EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Basics of transport and handling technology KKS/ZDMT

Presentation 4
AEROPLANES
Overview, air traffic, flying techniques, aerodynamics

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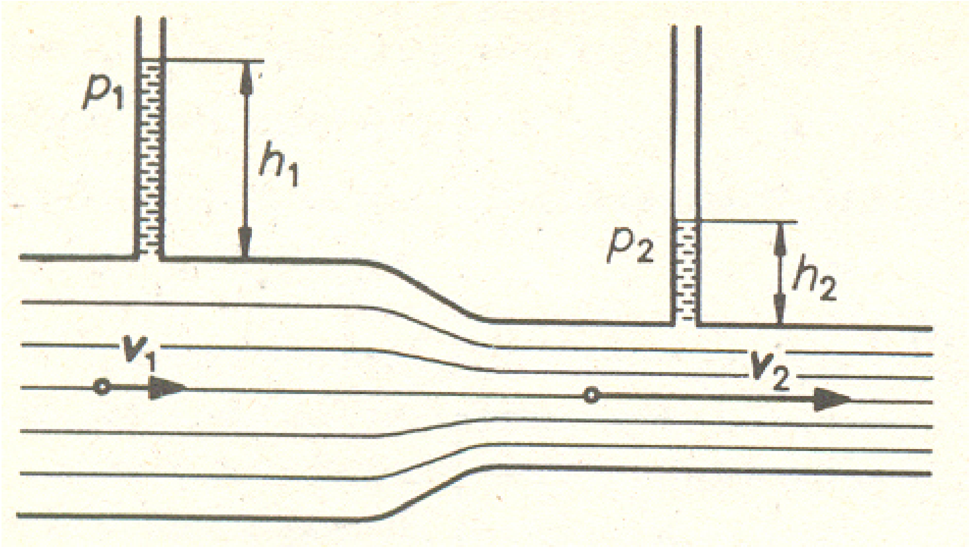
Basic aerodynamics – Bernoulli's equation

- Bernoulli’s equation expresses the law of the conservation of energy for the flow of an ideal fluid in a horizontal channel.

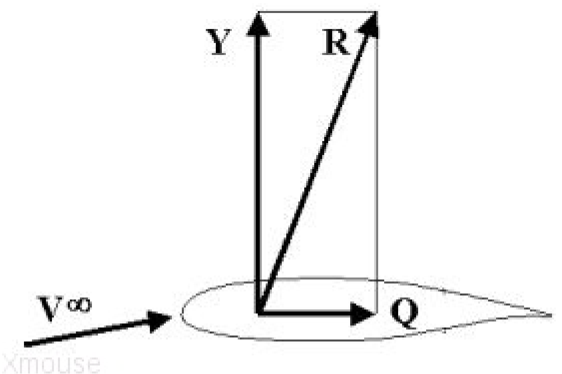
$$\frac{1}{2}\rho v_1{}^2 + p_1 = \frac{1}{2}\rho v_2{}^2 + p_2$$

$$S_1 \succ S_2 \Rightarrow v_1 \prec v_2 \Rightarrow p_1 \succ p_2$$



Basic aerodynamics– aerodynamic force

- Aerodynamic force is the force which a flowing fluid/gas exerts on a body immersed in it. It is usually divided into a component acting in the direction of the fluid flow Q (resistance) and a component perpendicular to the flow Y (lift).



$$R = c_R \frac{\rho V^2}{2} S$$

$$Q = c_x \frac{\rho V^2}{2} S$$

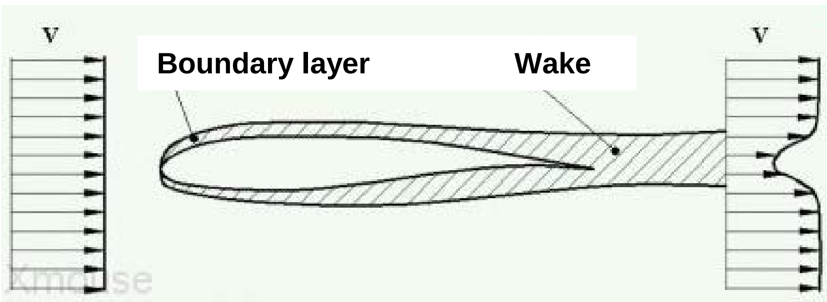
$$Y = c_y \frac{\rho V^2}{2} S$$

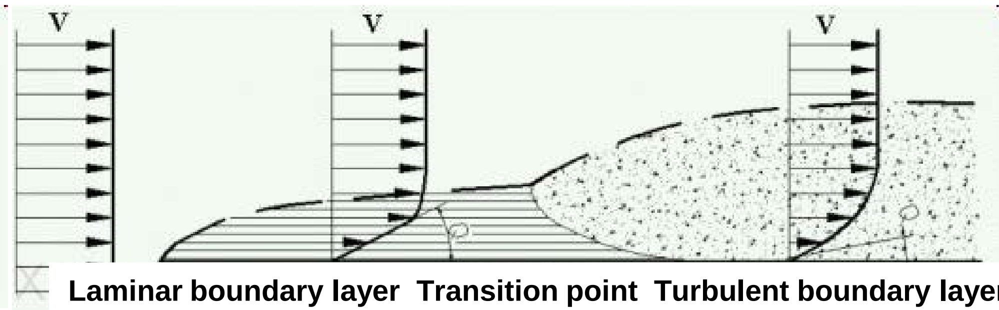
Any surface of the body can be taken as reference surface **S**. For a body used in aerodynamics the following reference surfaces can be used:

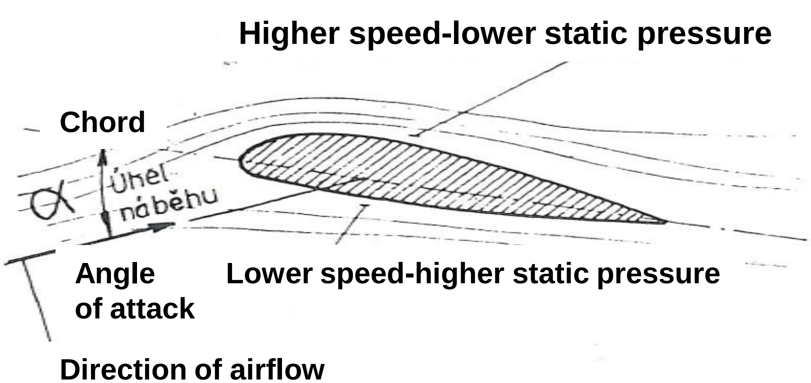
- For wing and tail surfaces
- For fuselage, pod, landing gear- surface with max. x-section perpendicular to direction of flow
- **For whole plane- surface of wing**

c_R coefficient of aerodynamic force
c_x coefficient of drag
c_y coefficient of lift
S reference surface

