Lecture – 7

An Introduction to Basic Principles of Atmospheric Flight Mechanics

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Aircraft Designs

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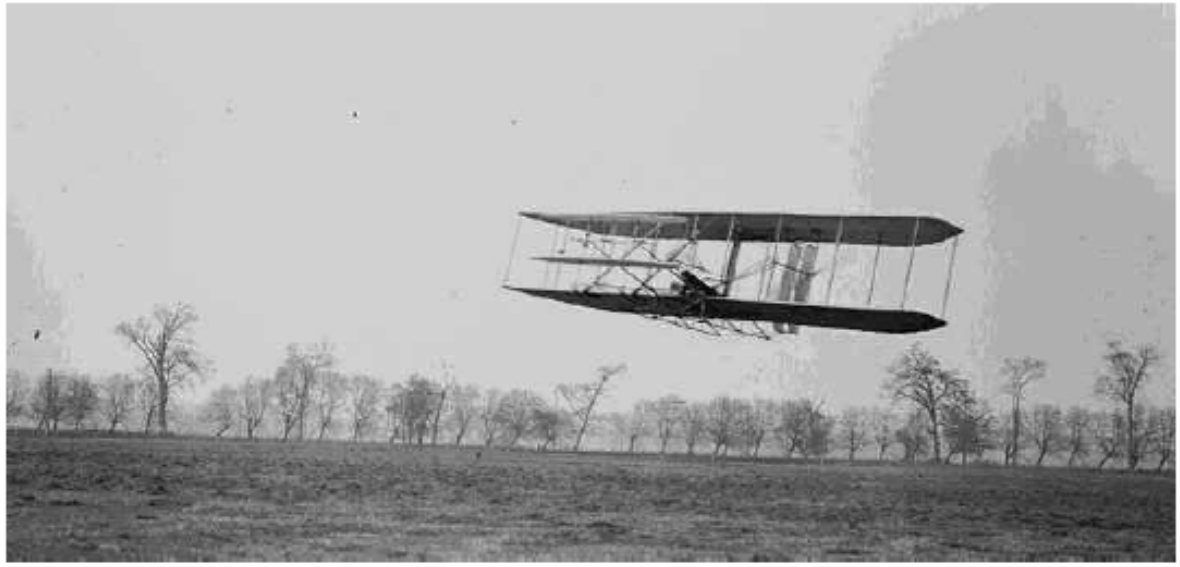
First to Fly

- Otto Lilienthal
  - First person to make repeated successful short flights
  - Used a fixed wing glider
  - Died after a crash in 1896, saying „Sacrifices must be made"

Wright Brothers

Wright brothers

- Started as glider engineers and pilots
- First engine powered flight in 1903
- First to actively manipulate the plane by control surfaces



Different airplane configurations

- Biplane:
  - More compact layout with shorter wingspan
  - Higher maneuverability
  - Very popular in the early days of aviation
  - But: more drag and less lift than a classical design with equal wing area

Different airplane configurations

- Sailplane:
  - Goal of energy efficiency and flight endurance
    - Large wingspan, low weight
    - Low speed
    - Low payload

Commercial Aircrafts

- High Lift/Drag ratio
- High fuel efficiency
- High reliability & safety requirements
- Good handling quality and passenger comfort
- All weather operational capability
- Speed and agility (maneuverability) are not critical

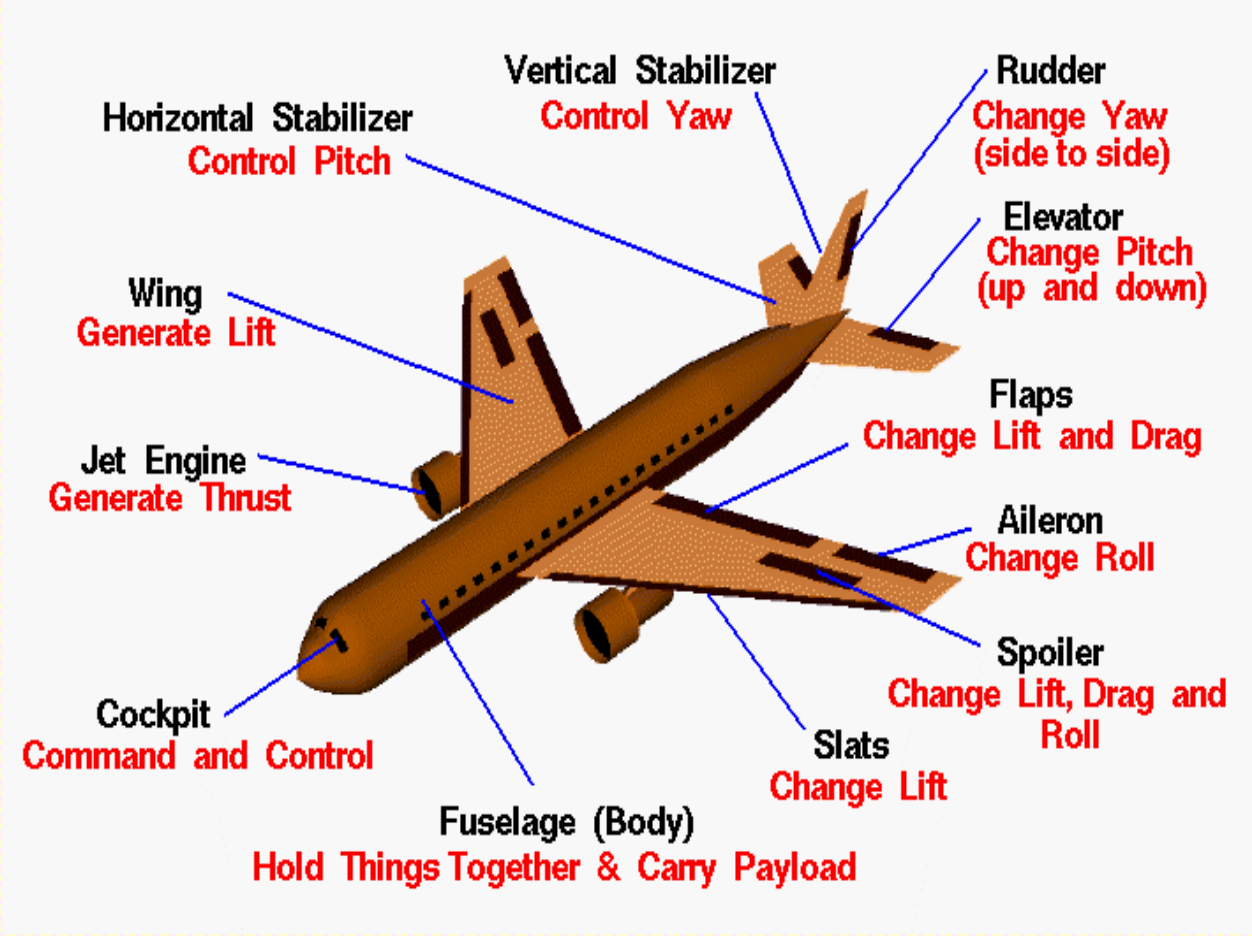
Different airplane configurations

- Fighter aircraft:
  - Goal of high speed, high climbing rate, high maneuverability, stealthiness
    - Strong engines, short wings with high chord length, complex geometry, large control surfaces
    - High fuel consumption (and thus limited operating range)

Different airplane configurations

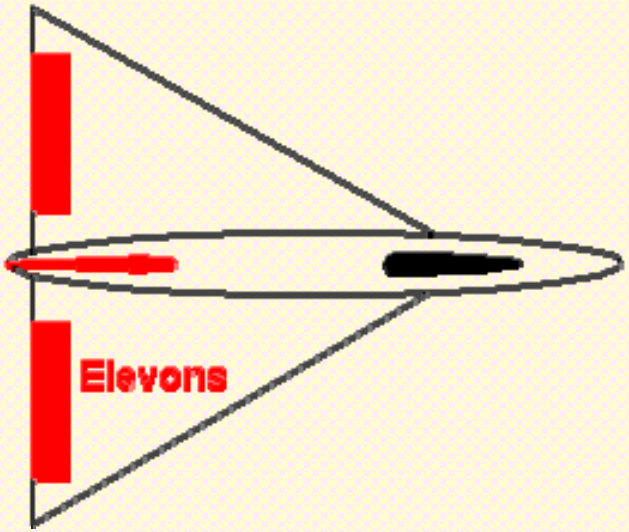
- Flying wing aircraft:
  - Most commonly used in the low to medium speed range
  - High stealth capabilities (low visibility for radar)
  - Fuel efficient due to low drag
  - Problem: no passenger windows (in commercial application)

Geometry of Conventional Aircrafts



Tailless Aircraft

- On the tailless aircraft the pitch controls and roll controls must both be on the wing. There can be separate elevators and ailerons or they can be combined into one set of controls known as Elevons and still usually has a vertical Fin with a rudder



Canard Aircraft

- Horizontal stabilizer and elevators are in front.
- Advantage: Better control characteristics (including elimination of the non-minimum phase behavior)
- Drawback: Disturbed flow pattern over the body, good aerodynamic modeling is difficult.

