Airframe-Engine Installation (page 6):

How many engines and where to put them?

MD-11 aircraft with 3 engines

Boeing-777 twin-engine aircraft

Older/smaller aircraft → tail mounted engines

2 underwing engines are most popular

Wing-mounted engines are easier to support and service

(engine weight ~ 8 tonne

Fewer engines are heavier (oversized to allow for failure of one engine). However, their cost (maintenance and purchase) and overall drag tend to be lower

For a 600-seat, long-range aircraft 4-engines are required:

(very high total thrust)

Apart from anything else, 2-engines wouldn´t fit under the wing!

engine size calculation in later lecture
(bypass ratio)

The ICAO Standard Atmosphere (page 9): or International Standard Atmosphere (ISA)

(page 32 in Thermofluids Data Book)

For the standard atmosphere, conditions at sea level are defined to be:

T_{sl} = 288.15 K p_{sl} = 101.325 kPa ρ_{sl} = 1.225 kg/m^3

At altitude: T, p, ρ are 3 unknowns ⇛ Need 3 equations

The atmosphere MUST satisfy the hydrostatic pressure gradient: $\underbrace{dp/dh = -\overset{\text{NOT CONSTANT!}}{\rho} g, \; p = \rho R T}_{\text{2 equations}}$

3rd equation

Between sea level and an altitude of 11 km:

$T = 288.15 - 0.0065h$ K — i.e. T drops 6.5 K/km

altitude h is expressed in m.

For altitudes between 11 km and 20 km: (the Tropopause)

T = 216.65 K (approx. –56.5 °C)

(see Figure 1.1 in booklet, page 10)

The “Isentropic” Atmosphere ($\underbrace{\text{exercise 1.4}}_{\text{a bit tricky!}}$, page 11):

Has the same sea level conditions, and still MUST satisfy the hydrostatic pressure gradient:

$$\underbrace{dp/dh = -\rho g.}_{\text{equation 1}} \qquad \underbrace{(\text{ and } p=\rho RT\ )}_{\text{equation 2}}$$

However, rather than explicitly specifying the temperature variation, one can assume an isentropic relationship between pressure and density (and also temperature):

$$\underbrace{p \propto \rho^{\gamma}}_{\text{equation 3}} \qquad \Rightarrow p^{\frac{1}{\gamma}} = K\rho$$

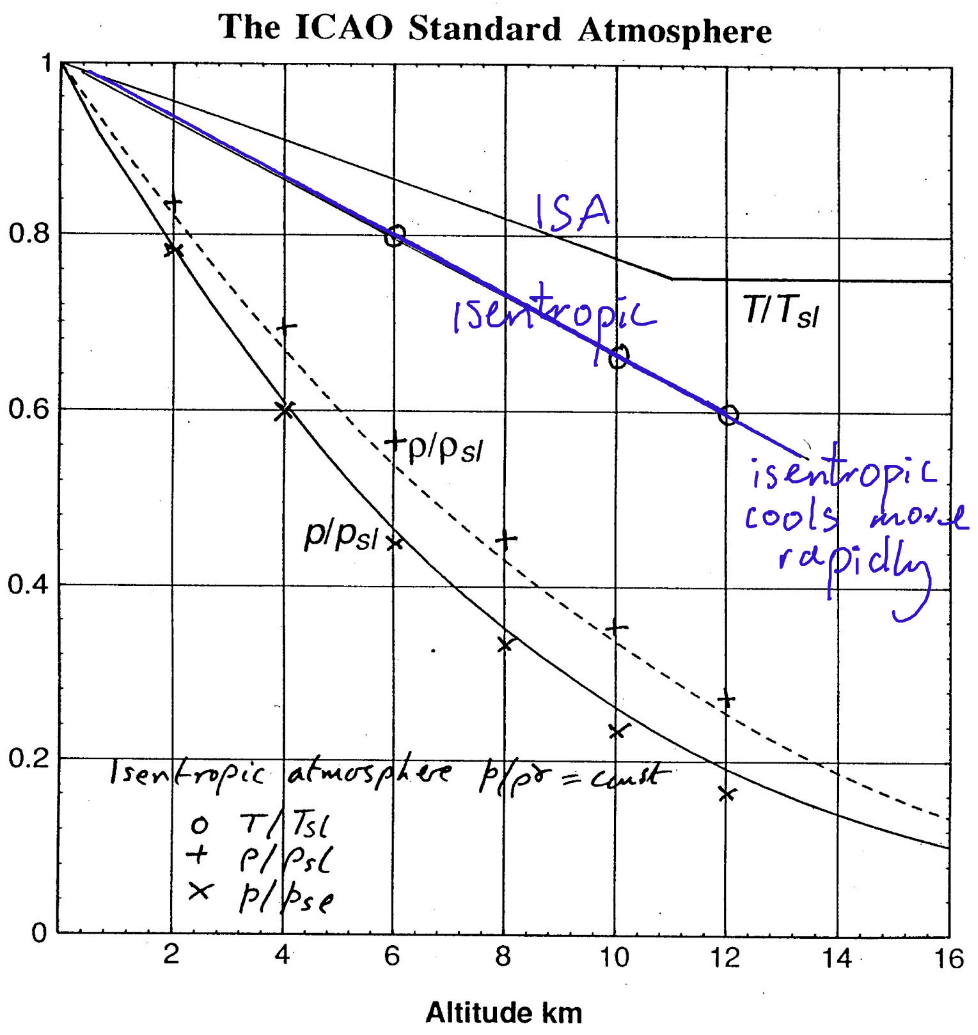
$$\frac{dp}{dh} = -\left(\frac{p^{1/\gamma}}{K}\right) g \quad \text{from equation 1}$$

