Fluid Mechanics

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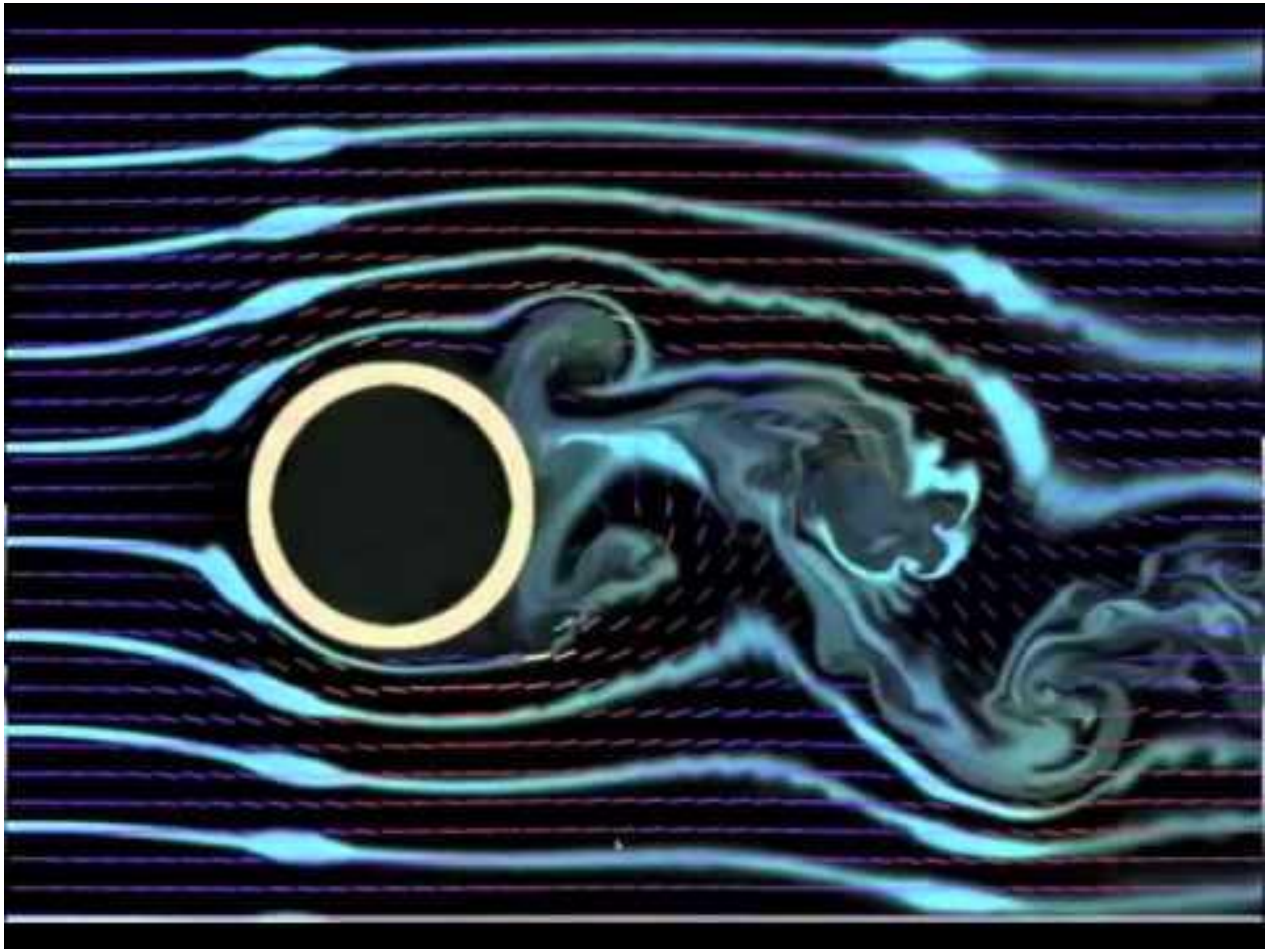
Fluid Kinematics



In Kinematics, the motion of fluids
is <u>analyzed based on the same principles</u>
that are used in analyzing the motions of rigid bodies.

But !

Fluid particles are moving relative to each other

<u>They are changing their neighbors continuously along the motion</u>

Analysis of motion of fluids much more difficult than the motion of rigid bodies.

The motion of fluids is analyzed using two techniques:

1.Lagrange Technique

In this technique, **the path that a moving fluid particle makes in time is analyzed.**

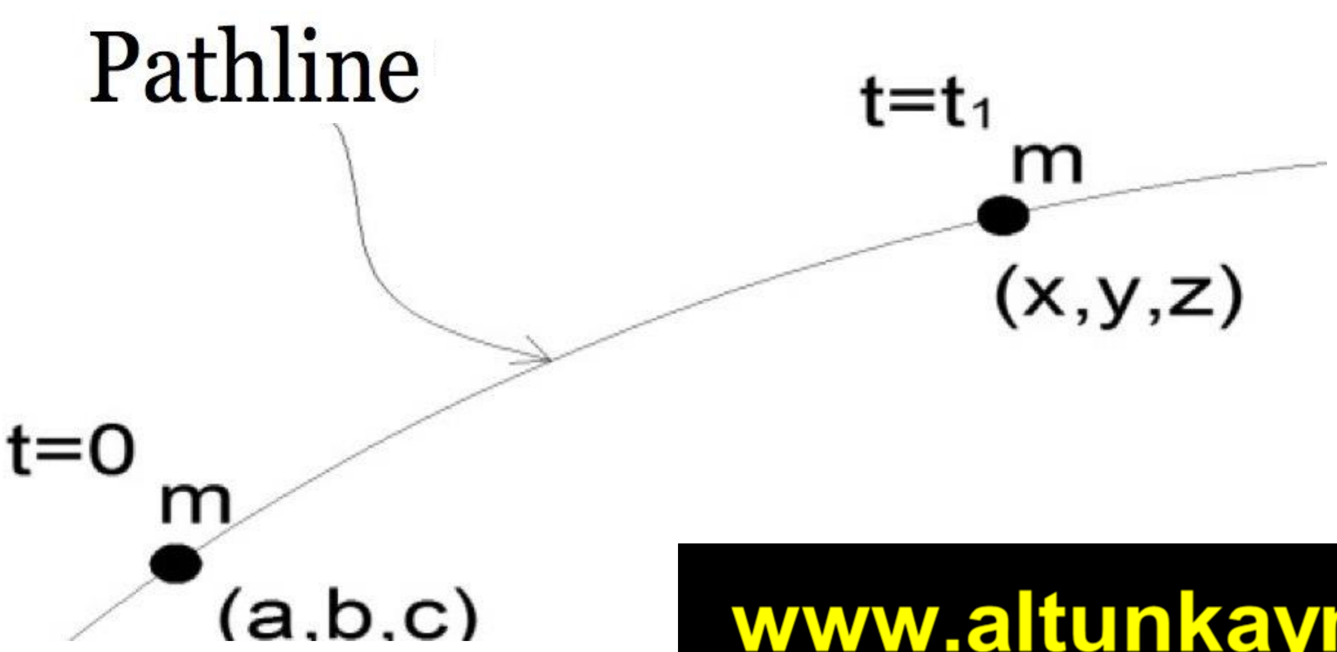
Joseph-Louis Lagrange

The Lagrange parameters are given in the following forms.

$$x = f(a,b,c,t)$$

$$y = f(a,b,c,t)$$

$$z = f(a,b,c,t)$$



$$u = \frac{dx}{dt}, \quad v = \frac{dy}{dt}, \quad w = \frac{dz}{dt}$$

$$a_x = \frac{du}{dt} = \frac{d^2u}{dt}$$

In the same manner, $a_y = \frac{dv}{dt} = \frac{d^2v}{dt}$ and $a_z = \frac{dw}{dt} = \frac{d^2w}{dt}$

$$\vec{a} = \vec{a}_{x_i} + \vec{a}_{y_j} + \vec{a}_{z_k} \text{ or } a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Similarly, $V = \sqrt{u^2 + v^2 + \underset{w}{a}^2}$ and in its vector form $\vec{V} = \vec{u}_i + \vec{v}_j + \vec{w}_k$

2. Euler's Technique

This technique is **not related** to the motion that **a certain fluid particle makes**.

Leonhard Euler

Rather, the change in time of kinematic dimensions **at any point in a fluid is analyzed.**

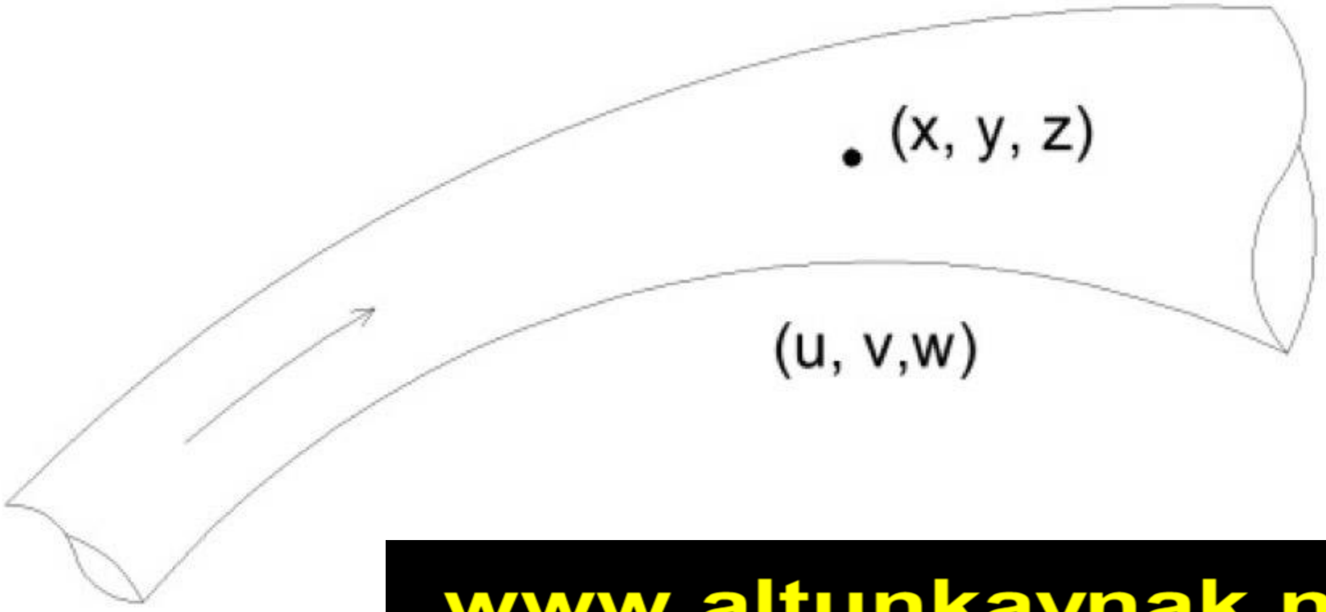
This means that, the change in kinematic dimensions are analyzed **with respect to time.**

Euler's parameters.