Force Balance in Flying Vehicles

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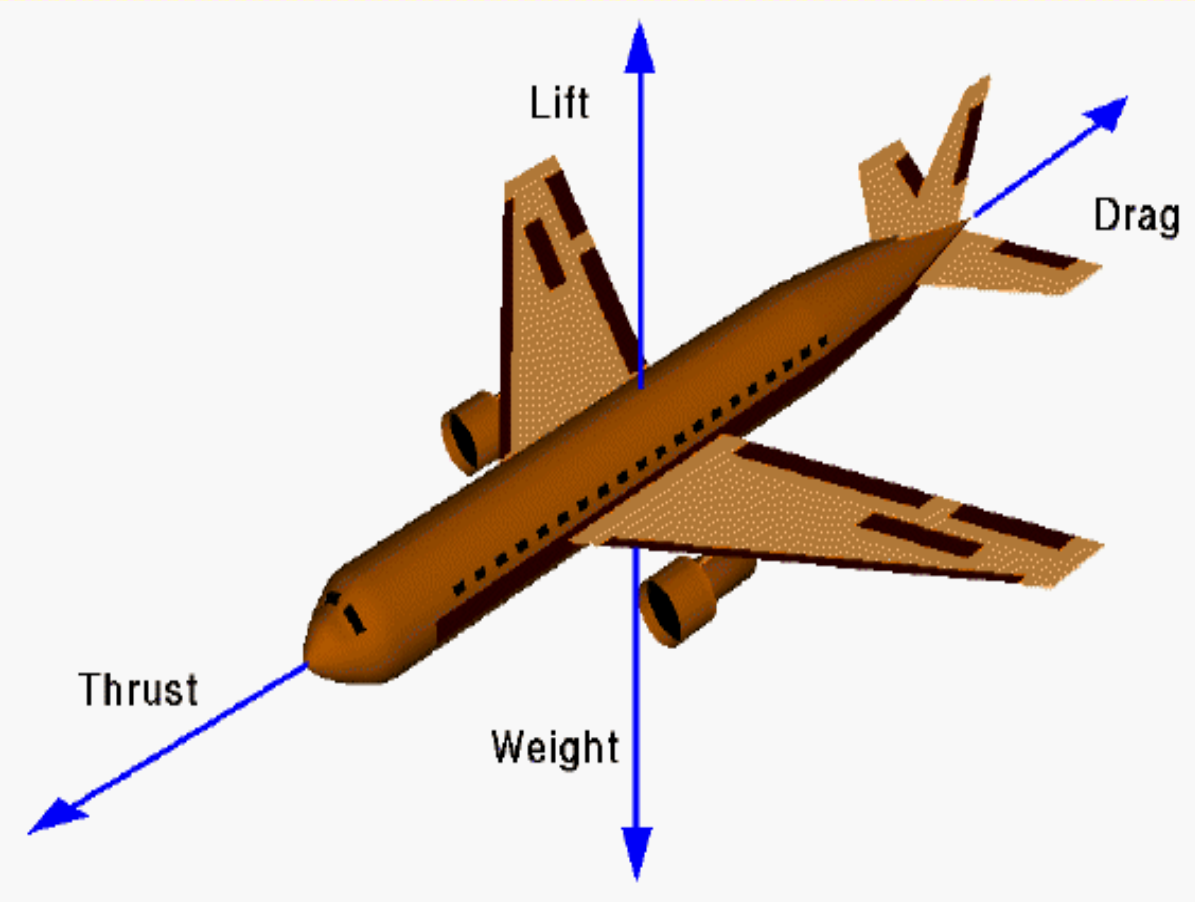
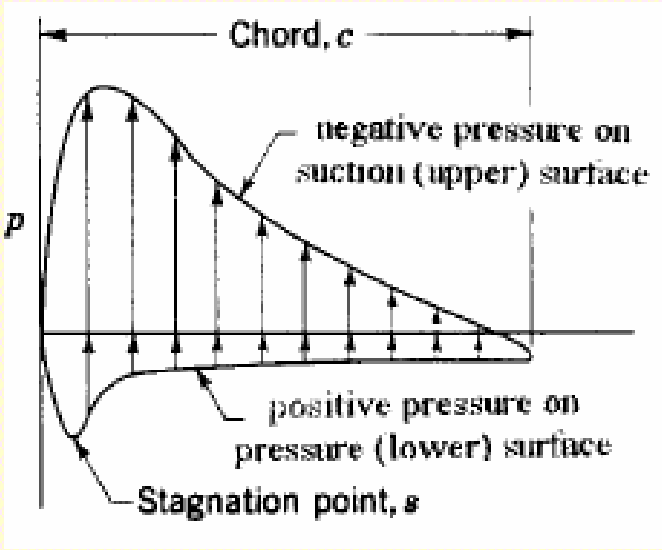
Basic Force Balance

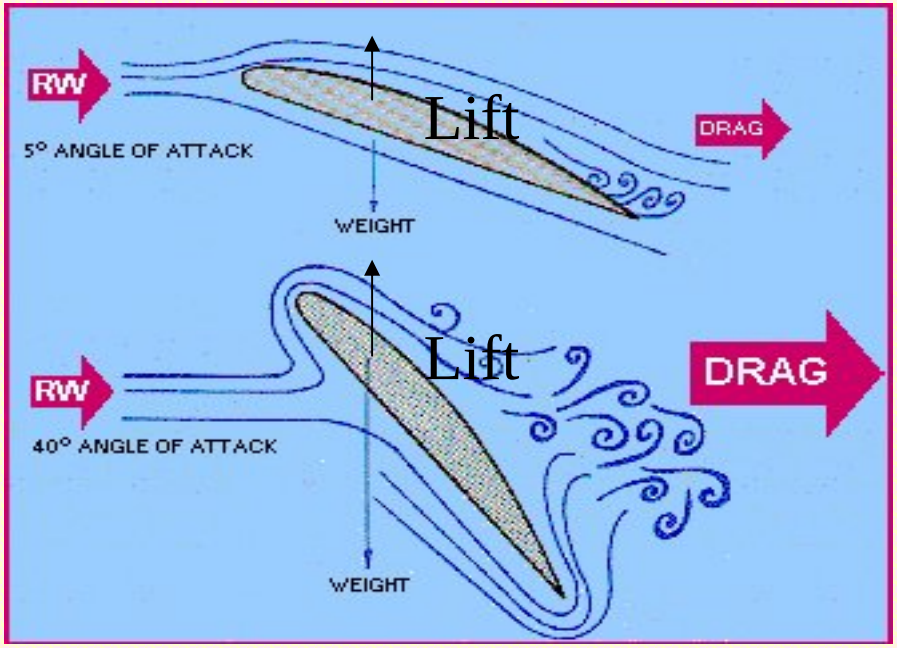
- Weight
- Lift
- Drag
- Thrust



Lift

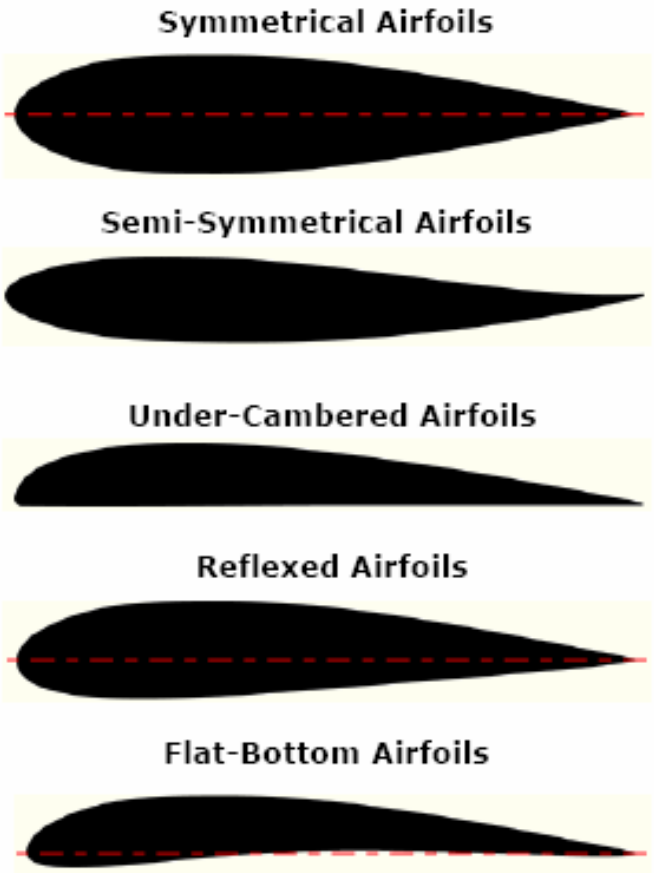
- Lift is generated by differential pressure on upper and lower side of the wing

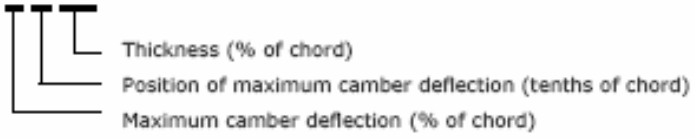




Airfoil Theory in 2D

- There isn't any « **ideal** » airfoil
- The choice of an airfoil depends on:
  - Flying speed
  - Wing loading
  - Construction method
  - Kind of flight (acrobatic, glide,...)
  - Placement on the airplane
    - Ex: tail airfoils are always symmetrical
- Standard airfoils
  - Goettingen
  - Eppler
  - Naca
  - Example: NACA 2412





Lift

$$L = \bar{q}\, S\, C_L = \left(\frac{1}{2}\rho V^2\right) S\, C_L$$

$\rho(h)$ = atmospheric density (a function of height)

