



Fluid Mechanics CEE 3311
LECTURES 6 & 7



Fluids in motion

L. Handia



Fluid kinematics

Refers to features of fluid in motion.

Description of fluid motion

Lagrangian and Eulerian descriptions of motion

Lagrangian – in the study of particle mechanics, where attention is focused on an individual particle, the **particle is observed** as a function of time.

➤ Its *position, velocity* and *acceleration* are listed and quantities of interest can be *calculated*.

➤ In the Lagrangian description *many particles* can be followed and their *influence on one another* noted.



Description of fluid motion

Eulerian – an alternative to following each fluid particle separately is to *identify a point in space* and then observe the velocity of *particles passing the point*; we can observe the rate of change of velocity as particles pass the point and we can observe if the velocity is *changing with time at that particular point*.

➤ Flow properties such as velocity are a function of both space and time. The region of flow that is being considered is called a *flow field*.



Description of fluid motion

Example.

An example may clarify these two ways of describing motion. An engineering firm is hired to make recommendations that would improve the traffic flow in a large city. The engineering firm has two alternatives: Hire college students to travel in automobiles throughout the city recording the appropriate observations (the Lagrangian approach), or hire college students to stand at the intersections and record the required information (the Eulerian approach). A correct interpretation of each set of data would lead to the same set of recommendations, that is, the same solution. In this example it may not be obvious which approach would be preferred; in fluids, however, the Eulerian description is used exclusively since the physical laws using the Eulerian description are easier to apply to actual situations.

In fluids the Eulerian description is used exclusively since the physical laws using the Eulerian description are easier to apply to actual situations.

Description of fluid motion

Pathlines, streaklines and streamlines

Three different lines help us in describing a flow field

1. Pathlines
2. Streaklines
3. Streamlines

Description of fluid motion

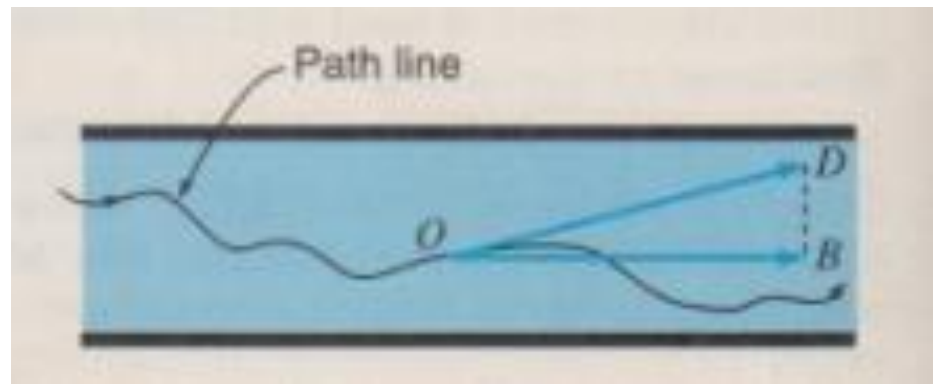
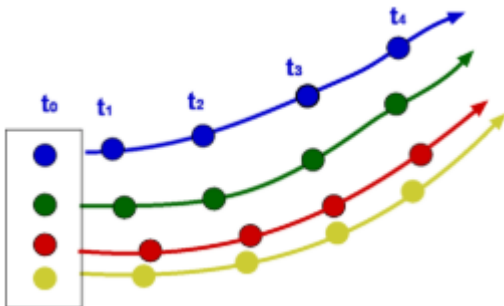
Pathlines, streaklines and streamlines

Pathline:

Definition 1: is the trace made by a single particle over a period of time. The pathline shows the direction of the velocity of the particle at successive instants of time.

Definition 2: is the locus of points traversed by a given particle as it travels in a field of flow; the pathline provides us with a “history” of the particle’s locations.

Definition 3: **Pathline is the line traced by a given particle.** This is generated by injecting a dye into the fluid and following its path by photography or other means

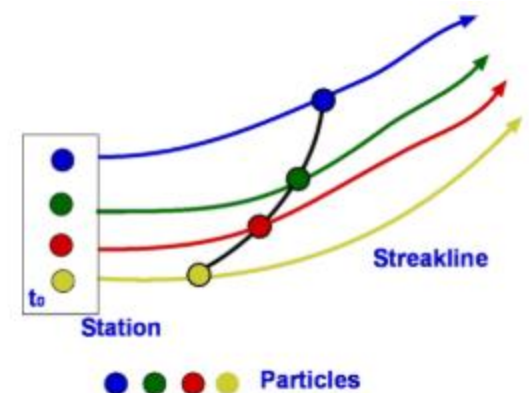
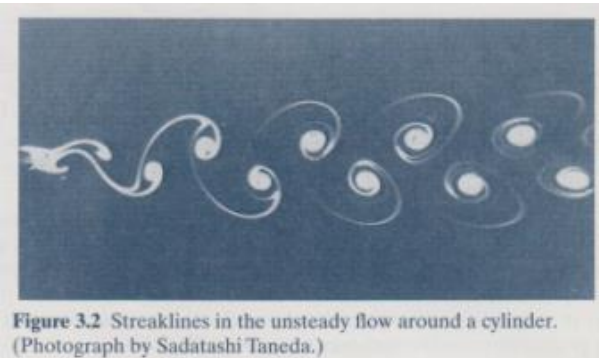


Description of fluid motion

Pathlines, streaklines and streamlines

Streakline: is defined as an instantaneous line whose points are occupied by all particles originating from specified point in the flow field. **Streaklines tell us where the particles are “right now”**.

Streakline concentrates on fluid particles that have gone through a fixed station or point. At some instant of time the position of all these particles are marked and a line is drawn through them. Such a line is called a streakline

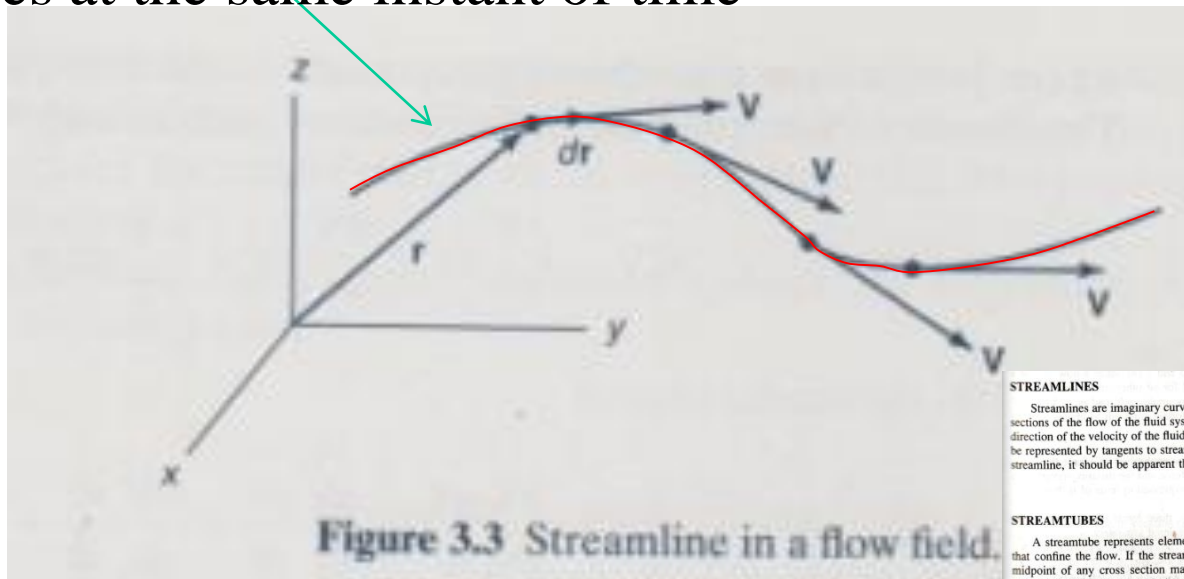


Description of fluid motion

Pathlines, streaklines and streamlines

1. **Streamline:** is a line in the flow possessing the following property: the velocity vector of each particle occupying a point on the streamline is tangent to the streamline.
2. A streamline is one that drawn is tangential to the velocity vector at every point in the flow at a given instant

Streamlines show the mean direction of a number of particles at the same instant of time



Description of fluid motion

Pathlines, streaklines and streamlines

In a steady flow the streamline, pathline and streakline all coincide. In an unsteady flow they can be different.