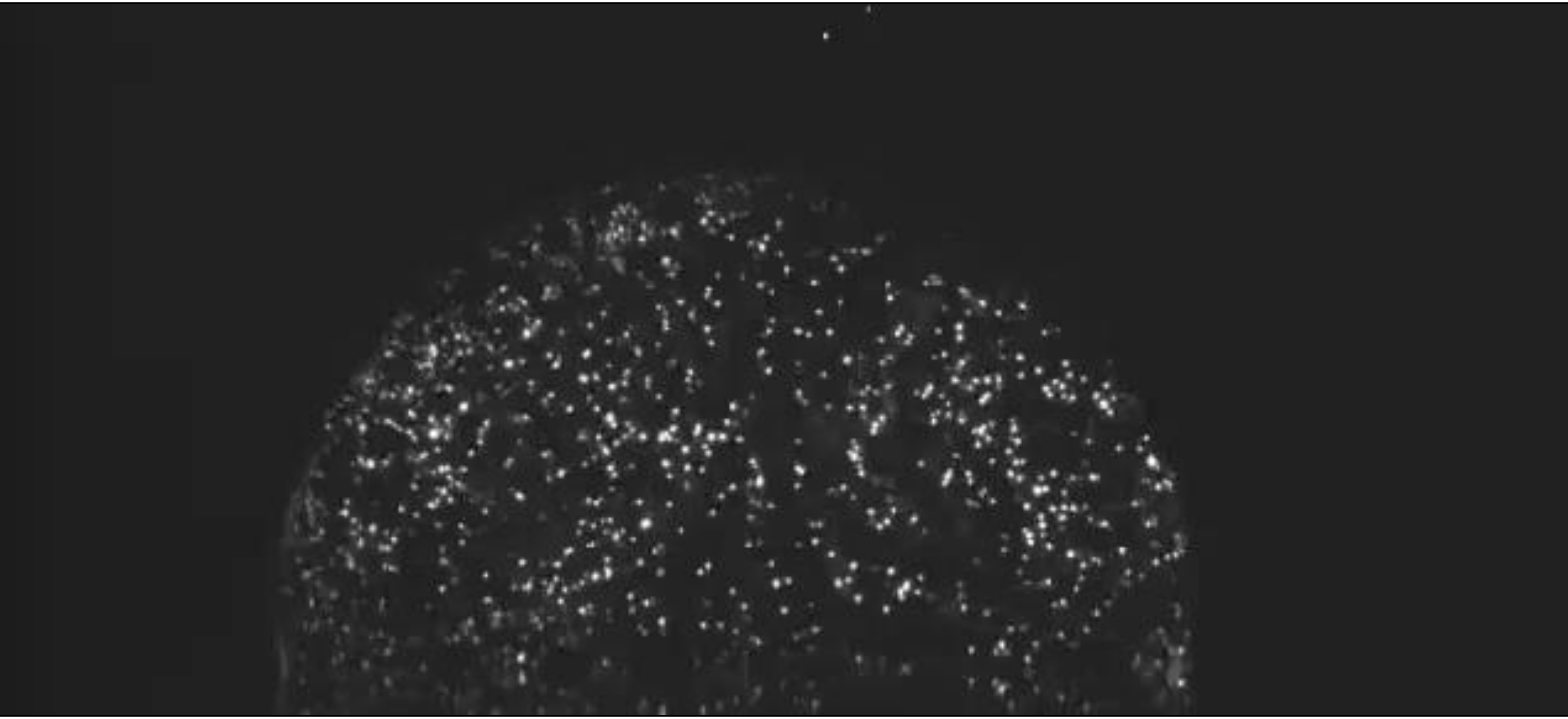
$$u = f(x, y, z, t)$$

$$v = f(x, y, z, t)$$

$$w = f(x, y, z, t)$$



The Lagrangian method of describing a flow involves tagging and following fluid particles as they move about.



The video shows convection within a small water droplet on a flat surface. The particles are made visible by shining a laser sheet through the droplet.

Acceleration Components

$$a_x = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}$$

$$a_y = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}$$

$$a_z = \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}$$

Local Acceleration

Convective Acceleration

The first terms in the right hand side of the above equations are called ***local acceleration***

The other terms in the right hand sides of the above equations are called ***convective acceleration****.*

Euler's parameters are the time derivatives of Lagrange parameters and, therefore, Lagrange parameters are the integrals of Euler's parameters.

Determination of Lagrange parameters is very difficult !!!

We will use Euler's parameters

In addition, in practical applications, what is important is:

The determination of change in the characteristics of the fluid at any point with time

Analysis of a fluid particle independently is ***not*** *of much practical use*

Steady and non-steady flows

If the flow is steady

$$\frac{\partial Q}{\partial t} = 0, \frac{\partial u}{\partial t} = 0$$

for a particular point

if the flow is unsteady

$$\frac{\partial Q}{\partial t} \neq 0, \frac{\partial u}{\partial t} \neq 0$$

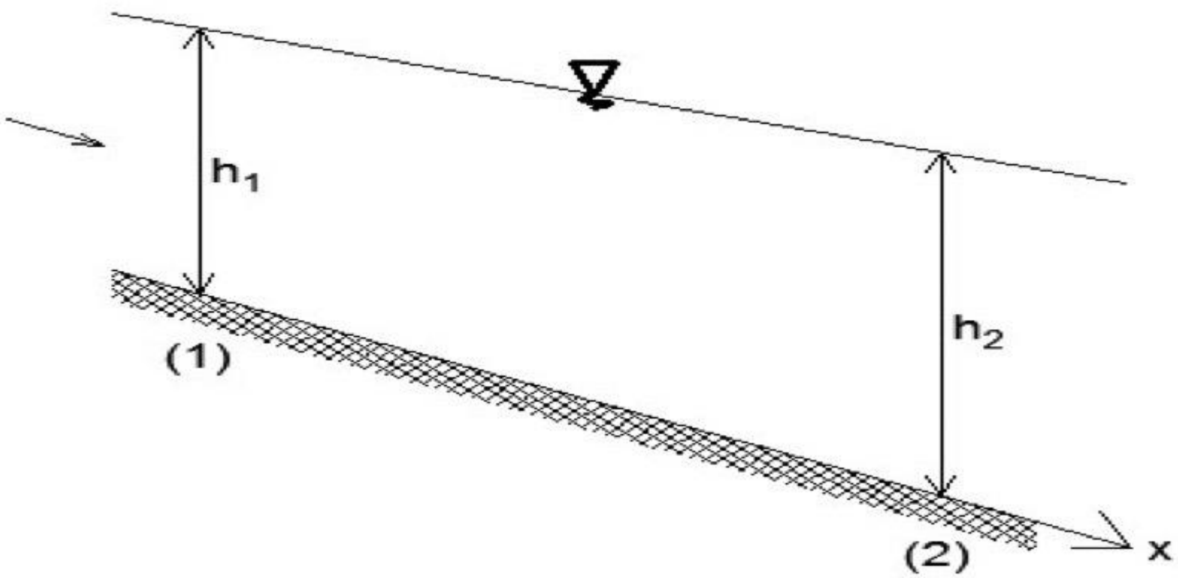
The low speed flow of water from a small nozzle is ***steady***

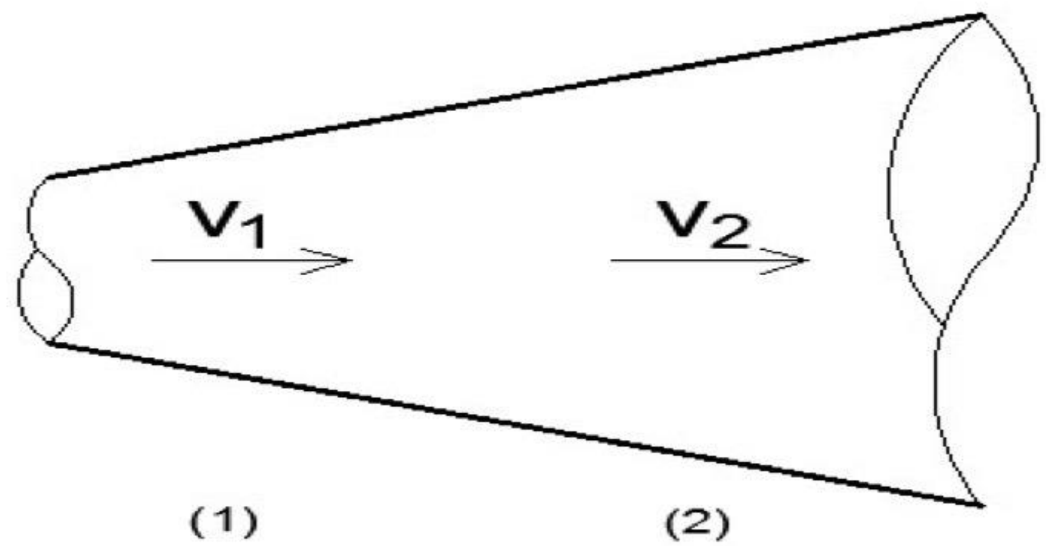
Unless the flow is disturbed (by poking it with a pencil, for example), it is not obvious that the fluid is **moving !!!!**