V = relative velocity of air

S = wetted surface area

C_L = coefficient of lift

$$\bar{q} = \left(\frac{1}{2}\rho V^2\right): \text{ Dynamic Pressure}$$

Dynamic pressure

Total pressure of any fluid

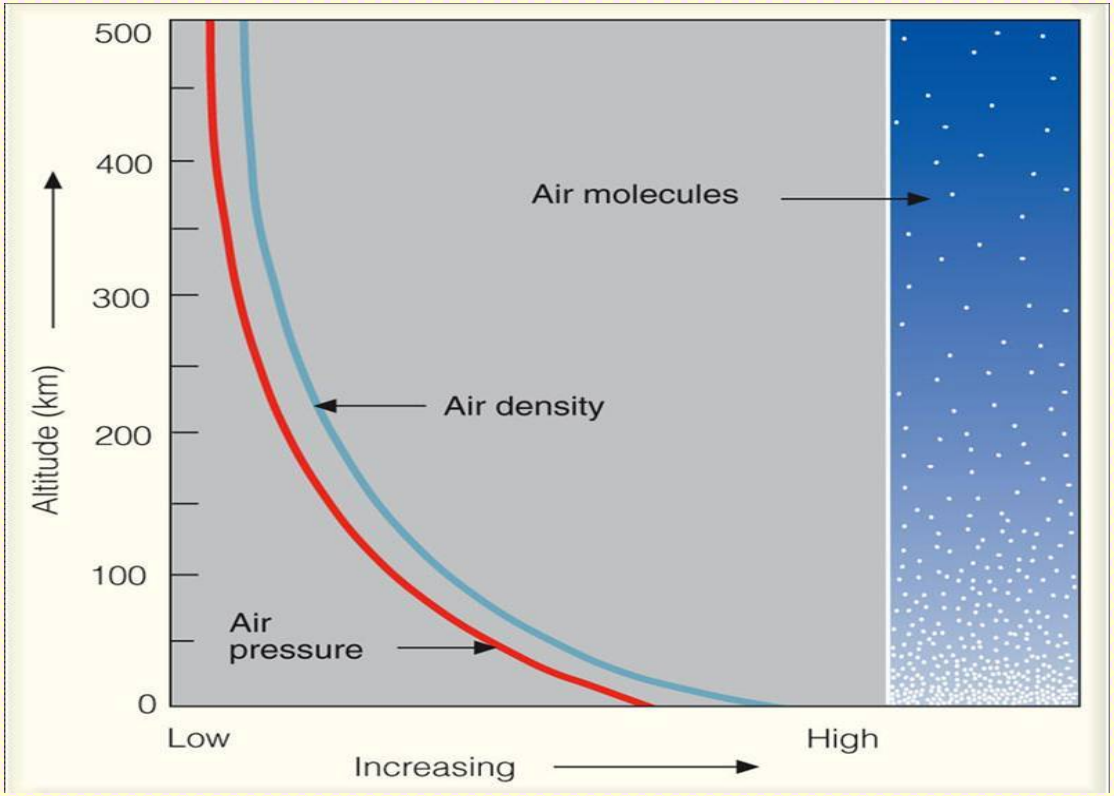
= static pressure + dynamic pressure

$$= \rho g h + \frac{1}{2}\rho V^2$$

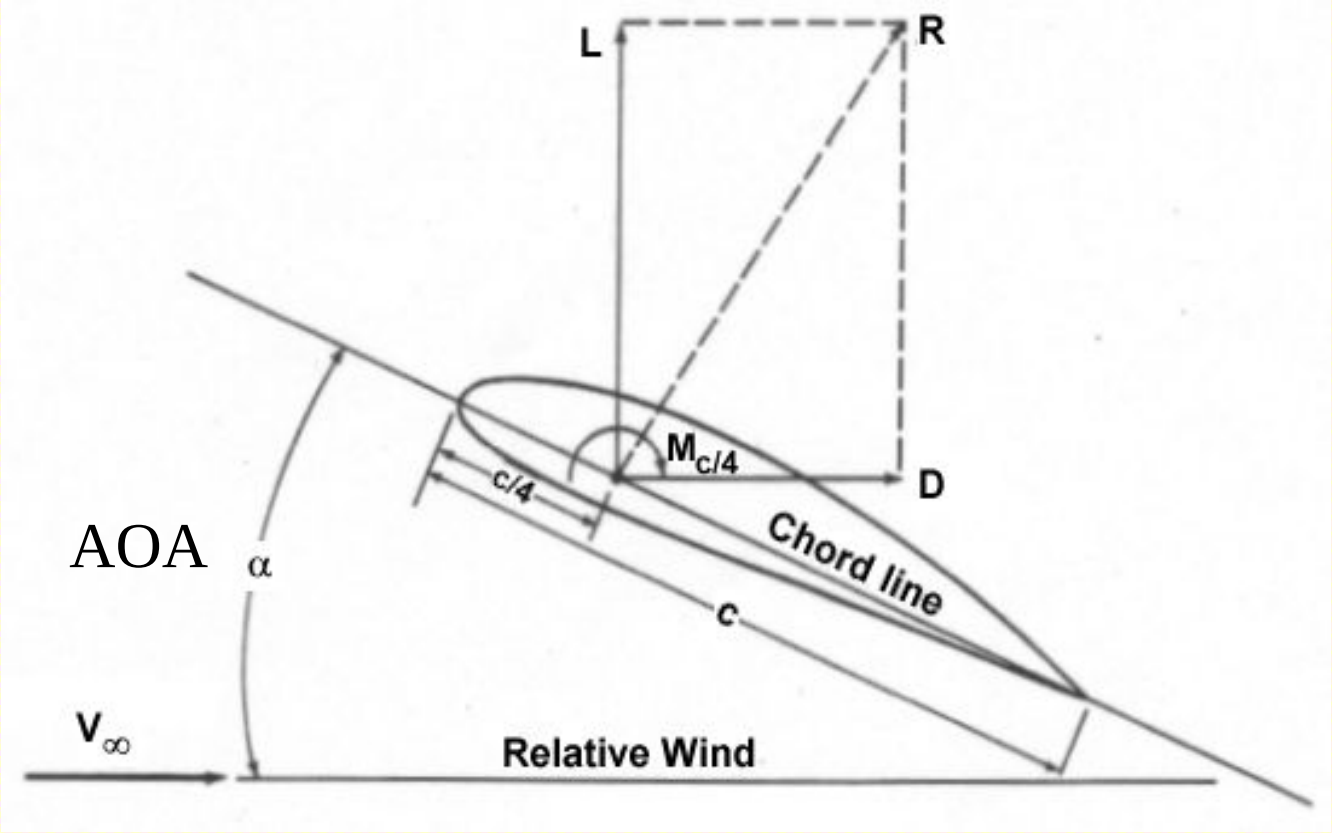
Dynamic pressure of a fluid represents its kinetic energy

Atmospheric density

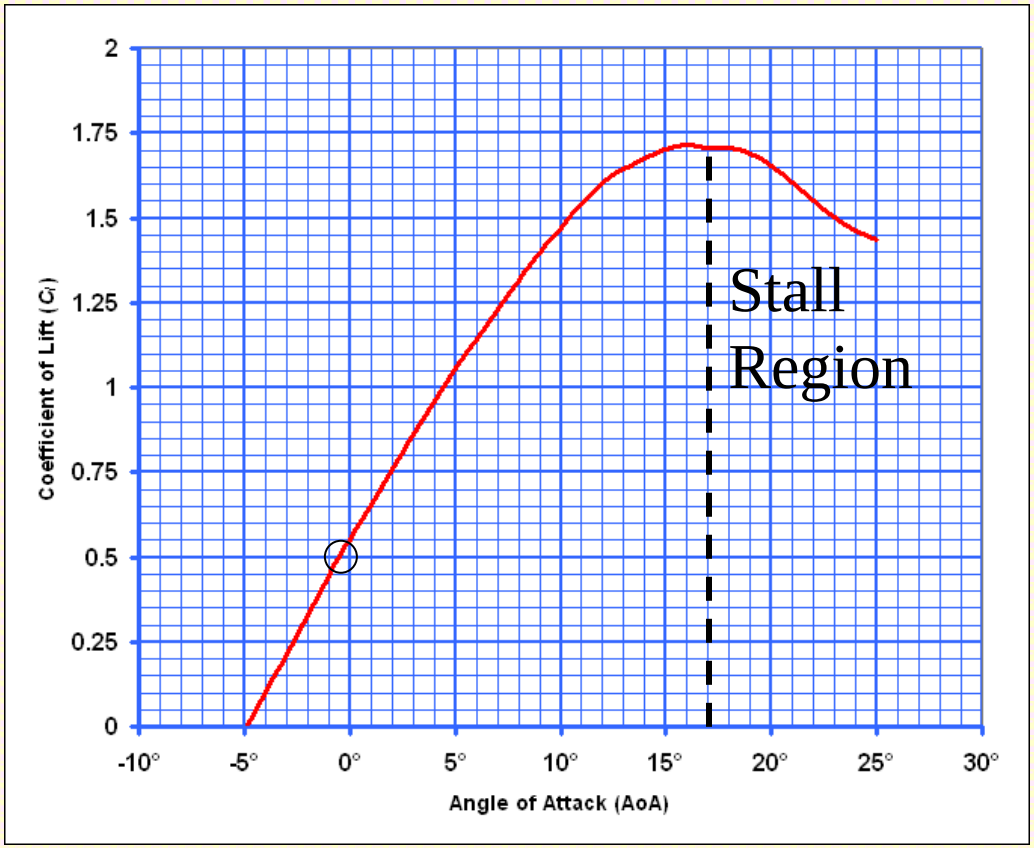
$$\rho = \rho_0 e^{-\left[\frac{g_0(h-h_0)}{RT}\right]}$$