INTEGRATE and APPLY EQUATION 2

Solving the equations yields (exercise 1.4b):

$$\Rightarrow \frac{p_h}{p_{sl}} = \left[1 - \tfrac{\gamma-1}{\gamma}\frac{gh}{RT_{sl}}\right]^{\gamma/(\gamma-1)} \quad \text{and} \quad \frac{T_h}{T_{sl}} = \left[1 - \tfrac{\gamma-1}{\gamma}\frac{gh}{RT_{sl}}\right]$$

ICAO Standard Atmosphere and "Isentropic" Atmosphere (pages 9 & 11, Ex. 1.4):



Isentropic atmosphere cools more rapidly than standard atmosphere.

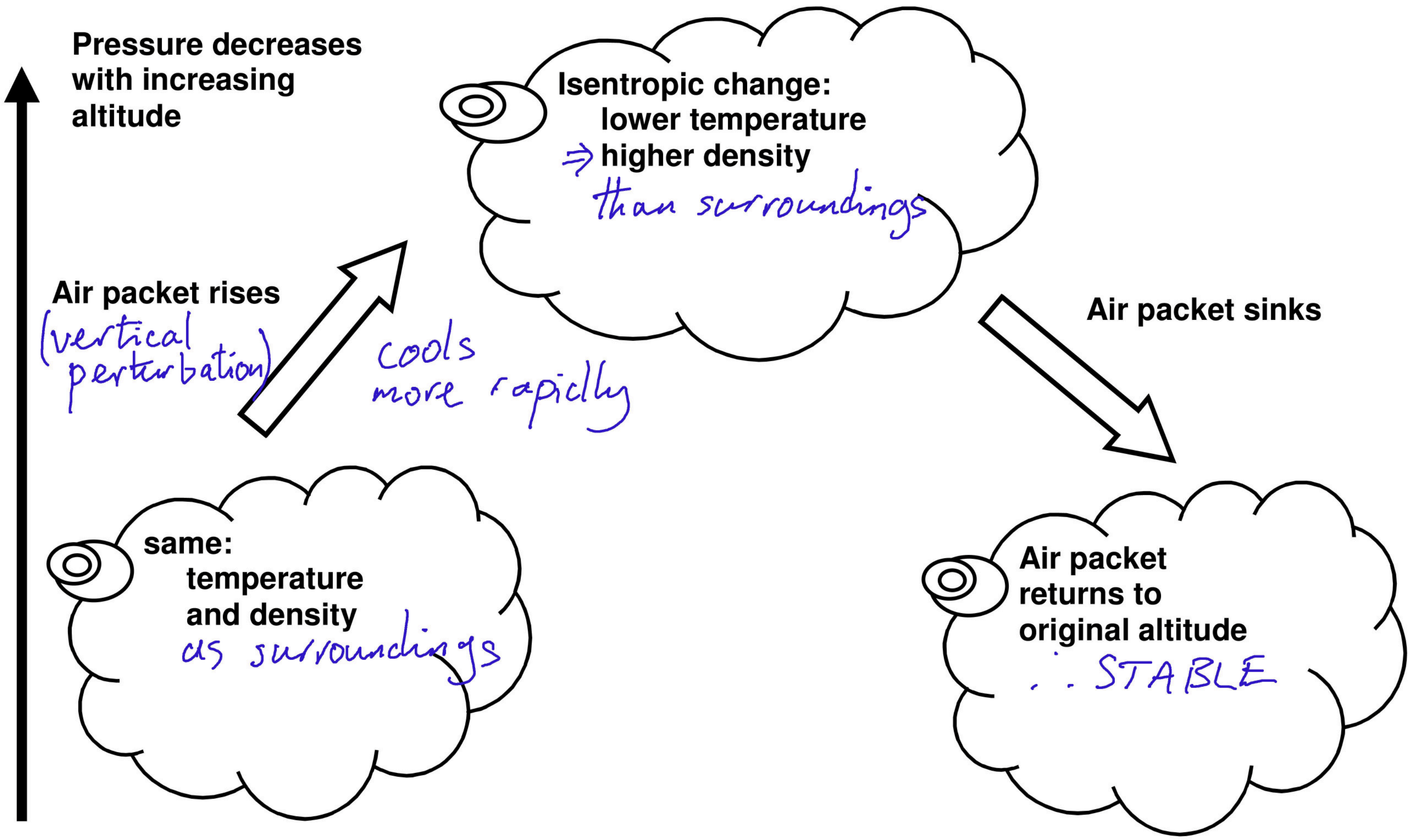
Pressure and density are similar for both atmospheres.