On the other hand, the flow within a clothes washer is highly ***unsteady***

Uniform and Non-uniform Flows

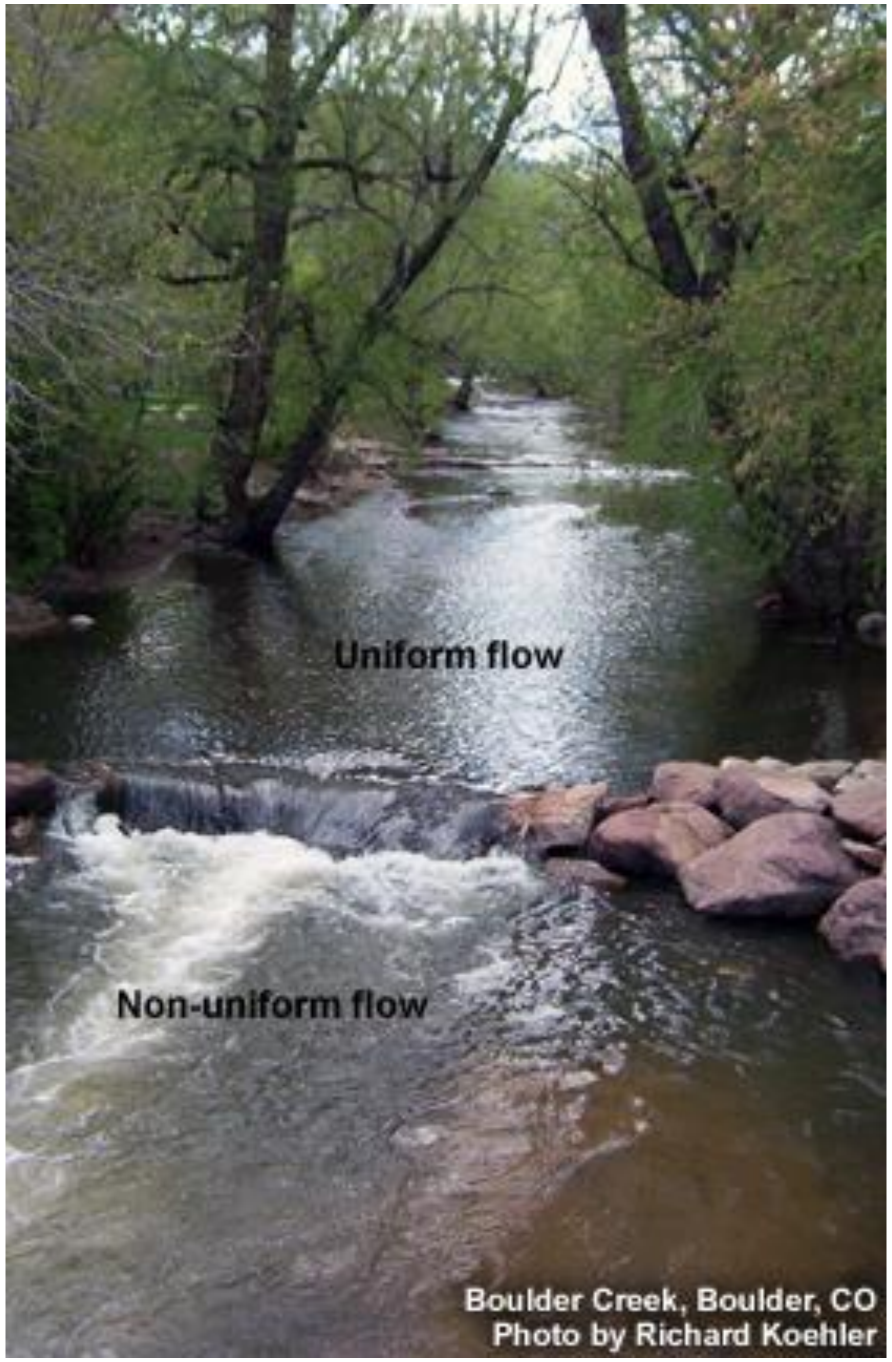
In a certain flow, if the flow characteristics remain all the same along the flow length at any time ,
the flow is called ***Uniform flow.***