Angle of attack



Coeff. of Lift vs Angle of attack



$$L = \left(\frac{1}{2}\rho V^2\right) S C_L$$

Lift coefficient

Drag

$$D = \left(\frac{1}{2}\rho V^2\right) S\, C_D$$

C_D = Coefficient of drag

= profile drag + induced drag

$$= C_{D_0} + K\, C_L^2$$

Mach Number $M = V / C$

V = velocity of object relative to medium

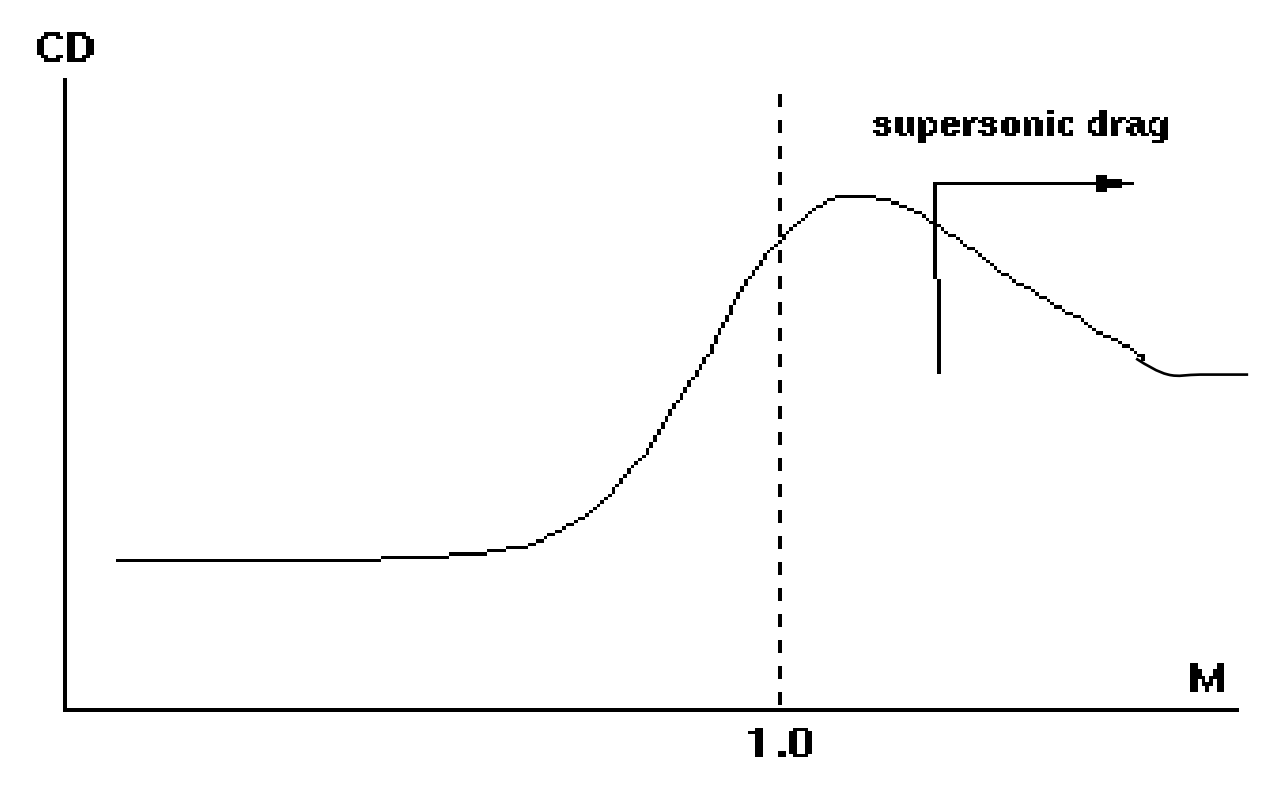
C = velocity of sound in the medium

= velocity of sound in air = 340 m/s at 25^0 C

$M < 1$	Subsonic
$M = 1$	Sonic
$0.8 < M < 1.2$	Transonic
$1.2 < M < 5$	Supersonic
$M > 5$	Hypersonic

$$C = \sqrt{\gamma RT} = \sqrt{\frac{\gamma P}{\rho}}$$

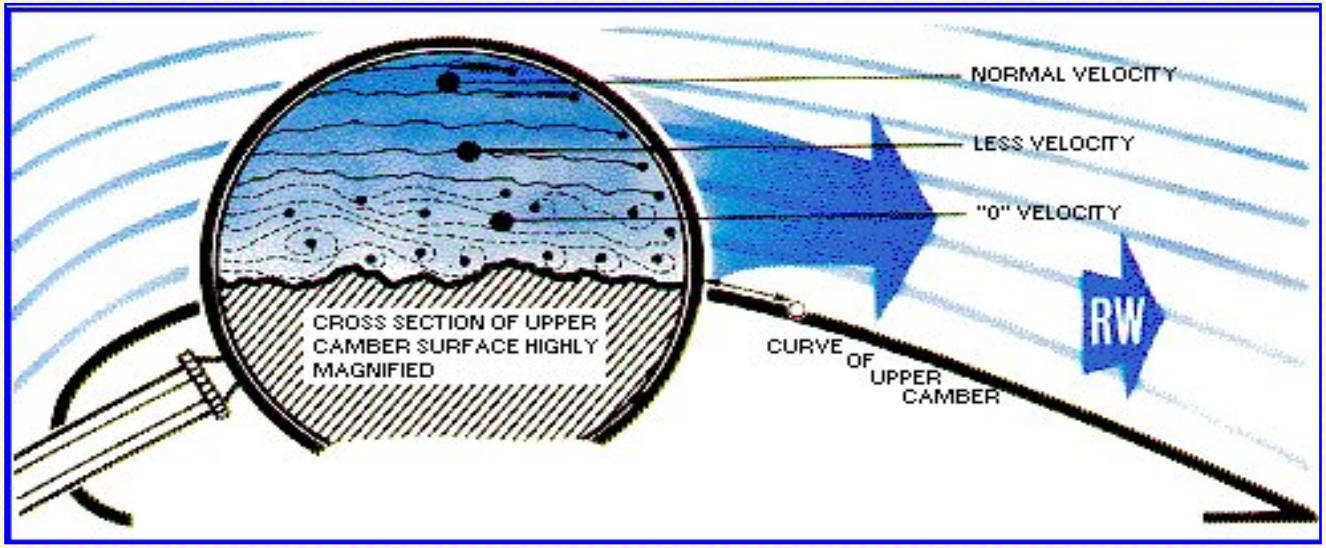
Drag vs Mach number



Drag

- Skin friction drag
- Pressure drag
- Induced drag

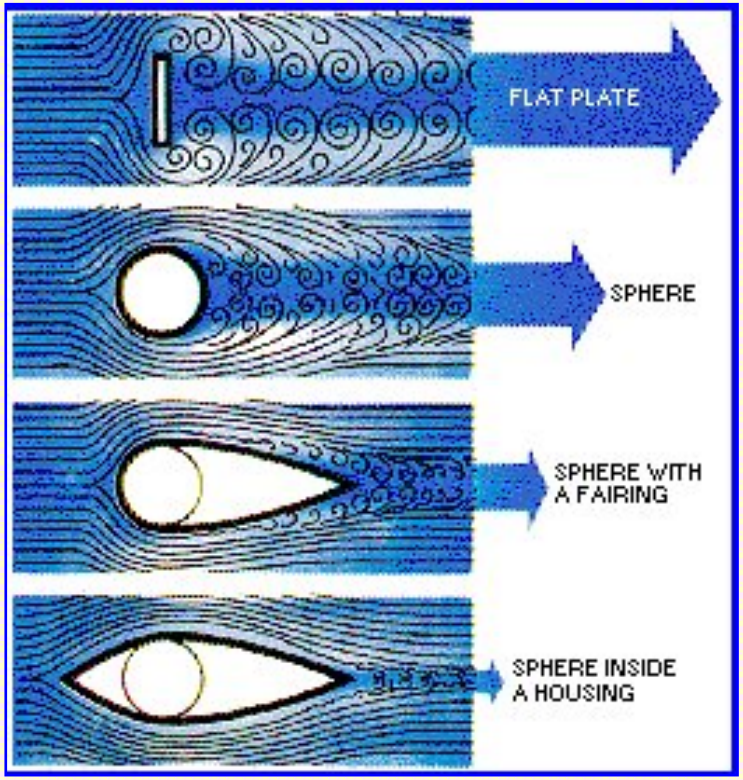
Skin friction drag



- It is caused by the interaction of the air particles against the surface of the aircraft. For the airplane, skin fiction drag can be reduced, by keeping an aircraft's surface highly polished and clean.

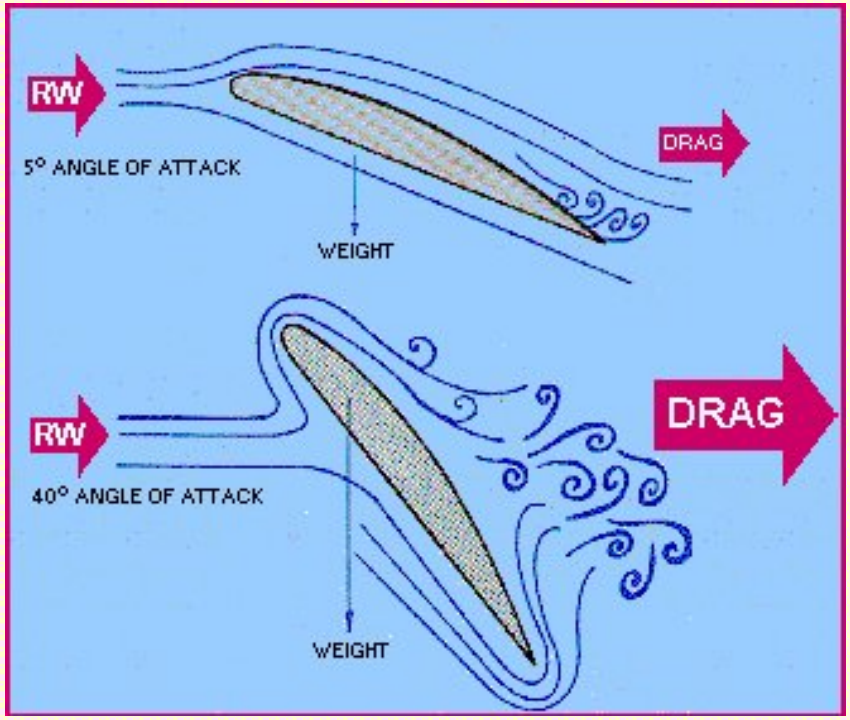
Form or Pressure drag

- *Pressure drag* is caused by the separation of air that is flowing over the aircraft or airfoil.
- **Note:** New generation cars are designed to reduces pressure drag, which leads to better mileage



Induced drag

- *Induced drag* is the drag created by the vortices at the tip of an aircraft's wing.
- *Induced drag* is more while maneuvering due to more flow separation over the entire body.

