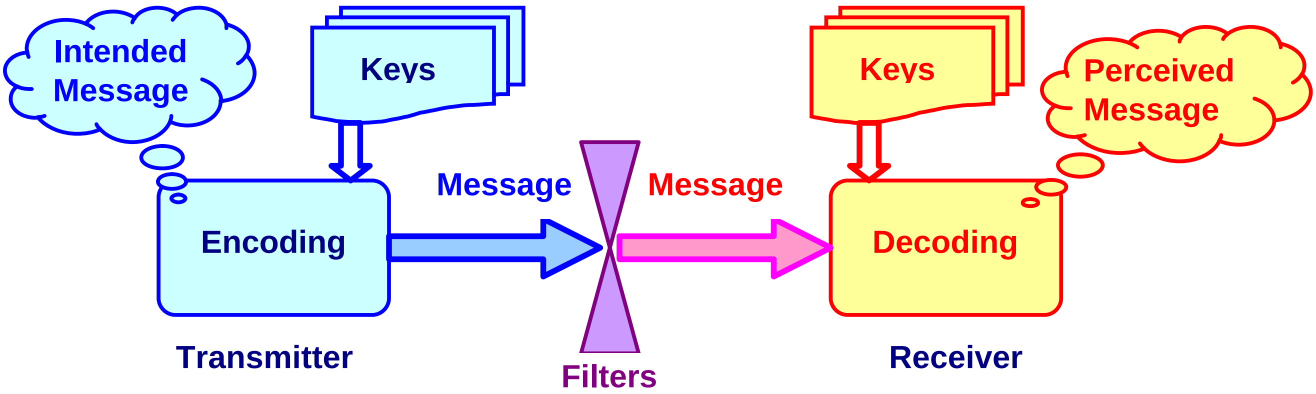
  Information flow bidirectional:

  Example: Talk, discussion, any interaction between people .....



The Communication Process





Communication Process

The keys used for encoding and decoding depend on the context and on personal conditions like

- **language, culture, motivation, self- image, attitude, mental associations, bias, prejudice, experience.....**

Keys used by the receiver are always different from those used by the transmitter.

Additionally, the sent message is distorted by external filters like

- **noise, darkness, malfunctioning communication equipment ....**

Keep in mind

> **Rarely, the perceived message completely matches the intended idea of the transmitter**
> **and**
> **Nobody can NOT communicate**

Levels of Communication

- **Factual level**

  facts, the transmitter informs about

- **Self- disclosure level**

  additional information about the transmitter

- **Relationship level**

  additional information about the relationship between transmitter and receiver

- **Appeal level**

  information about what the transmitter requests or expects the receiver to do

The receiver may have completely different view points referring to the levels of communication and, as a result, may perceive a message quite differently from that, the transmitter wanted to give

Example: Captain to Co-Pilot:

"Where is the approach chart?"

Captain transmits :

factual level:	**Where is the approach chart?**
self-disclosure:	**I need the approach chart, I'm in a hurry**
relation level:	**I'm the boss and it's your job to prepare the charts**
appeal level:	**I'd like you to cope with cockpit rules**

Co-Pilot perceives:

factual level:	**Where is the approach chart?**
self-disclosure:	**He is like a child, he needs my help all the time**
relation level:	**He doesn't appreciate the work I do, he just wants to show who is the boss**
appeal level:	**What shall I do? I'd better wait for him telling me what to do**

Barriers to effective communication

- different weighing of the levels of communication
- prejudice, biasing, intolerance, predictive preferences
- different ego states
- autocratic or egocentric leadership styles
- major difference in proficiency level
- excessive use of abbreviations (altitude, heading, speed, call sign)
- stress, high workload or fatigue
- distraction caused by nonessential conversation (sterile cockpit)

Factors supporting successful communication

- careful listening
- asking questions, until everything is clear
- respect
- clear and precise speaking (kiss = keep it short and simple)
- advocacy (active support of the own plan of action)
- ask for and give feedback
- paraphrase (restatement of perceived messages in other words)
- eye contact and congruent body language
- sterile cockpit rule : no nonessential duties during taxi, takeoff, landing and other flight operations below 10'000 ft except cruise

Keep in mind

Careful listening and the courage to ask questions are the first steps in successful communication

Example: Air Florida 90, B737, January, 13th 1982 at Washington National Airport, T/O in icing conditions with the first officer acting as PF:

FO: "Slushy runway, do you want me to do anything special for this or just go for it?"

Capt: "Unless you got anything special you'd like to do."

Conflicts

If each person in a cockpit advocates his or her respective position properly, conflicts are inevitable. There will be contradictory, incompatible elements in the relationship at the same time which lead to conflicts.

We distinguish intra- from interpersonal conflicts.

- **Intrapersonal conflict**

  incompatible elements occur within a single person

  Examples: **incompatible targets**
  incompatible decisions
  incompatible roles

- **Interpersonal conflict**

  incompatible elements occur within a relationship between different subjects, groups, organizations....