In all design exercises the ISA is assumed.

(sometimes corrections are applied for particular locations)

Stability of the ICAO Standard Atmosphere (page12):

If air is displaced upwards, will it continue to rise, or will it sink back?



Pressure decreases with increasing altitude

Isentropic change:
lower temperature
⇒ **higher density** than surroundings

Air packet rises (vertical perturbation)

cools more rapidly

Air packet sinks

same:
temperature and density as surroundings

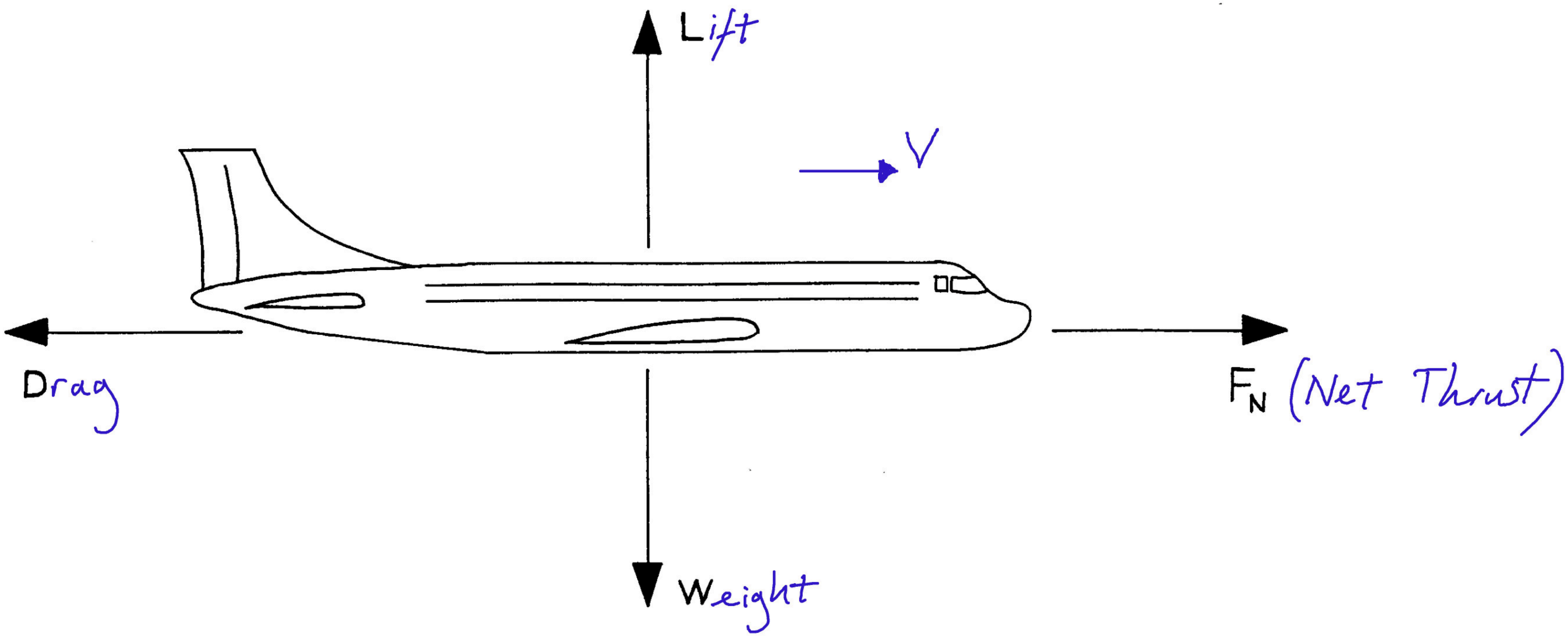
Air packet returns to original altitude
∴ STABLE

The ICAO Standard Atmosphere is, therefore, stable.

Steady level flight (page ~~15~~ 17):

Lift is the force, mainly from the wings, perpendicular to the direction of flight.

Drag is the backward force opposing the direction of travel.