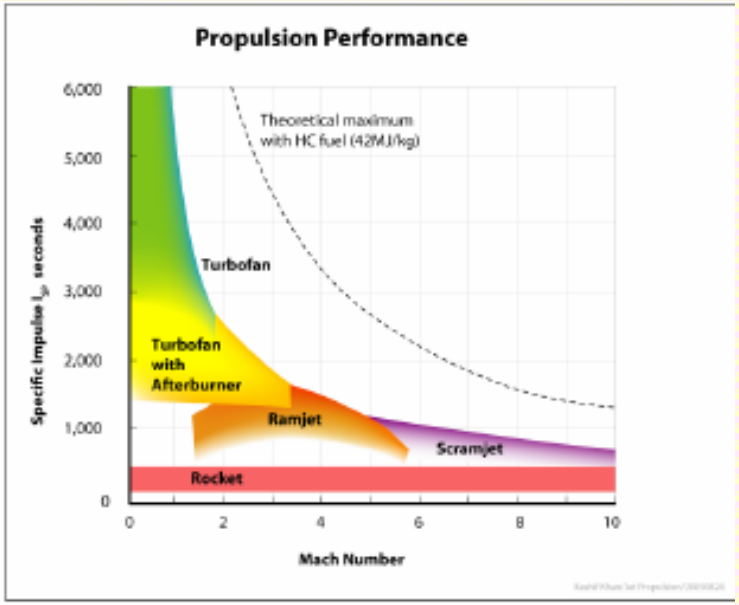


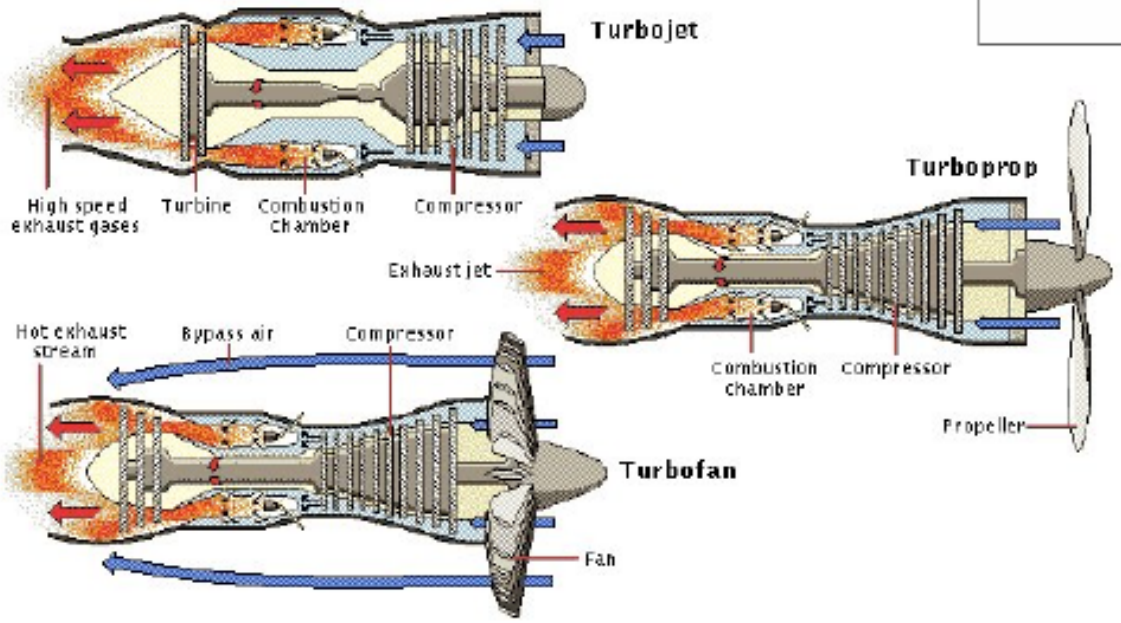
Thrust

- Thrust is produced by engines, which counteracts the drag and hence the airplane moves in forward direction.
- Types of engines
  - Propeller
  - Turboprop
  - Turbofan
  - Turbojet
  - Ramjet
  - Scramjet

Propulsion group types

- Jet engine





Propeller engine

Spitfire: Used by England in second world war.

Turboprop engine

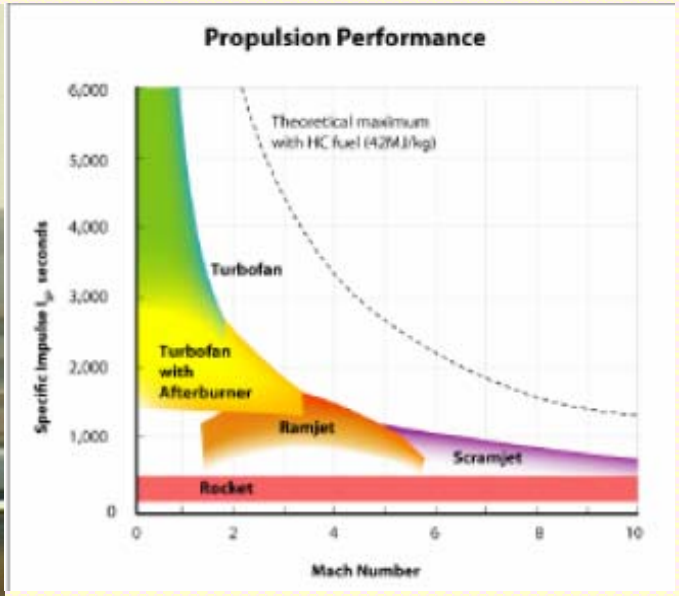
Used by ATR flights

Turbofan engine

Airbus A380 – *Largest Passenger Aircraft*

Engine Used: Either Rolls Royas or GE

Turbofan engine with afterburner



LCA - *Light Combat Aircraft*

Kaveri: An indigenous engine under development at GTRE (Gas Turbine Research Est.) under DRDO

Ramjet Engines

Brahmos: A supersonic cruise missile developed jointly by India and Russia.

Scramjet

X-43 is an experimental vehicle of NASA which used scramjet propulsion to reach up to MACH 9

Moment Balance in Flying Vehicles

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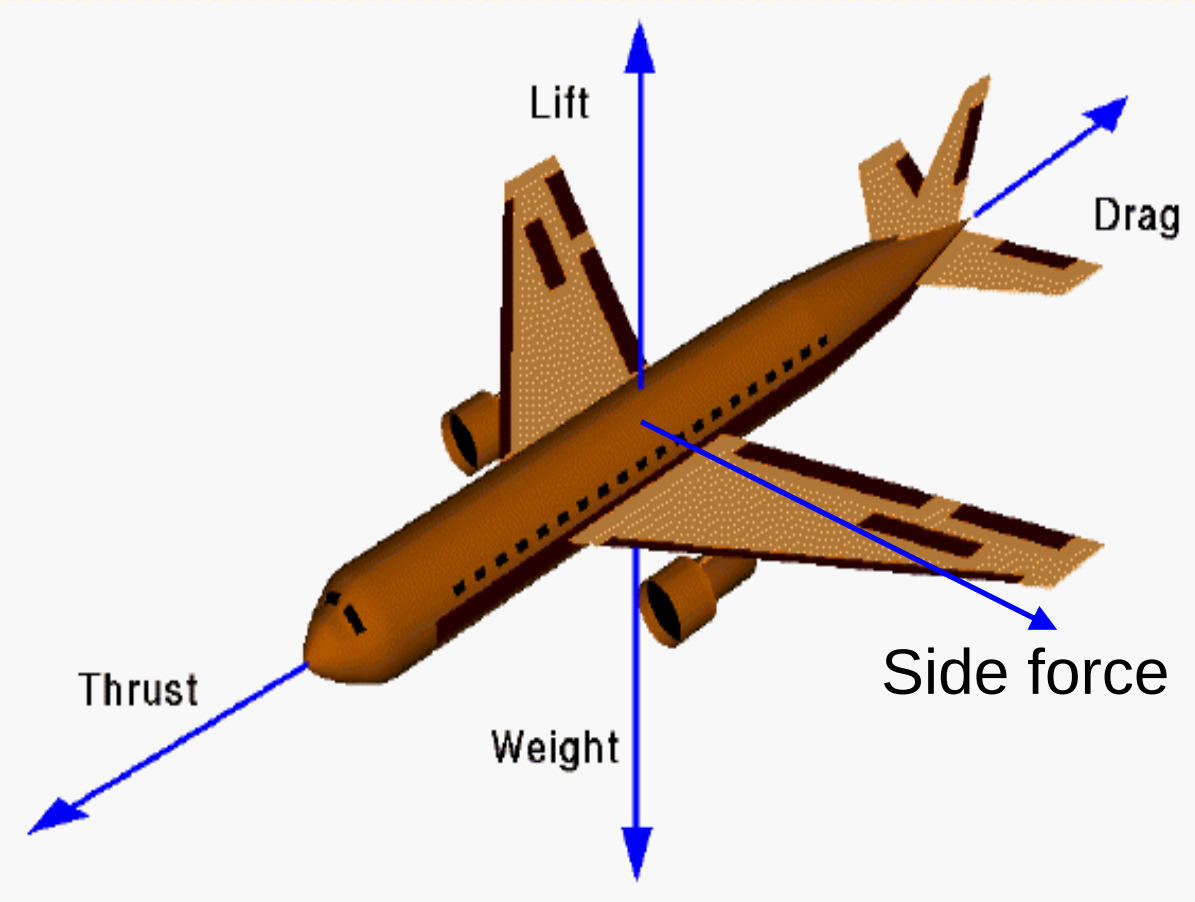
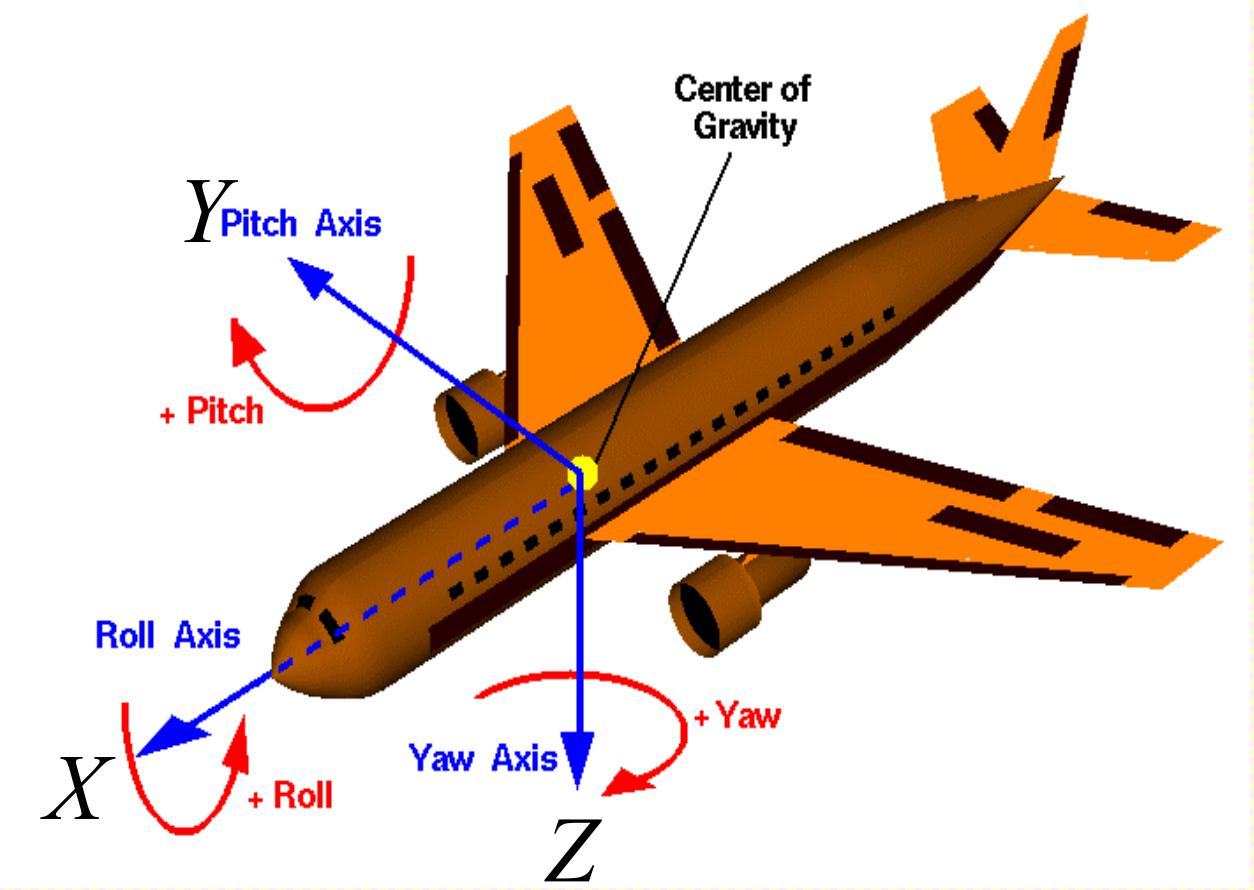
Basic Force Balance