  Examples: **incompatible ideas about facts**
  different ways of doing things (merging companies!)
  incompatible parameters defining the relationship such as different perceptions, moral concepts, needs, emotions, behavior, culture .....

Most interpersonal conflicts occur based on misunderstandings, due to different perception. Willingly induced conflicts are rare.

Conflicts are not necessarily bad, but they can be destructive when the argument is about who is right rather than what is right. Such arguments easily can trap your attention, leading to potentially dangerous situations.

Conflict Resolution Strategies:

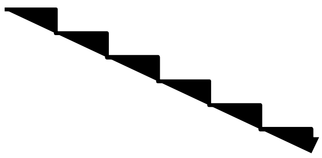
Mature conflict resolution:

encouraging	of others to express their opinions
decision	compulsory decisions are made
win-win- compromise	both partners can win
synergistic synthesis	the result is more than the sum of the parts
acceptance	conflicts which can not be solved for the time being, are temporarily accepted and solved later

Immature conflict resolution:

defense	argument, excuse, alibi, agitation, rationalizing (self satisfying but incorrect reasons)...
avoidance	escape, resignation
uneven compromise	loose-loose- solution

step by step conflict escalation



⇨debating, threatening, fighting, loss of self-image, deteriorating, until both contradictors are lost in the abyss

Critique

No one is perfect and therefore everyone needs feedback and critique to improve his or her future performance.

Because of the position, the captain's first responsibility is to provide feedback. However, he or she also makes mistakes that need to be pointed out, despite the facts that social norms do not encourage people to question those in authority over them.

CRM training should make you aware, that everyone has to expect a critique. It is good practice to ask for feedback rather than waiting for it to be given. The process of giving feedback and critique starts at the beginning of the flight planning and ends with a debriefing at the conclusion of the flight. Properly given and accepted critique can become a way of life in the cockpit to resolve conflicts and misunderstandings before they arise.

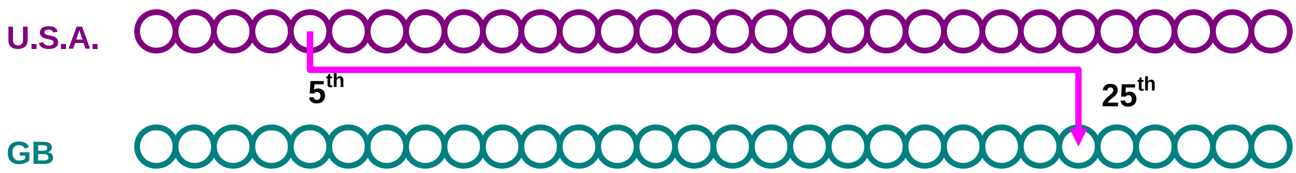
Different Cultures

Cultures have a set of behavioral rules, common sense and historical facts which are mostly unconscious to the members of the culture but nevertheless important in the kind people perceive their environment

Example: Both, American soldiers and British women perceived their partners as sexually very directly and straight when they started a relationship during and after WW II. Why?

Both, American and British culture name ~30 behavioral stages between first eye contact and having sex.

In America, kissing ranks very early at ~ 5th place. However, in England, kissing ranks much later at ~ 25th place.



Typical cultural differences in multi- cultural crews

- **Power distance Captain - Crew**

  long: India
  short: Austria, Denmark

- **Individualism**

  high: U.S.A.
  little: Iran

- **Uncertainty avoidance**

  strong: Japan
  little: Denmark

- **Masculinity**

  strong: Italy
  little: Sweden

Mental Workload

- total demand upon mental resources during accomplishment of a set of tasks

The demand is determined by

- characteristics of the task
- attributes of the subjects like skill level, experience, attitudes, ...
- unexpected events
- environmental conditions

Workload tolerance

- capacity of a subject to withstand increasing workload

Workload tolerance highly depends on

- personal health
- knowledge, experience and skill level
- personal fitness (endurance, stamina, strength)
- actual vigilance

Spontaneously, humans prefer a relatively high but controllable workload (~ 60...90%).