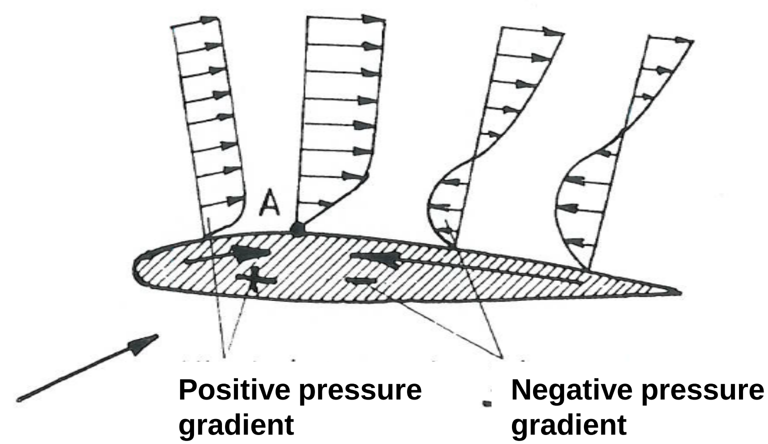
Basic aerodynamics– boundary layer







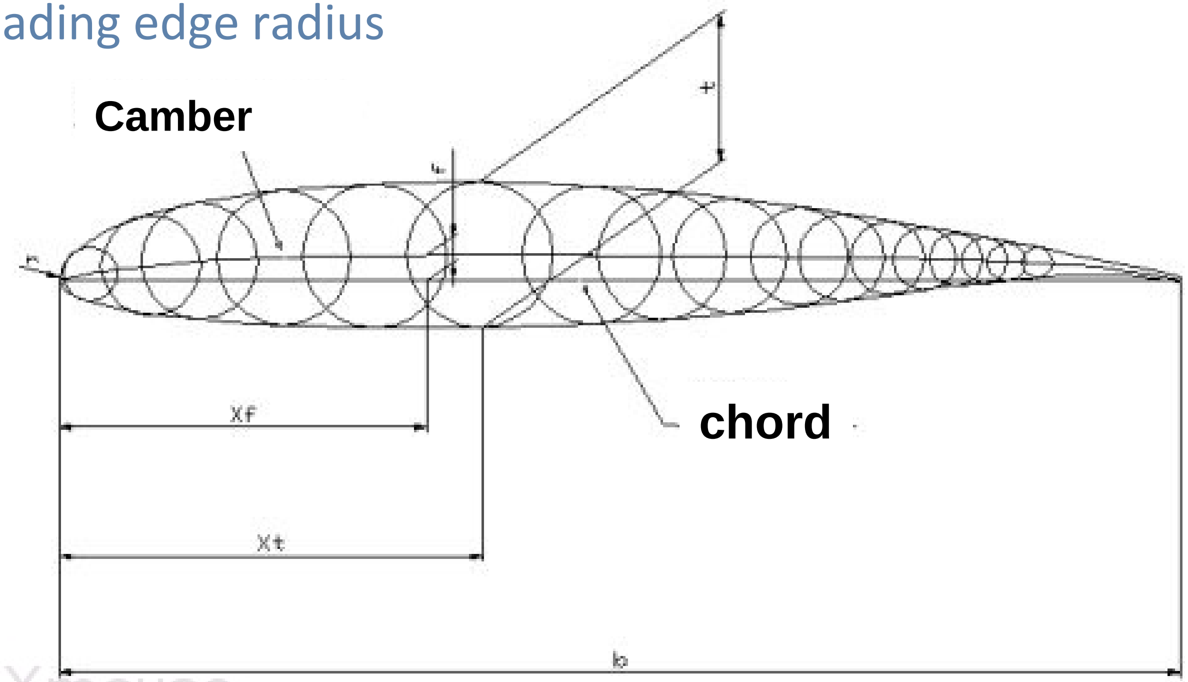
Airflow and pressure ratios on aerofoil



Pressure gradients on aerofoil-airflow in boundary layer before interruption of airflow

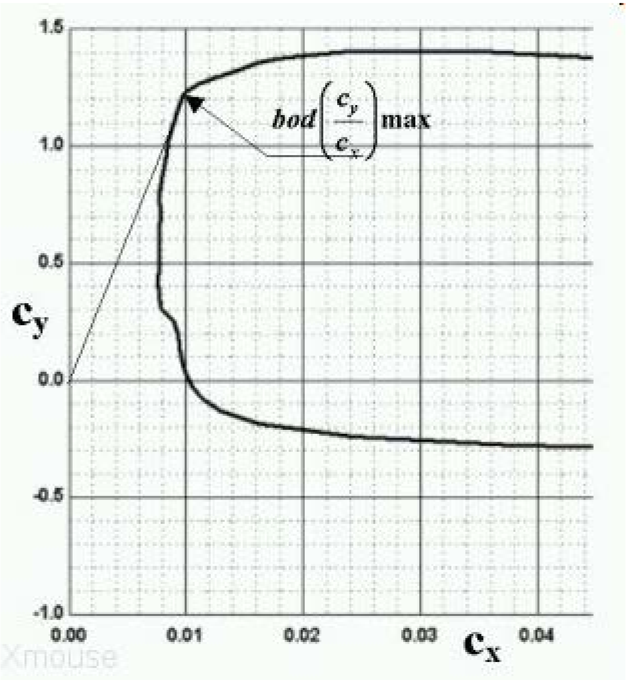
Basic aerodynamics– aerofoil

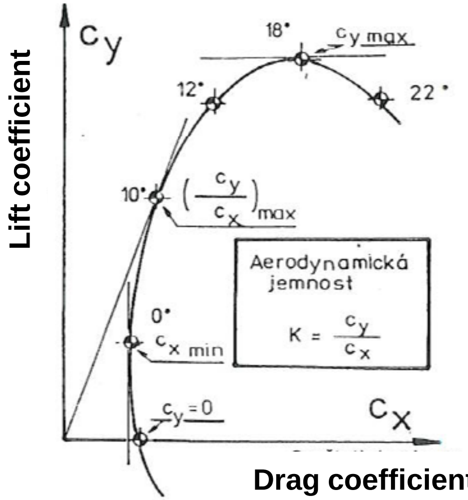
- b – chord line
- t – max. thickness
- f – max. camber
- x_t – position of max. thickness
- x_f – position of max. camber of camber mean line
- r – leading edge radius



Basic aerodynamics– polar curve

- An ideal curve has great lift and low drag (resistance). The relation between lift and drag is shown by the polar curve. Direct values for lift and drag are not entered into the graph; coefficients are used. If direct values were used, the polar would also depend on wing size, velocity and density of the fluid and other influences.

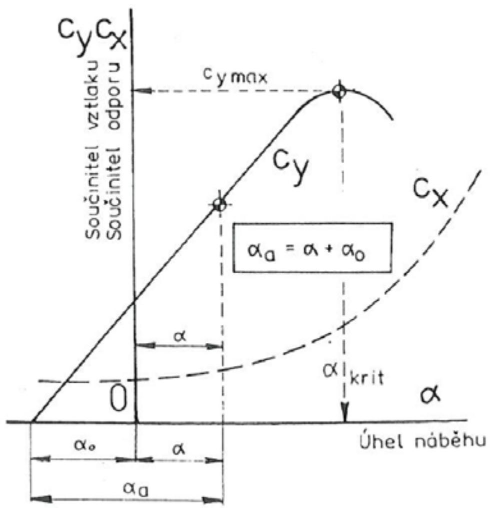


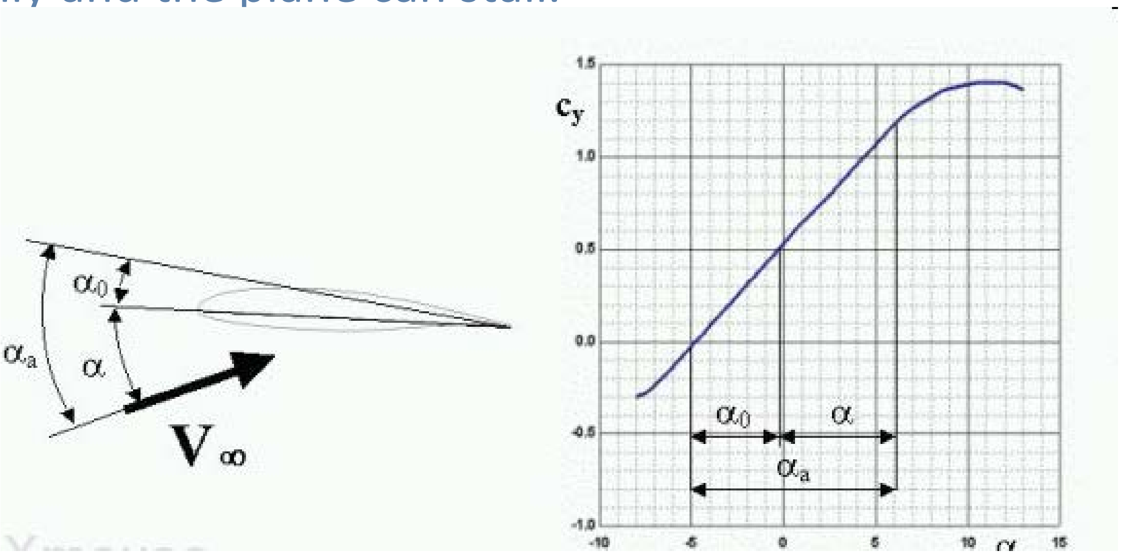


Characteristic points on polar curve

Basic aerodynamics – lift curve of aerofoil

- For normal thin aerofoils, lift increases with angle of attack almost linearly. A change occurs when the angle of attack is such that it breaks the smooth air flow, lift stops increasing and, after complete breakage of flow, lift drops dramatically and the plane can stall.