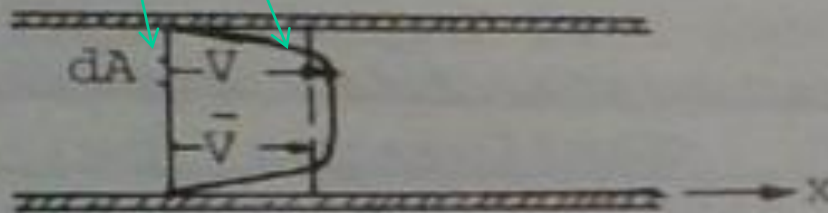
Description of fluid motion

Discharge

- Lecture handbook pp28

The discharge Q refers to the total quantity of fluid passing a given section in unit time. The velocity, in general, is variable across the section through which it flows, such as in Fig. 4.5. Then the rate of flow, discharge, past a differential area dA of the section is $V \cdot dA$, and the total rate of flow Q is obtained by integration over the entire flow section.

$$Q = \int_A V \cdot dA \quad (4.1)$$



actual velocity V
mean velocity $\bar{V} = \frac{1}{A} \cdot \int_A V \cdot dA$

Fig. 4.5 Flow between parallel plates

Description of fluid motion

Discharge

In this example the cross-sectional area was oriented normal to the velocity vector. If other orientations are considered, such as in Fig. 4.6, where flow occurs past section A-A, it can be seen that only the normal component of the velocity, the x-component in this case, contributes to flow through the section.

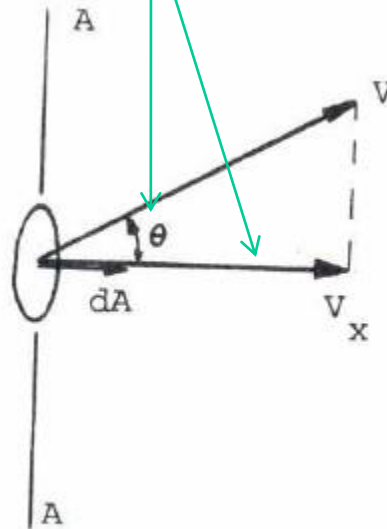


Fig. 4.6 Velocity not normal to the section

Description of fluid motion

Discharge

In formula

$$Q = \int_A \mathbf{V}_x \cdot d\mathbf{A} = \int_A V \cos \theta \cdot dA \quad (4.2)$$

Hence, always consider the area of a section which is normal to the total velocity or consider a velocity component which is normal to the given area.

The **mean** or **average velocity** is defined as the discharge divided by the total cross-sectional area

$$\bar{V} = Q/A$$

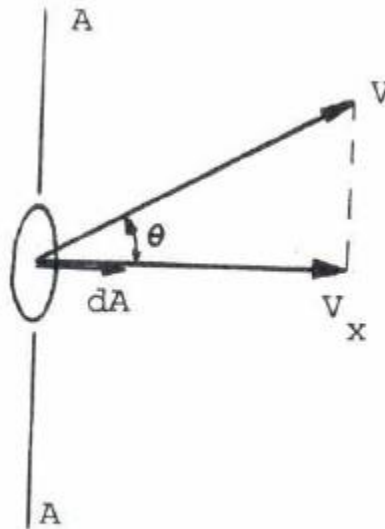


Fig. 4.6 Velocity not normal to the section

Classification of fluid motion

A. One-, Two- and Three Dimensional Flows

- In the Eulerian description of motion the velocity, in general, depends on three *space variables* and time. Such a flow is a three dimensional flow.
- A two dimensional flow is a flow in which the velocity vector depends on only two spatial variables.
- A one dimensional flow is a flow in which the velocity vector depends on only one space variable.

Classification of fluid motion

B. Ideal and real fluids

1. *Ideal fluids* $\tau = \mu \frac{du}{dy}$ $\mu = 0$

➤ An ideal fluid is assumed to have *no viscosity* and there are *no shear stresses*.

➤ There are no energy losses in the flow of an ideal fluid

2. *Real fluids* $\mu \neq 0$, therefore *friction* exists.

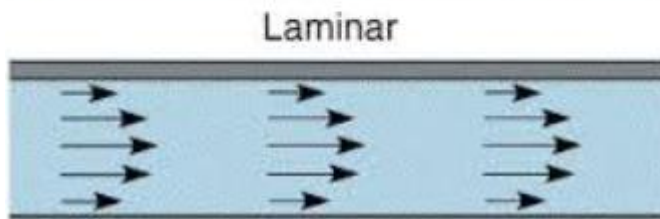
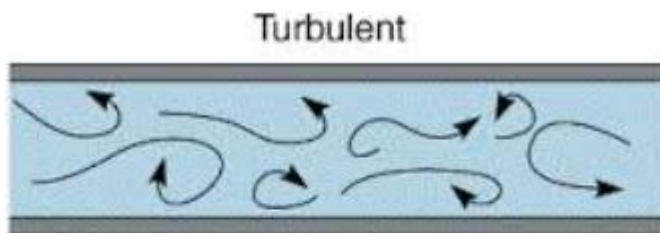
These are real fluids with *energy losses* resulting from flows. Real fluids are also *compressible* although in some fluids the compressibility may be negligible for particular purpose.

Classification of fluid motion

C. Laminar and turbulent flows

Laminar \Rightarrow the fluid flows with *no significant mixing* of neighbouring fluid particles. Laminar is derived from laminate; the fluid appears to move by the sliding of laminations of *infinitesimal* thickness over adjacent layers, with relative motion of fluid particles occurring at a molecular scale. Viscous shear stresses *always* influence a laminar flow.

Turbulent flow \Rightarrow fluid motion varies *irregularly* so that quantities such as velocity and pressure show a *random variation* with time and space coordinates.



Classification of fluid motion

Classification between laminar and turbulent flow is defined by the Reynold number.

$$\text{Re} = \frac{VL}{\nu} = \frac{\textit{inertial force}}{\textit{viscous force}}$$

where V is velocity, L characteristics length and ν is the kinematic viscosity.

The Reynolds number is one of the most important parameters in hydro-mechanics.

Very small Reynolds numbers characterise by definition flows in which the viscous forces dominate and the inertial reactions are negligible.

Very high Reynolds numbers characterise flows in which finally the viscous forces become negligibly small in comparison to the inertial reactions, as for instance in fully turbulent pipe or channel flows.

Classification of fluid motion

If the Reynolds number is relatively small, the flow is laminar; if it is large the flow is turbulent.

This is more precisely stated by defining a critical Reynolds number, Re_{crit} , so that the flow is laminar if $Re < Re_{crit}$.

For example, in a flow inside a rough-walled pipe it is found that $Re_{crit} \approx 2000$. This is the minimum critical Reynolds number and is used in most engineering applications.