- Weight
- Lift
- Drag
- Thrust
- Side force

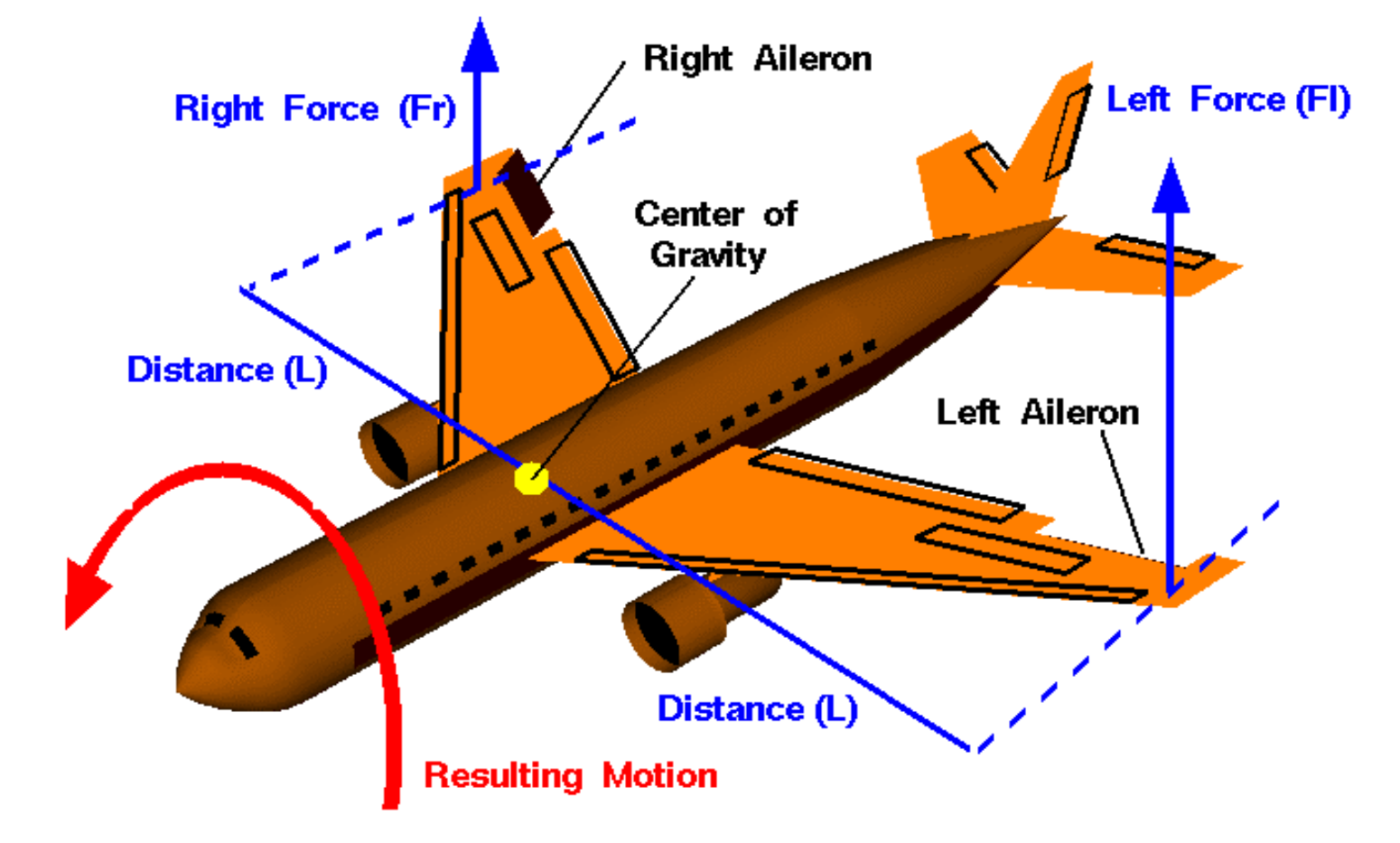


Basic Moment Balance

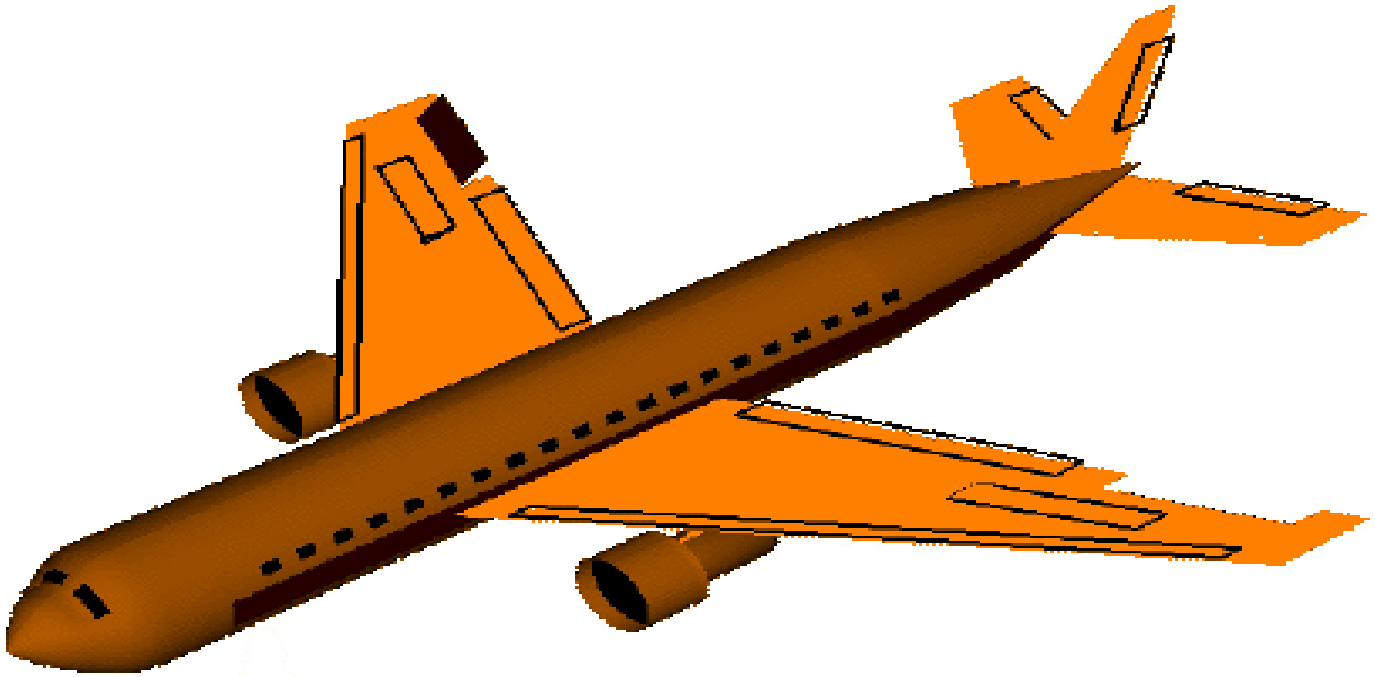
- Rolling
- Pitching
- Yawing



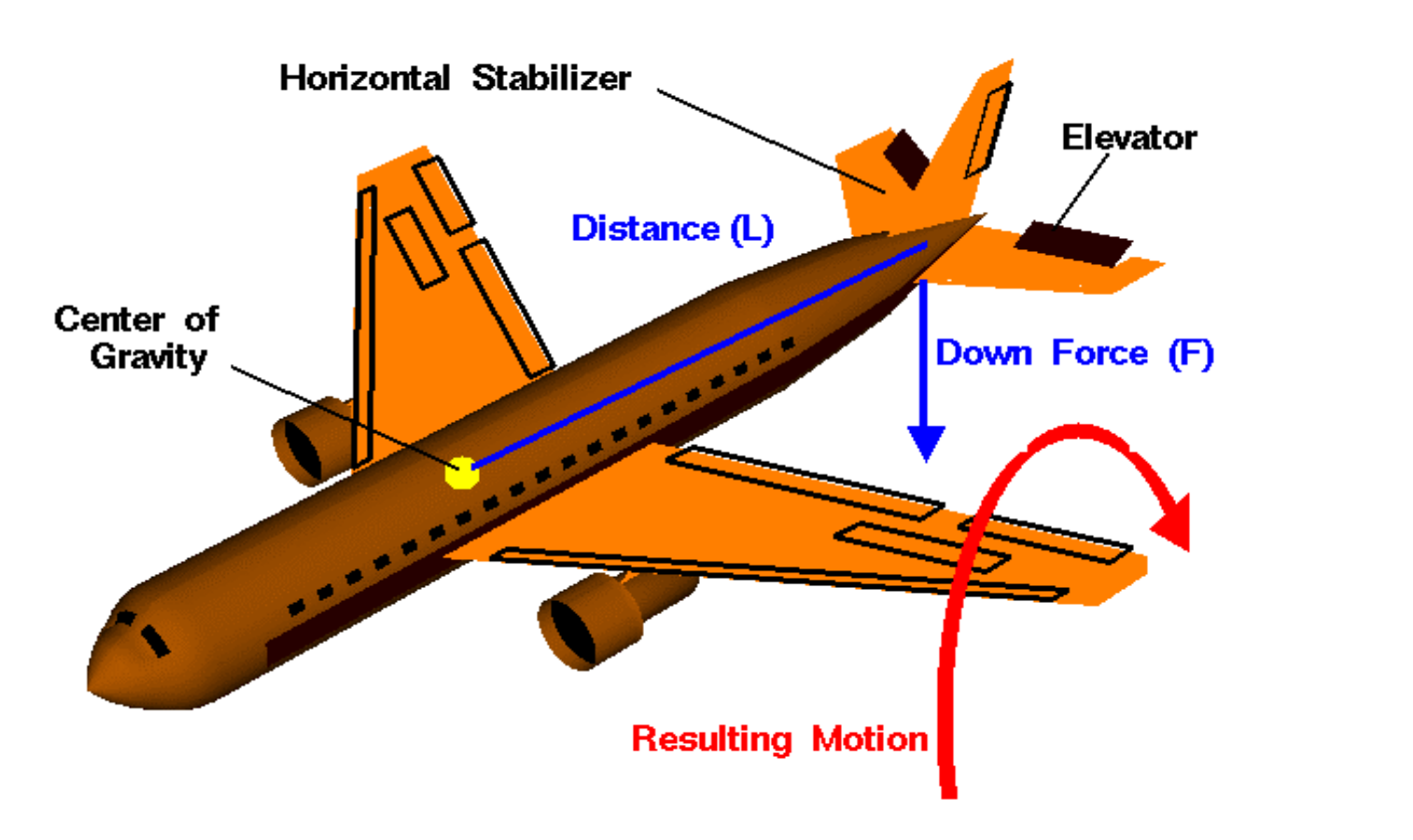
Ailerons ⇨ Roll



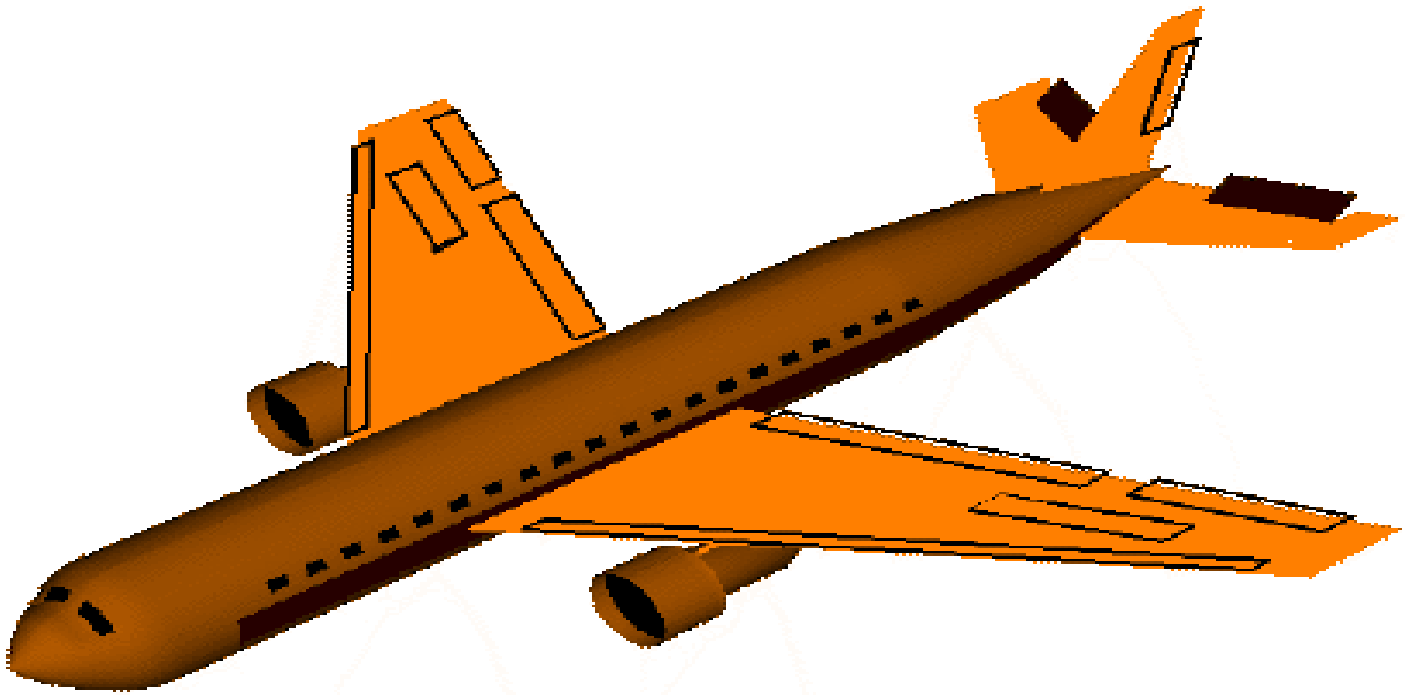
Aileron ⇨ Roll



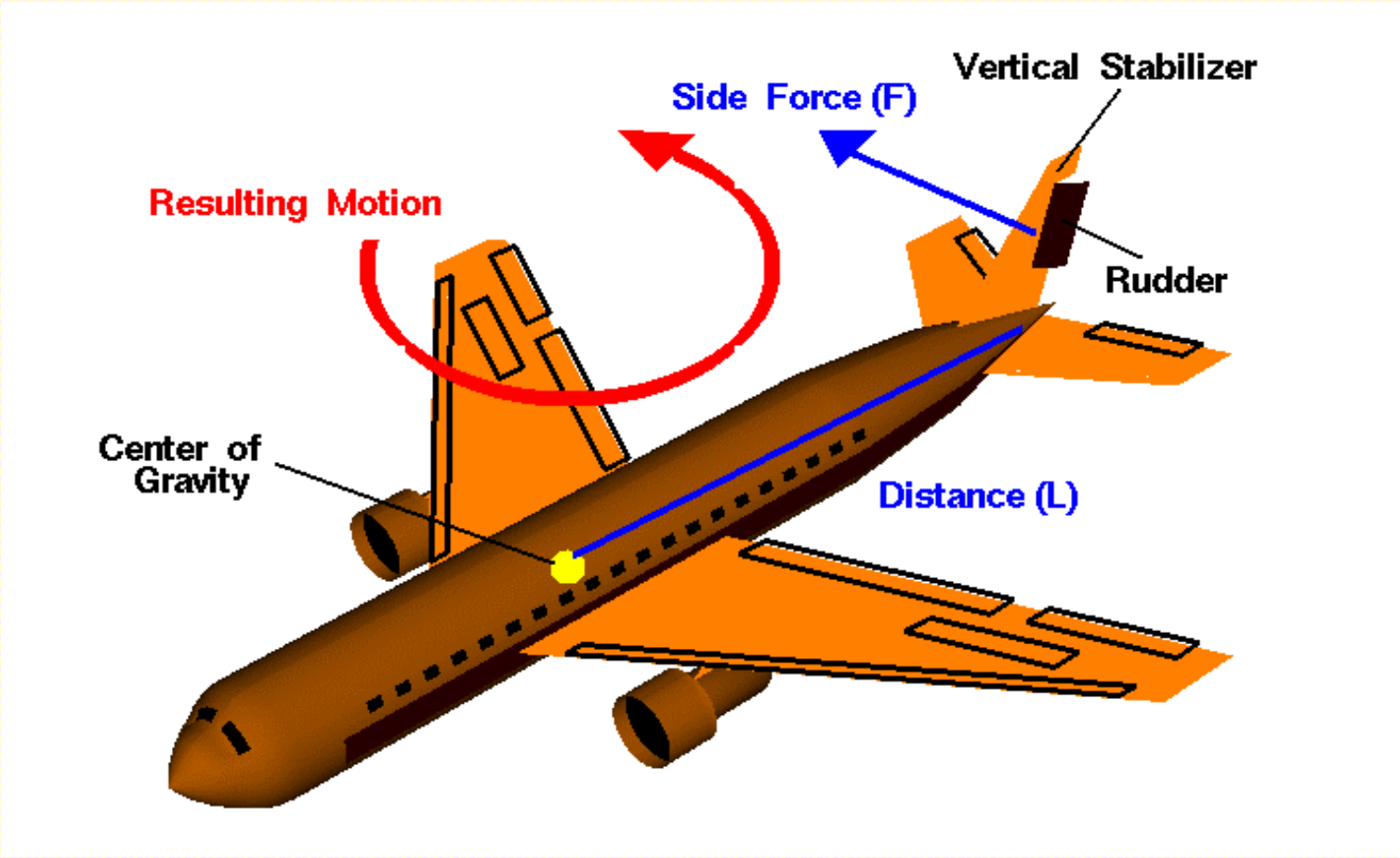
Elevator ⇨ Pitch



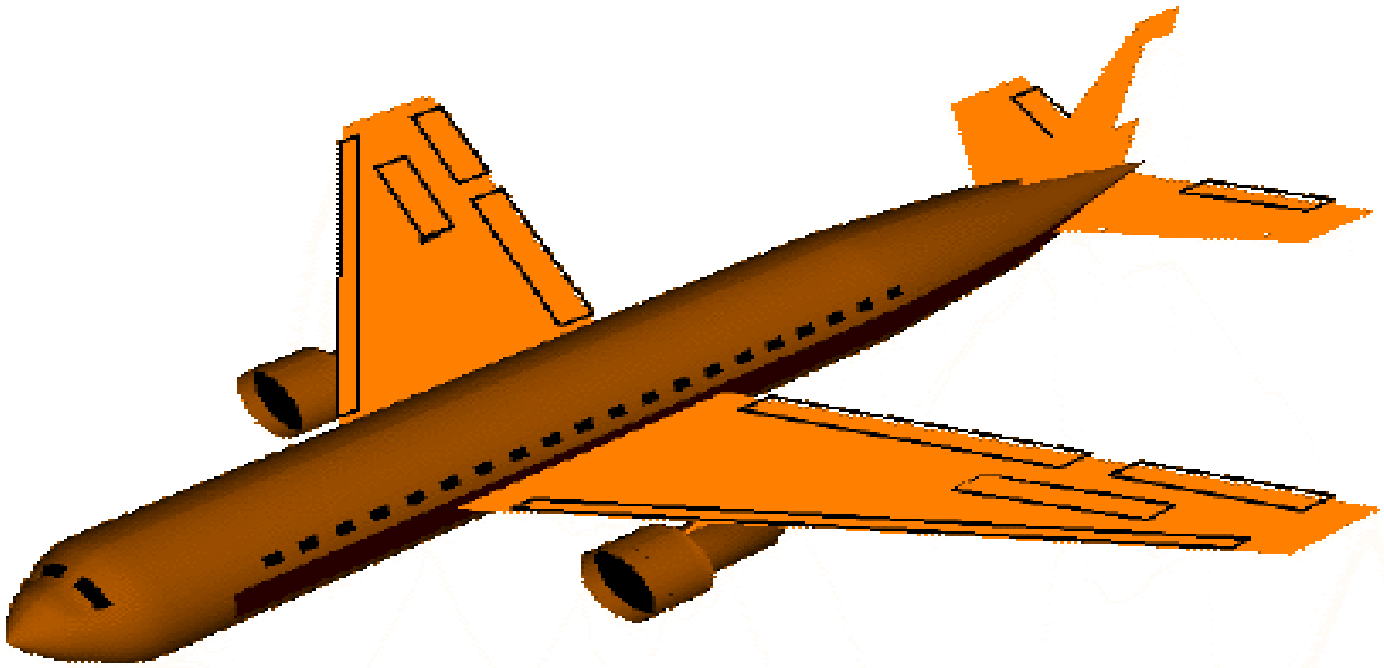
Elevator ⇨ Pitch



Rudder ⇨ Yaw


Vertical Stabilizer
Side Force (F)
Resulting Motion
Rudder