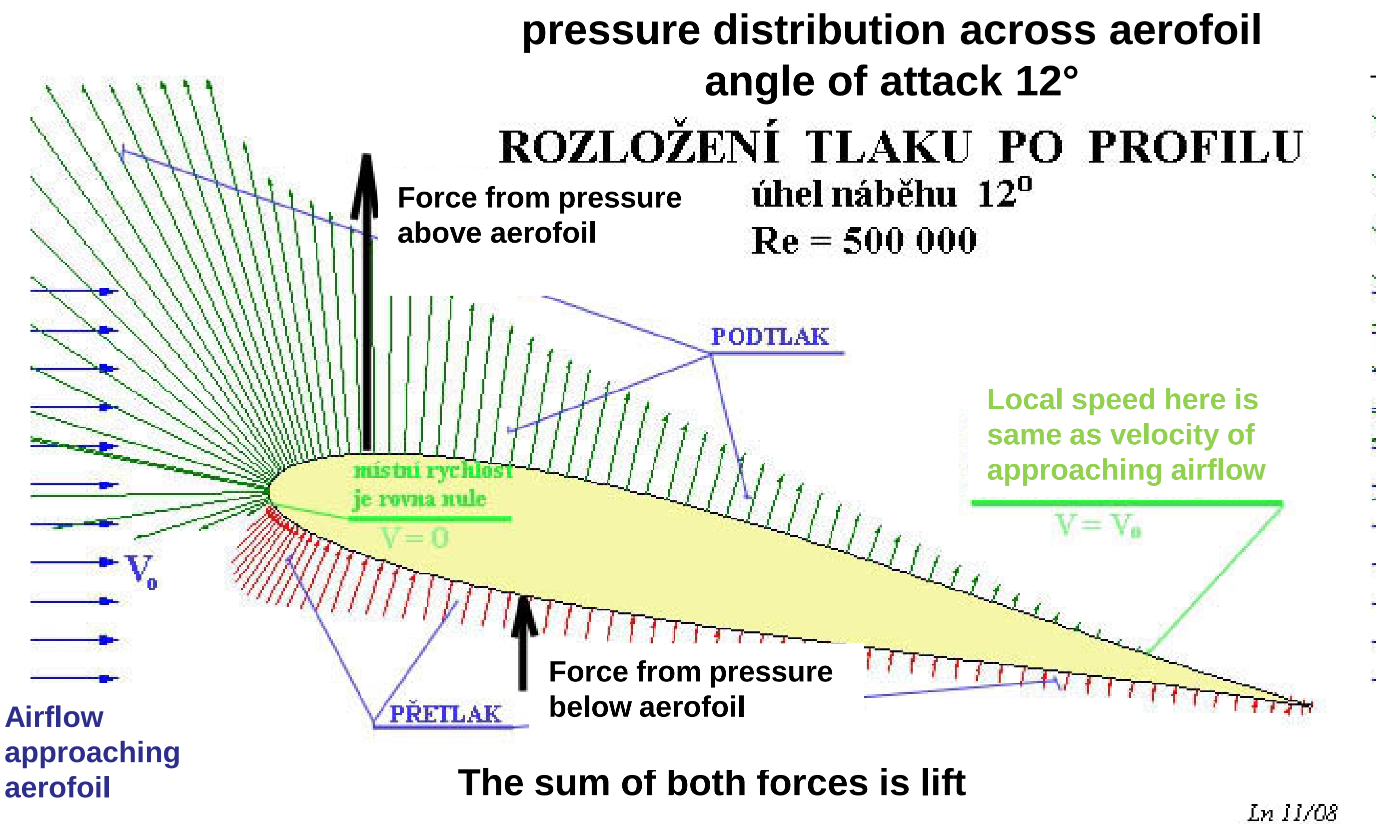




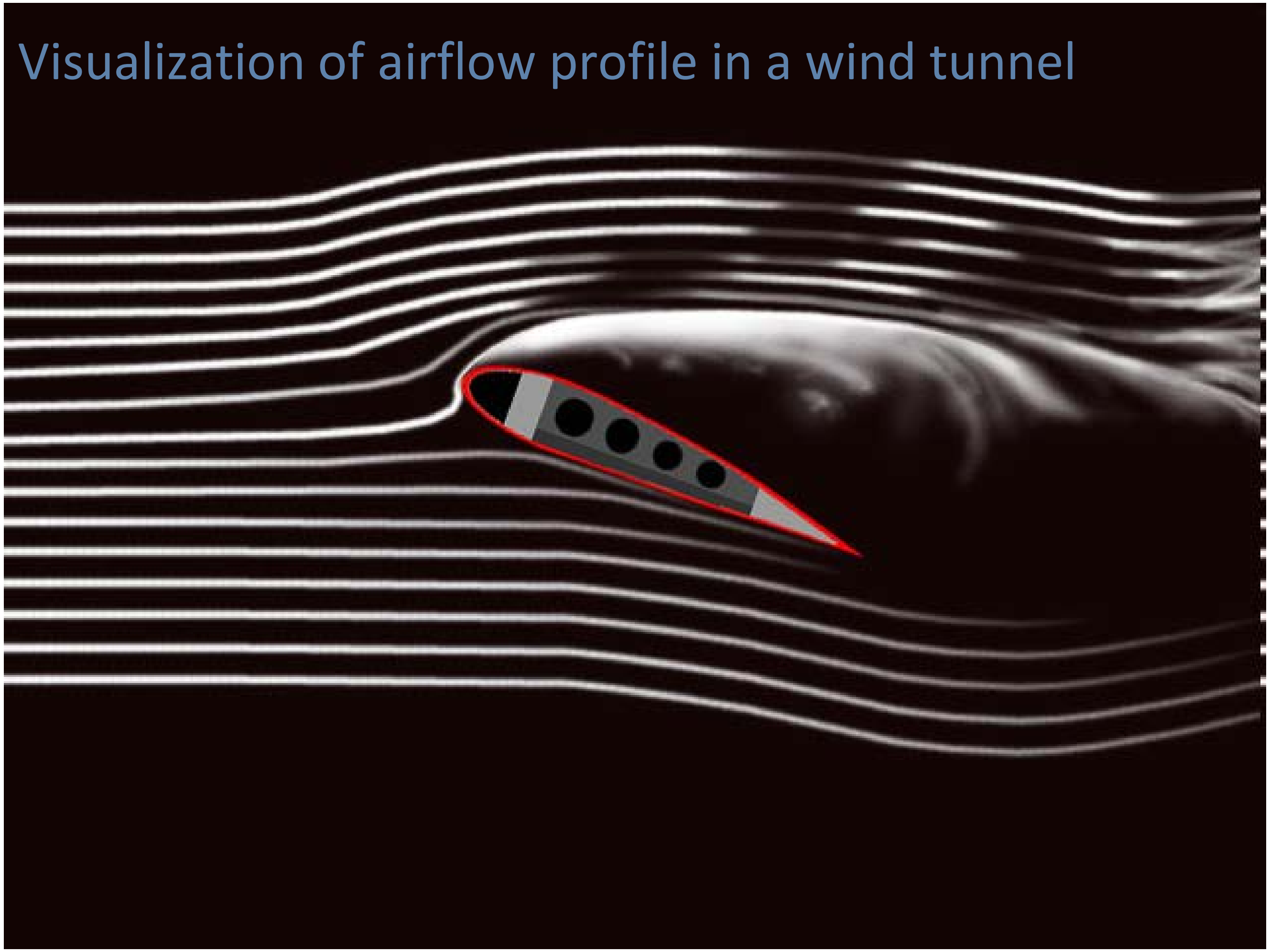
Lift and drag curve

α - Geometric angle of attack, i.e. angle between chord and direction of airflow at velocity v
αo - Angle of attack at zero lift, ‘zero lift angle’, i.e. angle between chord and airflow at zero lift
αa - Absolute angle of attack, i.e. angle between real airflow and direction of airflow at zero lift

Basic aerodynamics – airflow profile

- 

Basic aerodynamics – airflow profile



Basic aerodynamics – airflow profile

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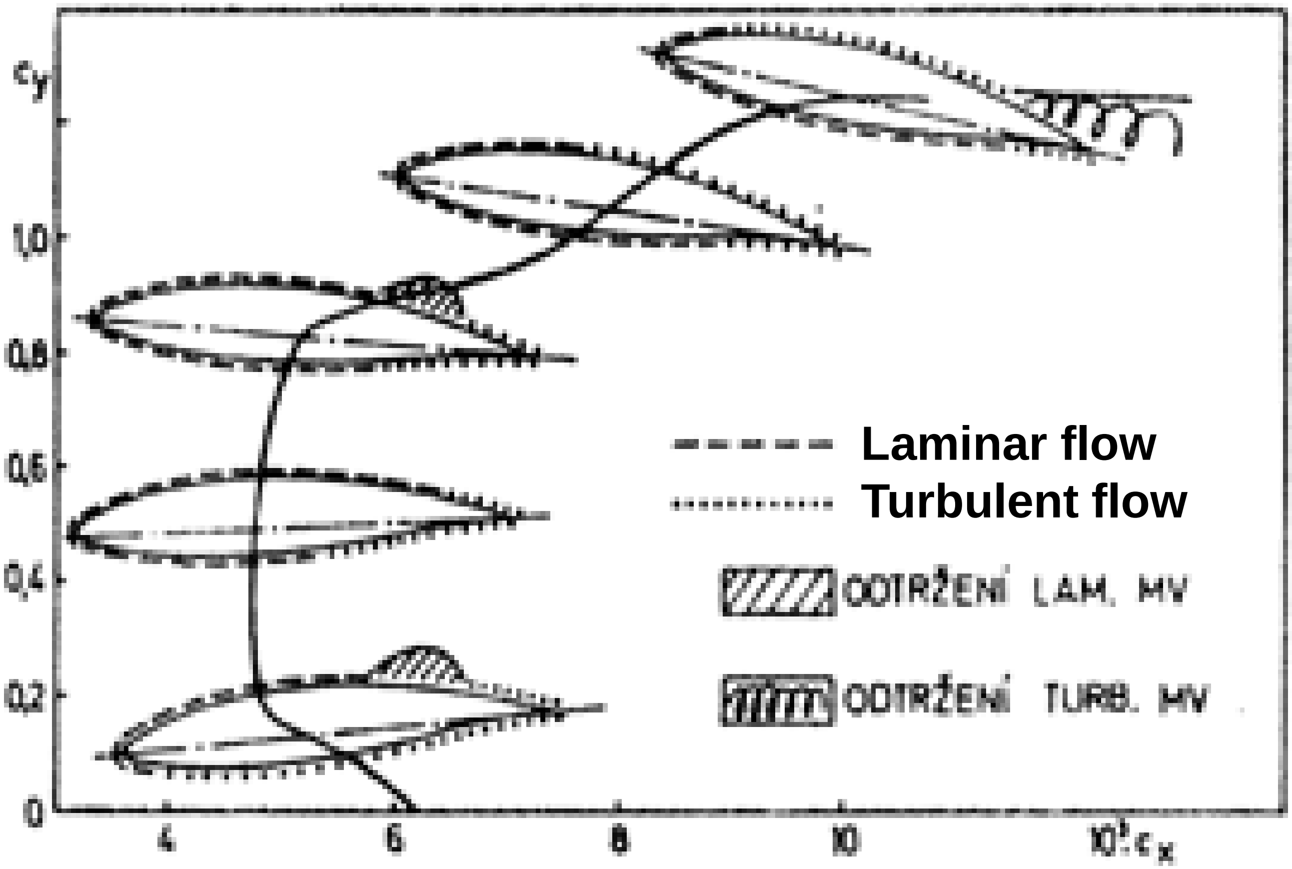