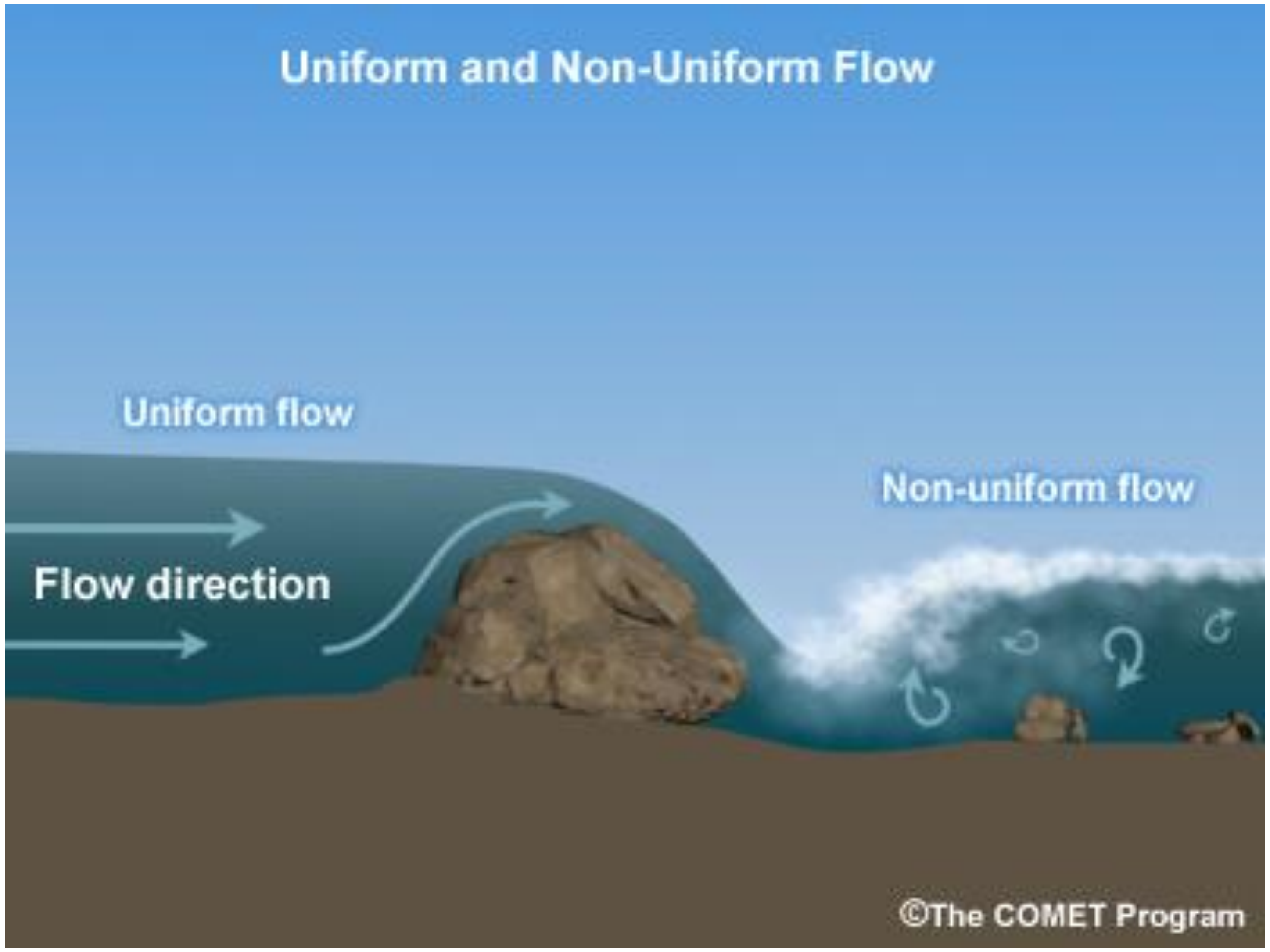


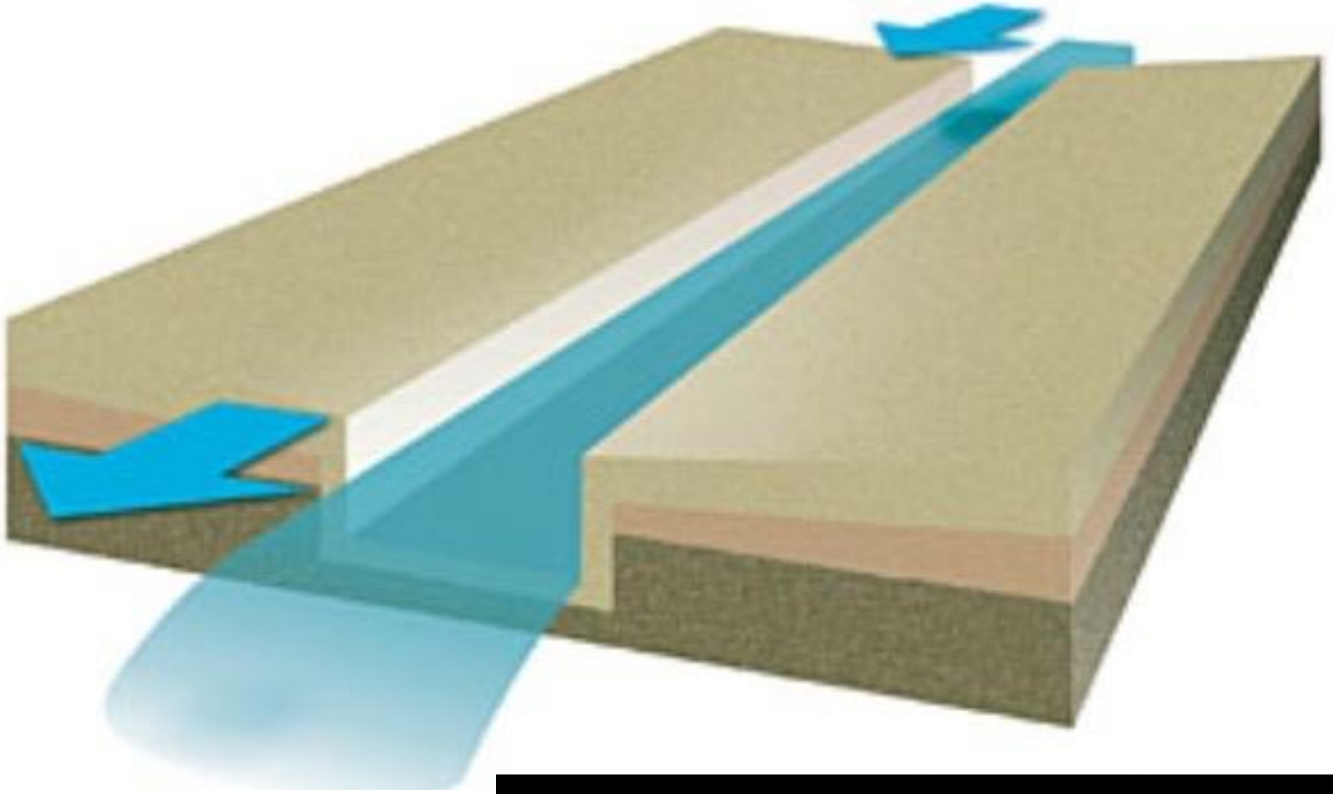


. For a flow to be uniform, the depth of flow along the length of flow should remain constant

(the channel should be **prismatic**, i.e. the cross-section of the
the
channel should not change along the flow).



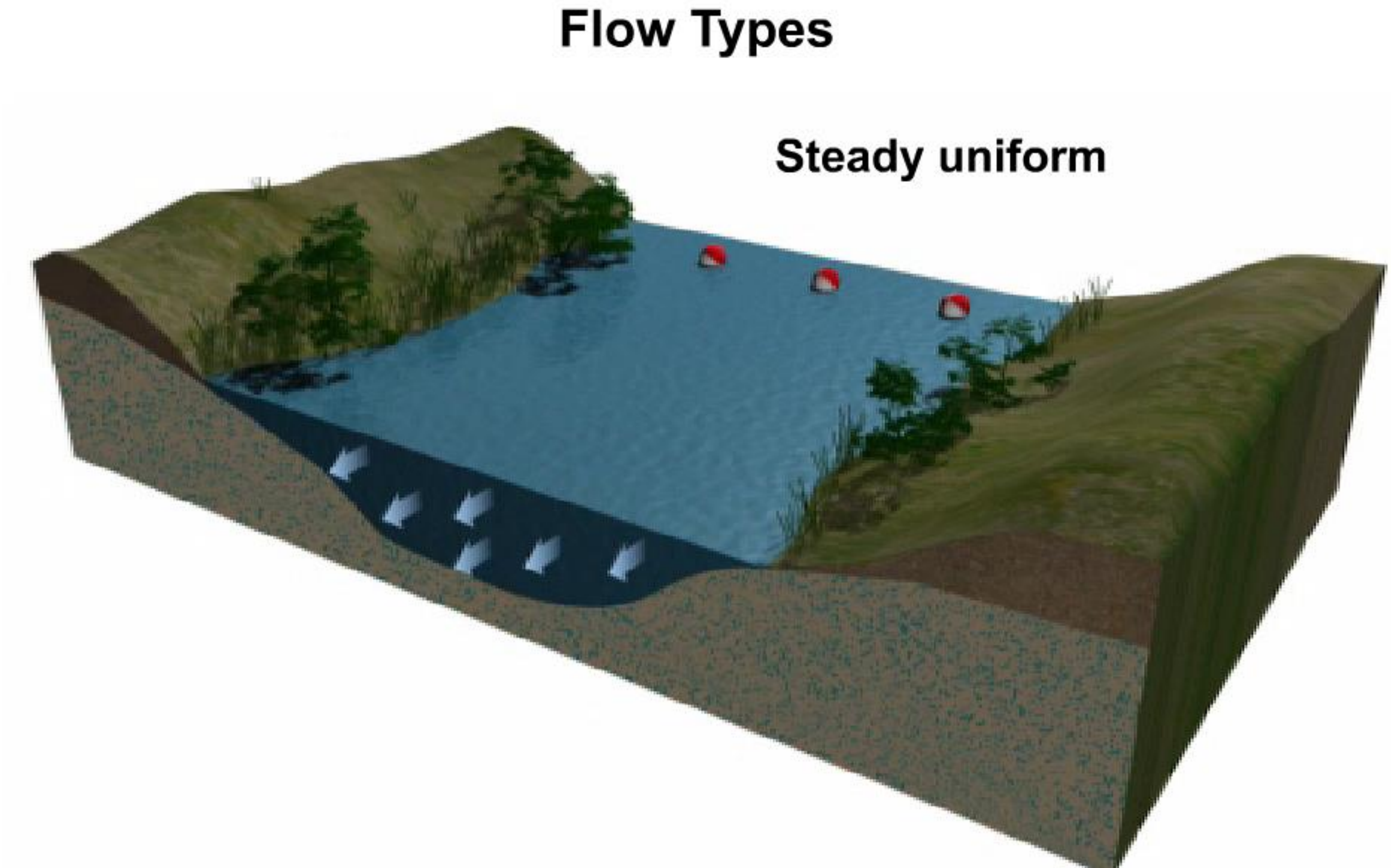




In this regard, ***<u>all uniform flows are steady, but not all steady flows are uniform</u>***.

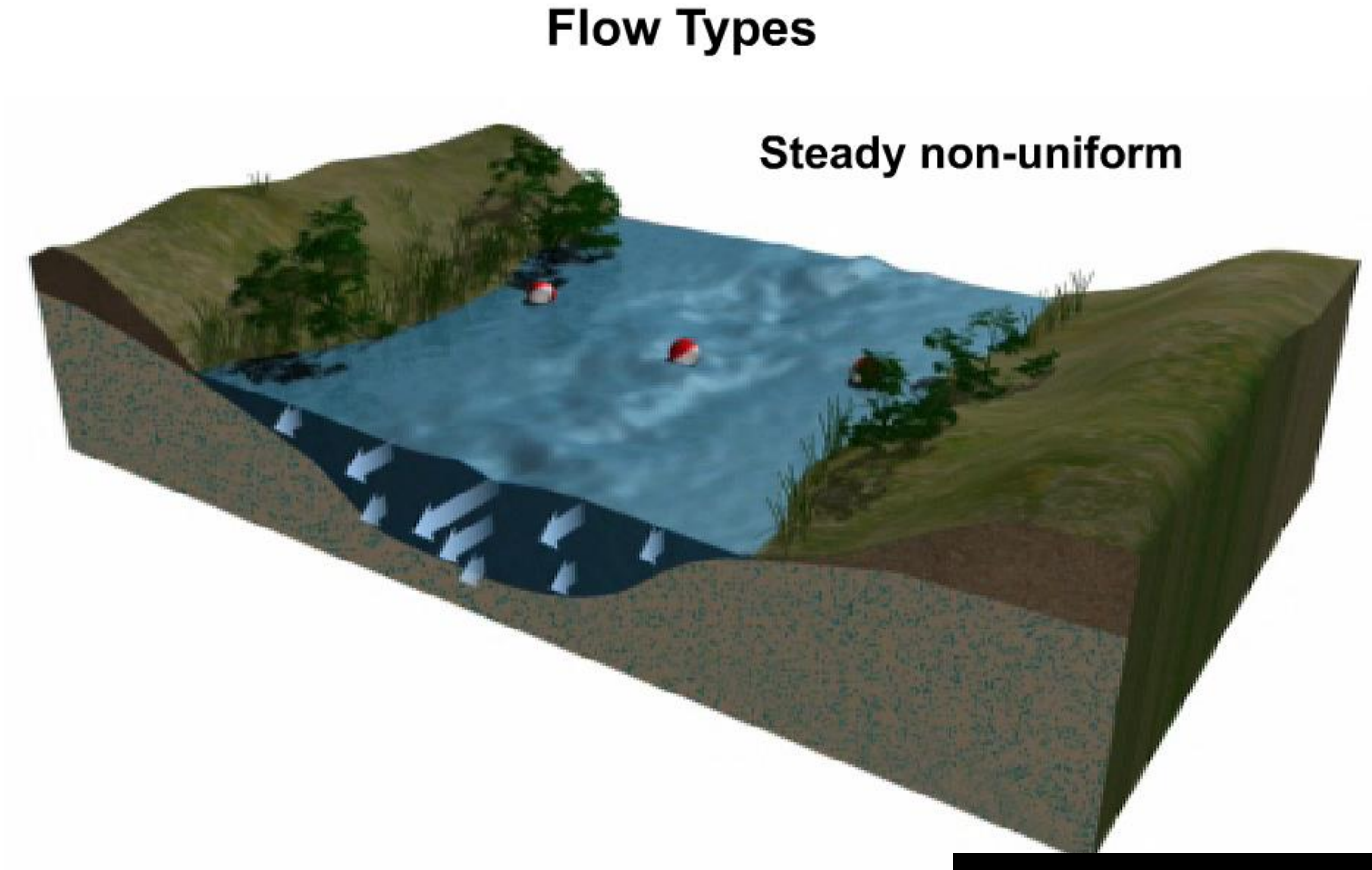
Steady uniform flow:

Conditions do not change with position in the stream or with time.