Human Overload

- Workload is above tolerance

  ⇨ performance collapse

Human Underload

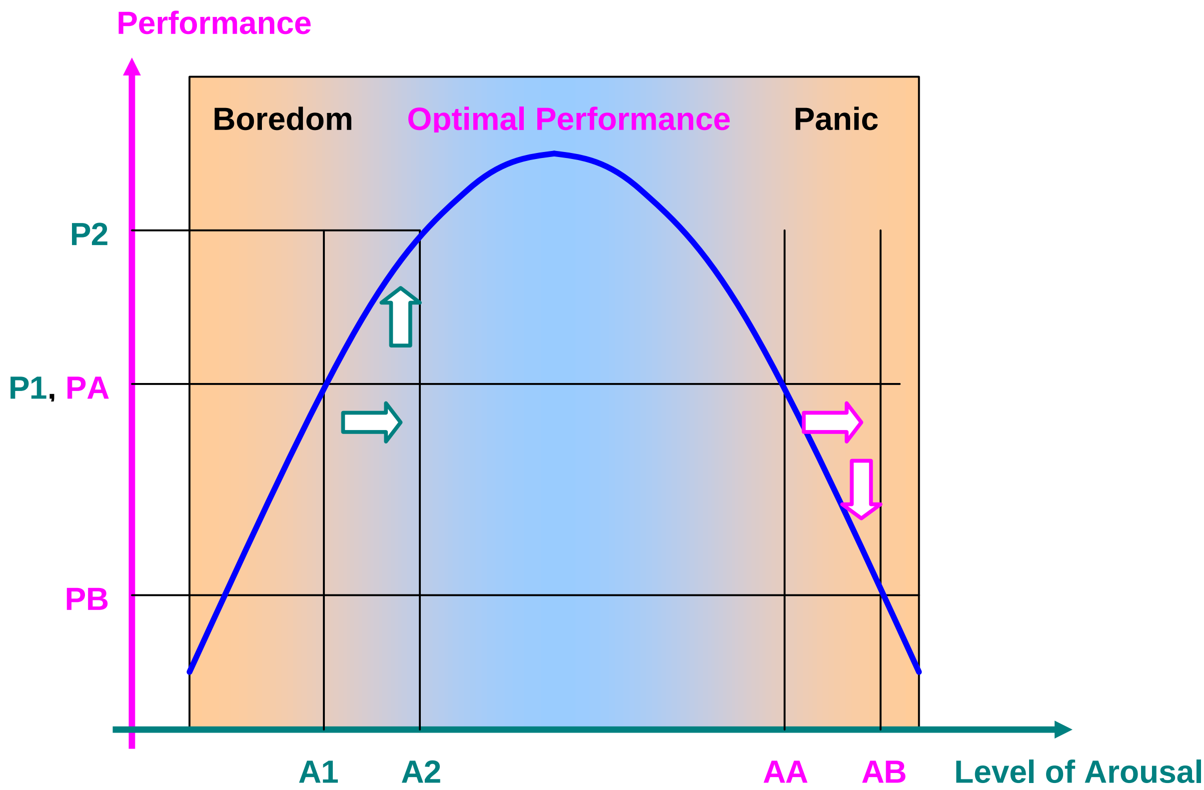
- Workload is far below the tolerance

  ⇨ boredom, disconnection from the process (out of the loop)

Arousal and Performance, the Yerkes – Dodson Law

- **Differential effect of an arousing stressor on extraverts and introverts**

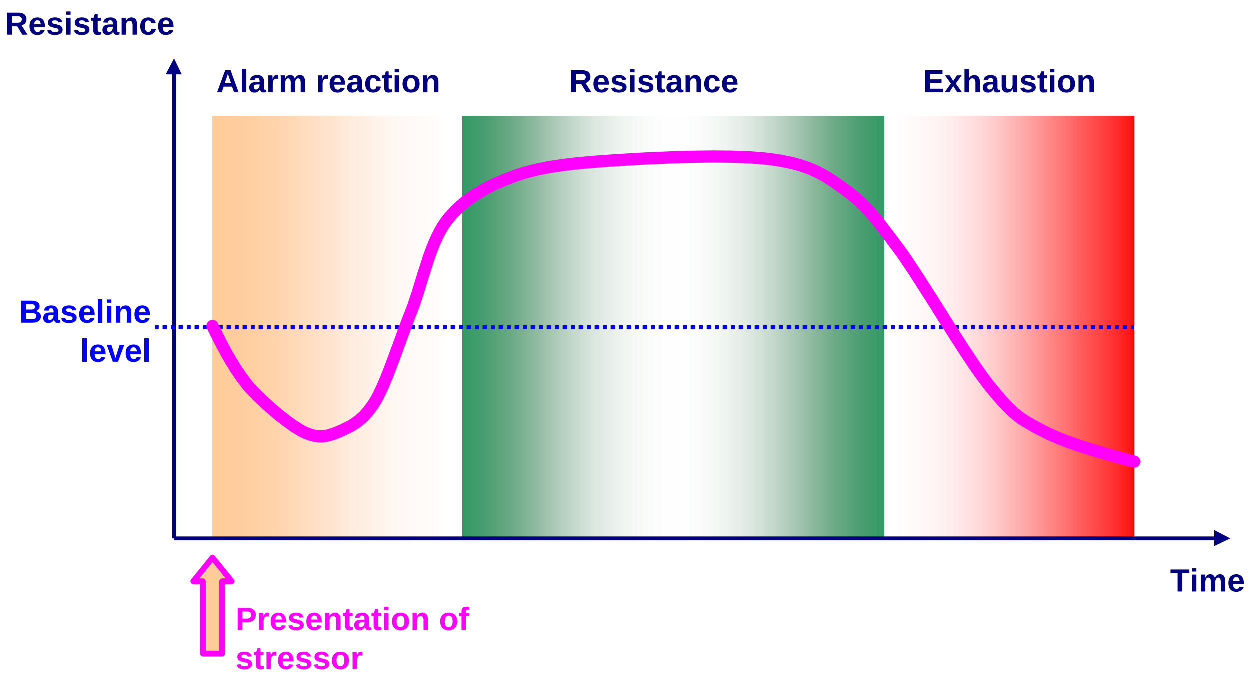
  Introverts are chronically over-aroused, whereas extraverts are chronically under-aroused. Exposure to a stressor that rises arousal level may increase the performance of the extravert but decrease the performance of the introvert.



