Introduction to Aerospace Engineering

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10 capsules

Capsule 01 : Basic Fundas
Lec 1 - Nomenclature of aircraft components
Lec 2 - Atmosphere and its properties.

Capsule 02 : Fluid Mechanics I
Lec 3 - Streamline + steady flow + incompressible flo
Lec 4 - Bernoulli's Eq + Coanda effect + Mach no

Capsule 03 : Fluid Mechanics II
Lec 5 - Reynold's No + Boundary Layer
Lec 6 - Laminar & Turbulent flow + Pressure and speed measurement.

Capsule 04 : Lec 7 - Airfoils
Lec 8 - Lift Generation + C_p and C_L calc.

Capsule 05 : Lec 9 - Critical mach no + Wave drag + Swept wings.
Lec 10 - Finite wings + induced Drags.

Capsule 06 : Lec 11 - Types of Propulsive systems
Lec 12 - Steady level flight + altitude effects.

Capsule 07 : 13 - Ceilings + Steady climbing Flight.
Lec 14 - sustained level turn + Pull up maneuver

Capsule 08 : Lec 15 - Range and Endurance
Lec 16 - Takeoff and landing

Capsule 09 : Lec 17 - Energy methods
Lec 18 - V-n diagram

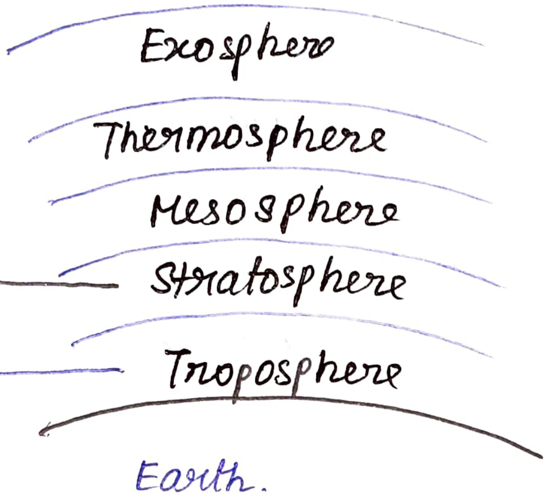
Capsule 10 : Lec 19 - Longitudinal static stability
Lec 20 - Control systems and neutral point.

Introduction to Flight

Standard Atmosphere

Atmosphere is formed of various layers

Each layer → different properties



Lowest layer.
Temp ↓ with altitude linearly
Air is heated from ground up.

Temp ↑ with altitude due to ozone layer. (25 km altitude)
Ozone absorbs and retains heat

- **Mesosphere** – coldest (−90°C)
  most meteors burn up here.
- **Thermosphere** – high temp – ~~10~~1500°C
- **Ionosphere** – due to high temp, molecules gets ionized.
- **Exosphere** – outermost.

O_2 – 21% N_2 – 78% Others 1%

Aerospace vehicles

- Atmospheric < 100km
- Space > 100km.

[most fly at
30k – 42k feet
9k to 12k km.]

International Standard Atmosphere (ISA)

- **Need** – Aircraft performance depends on atmosphere.

ex – mach 1.7 can be achieved in Russia at 10km altitude easily with Mig-27 but not in India.

So we need some normalisation

To relate: flight test
wind tunnel results
A/C design & performance
to a common reference.

Real atm properties → ~~constant~~

ISA → hypothetical model

Altitudes – 6 types:

- Geometric
- Absolute
- Geopotential
- Pressure
- Temperature
- Density

Indicated altitude - what pilot reads.

1) True/Geometric Altitude

→ from Mean Sea Level.
→ if no info given, its geometric alt
→ MSL can be diff at diff place.

2) Absolute Altitude

→ from center of earth.

$$\boxed{\underbrace{h_a}_{\text{abs alt}} = \underbrace{h_g}_{\text{geo alt}} + \underbrace{r}_{\text{radius of earth}}}$$

earth - not symmetric but oblate spheroid.