Basic aerodynamics – airflow profiles of angles of attack

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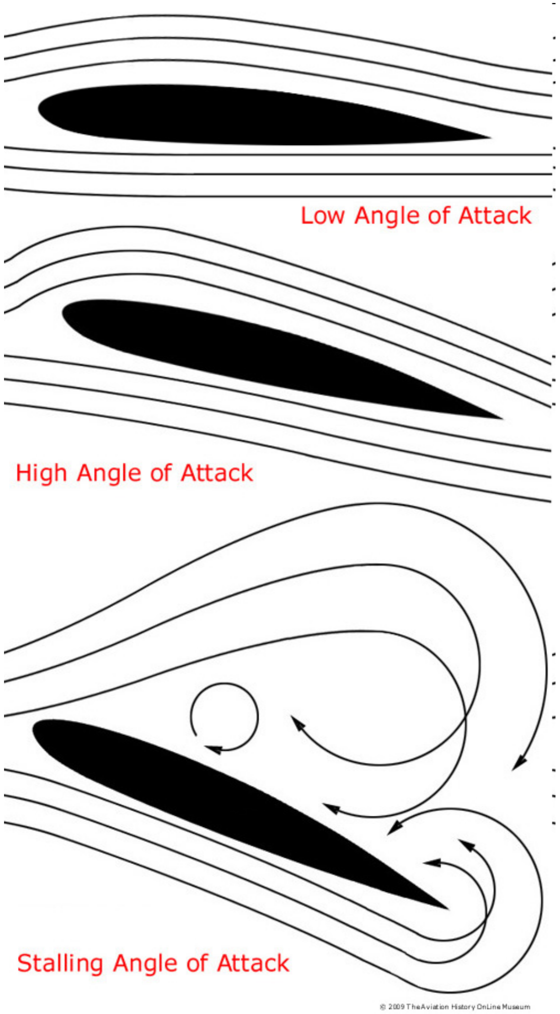
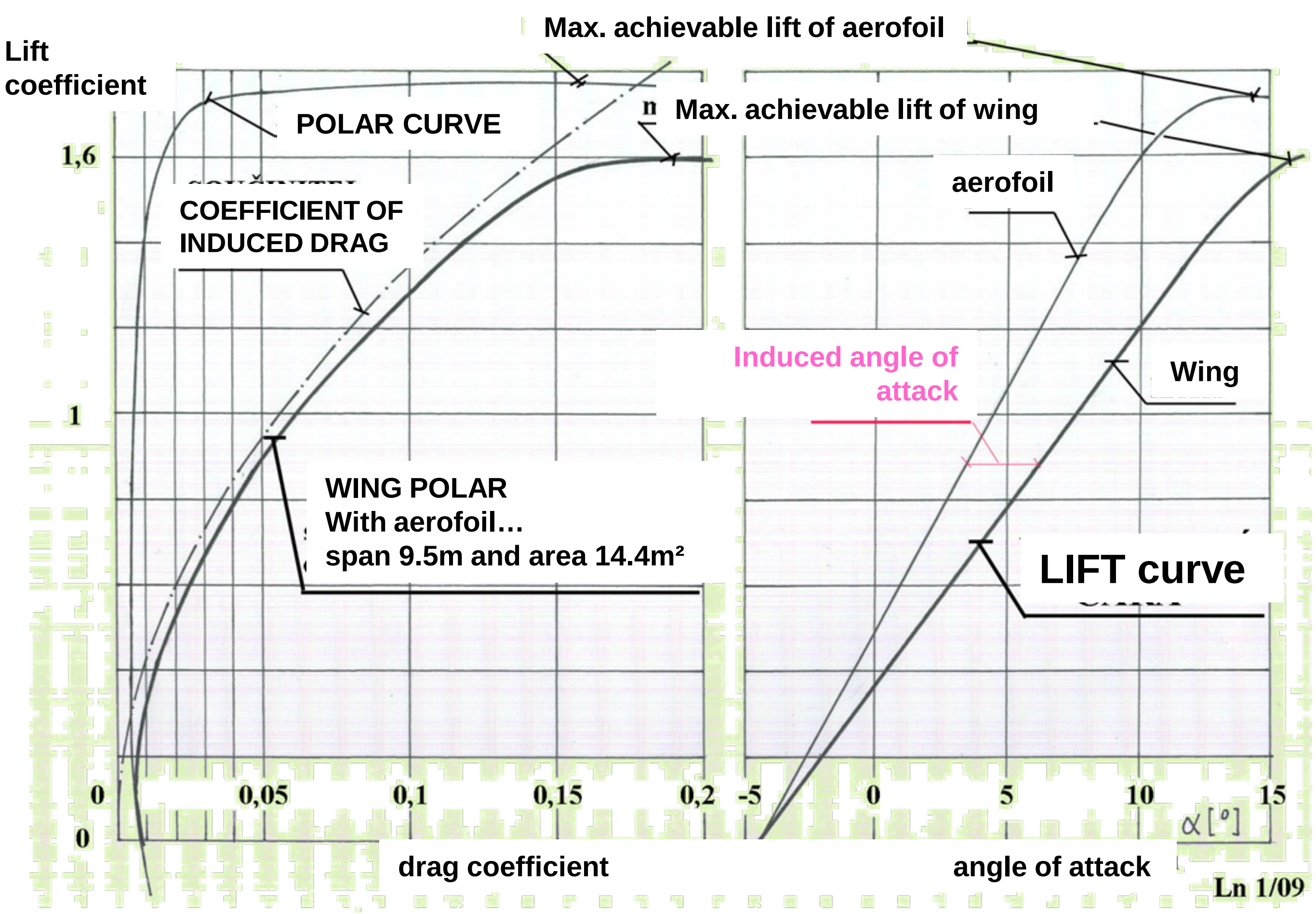
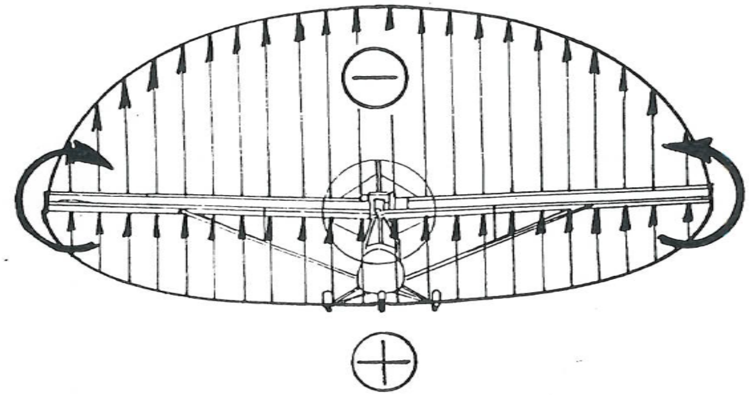


Basic aerodynamics – polar curve



Basic aerodynamics – polar curve

The wing polar curve is an aerodynamic characteristic of a wing to which are allocated the aerodynamic effects of other parts, most of which are drag. Their sum is then a curve, which is shifted to the right of the original (belonging only to the wing) along the coordinate axes of the two previously mentioned factors. And by the value of the coefficient of induced (harmful) resistance.