D. Steady flow

Conditions do not change with time at any single point

$$\frac{\partial p}{\partial t} = 0 \quad \text{where } p \text{ is any property}$$

E. Unsteady flow

$$\frac{\partial p}{\partial t} \neq 0$$

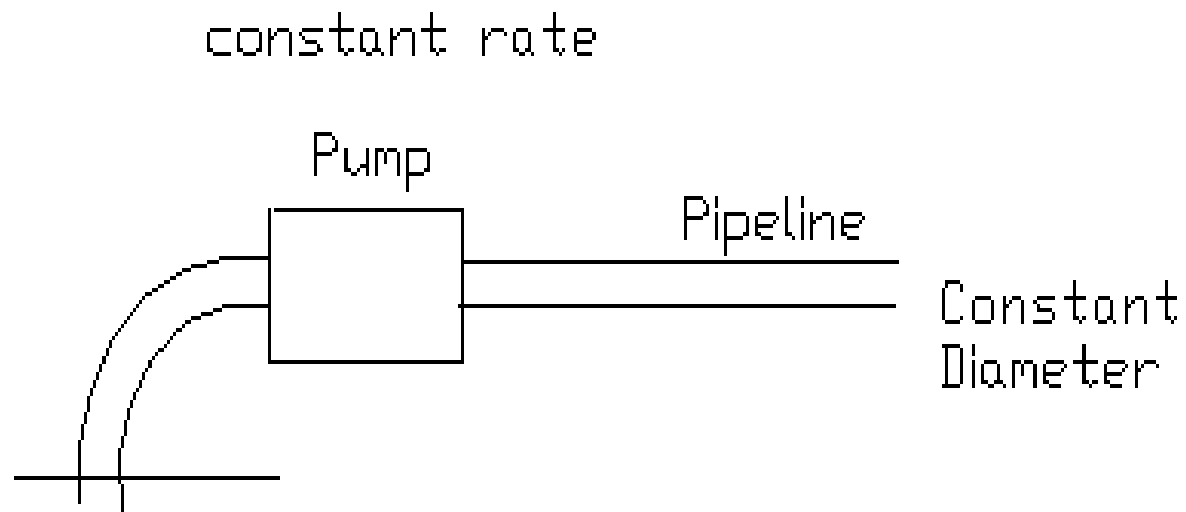
F. Uniform flow

$$\frac{\partial V}{\partial s} = 0 \quad \text{where } V = \text{velocity} \ \& \ S = \text{position}$$

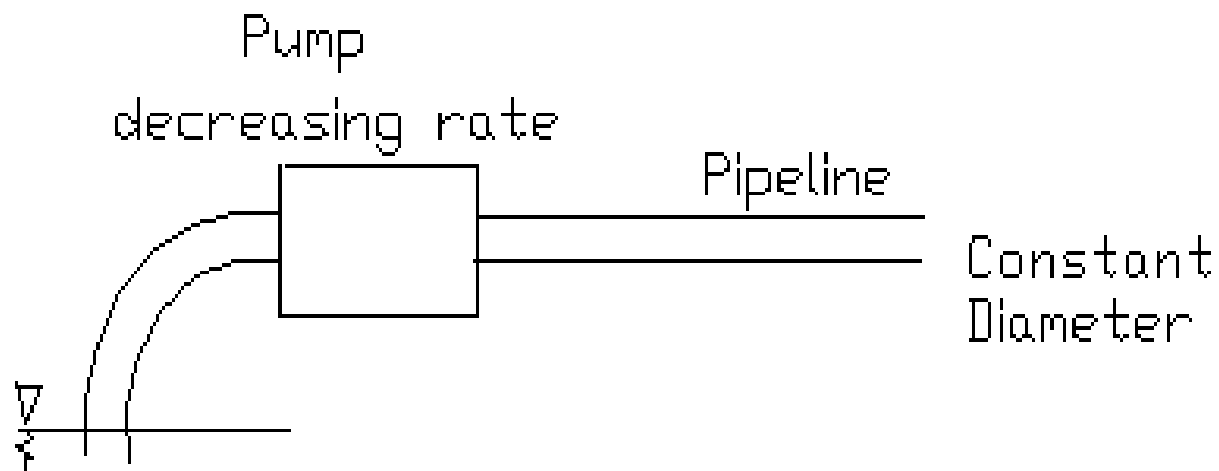
G. Non-uniform

$$\frac{\partial V}{\partial s} \neq 0$$

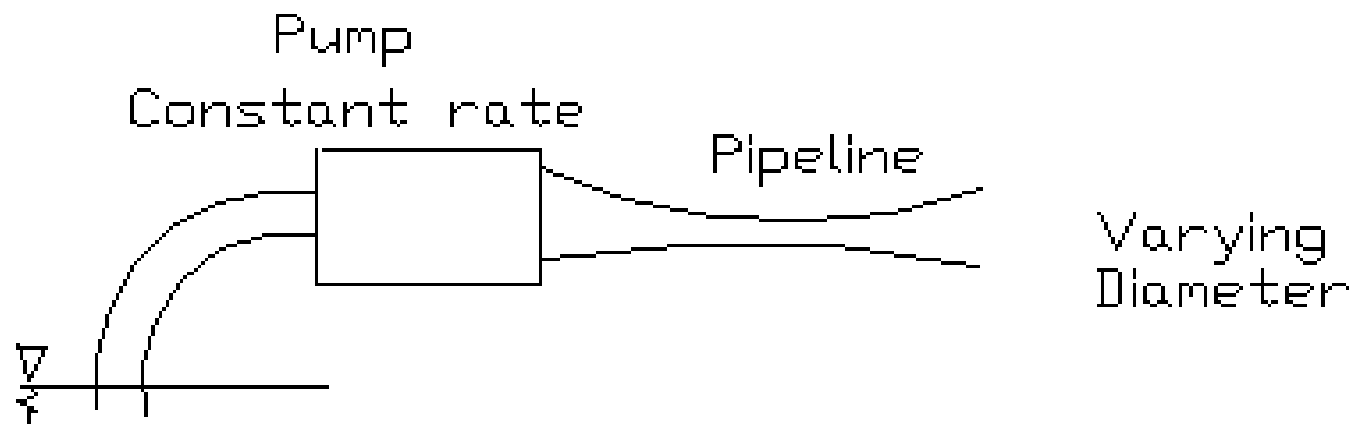
Uniform flow means that the water *cross section and depth* remain constant over a certain reach of the channel as well as over time



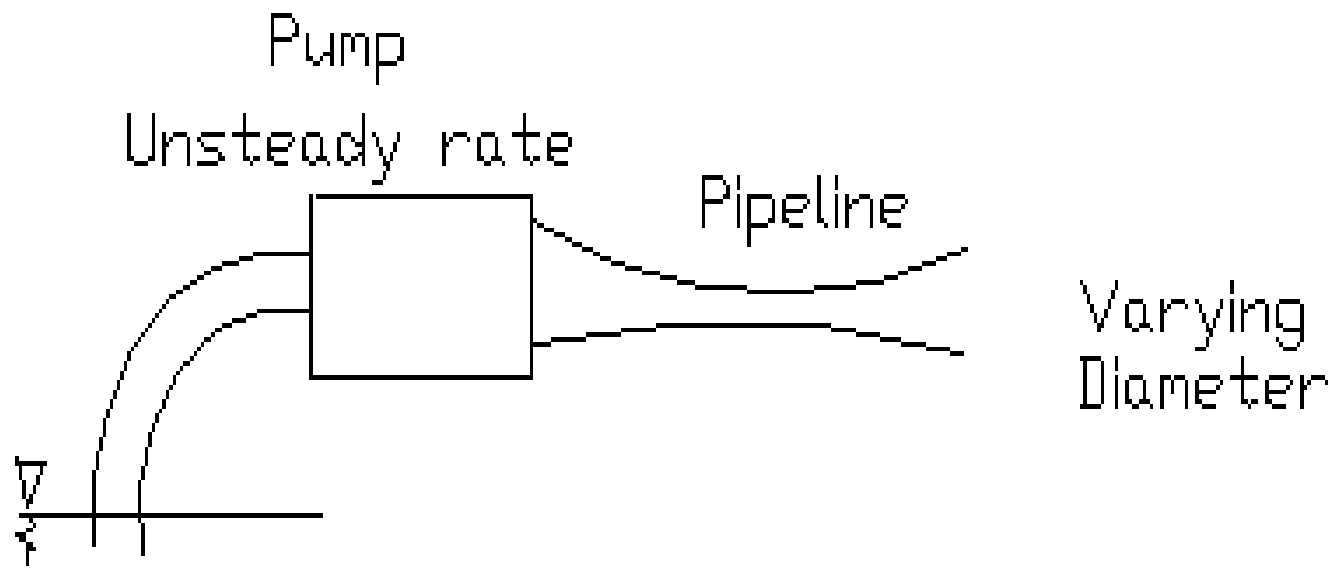
(a) Steady, Uniform



(b) Unsteady, Uniform



(c) Steady, Non-uniform



(d) Unsteady, Non-uniform

Acceleration

In general, the velocity of a fluid is a function both of position and time:

$$V_s = f(s, t)$$

in which V_s is the velocity along a streamline
 s is the position along a streamline

Over a small distance ds along a streamline the total increase of velocity dV_s is the sum of the increase due to its change of position and the increase due to passing an interval dt .