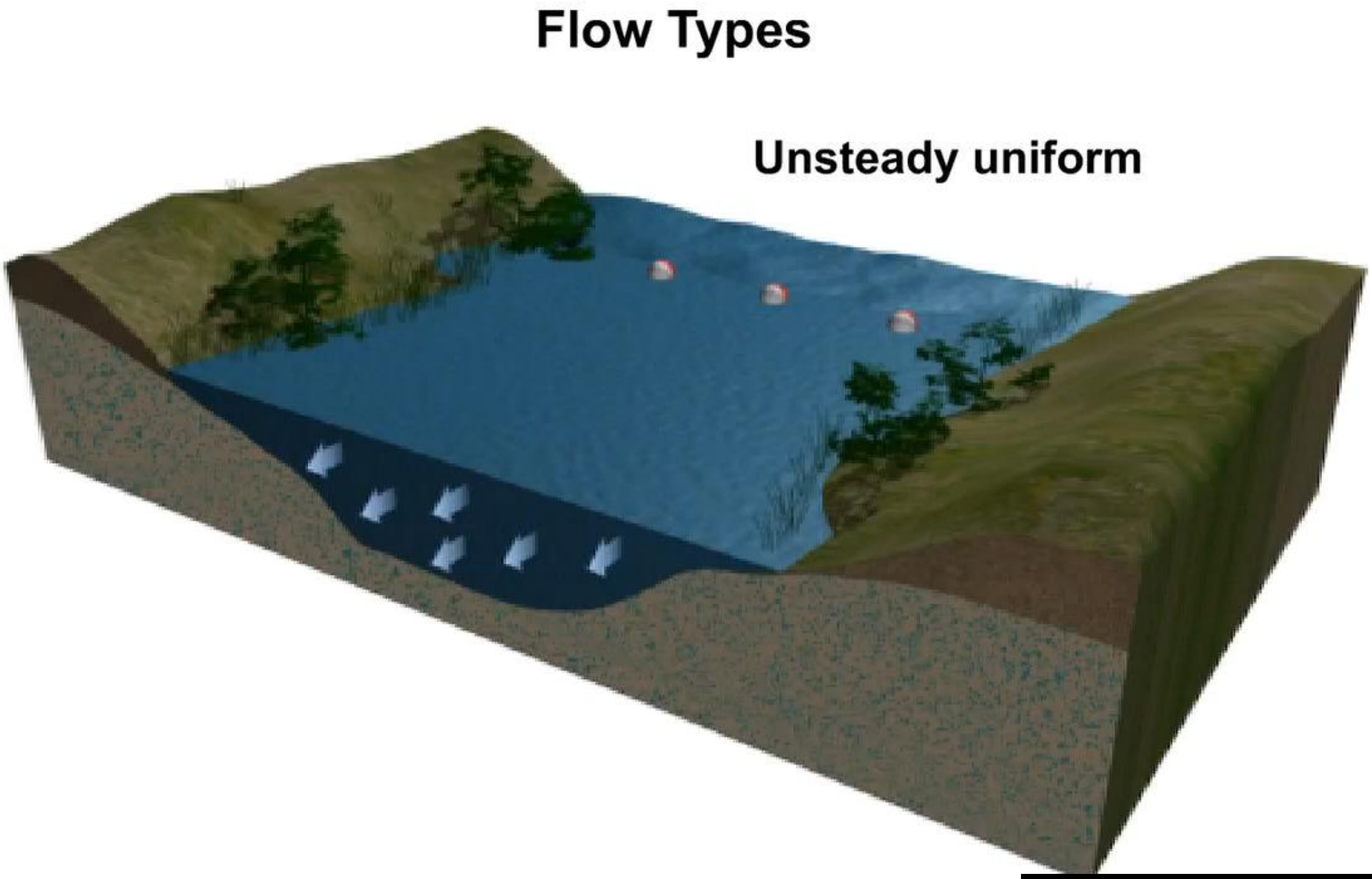
Steady non-uniform flow:

Conditions change from point to point in the stream but do not change with time.



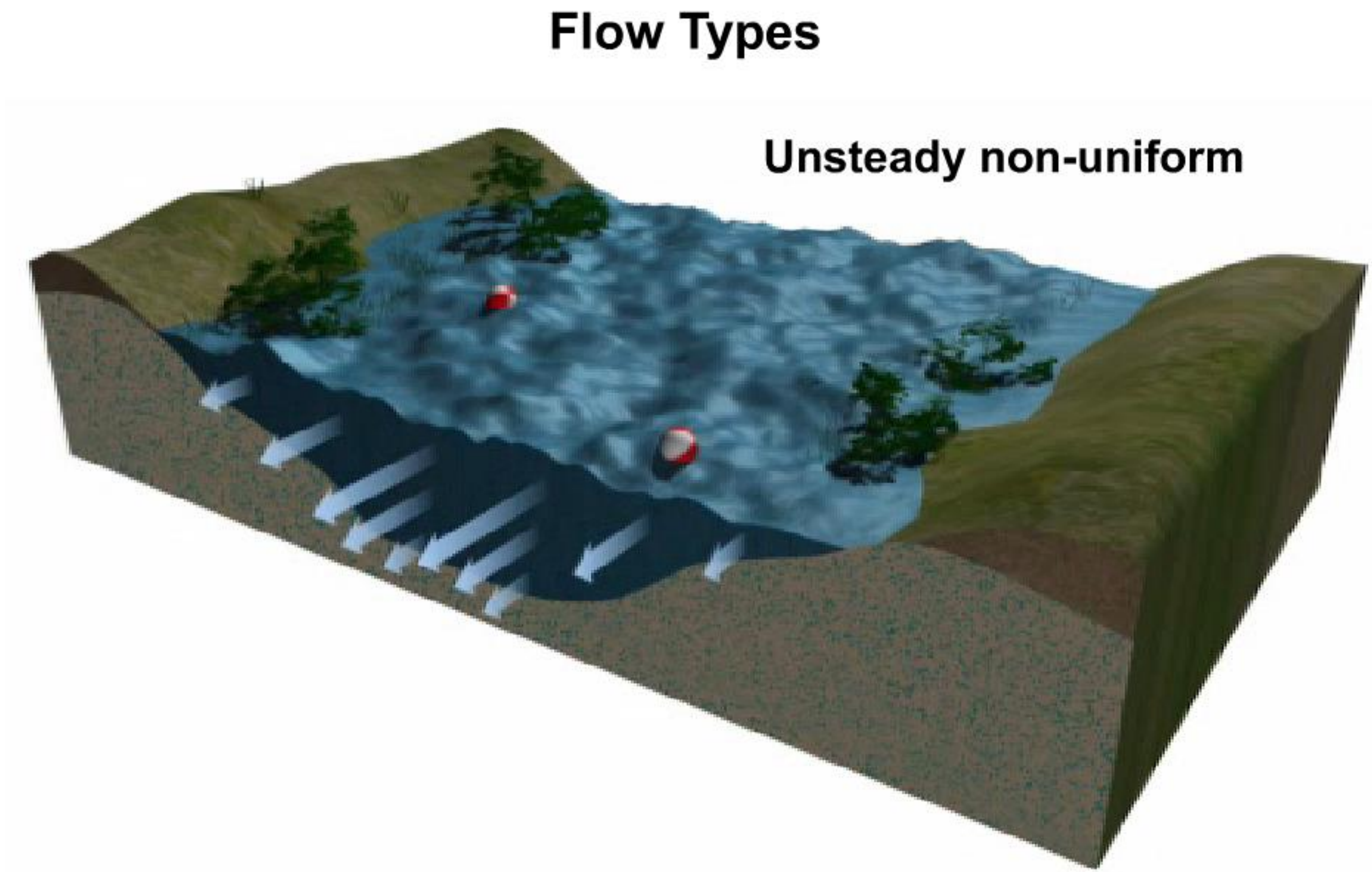
Unsteady uniform flow:

At a given instant in time the conditions at every point are the same, but will change with time.