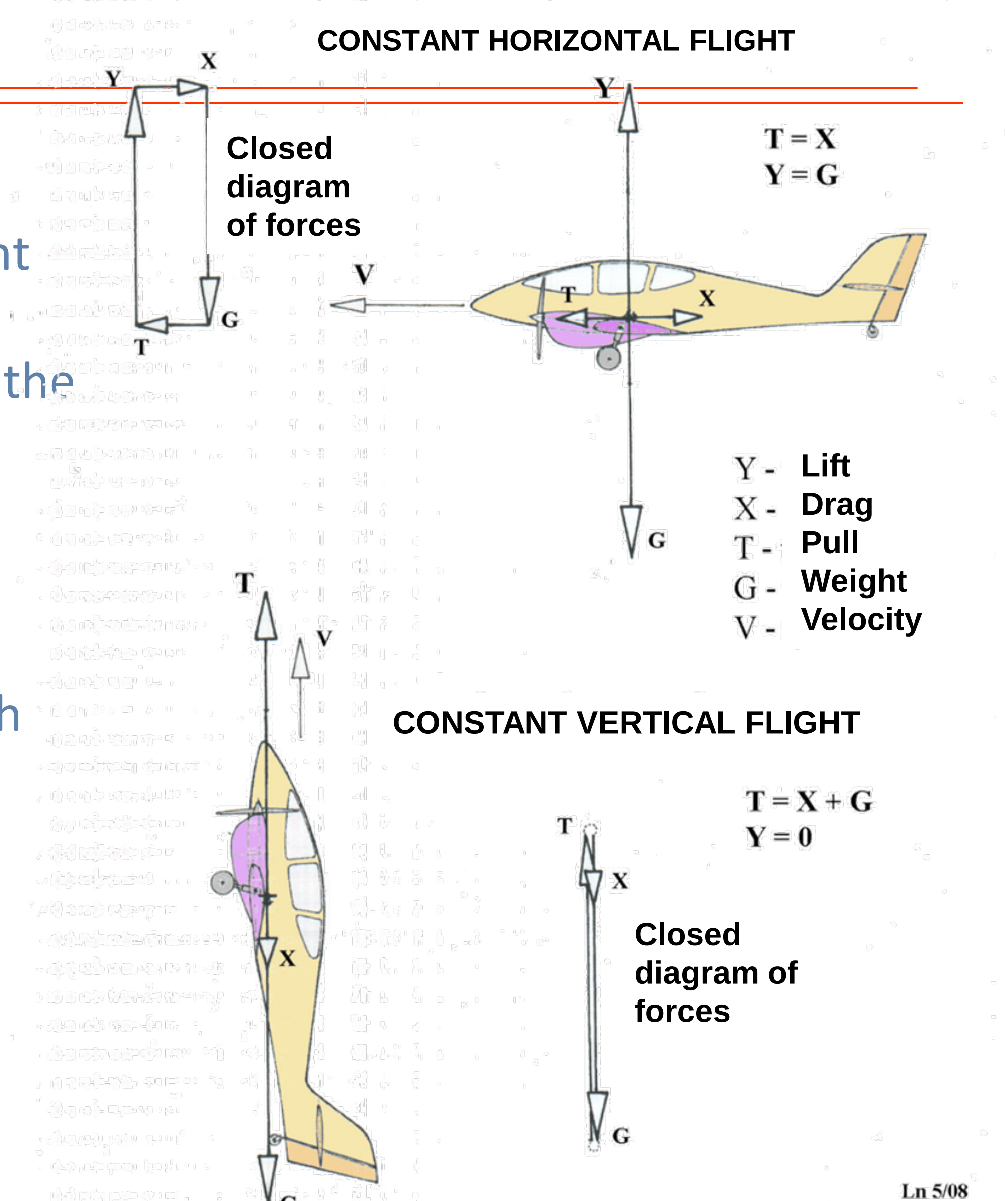


Origin of induced drag

Basic mechanics of flying

Linear horizontal flight

- Is horizontal flight at a constant speed and direction. If a plane flies in horizontal linear flight, the forces acting on it are in equilibrium.
- This means that lift Y is in equilibrium with gravity G and thrust of the engine P (=T) with resistance Q (=X).



Basic mechanics of flying

Linear horizontal flight

- The equilibrium of forces can be expressed by the following equations:

$$\boxed{\begin{aligned} Y &= G \\ P &= Q \end{aligned}}$$

$$Y = G = c_y \frac{\rho V^2}{2} S$$

$$V = \sqrt{\frac{2G}{\rho . S . c_y}}$$

$$v_{min} = \sqrt{\frac{2G}{\rho . S . c_{ymax}}}$$

$$G = mg = c_y \frac{\rho V^2}{2} S$$

$$P = c_x \frac{\rho V^2}{2} S$$

$$\frac{P}{G} = \frac{c_x \frac{\rho V^2}{2} S}{c_y \frac{\rho V^2}{2} S} = \frac{c_x}{c_y}$$

$$P_p = G \frac{c_x}{c_y}$$

$$\boxed{P_p = \frac{G}{K}}$$

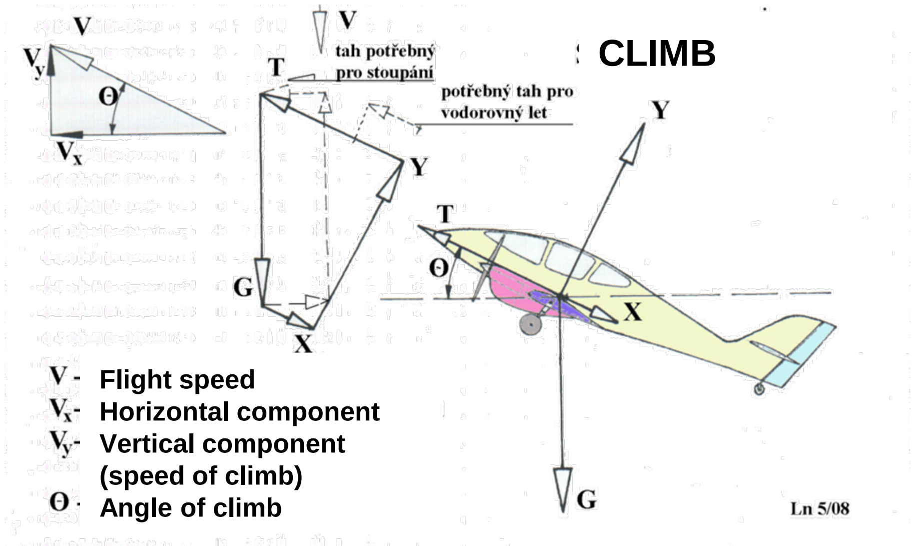
Basic mechanics of flying

Forces during flight

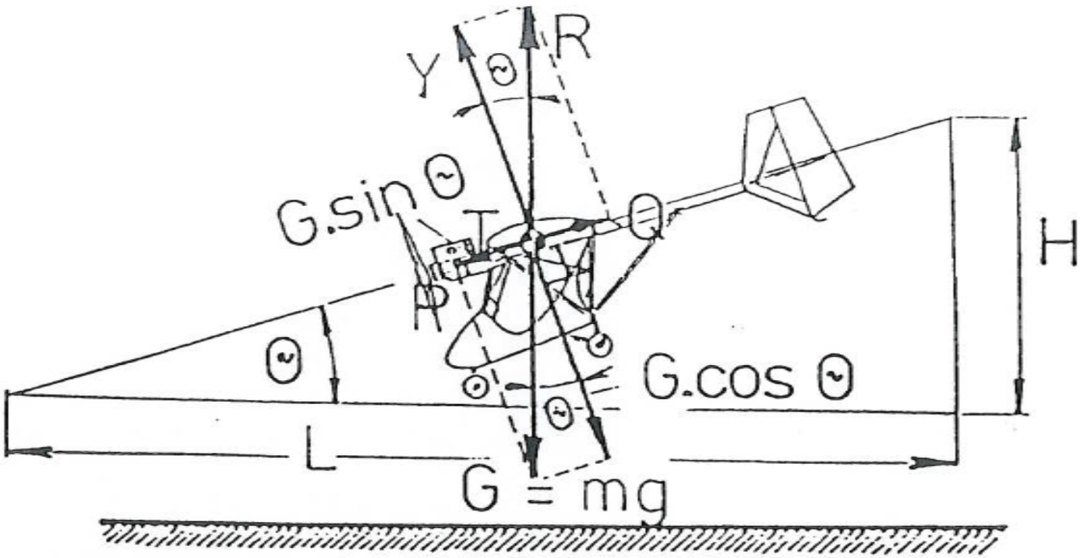
climbing:

$Y = G.\cos\Theta$

$P = G\sin\Theta + Q$



Basic mechanics of flying



Balance of forces acting on an aeroplane during constant descending flight.