Stress

- natural reaction or response of the human body and mind to an unexpected environmental condition called stressor
- controlled by the vegetative (autonomous) nervous system

General Adaptation Syndrome (Selye)



Alarm reaction

- shock phase due to Adrenaline ⇨ heart rate ⇧, respiration rate⇧, sweating ⇧ , blood sugar ⇧ , arousal ⇧, ...
- counter shock phase in which the body marshals defence mechanisms (Cortisone production)

Resistance

- coping process for successful adaptation (but decreased resistance to other noxious stimuli)

Exhaustion

- collapse of the defense mechanisms, leading to a large variety of symptoms and eventually severe illness .... death

Types of Stress

- **physical stress**
  - hypoxia
  - rapid decompression
  - vibration, noise
  - heat, cold, humidity or dryness

- **physiological stress**
  - hunger, thirst, low blood sugar level
  - lack of physical fitness, fatigue, sleep loss
  - discomfort associated with a full bladder or bowel
  - diseases

- **psychological or emotional stress**
  - social or emotional factors related to living
  - solving difficult problems like decision making

keep in mind

physical, physiological and psychological stress cumulate

Stress

acute stress **chronic stress**

Stress is not only dependant on the workload you experience but on your personal model of the situation including your idea of how high a workload should be. Many people experience stress which is actually homemade and could easily be reduced by facing the facts.

Stress highly depends on your personal judgment, adjusting the judgment can substantially reduce the stress.

Life Events Stress Profile (according to S. R. Trollip / R. S. Jensen)

LIFE CHANGE UNITS	Life Event
100	Death of spouse
73	Divorce
65	Marital separation
63	Jail term
63	Death of a close family member
53	Personal injury or illness
50	Marriage
47	Lost your job
45	Retirement
40	Pregnancy
39	Sexual difficulties
38	Change in financial state
37	Death of a close friend
35	Argument with spouse or partner
31	High mortgage or loan
29	Son or daughter leaving home
28	Outstanding personal achievement
26	You begin or end work
25	Change in living conditions
23	Trouble with boss or instructor
20	Change in residence
16	Change in sleeping habits
15	Family social events
15	Change in eating habits
13	Vacation
12	Christmas
11	Minor violation of the law

Characteristic Behavior under Stress during a Flight

- **Poor perception and incorrect interpretation (we perceive what we expect to perceive).**
- **Excessive concentration on a single aspect of a problem without realizing that other aspects could be of equal or even greater importance (focusing of attention).**
- **Rigid thinking and tunnel vision, often developing a "set", where the crew members reinforce each others belief, without actually checking the facts.**
- **Poor judgment and decision making, especially an inability to generate practicable alternatives or a second solution, if the first one fails.**
- **Regression to former practices (in an emergency, people tend to using their mother tongue and may well regress to earlier learning stages and e.g. mix up actual procedures and those of earlier flown aircraft).**
- **A tendency to cutting corners instead of using exactly the procedures specified in the checklists.**

Coping with Stress

Acute Stress

During a flight, coping with acute stress is difficult and depends highly on the personality characteristic of the pilot. Taking a deep breath and trying to relax for a short period may be helpful to reframe the stressful situation. However, the best way to cope with stress in flight is certainly to develop habits and strategies to avoid stress as far as possible by

- **Continuous training to increase your expertise**
- **Proactive workload management**
- **Building up a simple, general plan of action to organize priorities during phases of stress, which guarantees safety and is easy to use**
- **Applying CRM principles and adding some humor within the crew**
- **Learning relaxation and mental preparation techniques**

Proactive Workload Management

- Planning and Preparation
  - Anticipate periods of high workload and complete predictable tasks as soon as possible (proper preflight checks, pre-select frequencies, prepare charts, contemplate possible problems and suitable decisions, monitor ATIS and other sources of information, ...)