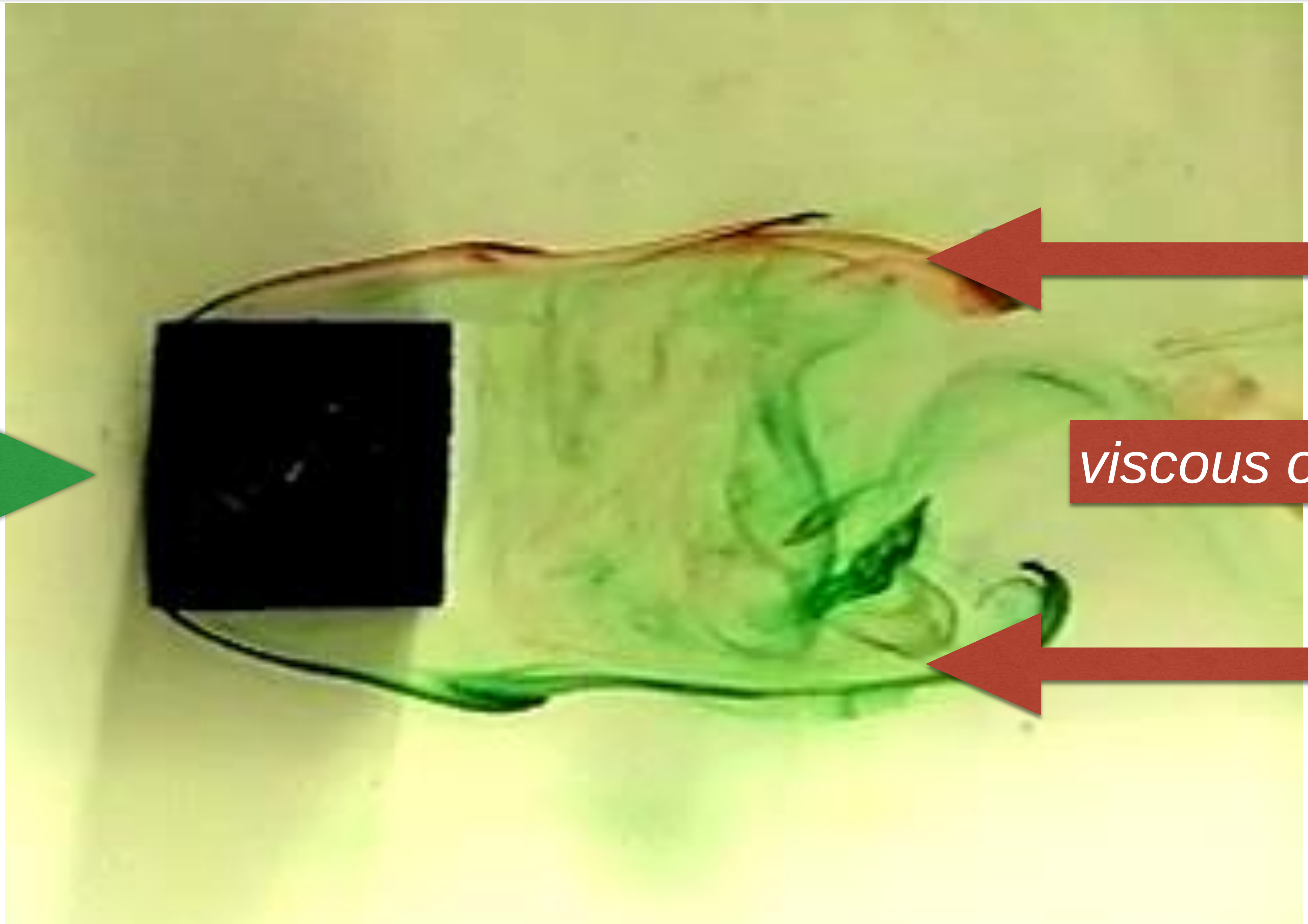
Unsteady non-uniform flow:

Every condition of the flow may change from point to point and with time at every point.



For the flow shown, the uniform upstream velocity is steady

upstream



viscous oil flow

the viscous oil flow past the block is unsteady

Why ???

. The periodic shedding of vortices (swirls) from alternate sides of the block gives a definite unsteady component to the flow

There are two types of variable flows:

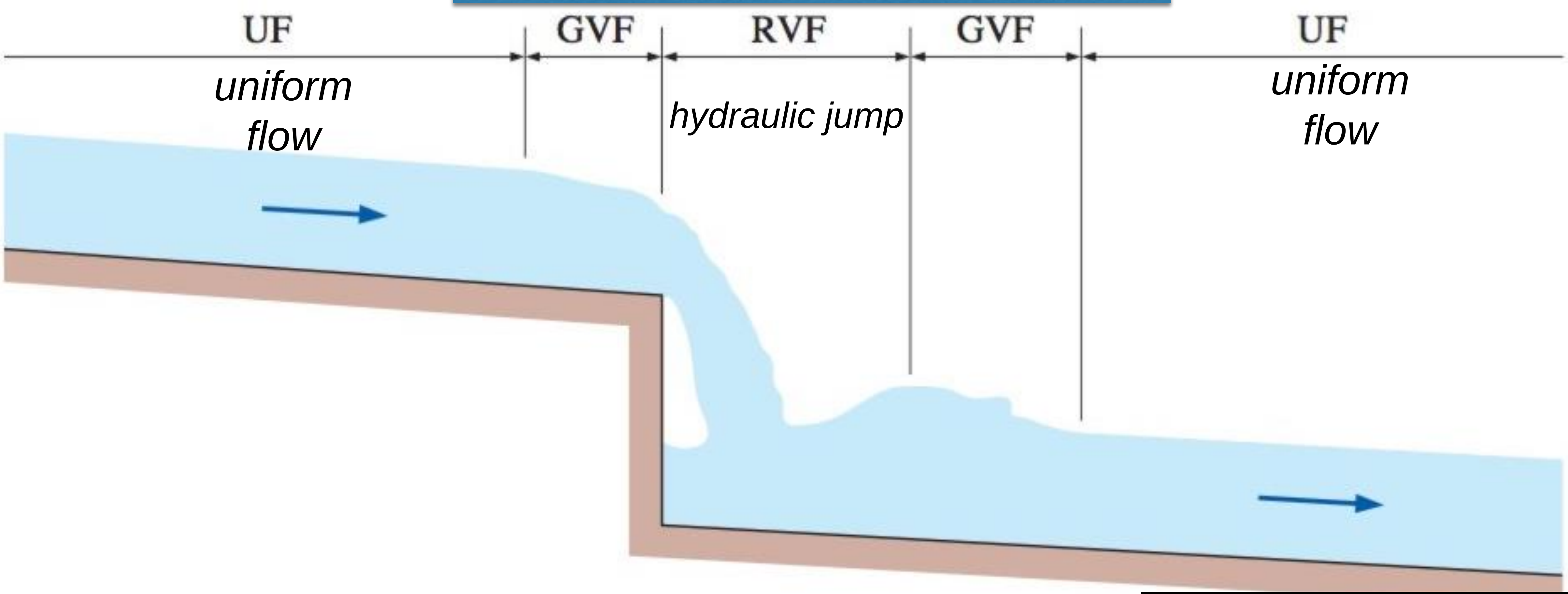
1. Gradually varied flows

2. Rapidly varied flows:

(example :flood flows, hydraulic jump etc…)

For these kind of flows

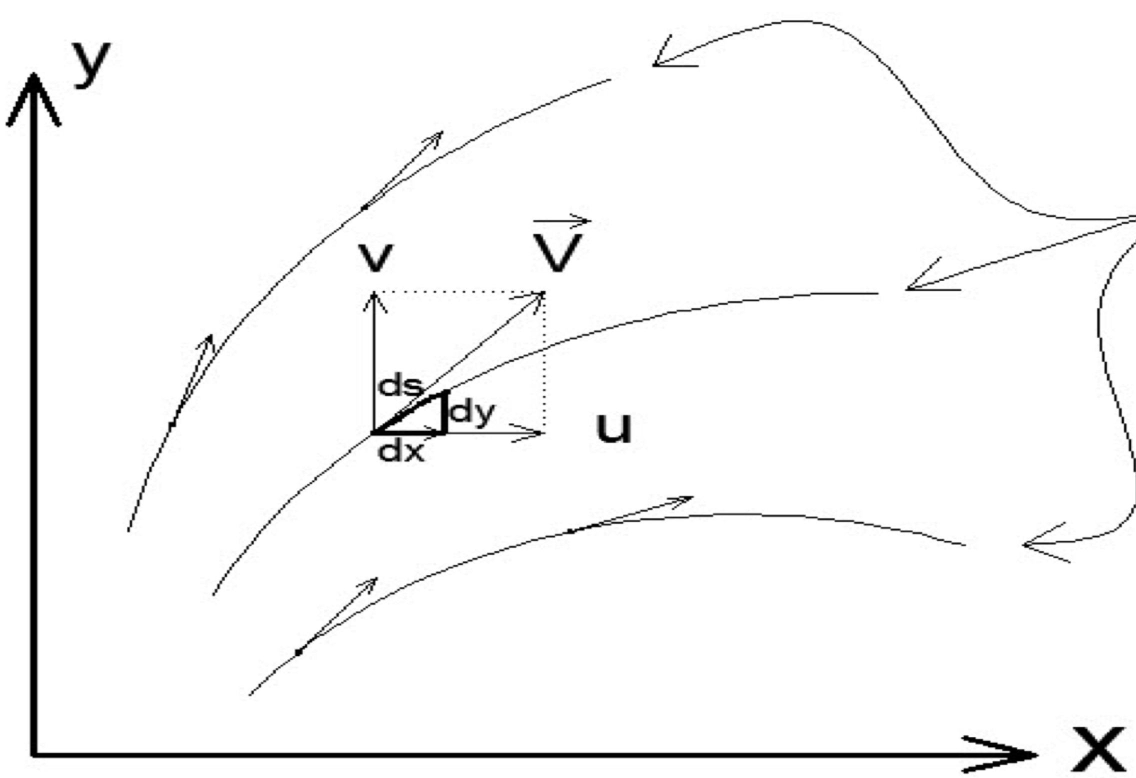
$$\frac{\partial h}{\partial x} \neq 0 \text{ and } \frac{\partial h_i}{\partial t} \neq 0$$



Streamlines

*Let's say that the **velocity vectors** at every point in a certain flow at any time are known.*

The line which is drawn as tangent to these velocity vectors is called Streamline.