Mathematically

$$dV_s = \frac{\partial V_s}{\partial s} ds + \frac{\partial V_s}{\partial t} dt$$

Hence the acceleration a_s along the streamline is given by

$$a_s = \frac{dV_s}{dt} = \frac{\partial V_s}{\partial s} \frac{ds}{dt} + \frac{\partial V_s}{\partial t} \frac{dt}{dt} = V_s \frac{\partial V_s}{\partial s} + \frac{\partial V_s}{\partial t}$$

in which

a_s is total acceleration

$V_s \frac{\partial V_s}{\partial s}$ convective acceleration

$\frac{\partial V_s}{\partial t}$ local acceleration

➤ In a pipe, local acceleration results if, for example, a valve is being *opened or closed*; and convective acceleration occurs in the vicinity of a *change in the pipe geometry*, such as a pipe contraction or an elbow.

➤ In both cases fluid particles change speed but *for very different reasons*.

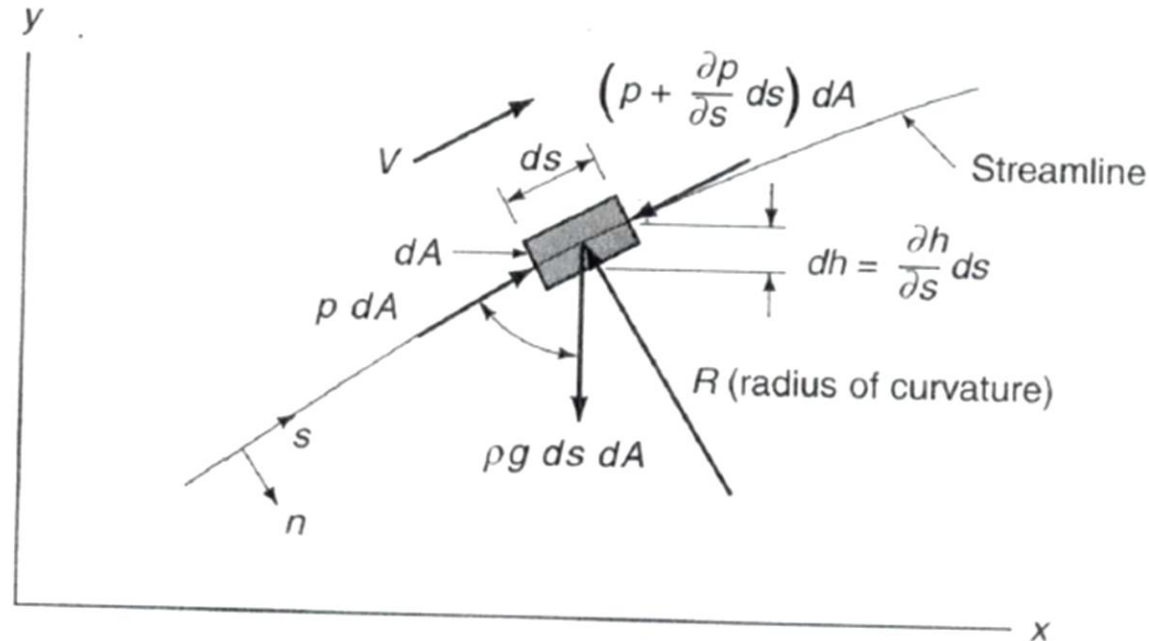
Bernoulli Equation

The Bernoulli equation is probably used more often in fluid flow applications than any other equation.

The derivation starts with the application of Newton's second law to a fluid particle. Let us use a particle positioned as shown in Fig 6.1, with length ds and cross sectional area dA .

Second law:

The [vector sum](#) of the [forces](#) F on an object is equal to the [mass](#) m of that object multiplied by the [acceleration](#) vector a of the object: $F = ma$.



Bernoulli Equation

The forces acting on the particle are pressure forces and the weight, as shown. Summing forces in the direction of motion, the s-direction, there results

Second law:

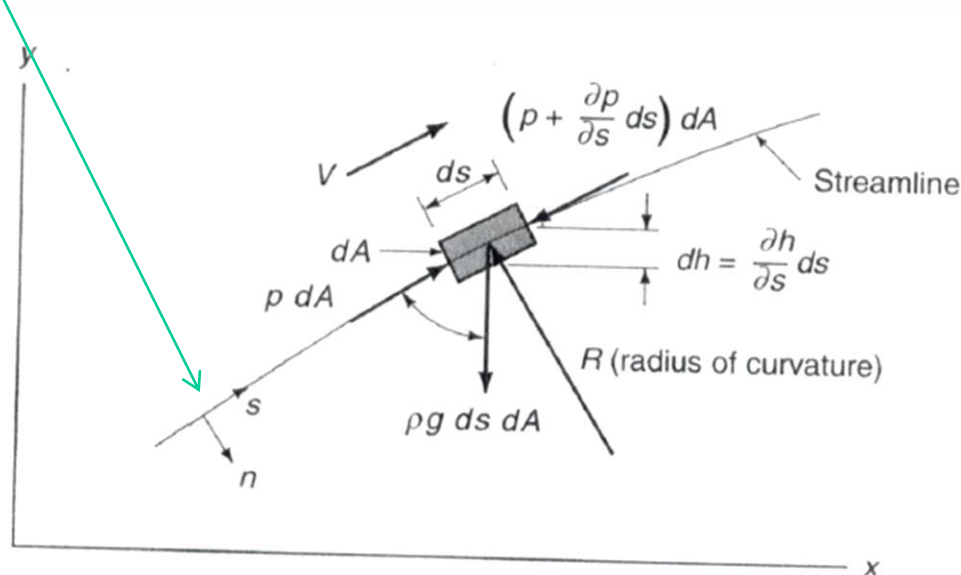
The **vector sum** of the **forces** F on an object is equal to the **mass** m of that object multiplied by the **acceleration** vector a of the object: $F = ma$.

$$p dA - \left(p + \frac{\partial p}{\partial s} ds \right) dA - \rho g ds dA \cos\theta = \rho ds dA a_s$$

where a_s is the acceleration of the particle in the s-direction. It is given by

$$a_s = V \frac{\partial V}{\partial s} + \frac{\partial V}{\partial t}$$

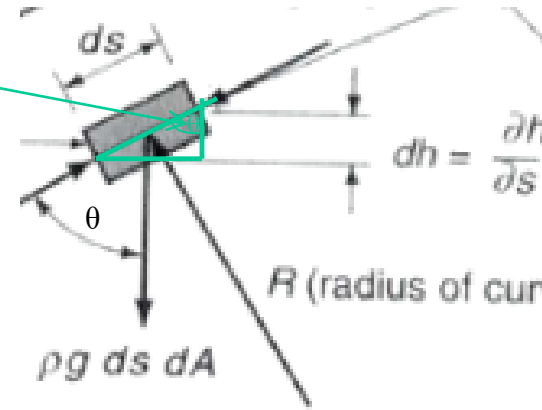
where $\frac{\partial V}{\partial t} = 0$ since we will assume steady flow. Also, we see that



so that (or since)

$$dh = ds \cos\theta = \frac{\partial h}{\partial s} ds$$

$$\cos\theta = \frac{\partial h}{\partial s}$$



$$p dA - \left(p + \frac{\partial p}{\partial s} ds \right) dA - \rho g ds dA \cos\theta = \rho ds dA a_s$$

$$p dA - \left(p + \frac{\partial p}{\partial s} ds \right) dA - \rho g ds dA \cos\theta = \rho ds dA a_s$$

$$ds dA$$

$$-\frac{\partial p}{\partial s} - \rho g \cos\theta = \rho a_s = \rho V \frac{\partial V}{\partial s} + \frac{\partial V}{\partial t}$$

$$-\frac{\partial p}{\partial s} - \rho g \cos\theta = \rho V \frac{\partial V}{\partial s} + 0 = \rho V \frac{\partial V}{\partial s}$$