3) Geopotential altitude

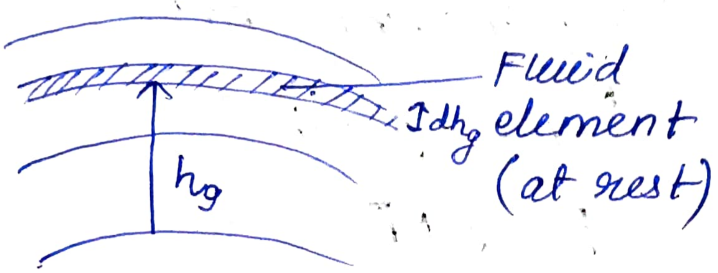
→ ~~zero pot~~ considering variation of gravity.

$$\boxed{h = \frac{r \times h_g}{r + h_g}}$$

$$\boxed{g = g_0 \left(\frac{r}{h_a}\right)^2 = g_0 \left(\frac{r}{r + h_g}\right)^2}$$

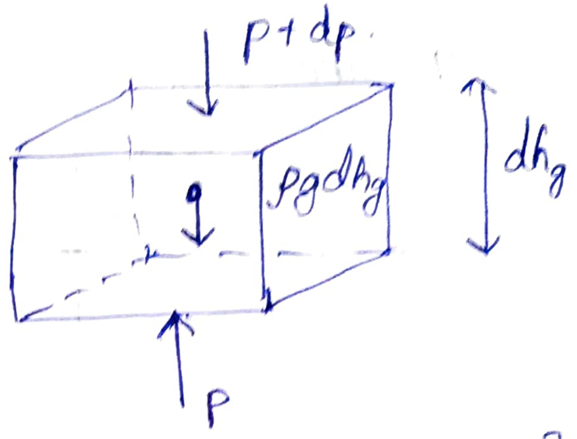
→ only considered for space vehicles.

▸ Hydrostatic Equation



Balancing the force,

$$[\, p = p + dp + \rho g\, dh_g \,]$$



$$\boxed{dp = -\rho g\, dh_g}$$

$$\left[\begin{array}{l} h_g \rightarrow +ve \\ p \rightarrow \downarrow \end{array}\right]$$

▸ Variation of parameters with altitude.

→ density, Temp, Pressure, viscosity.

Troposphere - Temp ↓ linearly from 288 - 212 K.

Pressure ↓ (non linearly). due to change in ρ.

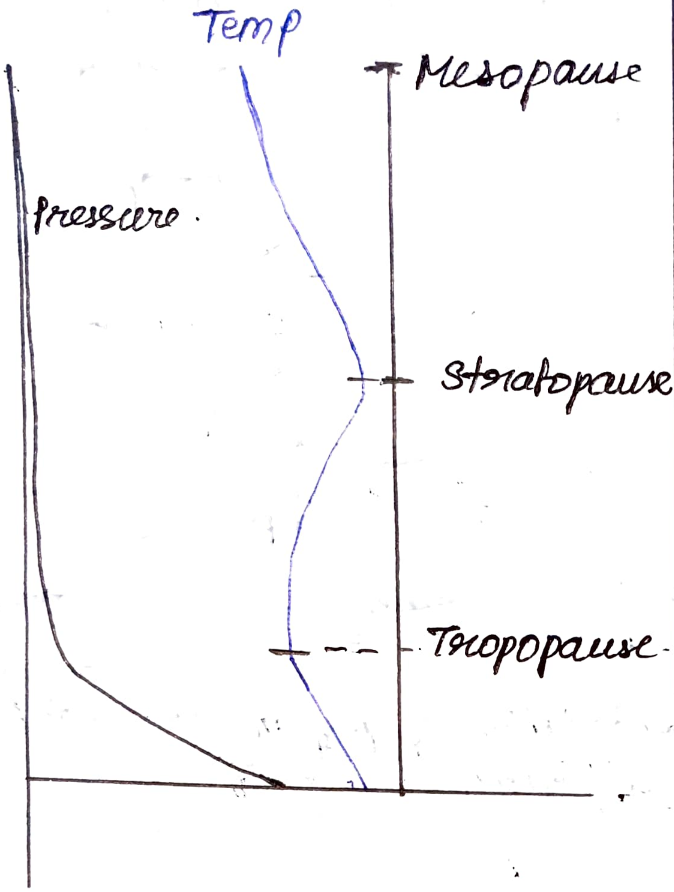
Stratosphere. - ~~Temp almost constant~~.