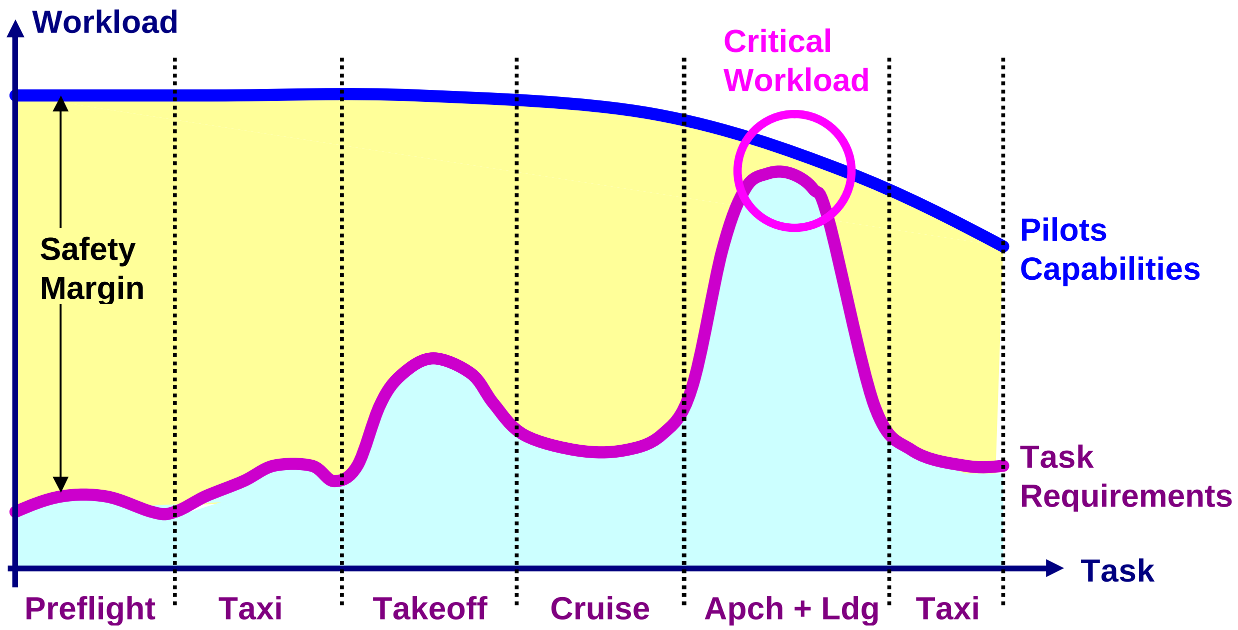
- Prioritizing
  - Do the most sensible tasks first (e.g. if you need to perform a go-around, set power, check attitude, gain speed, gain altitude and configure the aircraft properly before talking to ATC)
  - use the "Important / Urgent" Matrix to set priorities:

	Urgent	Not Urgent
Important	I	II
Not Important	III	IV

A tasks in quadrant I is always pressing, because we have to do it (important) and do it right now (urgent).
A tasks in quadrant II is important but we decide at what time we'll do it, because it is not urgent.
Tasks in quadrant III are disruptive, because they look urgent but are not important.
Tasks in quadrant IV are neither urgent nor important, it's just wasting time.

Proactive time management means: Complete the tasks in quadrant II before they get urgent and move to quadrant I.

- **Work Overload Awareness**



Accidents often occur when flying task requirements exceed the pilots capability. In the above example, the margin of safety is still positive during approach and landing. Supposed the flight is delayed some hours, the safety margin for the approach may well be negative.

To maintain an acceptable margin of safety anytime during the flight, a proactive workload awareness is crucial.

Coping with chronic stress

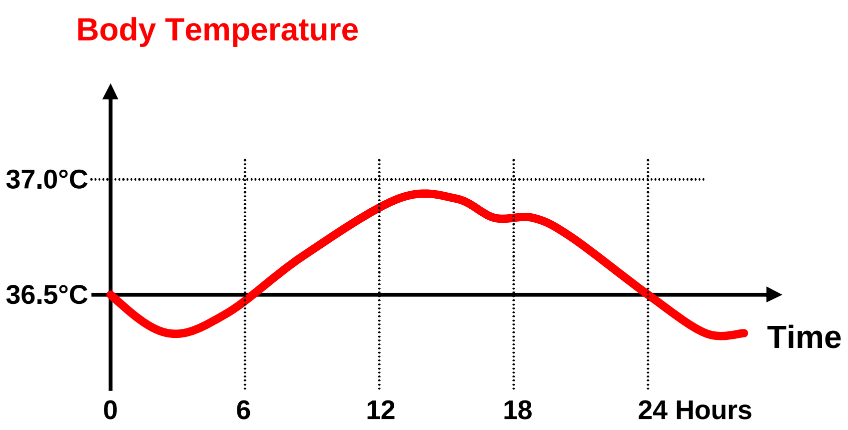
Life style management by continuous training including

- **Physical fitness**
- **Mental and psychological health**
- **Relaxation techniques**
- **Discussion and exchange of experience in stable and caring social and family relationships**
- **Balanced nutrition and adequate sleep**