GLIDING AND LANDING

Glide angle

Gliding is descending flight at angle of attack at normal limits with little or no power from a drive system. Gliding is characterized by the balance of resulting aerodynamic force *R* with the force of the aeroplane *G*, i.e.

$$G = R$$
$$mg = R$$

To analyse important relationships it is good to write the balance of forces in the direction of lift and drag, i.e. Perpendicular to the direction of flight:

$$Y = G.\cos\theta$$
$$Q = G.\sin\theta$$

Supposing from fig. on prev. page the aeroplane flies at height 'H' for a horizontal distance 'L'. Ratio L/H is the glide ratio. Considering the similarity to the triangle in fig. on prev. page, then:

$$K = \frac{L}{H} = \frac{Y}{Q}$$
$$K = \frac{C_y}{C_x}$$

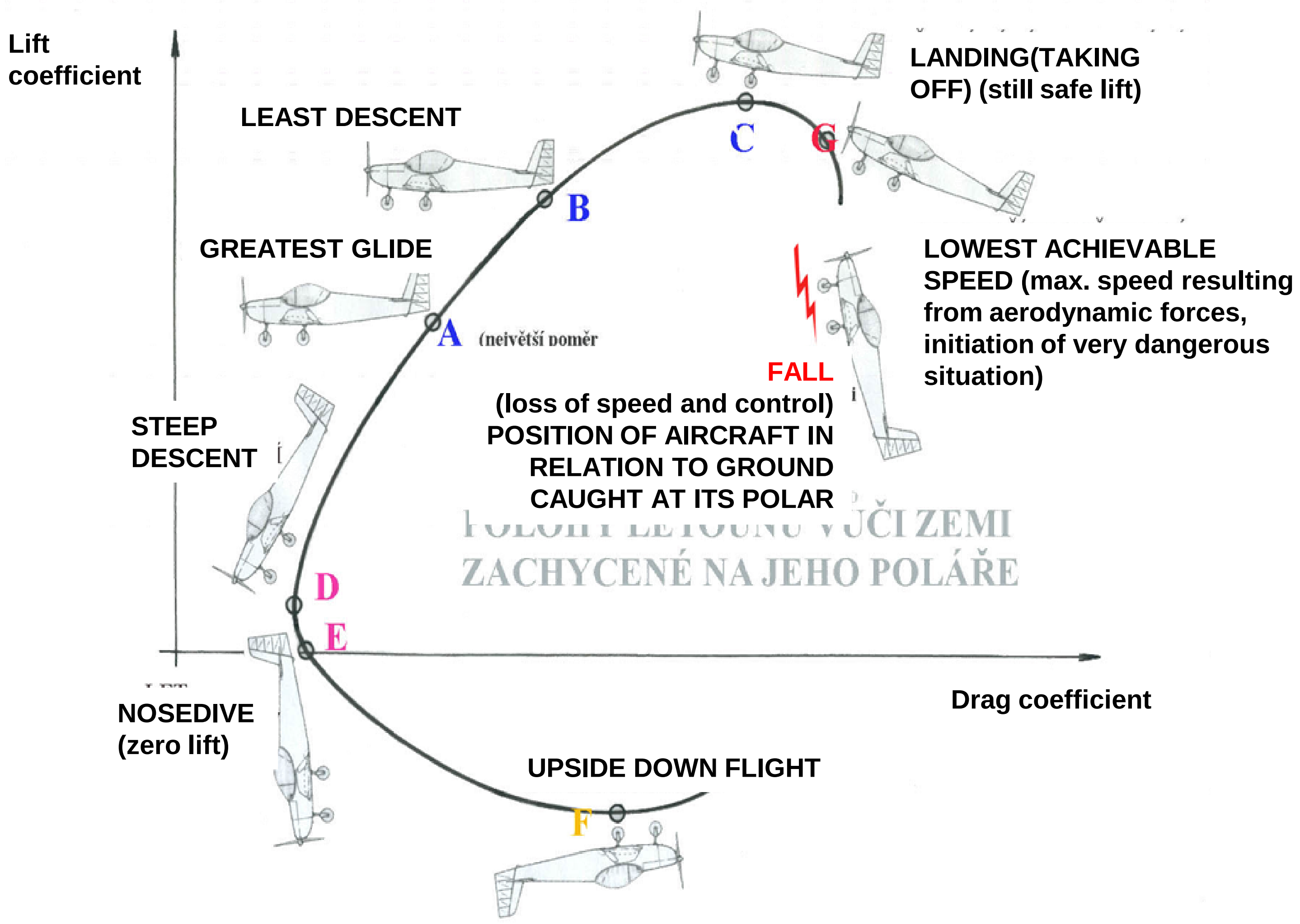
From the formulae it can be seen that gliding is dependent only on aerodynamic characteristics- ratio c_y and c_x. We have seen this ratio before and it is called L/D ratio 'K'

$$tg\Theta = \frac{Q}{Y} = \frac{C_x}{C_y}$$
$$tg\Theta = \frac{1}{K}$$

From the formulae it can be said that as L/D ratio increases, i.e. the aeroplane is aerodynamically clean, the glide angle decreases. Thus the smallest glide angle does not depend on height or weight. For best gliding, a plane must fly at optimum lift coefficient and for optimum glide speed must be valid:

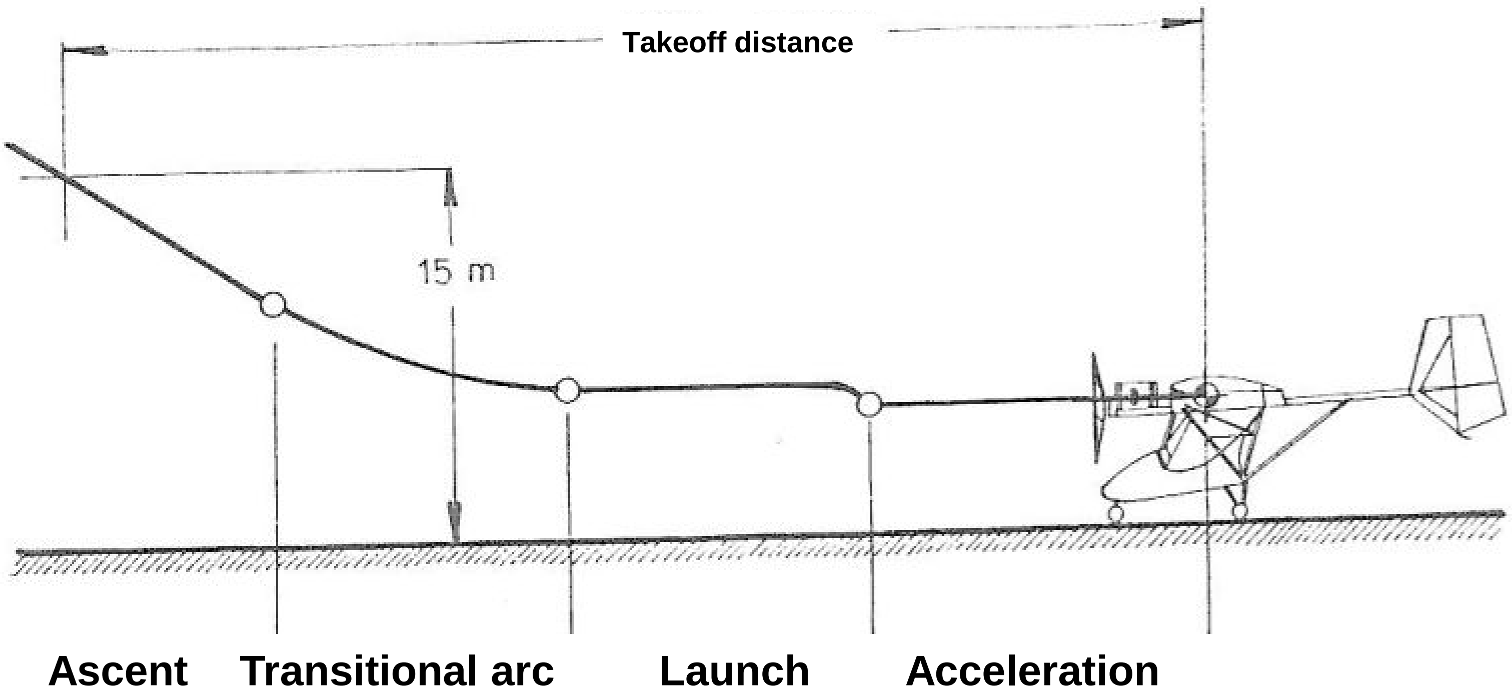
$$V_{opt} = \sqrt{\frac{2.G.\cos\Theta}{p.S.Cy_{opt}}}$$