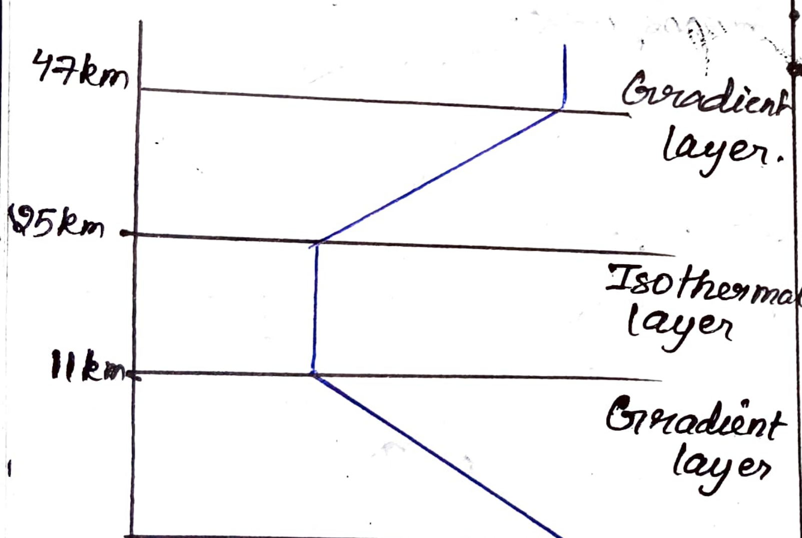
Pressure ↓. but rate of reduction decreases.

Temp first remains constant but then starts ↑.

After Stratopause

Temp starts ↓.
Pressure ↓.





0 – 11 km : $L = \frac{dT}{dh} = -6.5\ K/km$

11 – 25 km : $L = \frac{dT}{dh} = 0$

25 – 47 km : $L = \frac{dT}{dh} = 3\ K/km$

Pressure and Density variation with altitude

$$\boxed{\frac{P_1}{P_2} = e^{-(g_0/RT)(h_2-h_1)}}$$

$$\boxed{\frac{\rho_1}{\rho_2} = e^{-(g_0/RT)(h_2-h_1)}}$$

$$\cancel{\frac{P_1}{P_2} = \left(\frac{T_1}{T_2}\right)^{5.658}} \qquad \cancel{\frac{\rho_1}{\rho_2} = \left(\frac{T_1}{T_2}\right)^{4.658}}$$

Isothermal Region.

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{-\frac{g_0}{LR}}$$

$$\frac{\rho_2}{\rho_1} = \left(\frac{T_2}{T_1}\right)^{-\left(\frac{g_0}{LR}+1\right)}$$

Gradient layer

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{5.658} \qquad \frac{\rho_2}{\rho_1} = \left(\frac{T_2}{T_1}\right)^{4.658}$$

Two magical eqn.

$$\boxed{\begin{aligned} dp &= -\rho g\, dh \\ p &= \rho R T \end{aligned}}$$

▷ Viscosity

Sutherland's Formula

$$\boxed{\mu = \mu_0 \left(\frac{T}{T_0}\right)^{1.5} \left(\frac{T_0 + 110.4\,K}{T + 110.4\,K}\right)}$$

$\mu_0 = 1.716 \times 10^{-5}\ kg m^{-1} s^{-1}$

$T_0 = 273.15\ K$

④ Pressure Altitude :

if aircraft is at height h where ambient pressure is P the height where pressure acc to ISA is P is called pressure alt. (for pilot)

⑤ Density Altitude :

Density of air ~~at~~ is 1.2256 kgm^{-3} at sea level. where density alt is 0.

(for airports)

It is pressure alt corrected for non-standard temp.

⑥ Temp Altitude :

Alt corresponding to temp values in ISA table.

In cold weather, the indicated altitude may we ~~to~~ higher than true altitude.

India → Indian Reference Atmosphere.