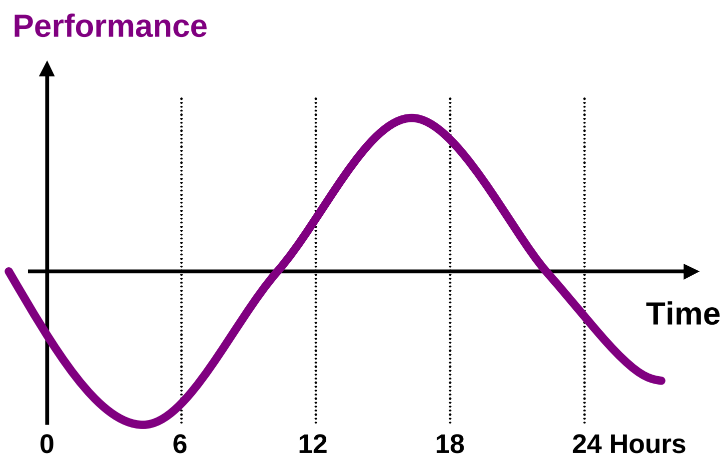
Body Rhythms and Sleep

- Circadian Rhythm
  - internal biological clock with a free-running period of about 25 hours
  - synchronized by environmental cues called "Zeitgebers" like
    - daily alternation of light and dark
    - daily schedule, meals, social or physical activity
  - controls the normal pattern of sleep and wakefulness and a lot of additional metabolic functions (e.g. cortisol release)

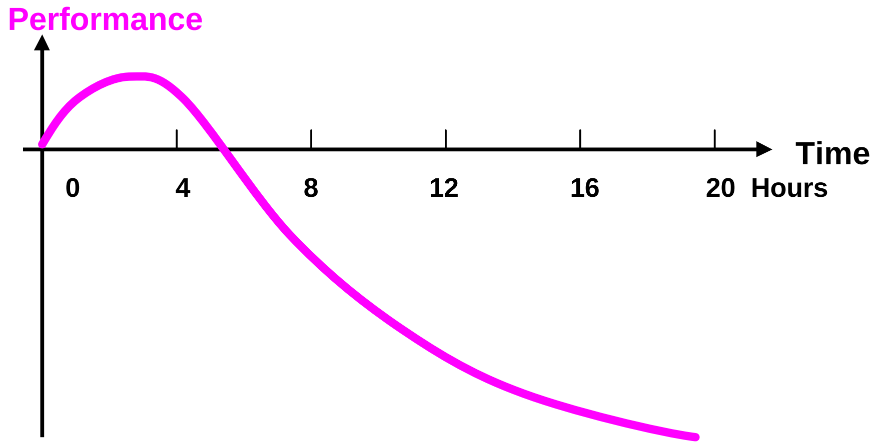
- Body Temperature



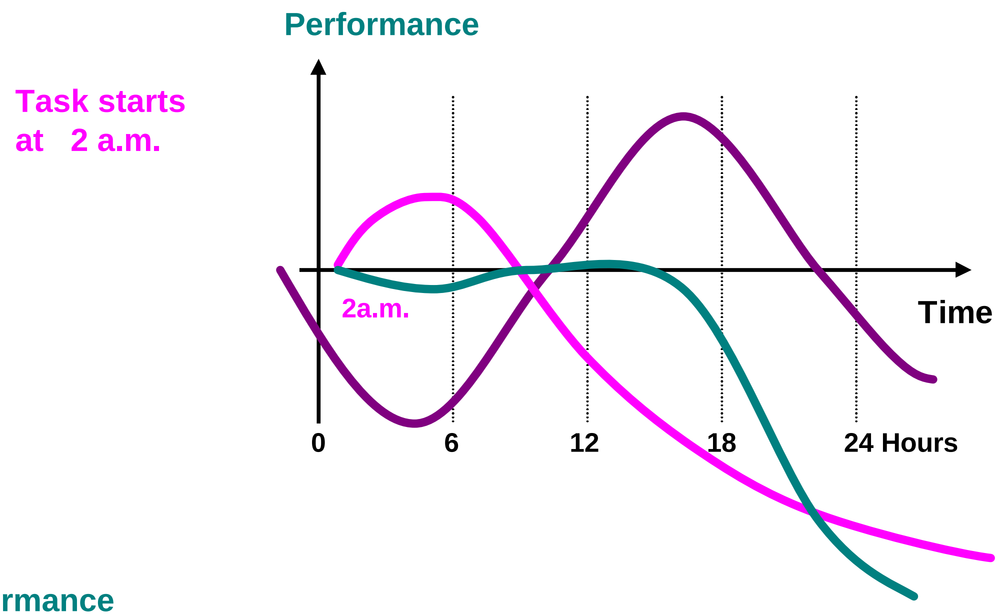
- Performance
  - Change in performance with time of day