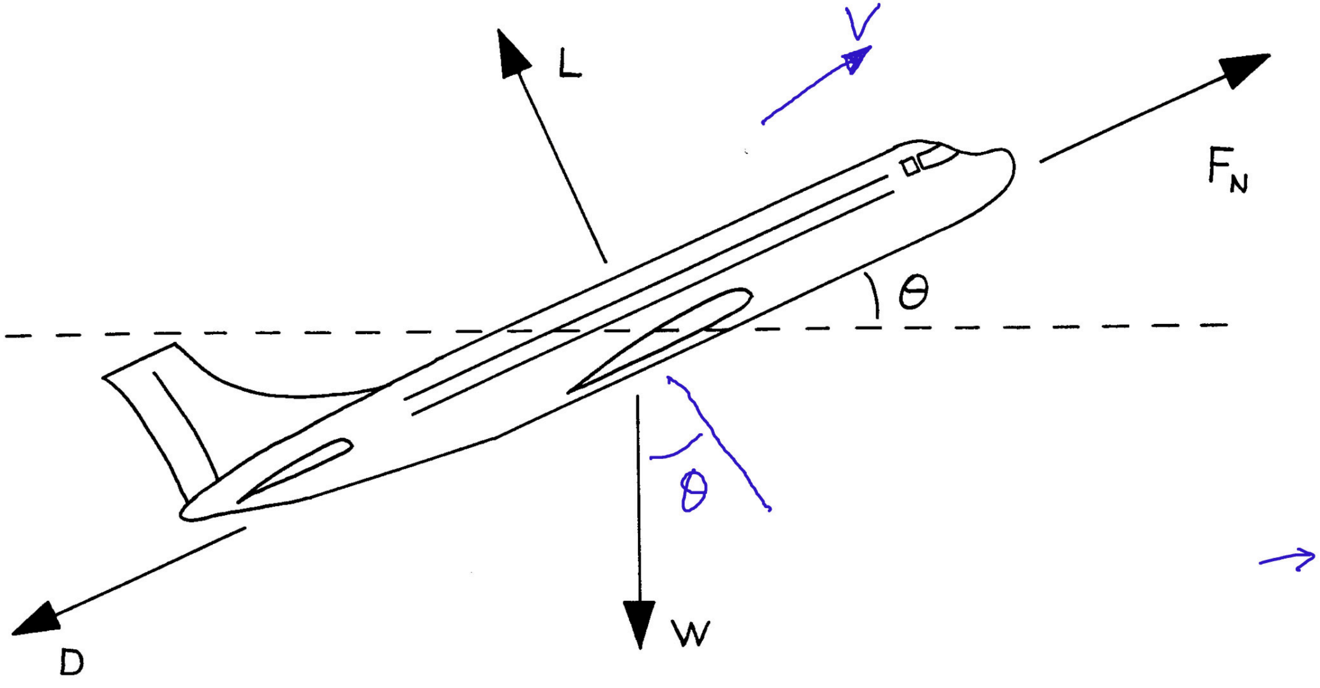
Equilibrium:

$$\left.\begin{array}{ll} \text{Lift = Weight} & L = W \\ \text{Net Thrust = Drag} & F_N = D \end{array}\right\}$$

$$F_N / W = \frac{1}{L/D} \simeq 0.05$$

$$L/D \simeq 20$$

Steady climb at an angle θ (page 22):



$$L = W\cos\theta \quad - ①$$

$$F_N = D + W\sin\theta \quad - ②$$

At top-of-climb, (engine design point)

$\theta \approx 0.33°$

$\rightarrow \sin\theta \simeq 0.0058$

$\cos\theta \simeq 1$, $L = W$ from ①

So the ability to climb depends on the difference between net thrust and drag.

$(W\sin\theta = F_N - D)$

$$\text{from ②,} \quad F_N / W \approx \underset{0.05}{\frac{1}{L/D}} + \underset{0.0058}{\sin\theta}$$

} 11% more thrust at top-of-climb than cruise.

Non-dimensional variables are used if possible (page 15):

For aircraft aerodynamics,

Lift coefficient $C_L = \frac{L}{\frac{1}{2}\rho AV^2}$

Drag coefficient $C_D = \frac{D}{\frac{1}{2}\rho AV^2}$

Mach number $M = \frac{V}{a} = \frac{\text{Flow Speed}}{\text{Pressure Wave Speed}}$

where:

V is the flight speed (m/s)

A is the wing area (m^2)

ρ is the local air density (kg/m^3)

$a=\sqrt{\gamma RT}$ is the speed of sound based on the local temperature

In addition,

Lift / drag ratio $= \underline{L/D = C_L/C_D}$ represents the amount lifted in steady level flight for a given engine thrust. It is a measure of how good is the aeroplane or wing.

Non-dimensional

Later we will see that $\underline{VL/D \text{ (or } ML/D)}$ indicates how far one can transport a given weight for a given thrust. Want to maximise this at cruise condition.