very hot climate - ~~Arctic~~ Tropical maximum +65°C

very cold climate → Arctic minimum -75°C

▶ Weather Effects

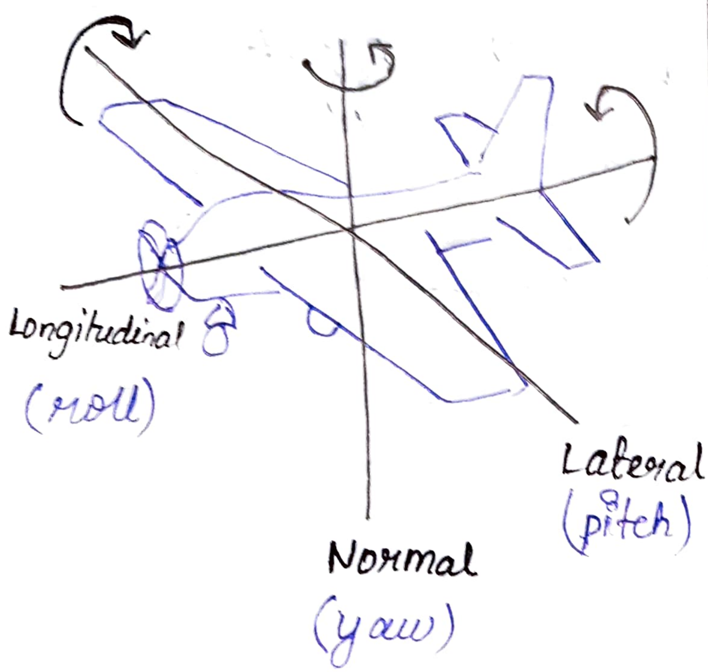
Rain

Wind

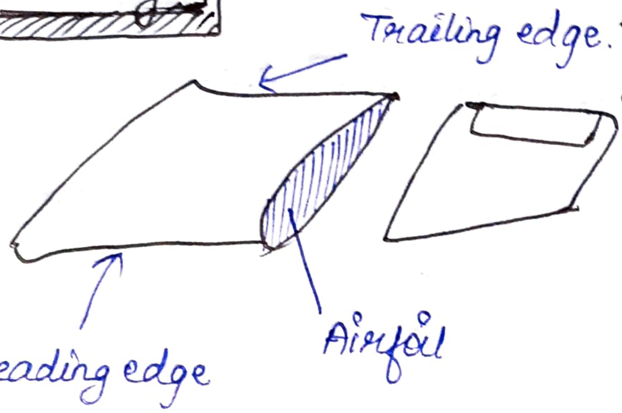
Turbulence.

▶ Aircraft Component Nomenclature

▶ Axes of movement.



▶ The wing



▷ Flight control Surfaces

specialized aerodynamic devices

• High lift devices - increases lift.

① Ailerons

Both ailerons work together but in opposite sense.
one goes up, other goes down.

The aileron which goes down → generates more lift.

Both ailerons together generate a moment which overcomes roll inertia.

→ Ailerons sometimes split into inboard and outboard.
due to stress consideration.

inboard - small moment arm
outboard - large moment arm.

- for split roll - ~~to~~ deflect both
- for high speed roll - only outboard
- for low speed roll - only inboard

Ailerons: Location - outer trailing edge
Function - roll control.

② Flaps

Location - trailing edge inboard to ailerons.

Function - higher lift at low speeds.

Two types - outboard & inboard
(∵ actuators which deflect them need lot of power).

Types of flaps:

a) Simple (Hinged) Plain Flap.

→ 20% of inboard section is hinged.

b) Split Flaps:

→ splitting last 20% of wing forms this flap.

→ top surface - stationary
lower surface - lowers.

c) Fowler Flaps

→ sophisticated wing area ↑
camber ↑

d) Slotted flaps

→ air gaps present.

simple split Fowler

slotted

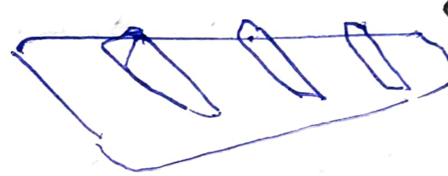
- Ailerons + Flap → Flaperon
- Spoilers - Drag ↑ Lift ↓
fully deployed on landing.

Leading edge devices

nacelle - covering of engine.
↳ it is not circular rather elliptical to increase ground clearance despite being aerodynamically ~~bad~~ worse.

- Slats (Fixed type)

- Retractable Slats
can be retracted to reduce drag.
- Krueger Flaps → b/w fuselage and closest engine
- Flap track fairings



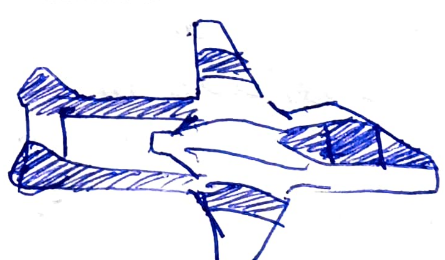
- ~~Airbreaks~~ Airbrakes
many fighter aircrafts have airbrakes behind the cockpit.