Basic mechanics of flying



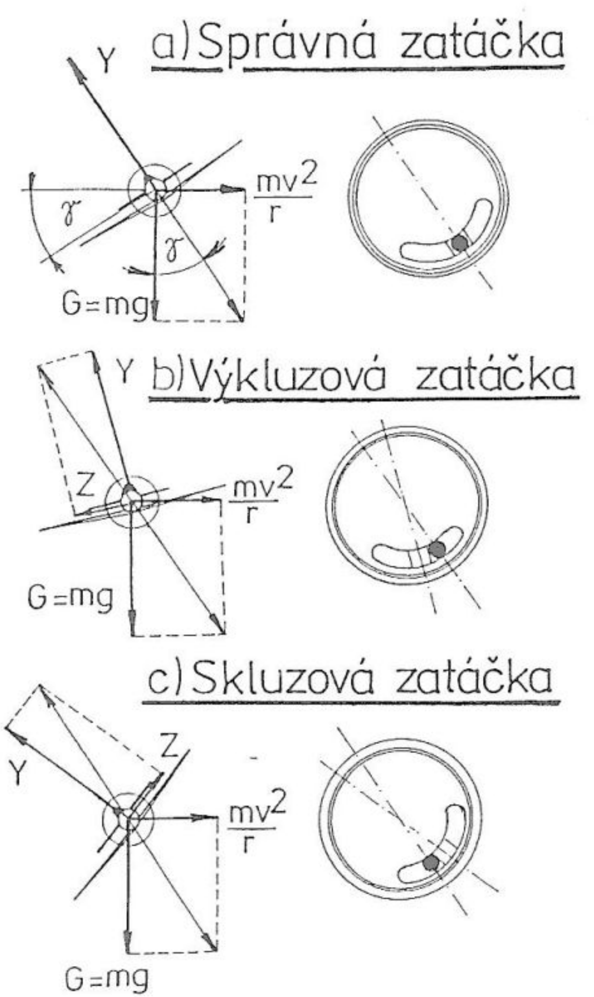
Zdroj: www.airspace.cz

Basic mechanics of flying - takeoff



Individual phases of takeoff

Basic mechanics of flying– flying in a circle, turning



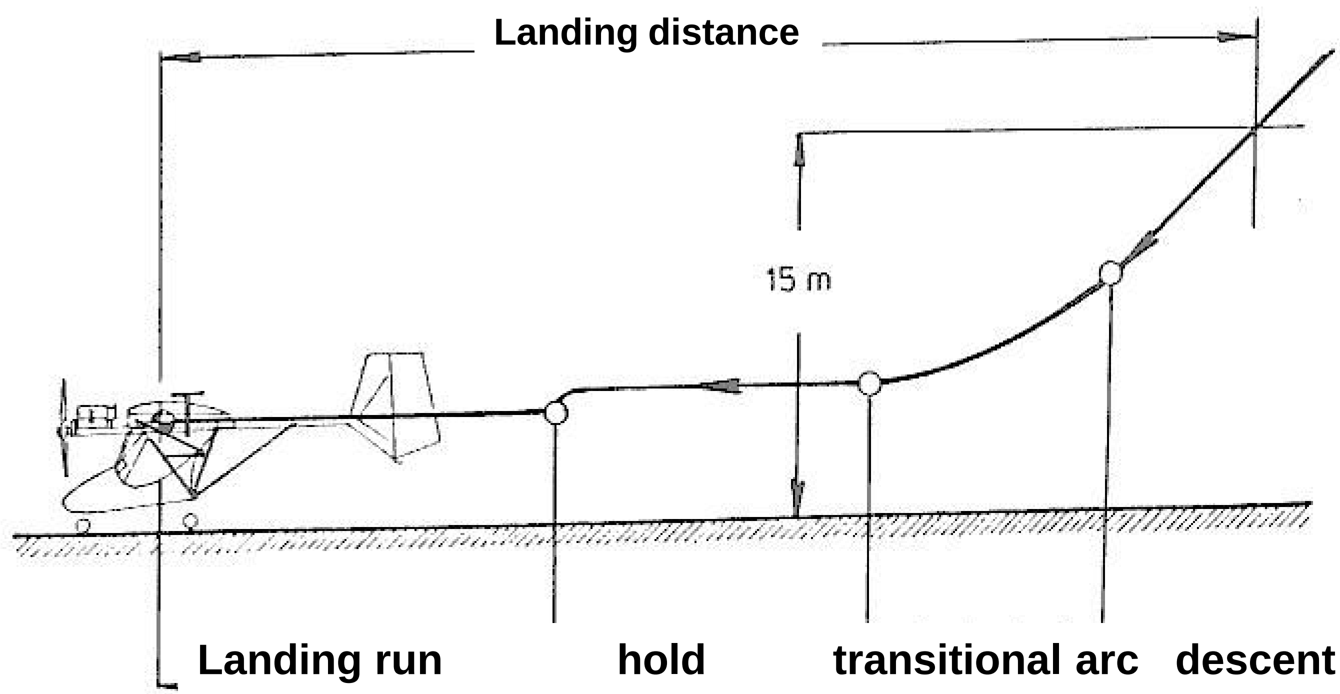
Síly působící na letoun při letu v zatáčce správné, skluzové a výkluzové

a) **Correct turn**

b) **Skid Turn**

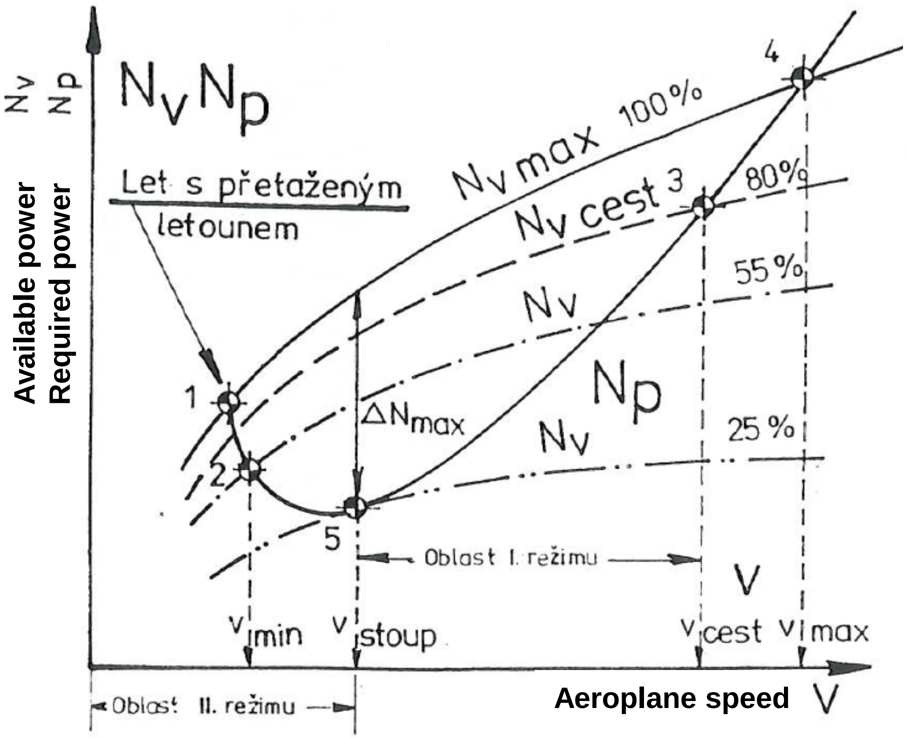
c) **Slip turn**

Basic mechanics of flying - landing

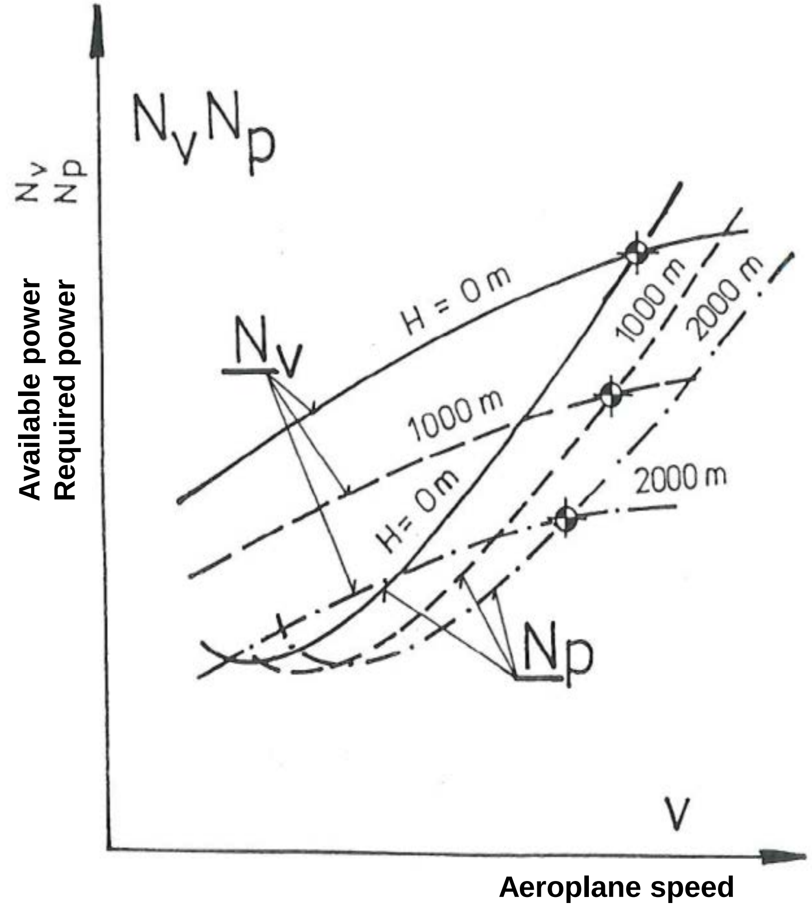


Individual phases of landing

Basic mechanics of flying–Equilibrium diagram of aircraft performance



Equilibrium diagram of aircraft performance



Relation of available and required engine power on height of flight

International Standard Atmosphere (ISA)

The International Standard Atmosphere (ISA) is a simplified model of the earth’s atmosphere.