Now, we assume constant density and note that $V \frac{\partial V}{\partial s} = \frac{\partial V^2/2}{\partial s}$
 i.e., ρ is the same along the streamline and through out the whole liquid

$$-\frac{\partial p}{\partial s} - \rho g \cos\theta = \rho V \frac{\partial V}{\partial s} + 0 = \rho V \frac{\partial V}{\partial s}$$

$$V \frac{\partial V}{\partial s} = \frac{\partial(V^2/2)}{\partial s} = \frac{2V}{2} \frac{\partial V}{\partial s} = V \frac{\partial V}{\partial s}$$

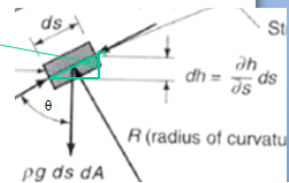
$$-\frac{\partial p}{\partial s} - \rho g \cos\theta = \rho \frac{\partial V^2/2}{\partial s}$$

with $\partial h = \partial s \cos\theta$

so that (or since)

$$dh = ds \cos\theta = \frac{\partial h}{\partial s} ds$$

$$\cos\theta = \frac{\partial h}{\partial s}$$



$$-\frac{\partial P}{\partial s} - \rho g \frac{\partial h}{\partial s} = \rho \frac{dV^2/2}{\partial s}$$

$$\frac{\partial P}{\partial s} + \rho g \frac{\partial h}{\partial s} + \rho \frac{dV^2/2}{\partial s} = 0$$

$$\frac{\partial}{\partial s} \left(P + \rho g h + \rho V^2/2 \right) = 0$$

$$\frac{\partial}{\partial s} \left(P + \rho gh + \rho V^2 / 2 \right) = 0$$

$$\frac{\partial}{\partial s} \left(\frac{P + \rho gh + \rho V^2 / 2}{\rho} \right) = 0$$

$$\frac{\partial}{\partial s} \left(\frac{V^2}{2} + \frac{p}{\rho} + gh \right) = 0$$

This is satisfied if, along a streamline

$$\frac{V^2}{2} + \frac{p}{\rho} + gh = \text{constant}$$

$$\frac{V^2}{2} + \frac{p}{\rho} + gh = \text{const}$$

or, between two points on the same streamline

$$\frac{V_1^2}{2} + \frac{p_1}{\rho} + gh_1 = \frac{V_2^2}{2} + \frac{p_2}{\rho} + gh_2$$

This is the well known **Bernoulli equation** in honour of Daniel Bernoulli (1700-1782), the Swiss physicist who presented this theorem in 1738. Note the assumptions:

Bernoulli equation

- Assumptions of the Bernoulli equation:
 - Inviscid fluid (no shear stresses-no friction). An inviscid flow is the flow of an ideal fluid
 - Steady flow ($\partial V / \partial t = 0$)
 - Along a streamline ($a_s = V \frac{\partial V}{\partial s}$)
 - Constant density ($\frac{\partial \rho}{\partial s} = 0$)

Bernoulli equation

- If the equation is divided by g , Bernoulli equation becomes

$$\frac{V_1^2}{2g} + \frac{p_1}{\rho g} + h_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho g} + h_2$$

- $\frac{p_1}{\rho g}$ is the static pressure head
- $\frac{V_1^2}{2g}$ is the dynamic pressure
- $\frac{p}{\rho g} + h$ is the piezometric head
- $\frac{V^2}{2g} + \frac{p}{\rho g}$ is the total pressure head or stagnation pressure head
- The sum of all 3 terms is the total head or energy head

Bernoulli equation

Application of the Bernoulli equation

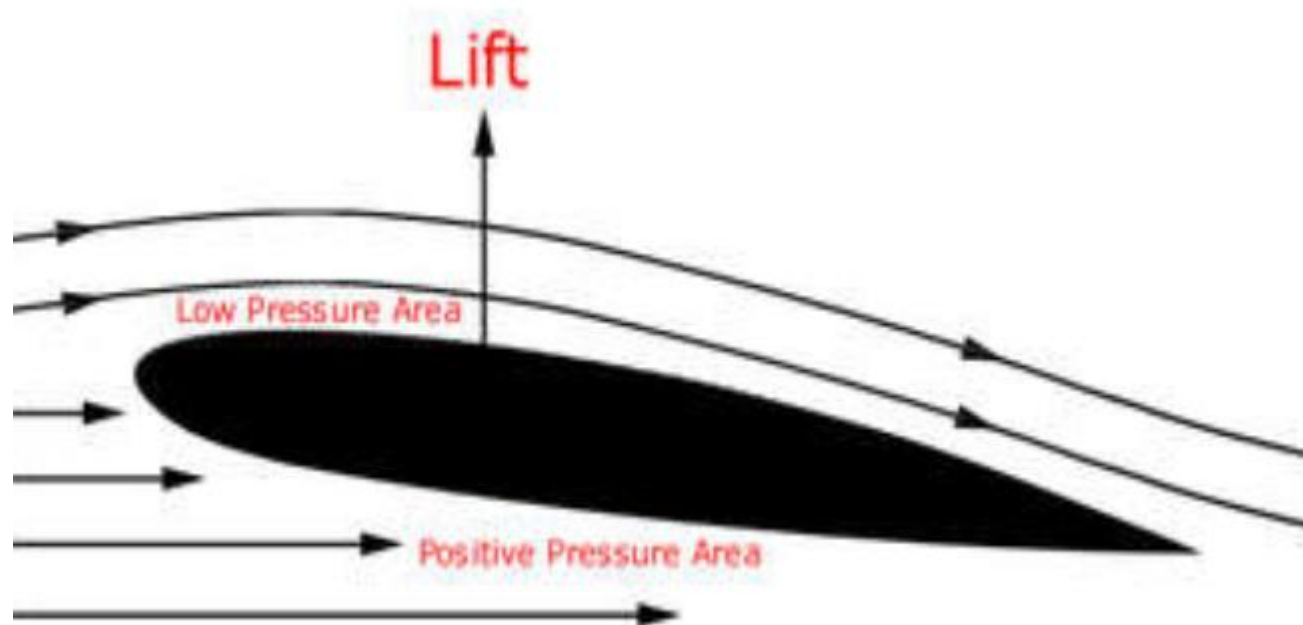
- Care must be taken never to use the equation in an unsteady flow or if viscous effects are significant. The equation is used:
 - to determine how high the water from a fireman's hose will reach



Bernoulli equation

Application of the Bernoulli equation

- to find the pressure on the surface of a low-speed airfoil (airfoil is a shape of a wing, blade or sail)



Bernoulli equation

Application of the Bernoulli equation

- to find the wind force on the window of a building
(Matthew 7:24-27)

²⁴ “Therefore everyone who hears these words of mine and puts them into practice is like a wise man who built his house on the rock. ²⁵ The rain came down, the streams rose, and the winds blew and beat against that house; yet it did not fall, because it had its foundation on the rock. ²⁶ But everyone who hears these words of mine and does not put them into practice is like a foolish man who built his house on sand. ²⁷ The rain came down, the streams rose, and the winds blew and beat against that house, and it fell with a great crash.”

(One of the primary ways windows fail in hurricanes is broken glass from wind pressure, according to Graham Architectural Products. Hurricane wind speeds range from 119km/h to above 249km/h)

Bernoulli equation

Application of the Bernoulli equation

- In internal flows over relatively short distances, e.g., flow through a contraction or flow from a plenum (air filled space that receives air from a blower for distribution)

Bernoulli equation

Application of the Bernoulli equation

1. Pitot tubes

A. Simple pitot tube

- The velocity can be measured simply by installing a simple pitot tube.