The Fuselage

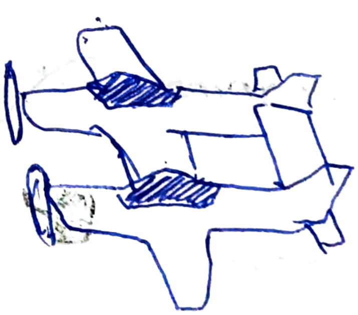
Types:

① Conventional:

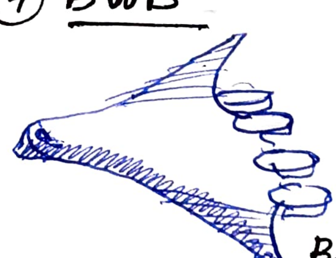
② Twin boom



③ Twin fuselage



④ BWB



Blended wing body

⊙ APU - auxiliary power unit

→ gas turbine engines,
→ provide power for ground operation.
→ runs accessories and systems when engines are shutdown
→ provide power to start main engine.

when main engines → fail
APU → fail

then RAT → Ram Air Turbine

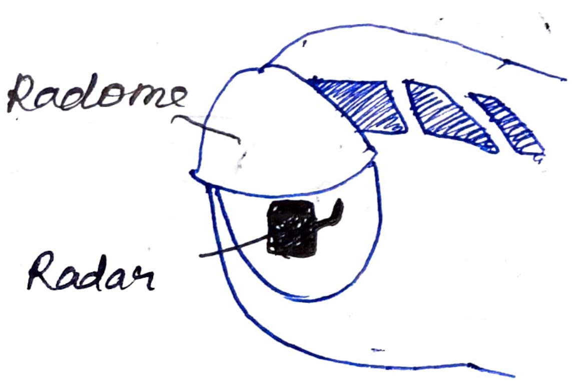
→ generates power from ~~ram~~ ram pressure of airstream.
→ in emergency.

⊙ **Tail Skid Device**

avoid rubbing of fuselage to ground.

⊙ **Radome** → Radar Dome.

- weather proof antenna closure.
- minimal attenuation
- rotating antenna concealed.
- Radar transparent material.



⊙ **Horizontal Stabilizers**

→ partially or fully moving
→ allows longitudinal balance.

~~Canard~~

- conventional
- canard config → closed couple → lifting → control
- Three surface configuration

⊙ **Elevator.**

controls pitch.

- trim tabs - reduces hinge moment required to operate the stabilizer

→ reduces force on control yoke.

⊙ **Vertical Stabilizer**

→ provide directional stability.

→ movable rudder controls yaw.

- Conventional
- T Tail config
- Twin tail
- V tail
- Triple Tail

⊙ **Ventral Fin**

rear underside of fuselage.

improves responsiveness towards rolling.

⊙ Podded Engines
- underwing mounted - attached to undersurface of wing.
- pylons used for attachement
- overwing mounted.
- overfuselage mounted.

The Essentials of Incompressible Flow

Basic Fluid Kinematics.
- euler vs Lagrange approach
- material derivative concept
- steady and uniform flow

Lagrangian measurement
→ when we focus on 'one' moving particle in a fluid.

→ identifying and tracking a particular fluid element.

→ Properties of the element → $f(t)$

$\vec{R}_{particle}$ = position vector

$$\vec{V}_{particle}(t) = \frac{d\vec{R}_{particle}(t)}{dt}$$

$$\vec{a}_{particle}(t) = \frac{d\vec{V}_{particle}(t)}{dt}$$

→ physical implications.

Eulerian measurement
→ when we fix ourself at a point ~~at~~

→ Observe the motion at that point.

→ Observing a spatial point or region.

→ Properties ↔ field functions of space & time.