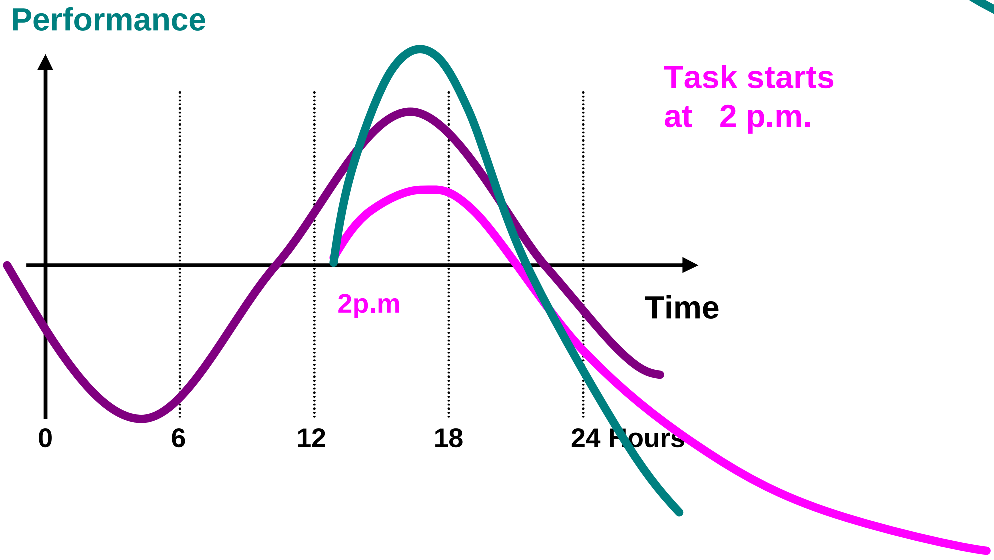


- **Change in performance with time on task**



- **Overall performance depends highly on the time the task starts**





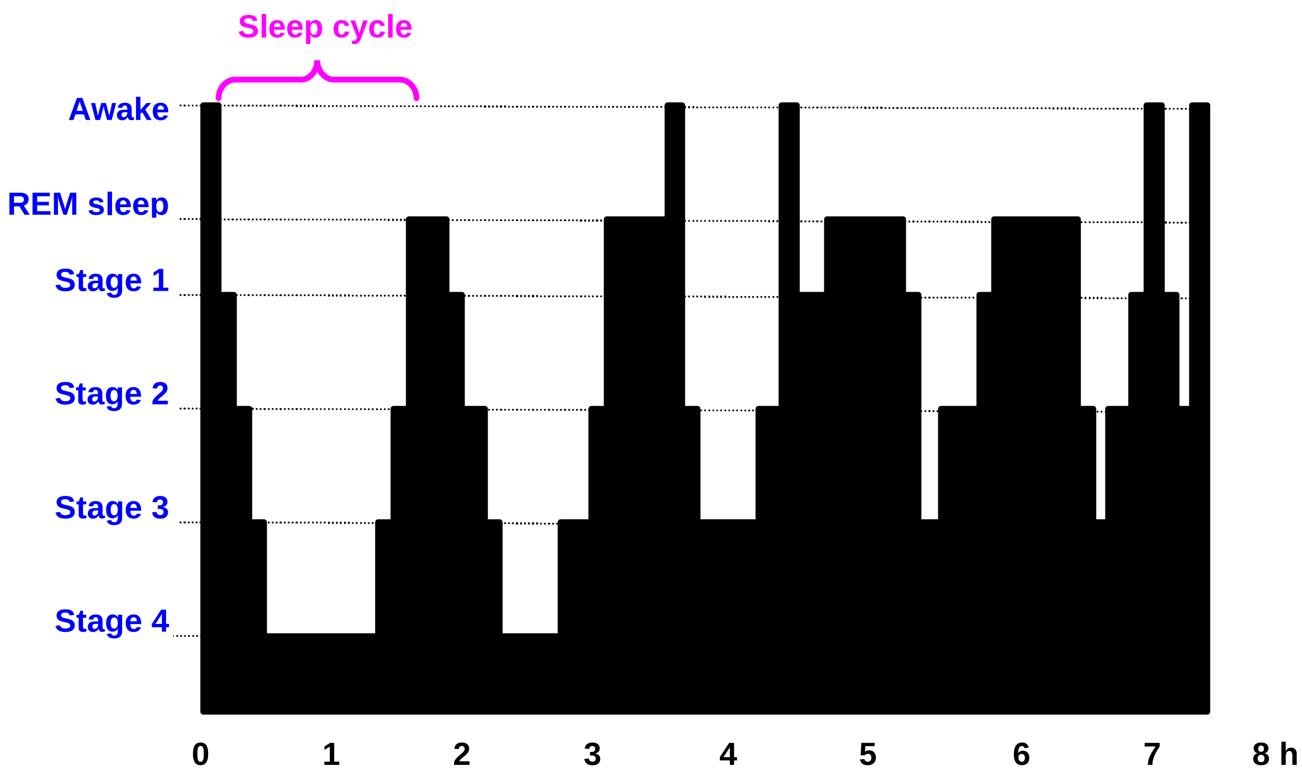
Sleep

Sleep is of prime interest in aviation because it is frequently disturbed and its sudden uncontrolled occurrence in the cockpit can be extremely harmful.