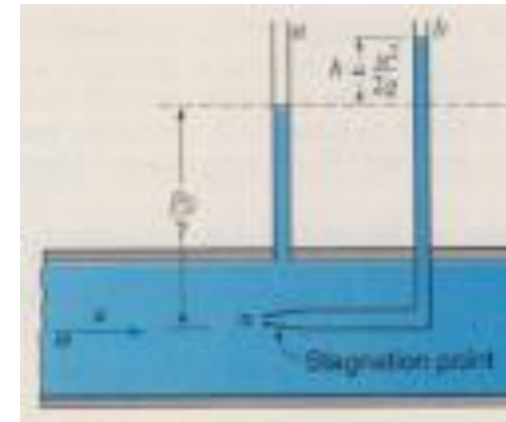
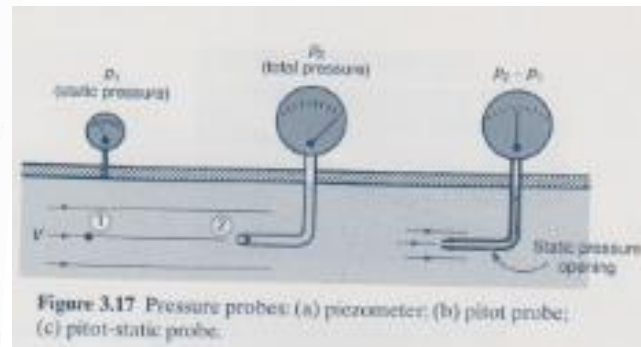
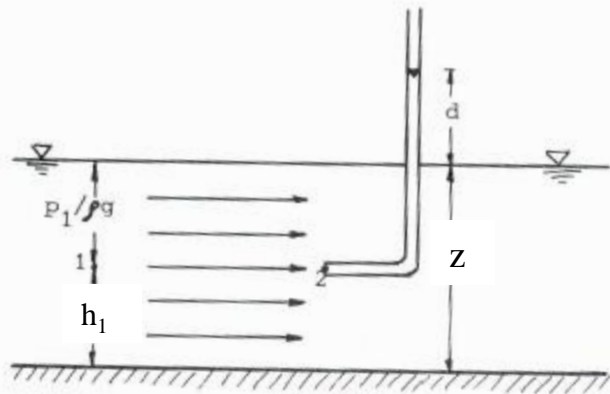


Fig. A: simple pitot tube

Bernoulli equation

Application of the Bernoulli equation

Applying Bernoulli equation between 1 and 2.

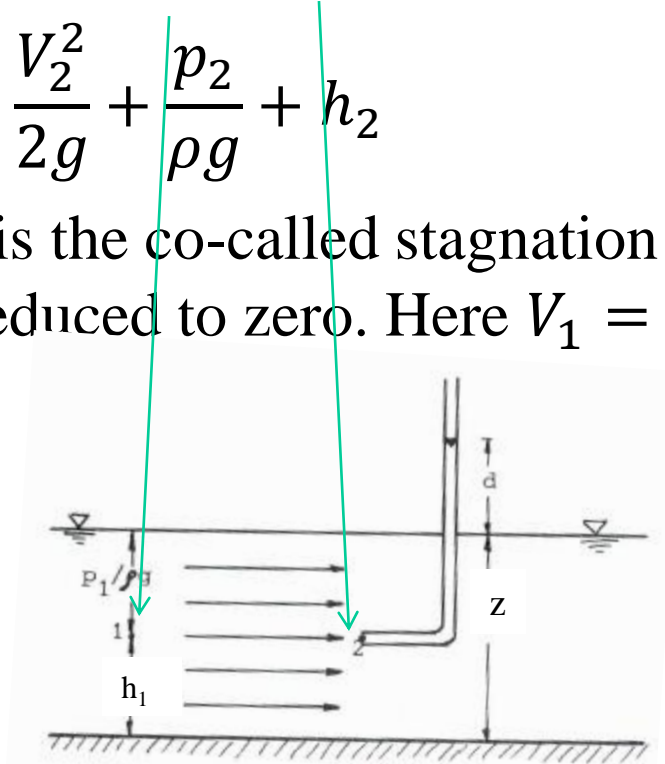
$$\frac{V_1^2}{2g} + \frac{p_1}{\rho g} + h_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho g} + h_2$$

- $h_2 = h_1$ and $V_2 = 0$. Point 2 is the so-called stagnation point, where the velocity is reduced to zero. Here $V_1 = V$.

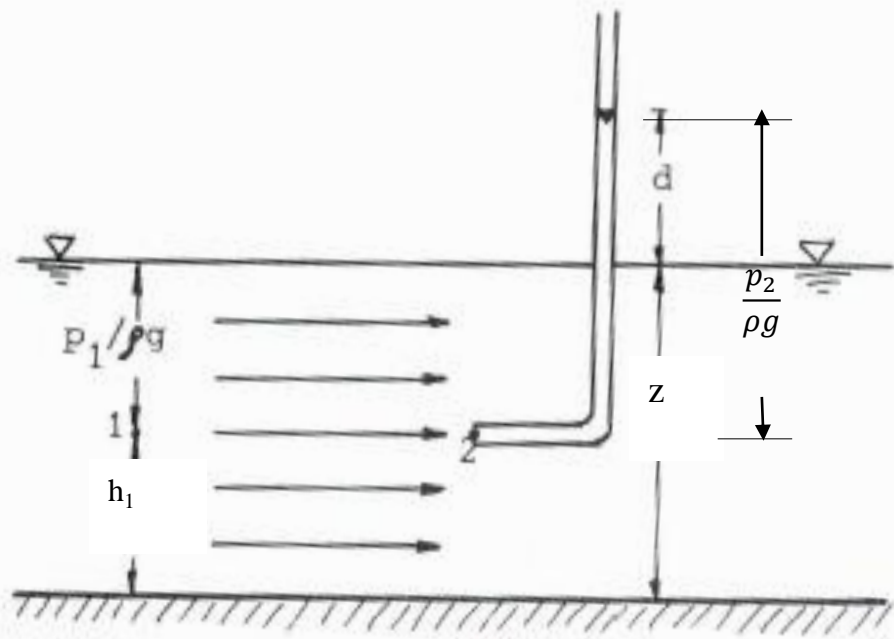
- $\frac{V^2}{2g} + \frac{p_1}{\rho g} + h_1 = 0 + \frac{p_2}{\rho g} + h_2$

- $\frac{V^2}{2g} + z = z + d$

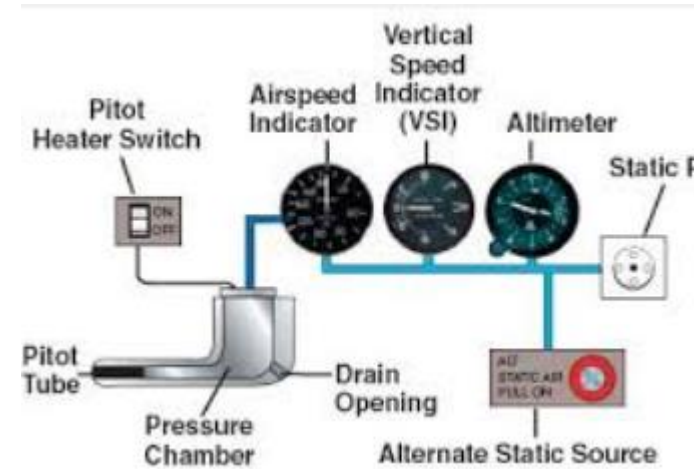
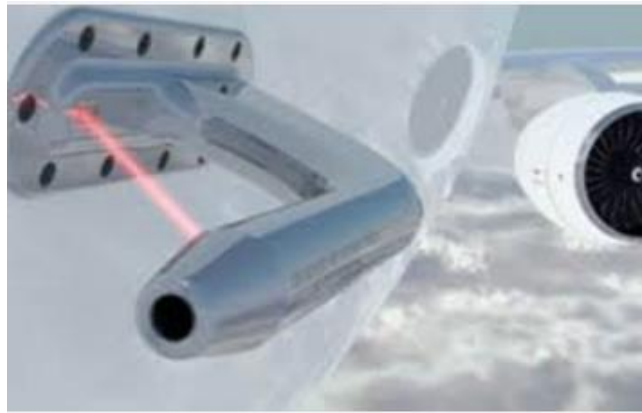
- $V = \sqrt{2gd}$



Simply stated, the rise d in the tube at point 2 is due to the velocity head being converted to pressure head as elevation head is the same at points 1 and 2. See next slide



Uses of pitot tubes



As the [airplane](#) moves through the air, air enters the pitot tube and puts pressure (dynamic) on a diaphragm inside the airspeed indicator.