The model assumes that:

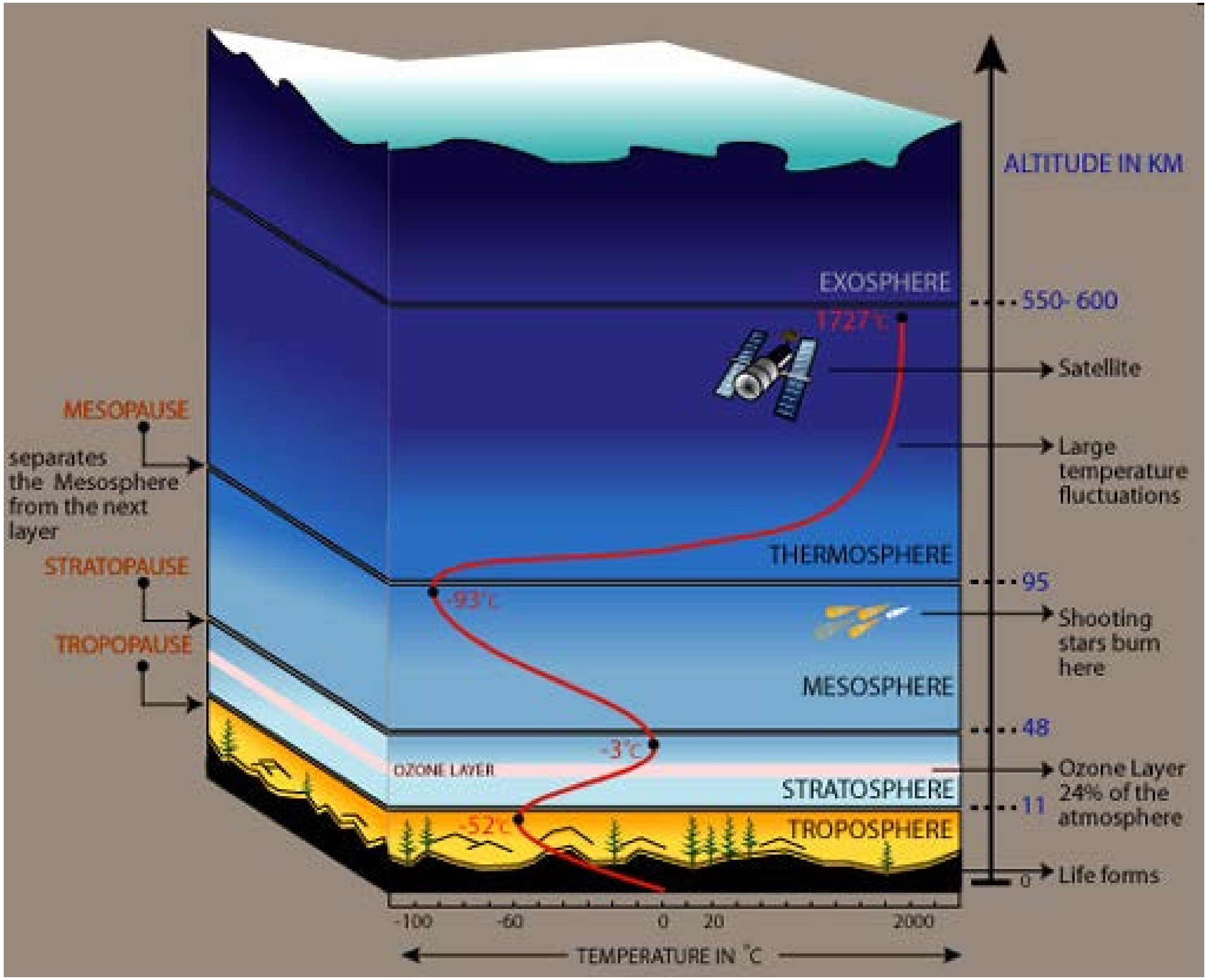
- The atmosphere is homogenous, composed of 78% nitrogen, 21% oxygen, 1% other gases
- Air is an ideal gas, i.e. equation of state of gases is valid
- Gravitational acceleration is constant g = 9.81
- Conditions are at H = 0 m (sea level)
- **Air pressure is 1013.25 hPa**
- Air density is 1.225 kg/m3
- Air temperature is 15°C
- **Up to 11 km (i.e. up to the tropopause) temperature drops by 6.5°C every 1,000m then remains constant at –56.5°C**

International Standard Atmosphere (ISA)

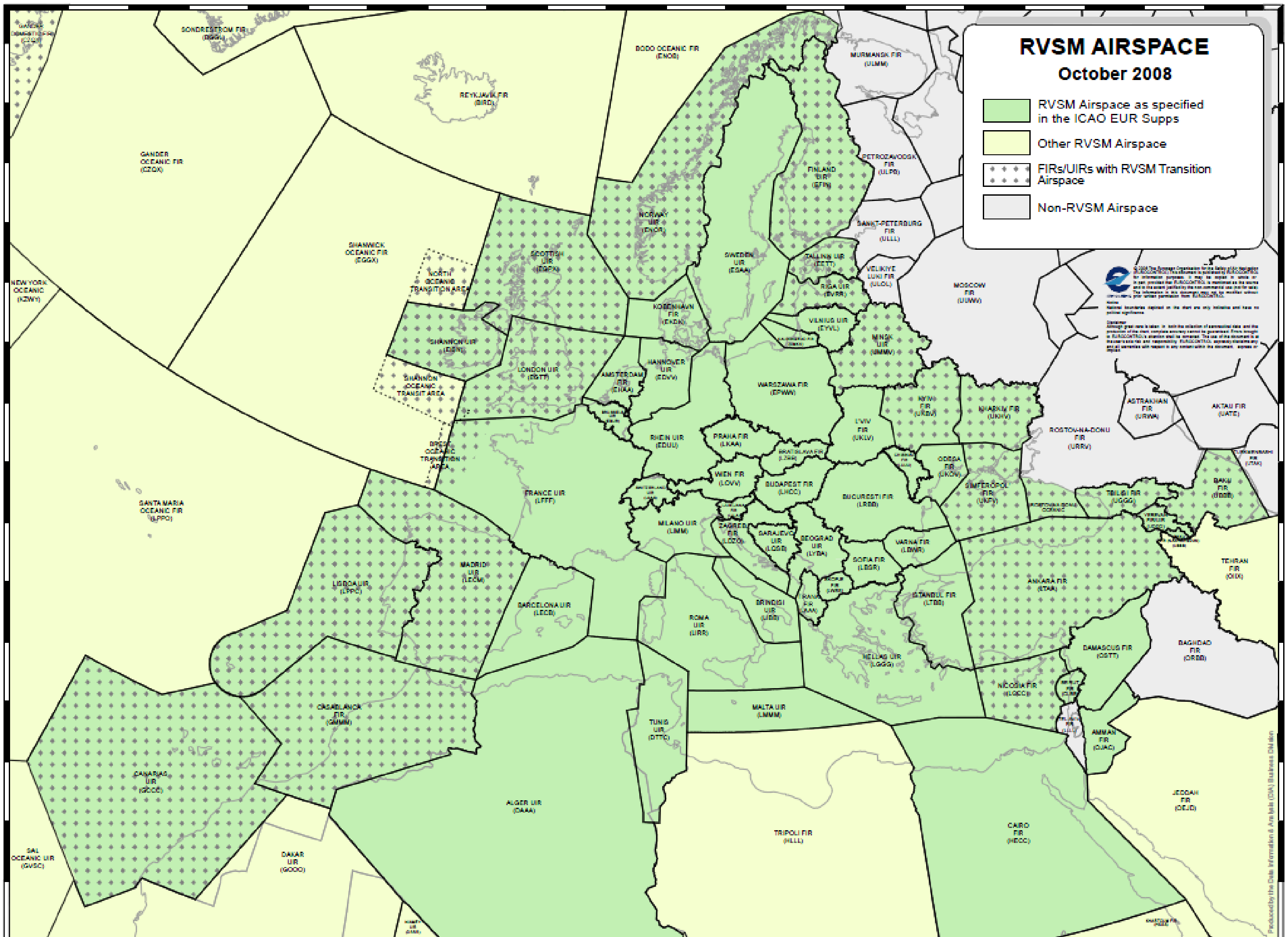
- Temperature $t = 15 - 0.0065 * H$
- Pressure $p = 1013.25(1 - H / 44308)exp5.2553$
- Density $q = 1.225(1 - H / 44308)exp4.2553$
- (H is height above sea level in metres)

Height above sea level [m]	**0**	**2000**	**5000**	**10000**
Temperature[°C]	15	2	-17,5	-50
Pressure [MPa] (kg/cm2)	0.101 (1.033)	0.045 (0.458)	0.030 (0.307)	0.015 (0.151)
Specific density[kg/m3]	1.226	1.007	0.736	0.413

International Standard Atmosphere (ISA)



Division of European airspace



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