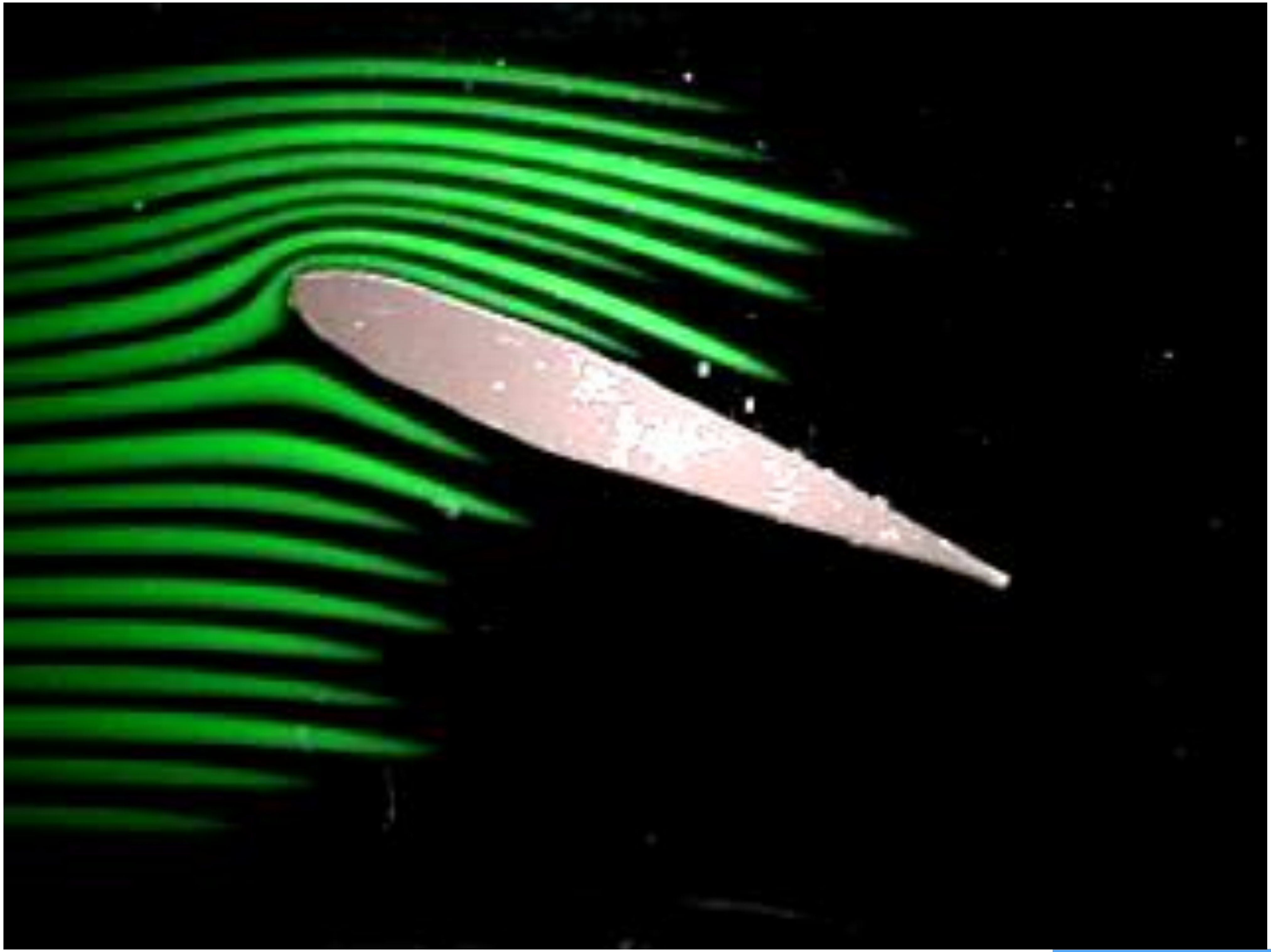


At the moment $t = t_1$ Streamlines

If we consider one velocity vector

$$\tan\alpha = \frac{dy}{dx} = \frac{v}{u}$$

The streamlines for very slow flow past a model airfoil are made visible by injecting dye as several locations upstream of the airfoil.



If we write this equation in a differential form,
we will get the differential form of the stream line equation

$$udy = vdx \text{ or } udy - vdx = 0$$

we know that

$$dx = udt\ ,\ dy = vdt \text{ and } dz = wdt$$

Equating these relationship for ***dt*** *:*

$$dt = \frac{dx}{u(x,y,z)} = \frac{dy}{v(x,y,z)} = \frac{dz}{w(x,y,z)}$$

This equation is nothing but ***equation of path described in earlier section.***

Pathlines

A pathline is the line traced out by a given particle as it flows from one point to another.

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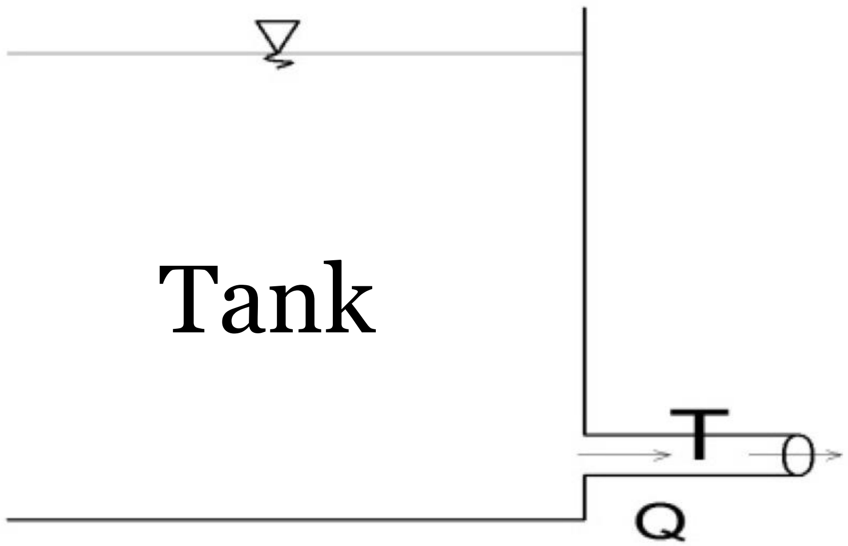
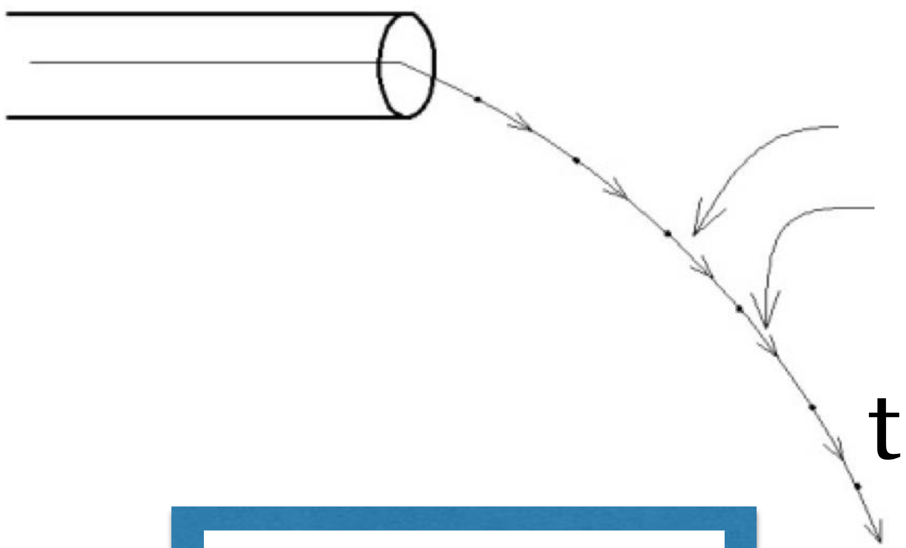
The lawn sprinkler rotates because the nozzle at the end of each arm points "backwards".

Let discharge, be constant at the outlet of the given figure.





This means that

$$\frac{\partial Q}{\partial t} = 0$$

This indicates that the ***depth, does not change with time, making the flow steady.***

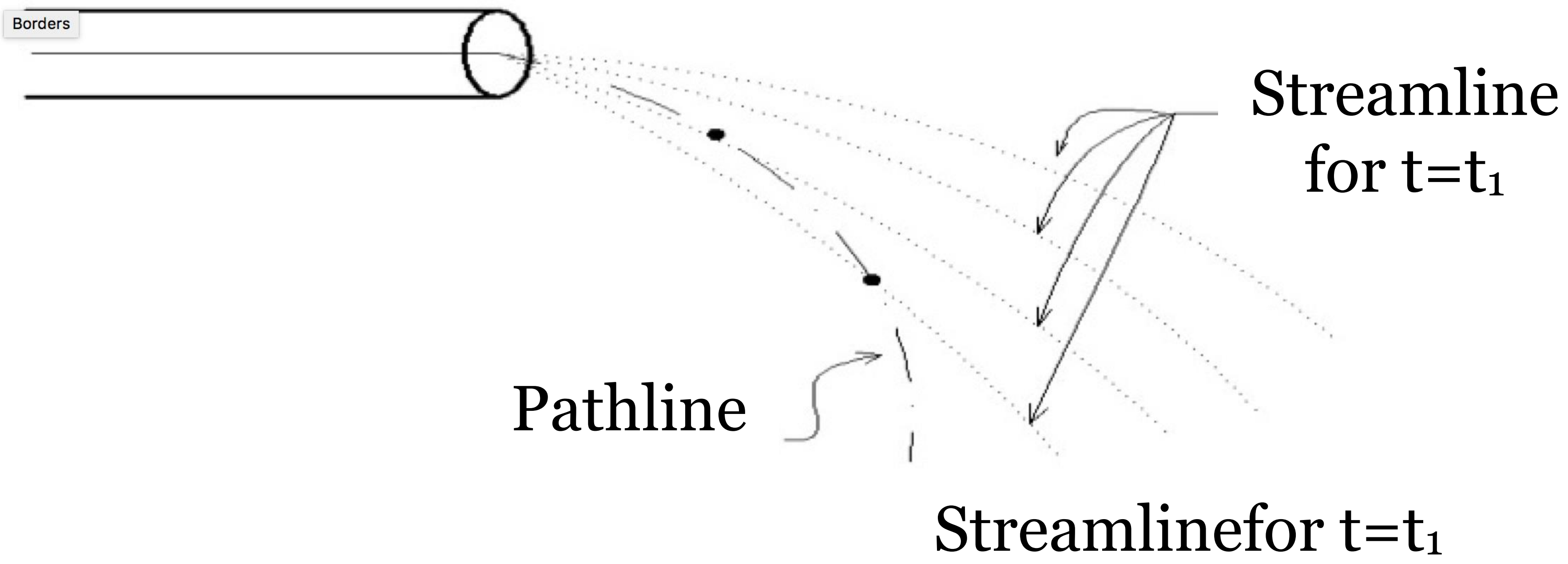
In this case, the flow lines and the flow path overlap on each other.