Weather instruments at [Mount Washington Observatory](#). Pitot tube static anemometer is on the right.

It is widely used to determine the airspeed of an [aircraft](#), water speed of a [boat](#), and to measure liquid, air and gas flow velocities in [industrial](#) applications.

Pitot tubes on aircraft commonly have heating elements called pitot heat to prevent the tube from becoming clogged with ice. The failure of these systems can have *catastrophic consequences*, as in the case of [Austral Líneas Aéreas Flight 2553](#), [Birgenair Flight 301](#) (investigators suspected that some kind of insect could have created a nest inside the pitot tube: the prime suspect is the [black and yellow mud dauber](#) wasp), [Northwest Airlines Flight 6231](#), [Aeroperú Flight 603](#) (blocked static port), and of one [X-31](#). The French air safety authority [BEA](#) said that pitot tube icing was a contributing factor in the crash of [Air France Flight 447](#) into the [Atlantic Ocean](#). In 2008 [Air Caraïbes](#) reported two incidents of pitot tube icing malfunctions on its A330s.¹

Bernoulli equation

Application of the Bernoulli equation

1. Pitot tubes

B. Pitot static tube

- This is used to measure the difference between total and static pressure with one probe.

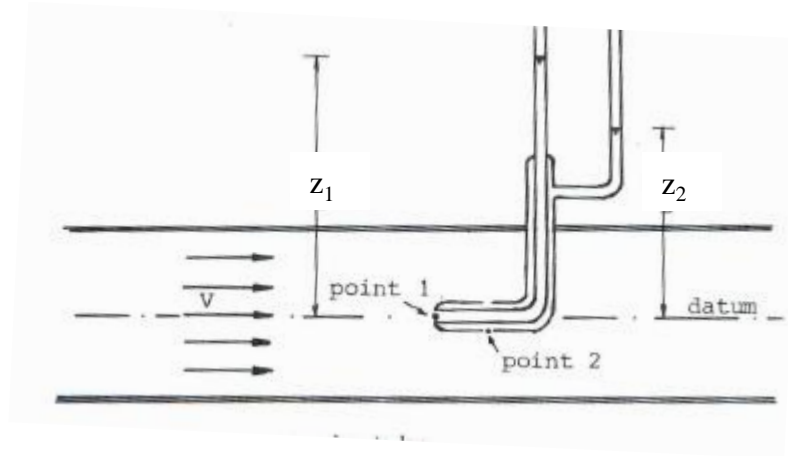


Fig. B: pitot static tube

Bernoulli equation

Application of the Bernoulli equation

Applying Bernoulli equation between 1 and 2.

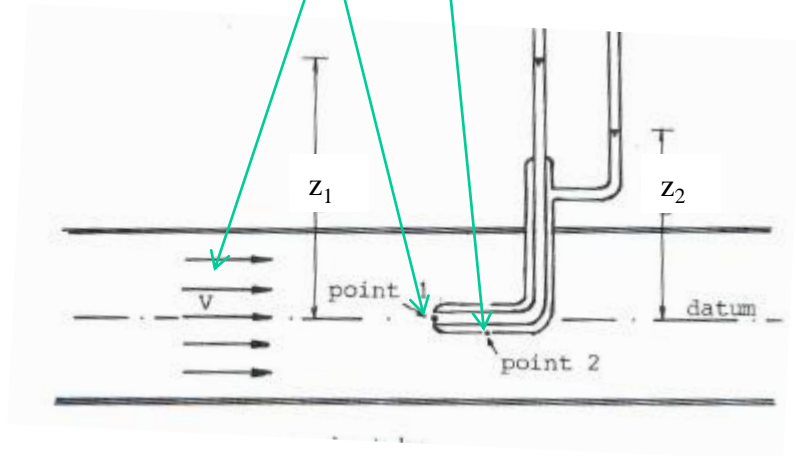
$$\frac{V_1^2}{2g} + \frac{p_1}{\rho g} + h_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho g} + h_2$$

- $V_1 = 0$. Point 1 is the so-called stagnation point, where the velocity is reduced to zero. Here $V_2 = V$.

- $0 + \frac{p_1}{\rho g} + h_1 = \frac{V^2}{2g} + \frac{p_2}{\rho g} + h_2$

- $z_1 = \frac{V^2}{2g} + z_2$

- $V = \sqrt{2g(z_2 - z_1)}$



Application of the Bernoulli equation

2. Flow through a sharp edged orifice

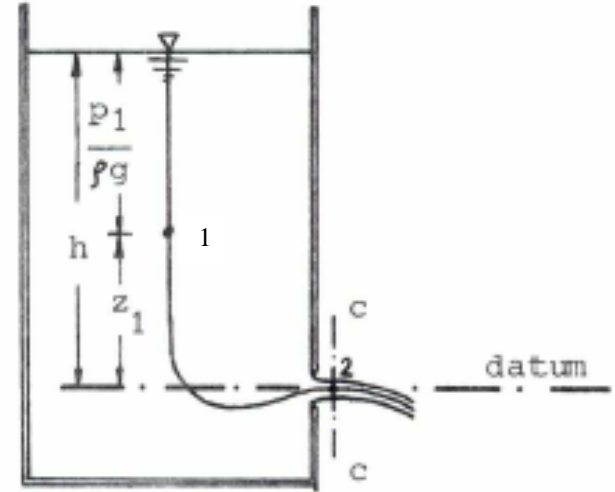
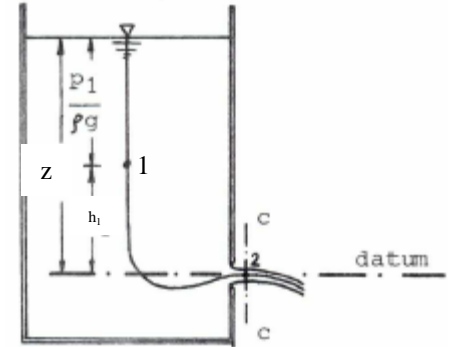


Fig Flow through a sharp-edged orifice

- At section c-c the contraction of the jet is maximal. This section is called the vena contracta and at this point the flow is uniform (streamlines are straight and parallel) & therefore the pressure is also uniform i.e., the pressure at the vena contracta equals that of the atmospheric pressure.

Application of the Bernoulli equation



- $$\frac{V_1^2}{2g} + \frac{p_1}{\rho g} + h_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho g} + h_2$$

- The tank is large compared to the orifice and point 1 sufficiently far from the orifice. Therefore, V_1 may be assumed negligible compared to V_2

- $$0 + z = \frac{V_2^2}{2g} + 0 + 0$$

- $$V_2 = \sqrt{2gz}$$

Application of the Bernoulli equation

3. Flow through a sharp crested notch

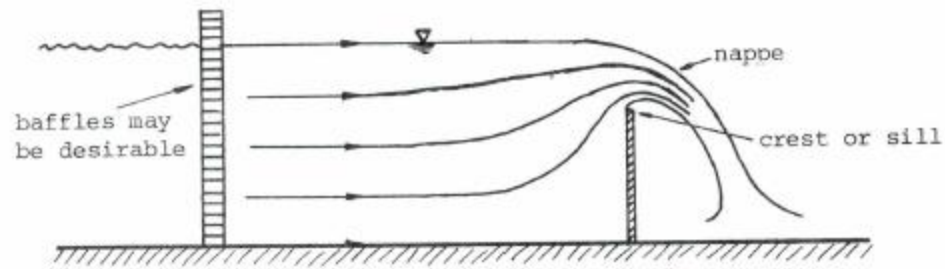


Fig Flow through a sharp-edged orifice

Application of the Bernoulli equation

- Assumptions (see lecture handbook)