Center of Gravity
Distance (L)

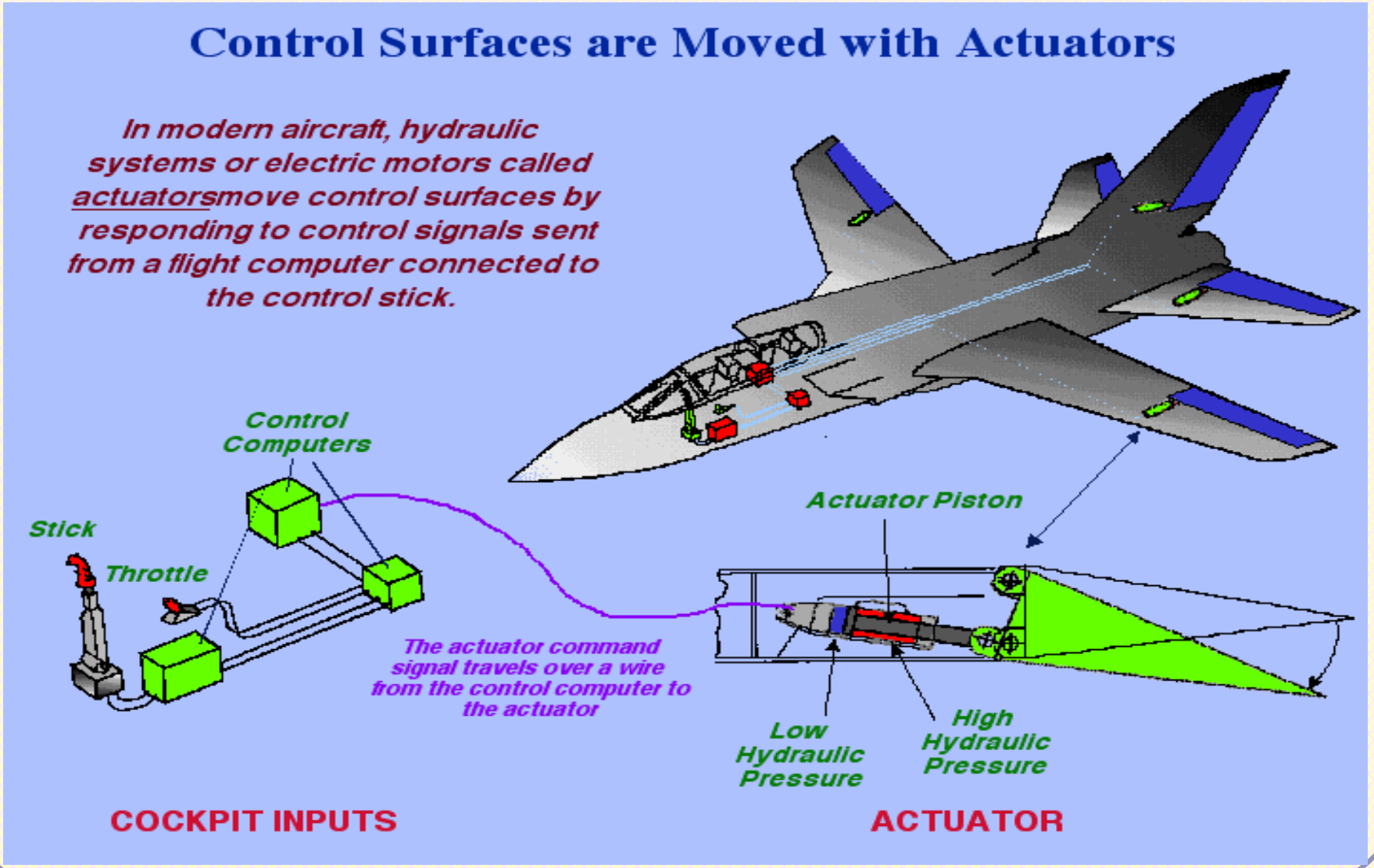
Rudder ⇨ Yaw



Sensors

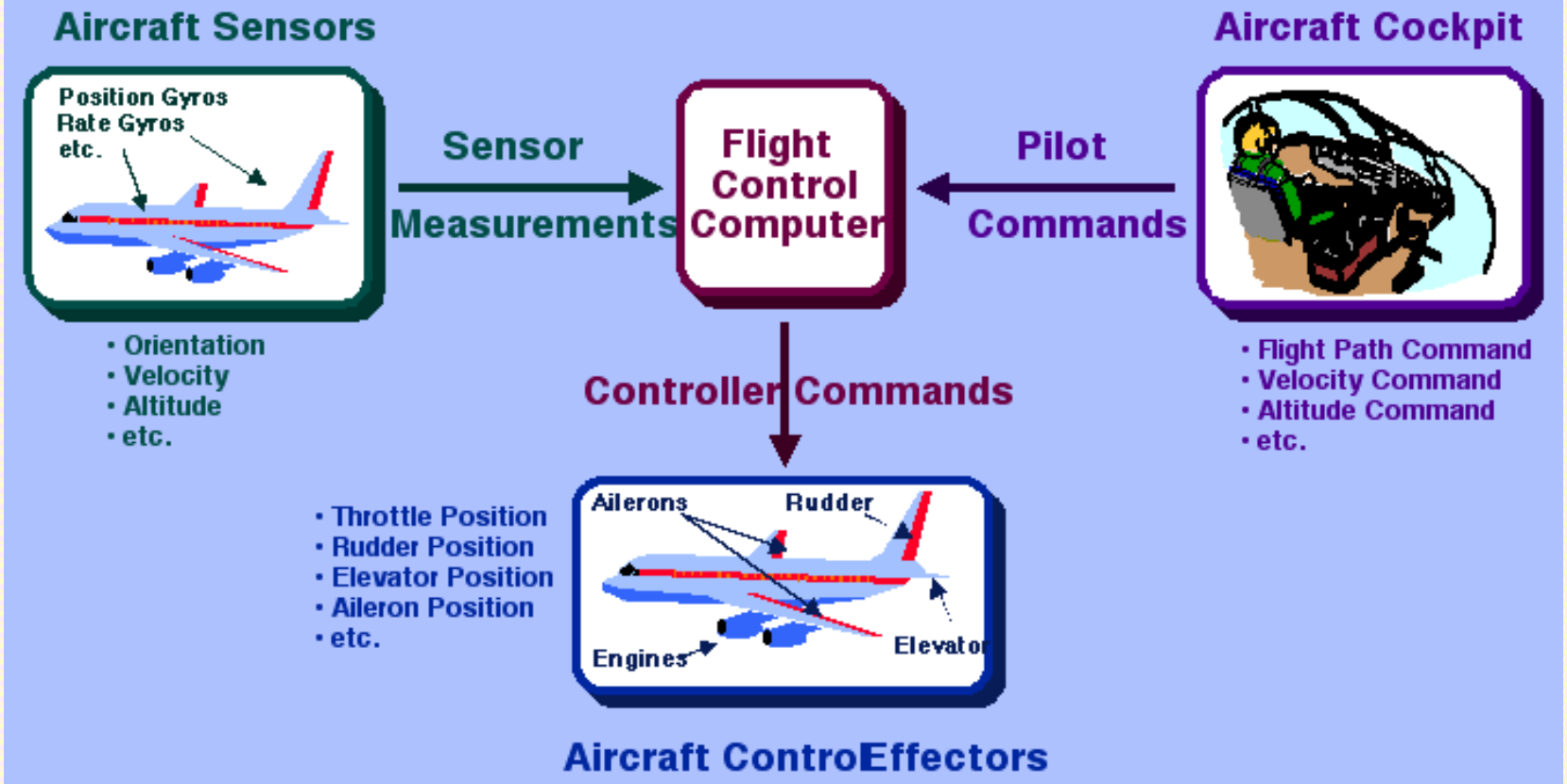
- **Altimeter:** Height above sea level
- **Air Data System:** Airspeed, Angle of Attack, Mach No., Air Temperature etc.
- **Magnetometer:** Heading
- **Accelerometers:** Translational motion of the aircraft in the three axes
- **Gyroscopes:** Rotational motion of the aircraft in the three axes
- **GPS:** Accurate position, ground speed

Actuators


Control Surfaces are Moved with Actuators
In modern aircraft, hydraulic systems or electric motors called actuatorsmove control surfaces by responding to control signals sent from a flight computer connected to the control stick.
Control Computers
Stick
Throttle
The actuator command signal travels over a wire from the control computer to the actuator
Actuator Piston
Low Hydraulic Pressure
High Hydraulic Pressure
COCKPIT INPUTS
ACTUATOR

"Putting it All Together"

Flight Control System



Thanks for the Attention...!