[If a function is determinable at any arbitrary point in a field it is called a field function]

ex) velocity field can be written as:

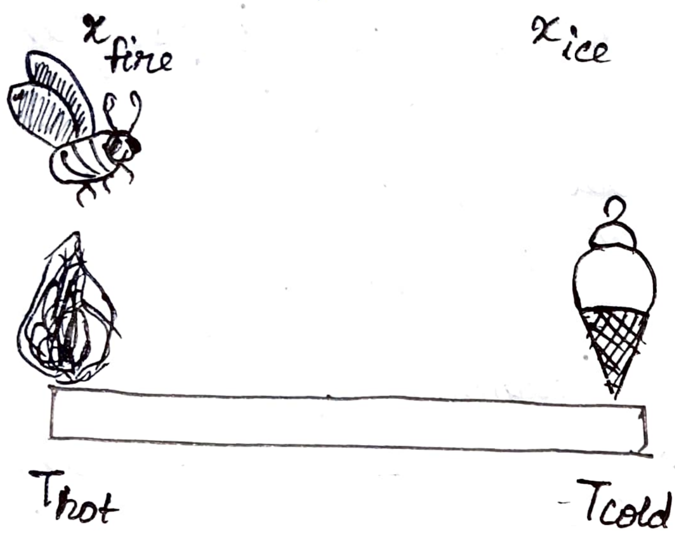
$$\vec{V} = \vec{V}(x, y, z, t)$$

for ex →

$$\vec{V}(x=3, y=1, z=5, t=3.5) = 2\hat{i} + 9\hat{j} + 7\hat{k}$$

It means, at time $t = 3.5$ particle is at $(3,1,5)$ and has a velocity of $2\hat{i}+9\hat{j}+7\hat{k}$

Experiment ~~put~~



We put a thermometer on bumblebee. which moves from hot to cold.

→ lagrangian approach
⇒ T changes for fly due to its motion

→ Rate of T change ↑
if 1) speed ↑
2) Temp gradient ↑

$$\boxed{\underbrace{\frac{dT}{dt}}_{\text{Rate of Temperature change}} = \underbrace{\frac{dT}{dx}}_{\text{Temperature gradient}} \times \underbrace{V_{fly}}_{\text{Speed of fly}}}$$

Temperature is a function of both position and time

$$\boxed{T = T(x,t)}$$

By total derivative theorem

$$T = T(x,t)$$

$$\cancel{DT}\ \therefore \boxed{\frac{dT}{dt} = \frac{\partial T}{\partial x}\cdot\frac{dx}{dt} + \frac{\partial T}{\partial t}\cdot\frac{dt}{dt}}$$

$$\boxed{\frac{dT}{dt} = \frac{\partial T}{\partial x}\cdot V + \frac{\partial T}{\partial t}}$$ for one dimension

For 3 dimensions:

$$\boxed{\frac{dT}{dt} = \frac{\partial T}{\partial t} + \vec{V}\cdot\nabla T}$$

$$\boxed{\nabla T = \frac{\partial T}{\partial x}\hat{i} + \frac{\partial T}{\partial y}\hat{j} + \frac{\partial T}{\partial z}\hat{k}}$$

For any field function f,

$$\boxed{\frac{df}{dt} = \frac{\partial f}{\partial t} + \vec{V}\,\nabla f}$$

- Total/ material/ Lagrangian derivative → It tells how quickly f changes for the moving element
- Local/ eulerian derivative → It tells how quickly f changes at a particular point in space
- Transport derivative → It tells how ~~then~~ quickly f changes by virtue of element motion.

Q) What is incompressible flow?

density = constant ?

$\frac{\partial \rho}{\partial t} = 0$?

Fluid → incompressible ?

Total derivative.

$$\boxed{\frac{d\rho}{dt} = 0} \rightarrow \text{incompressible flow.}$$

Continuity Equation.

$$\boxed{\frac{d\rho}{dt} + \rho(\nabla . \vec{V}) = 0} \quad \text{— (1)}$$

Consider a flow for which, $\frac{d\rho}{dt} = 0$.

Then eq (1) becomes

$\Rightarrow \rho(\nabla . \vec{V}) = 0$

$\Rightarrow \boxed{\nabla . \vec{V} = 0} \quad [\because \rho \neq 0]$

$\nabla . \vec{V} \equiv$ volumetric strain rate.

time rate of change of volume δQ of a moving fluid element per unit volume.

$$\nabla . \vec{V} = \frac{1}{\delta Q} . \frac{d(\delta Q)}{dt}$$

ρ = constant → incompressible fluid

$\frac{d\rho}{dt}$ = constant → incompressible flow

(*) Compressible fluids can undergo incompressible flow

▶ Flow Visualization

tools:
- streamlines
- streaklines
- pathlines
- timelines

Streamline - curve tangent everywhere to the instantaneous local velocity vector.

→ eulerian concept

→ can change with time

→ never intersect.