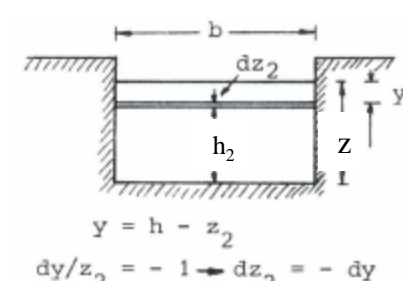
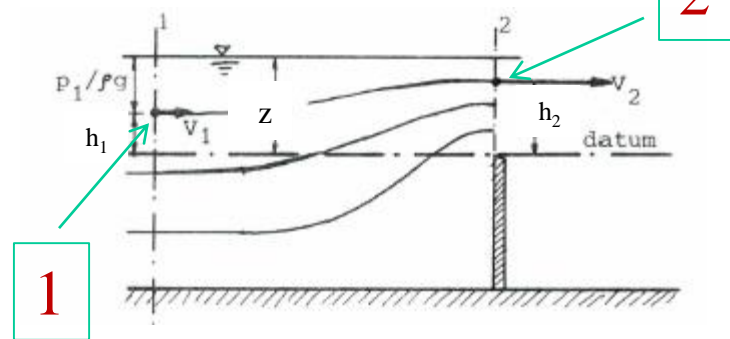
- $$\frac{V_1^2}{2g} + \frac{p_1}{\rho g} + h_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho g} + h_2$$

- V_1 is negligible compared to V_2 and $p_2 = p_a = 0$

- $$0 + z = \frac{V_2^2}{2g} + h_2$$

- $$V_2 = \sqrt{2g(z - h_2)}$$

a) upstream of the notch (section 1), the velocities of particles in the stream are uniform and parallel; thus the pressure there varies according to the hydrostatic equation $p = \rho g h$. (in practice it is often necessary to install baffles to achieve reasonable steady and uniform conditions);
 b) the free surface remains horizontal as far as the plane of the notch, and all particles passing through the notch move horizontally, and perpendicular to its plane;
 c) the pressure throughout the nappe is atmospheric;
 d) the effects of surface tension and viscosity are negligible.

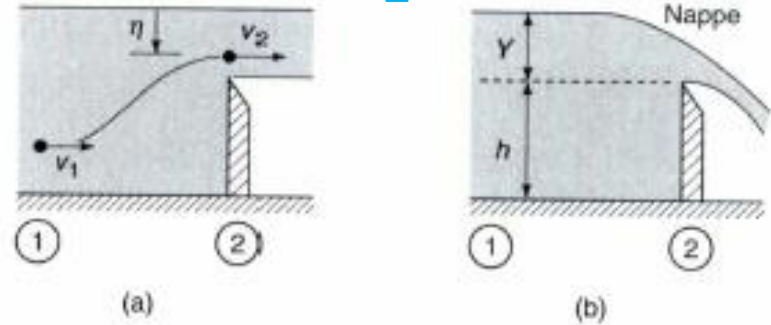


Note: points 1 & 2 are along a streamline

Application of the Bernoulli equation

- If η replaces $(z-h_2)$
- $V_2 = \sqrt{2g\eta}$
- If b is the width of the crest to the normal flow, the ideal discharge is given as

$$Q = b \int_0^Y V_2 d\eta = b \int_0^Y \sqrt{2g\eta} d\eta = b \frac{2}{3} \sqrt{2g} Y^{3/2}$$



predict the ideal flow shown in fig (b)

Application of the Bernoulli equation

- Experiments have shown that the magnitude of the exponent is nearly correct but that a discharge coefficient C_d must be applied to accurately predict the real flow shown in Fig (b) C_d

For rectangular weir
 $C_d = 0.61 + 0.08 \frac{Y}{h}$

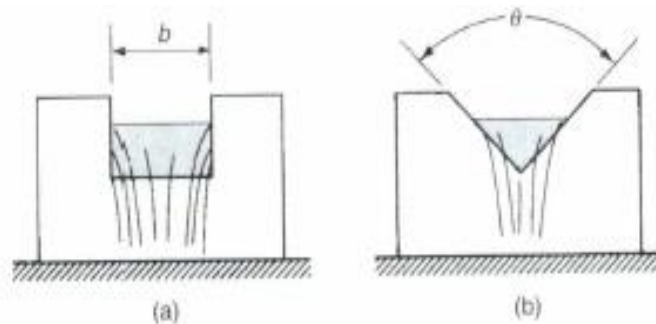


Fig Contracted rectangular and V-notch weirs

- $Q = C_d \frac{2}{3} \sqrt{2g} b Y^{3/2}$

Example 1

Determine the discharge of water over a rectangular sharp-crested weir, $b = 1.25$ m, $Y = 0.35$ m, $h = 1.47$ m, with side walls and with end contractions. If a 90° V-notch weir were to replace the rectangular weir, what would be the required Y for a similar discharge?

Solution: For the rectangular weir, using Eq. 10.4.26, the discharge coefficient is

$$\begin{aligned}C_d &= 0.61 + 0.08 \frac{Y}{h} \\ &= 0.61 + 0.08 \times \frac{0.35}{1.47} \\ &= 0.63\end{aligned}$$

Substitute into Eq. 10.4.25 and calculate

$$\begin{aligned} Q &= C_d \frac{2}{3} \sqrt{2g} b Y^{3/2} \\ &= 0.63 \times \frac{2}{3} \times \sqrt{2 \times 9.81} \times 1.25 \times 0.35^{3/2} \\ &= 0.48 \text{ m}^3/\text{s} \end{aligned}$$

With end contractions the effective width of the weir is reduced by $0.2Y$, resulting in

$$\begin{aligned} Q &= C_d \frac{2}{3} \sqrt{2g} (b - 0.2Y) Y^{3/2} \\ &= 0.63 \times \frac{2}{3} \times \sqrt{2 \times 9.81} \times (1.25 - 0.2 \times 0.35) \times 0.35^{3/2} \\ &= 0.45 \text{ m}^3/\text{s} \end{aligned}$$

With a discharge of $Q = 0.48 \text{ m}^3/\text{s}$, use Eq. 10.4.27 to find Y for the 90° V-notch weir:

$$\begin{aligned} Y &= \left[\frac{Q}{C_d \times \frac{8}{15} \times \sqrt{2g} \tan(\theta/2)} \right]^{2/5} \\ &= \left[\frac{0.482}{0.58 \times \frac{8}{15} \times \sqrt{2 \times 9.81} \times \tan 45^\circ} \right]^{2/5} = 0.66 \text{ m} \end{aligned}$$

Example 2

The wind reaches a speed of 100 km/h in a storm. Calculate the force acting on a 1 m × 2 m window facing the storm. The window is in a high-rise building, so the wind speed is not reduced due to ground effects. Use $\rho = 1.2 \text{ kg/m}^3$.

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Solution: The window facing the storm will be in a stagnation region where the wind speed is brought to zero. Working with gage pressures, the pressure p upstream in the wind is zero. The velocity V must have units of m/s. It is

$$V = 100 \frac{\text{km}}{\text{h}} \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1000 \text{ m}}{1 \text{ km}} = 27.8 \text{ m/s}$$

Bernoulli's equation then allows us to calculate the pressure on the window as follows:

$$\begin{aligned} \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + h_2 &= \frac{V_1^2}{2g} + \frac{p_1}{\gamma} + h_1 \\ \therefore p_2 &= \frac{\rho V_1^2}{2} \\ &= \frac{1.2 \times (27.8)^2}{2} = 464 \text{ N/m}^2 \end{aligned}$$

where we have used $h_2 = h_1$, $p_1 = 0$, $V_2 = 0$, and $\gamma = \rho g$. Multiply by the area and find the force to be

$$\begin{aligned} F &= pA \\ &= 464 \times 1 \times 2 = 928 \text{ N} \end{aligned}$$