The electroencephalogram EEG has contributed a lot to the present-day knowledge about sleep. Due to the typical changes of the EEG, we distinguish four stages of sleep:

- **Stage 1 = drowsy sleep:** Alpha waves, slow eye movements
- **Stage 2 = onset of sleep:** K-complexes, spindles
- **Stage 3 = deeper sleep:** 20 ... 50% slow waves, ~ 2 Hz
- **Stage 4 = deep sleep:** > 50% slow waves = 2 Hz (Delta waves)
- **REM sleep = Rapid Eye Movements:** Low voltage, mixed frequency with episodic rapid eye movements

Sleep period



The first deep sleep period is usually the longest, the first REM sleep period the shortest of the sleep pattern. As the sleep continues, the deep sleep periods become shorter, the REM sleep periods longer.

There is considerable evidence that deep sleep restores the body while REM sleep restores the brain.

Sleep is an absolute requirement for all humans. Though sleep is an elementary physiological need, there is a wide range in the duration an individual needs to sleep.

If test persons repeatedly are woken up at the beginning of the first REM sleep or are not allowed to sleep at all, they become depressed, demotivated and even psychotic after a few days.

Generally, subjects having a high aerobic endurance, sleep better, need less sleep and have fewer problems to cope with sleep loss. Regular aerobic training therefore is an important exercise for pilots.

Keep in mind

> During the first part of a sleep period deep sleep predominates and restores the body,
> during the second part REM sleep predominates and restores the brain.

Disorders of sleep and arousal

In aviation, disturbed sleep most frequently occurs due to the irregularity of work with rest periods at unusual times. Other reasons can be psychological disorders like depression, interpersonal problems or physical illness.

Transmeridian Flights and Jet Lag

After westward flights across 5....6 time zones, individuals tend to fall asleep quickly and sleep more deeply. However, REM sleep is likely to increase. After 4...5 nights the normal sleep pattern are usually reestablished.

After eastward overnight flights across 5....6 time zones, the first night sleep may be even better than before (supposed the subject didn't sleep on the plane or during the day). Later however, sleep onset is often delayed due to the advanced sleep period in the new time zone. REM sleep, slow wave sleep, total sleep time and sleep efficiency are reduced and there are more awakenings. Adaptation to normal sleep patterns usually needs more time than after westward flights. The difference may be explained by the free running period of the circadian rhythm of 25 hours, which results in a tendency to stretch the day after transmeridian flights rather than to shorten the day.

Rule of thumb

To compensate a jet lag, you need approximately ~1 day per 1 hour of time difference

Organizing Periods of Rest during Return Flights

- **Principe: For short stopovers, keep tuned to your home rhythm**

  After westward flights split sleep time into a first period immediately after arrival and a nap during the next afternoon before the return flight.

  Before an eastward transmeridian flight leaving in the evening, it can be helpful, to have a nap in the afternoon and another nap after arrival to compensate the lost night. The next night sleep will generally be restful and restore the crew for the return flight.

Fatigue

Fatigue is a condition where performance rapidly degrades, generally due to prolonged time at work. Fatigued people show a couple of objective signs which indicate that their mental and emotional capacity has decreased:

- increased reaction time, slower thinking,
- hypovigilance, poor concentration
- narrowed and / or focused attention
- lack of flexibility
- decreased discipline with a tendency to accept lower standards of accuracy and performance
- increased acceptance of higher risks
- increased irritability, lack of patience

Acute Fatigue

- caused by intense mental or physical activity for a prolonged period, especially if the task requires undivided attention
- aggravated by several factors like
  - lack of sleep
  - poor nutrition
  - stress, heavy workload
  - noise and vibration
  - wide variation of humidity and temperature
  - uncomfortable working conditions
  - night flights
  - boredom, monotony

Chronic Fatigue

- caused over a longer time by continuous strain due to domestic or work pressure combined with stress and inadequate rest
- aggravated by factors like
  - chronic lack of sleep
  - disturbed circadian rhythm
  - underlying disease
  - psychological problems

Chronic fatigue can cause physical discomfort like stomach disorders, intestinal problems, skin rashes, general aches and pains throughout the body and may trigger emotional illness.

Treatment and Prevention of Fatigue

Acute fatigue is accepted as a normal part of everyday life. It is easily treated by relaxing, a healthy meal and a good night's sleep.

Chronic fatigue requires a much longer treatment and can only be alleviated, if the root causes are eliminated.

The best strategy to cope with fatigue is to prevent it. The pilot's best weapons to prevent fatigue are:

Pilot's short term weapons to prevent fatigue:

- **Keep a close eye on your rest periods and avoid flying when fatigued (controlled naps on the flight deck can be a helpful strategy to improve alertness!)**
- **Take a good night's sleep before a long haul flight**
- **Give yourself time to relax before a flight and to prepare for it mentally**
- **Eat a healthy diet and drink enough**

Pilot's long term weapons to prevent fatigue:

- **Improve your physical fitness by regular workout**
- **Practice mental and emotional training to keep a healthy mental attitude**
- **Practice proactive workload management (see human over- and underload)**

Keep in mind

Fatigue is frequently part of an error chain and you should be aware of its detrimental effects