If the flow is un-steady

$$\frac{\partial Q}{\partial t} \neq 0 \text{ and } \frac{\partial h}{\partial t} \neq 0$$

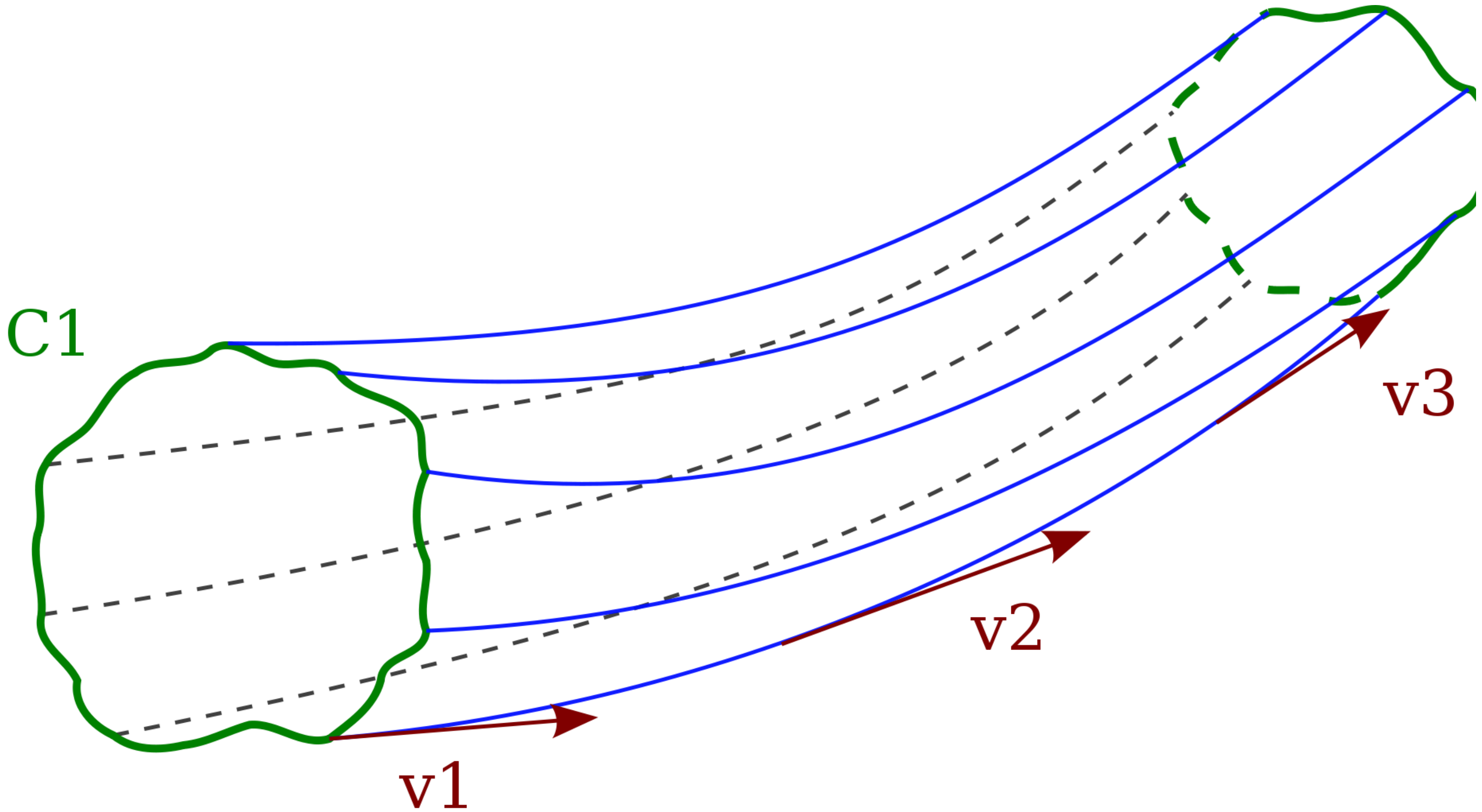
The flow path and the flow lines do not overlap on each other.

The flow path tends to move near the container as the depth, of the fluid decreases with time.



Flow pipes

*A group of flow lines passing through all points of a certain closed curve are called **flow pipes.***



These pipes are similar to pipes having rigid walls, and hence, the name has been given. There is no velocitycomponent in the direction normal to the wall.

Fluid string

This is a name given to a flow pipe with minute cross-sectional area.

Discharge:

This is the volume of fluid passing through a cross-sectional area per unit time.

$$Q = \frac{\forall}{T}$$

It is usually given in units

$$\frac{m^3}{s}$$

We can write this unit in the following form

$$\frac{m^3}{s} = m^2 . \frac{m}{s} \Rightarrow Q = A \times V$$

This shows that discharge can also be defined as the product of the velocity of flow and the cross-sectional areawhere the flow is passing through.

One, Two and Three Dimensional Flows

Terms one, two or three dimensional flow refer to the number of space coordinates required to describe a flow.

One dimensional (1-D) flow:

This is a flow where the flow characteristics variation ***only along with one direction.***

In this flow, flow characteristics do not change between points found on the same cross-sectional area. If we consider a mean cross-sectional flow velocity, pipe flows can be taken as examples of one dimensional flows.

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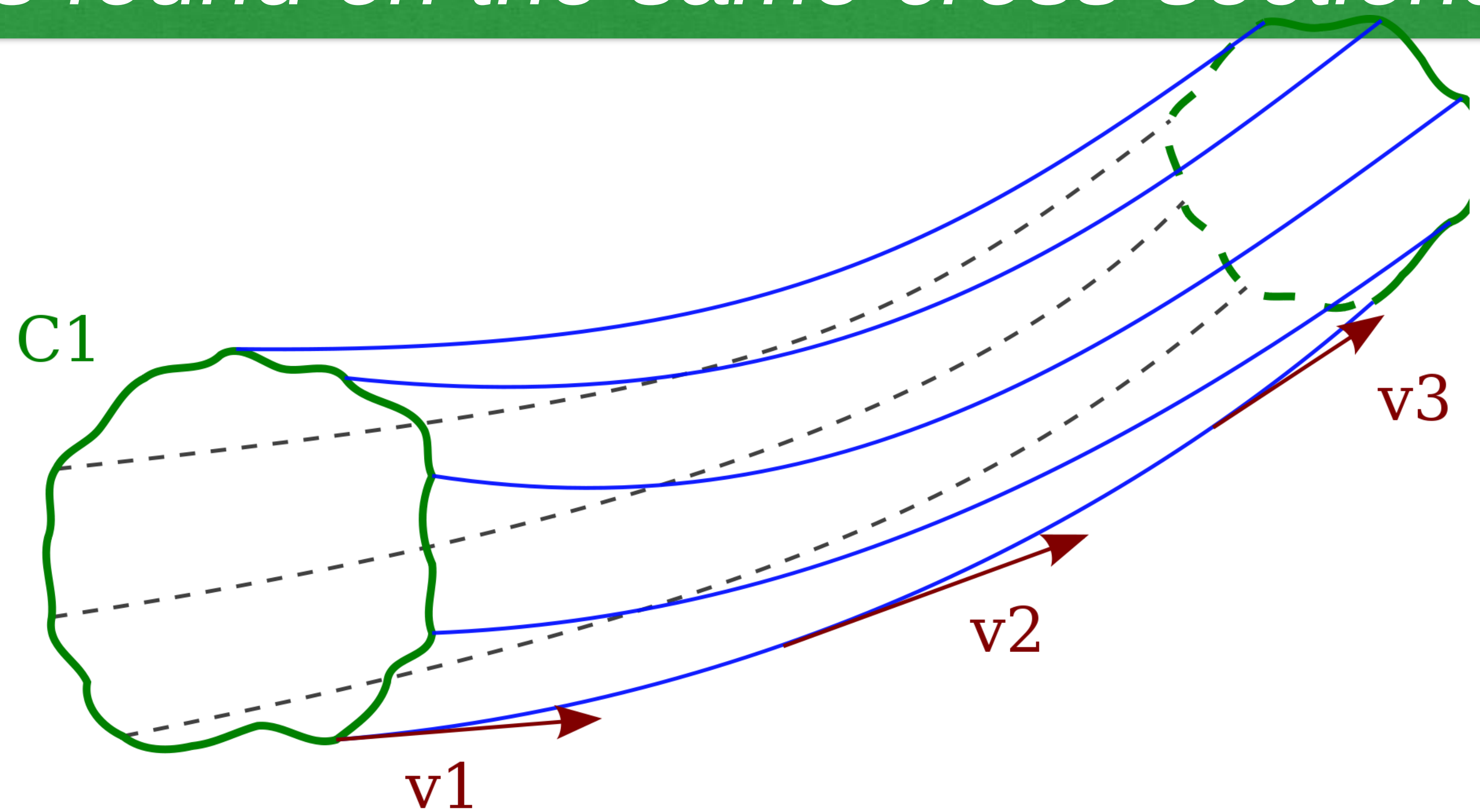


If we consider a mean cross-sectional flow velocity, pipe flows can be taken as examples of one dimensional flows.

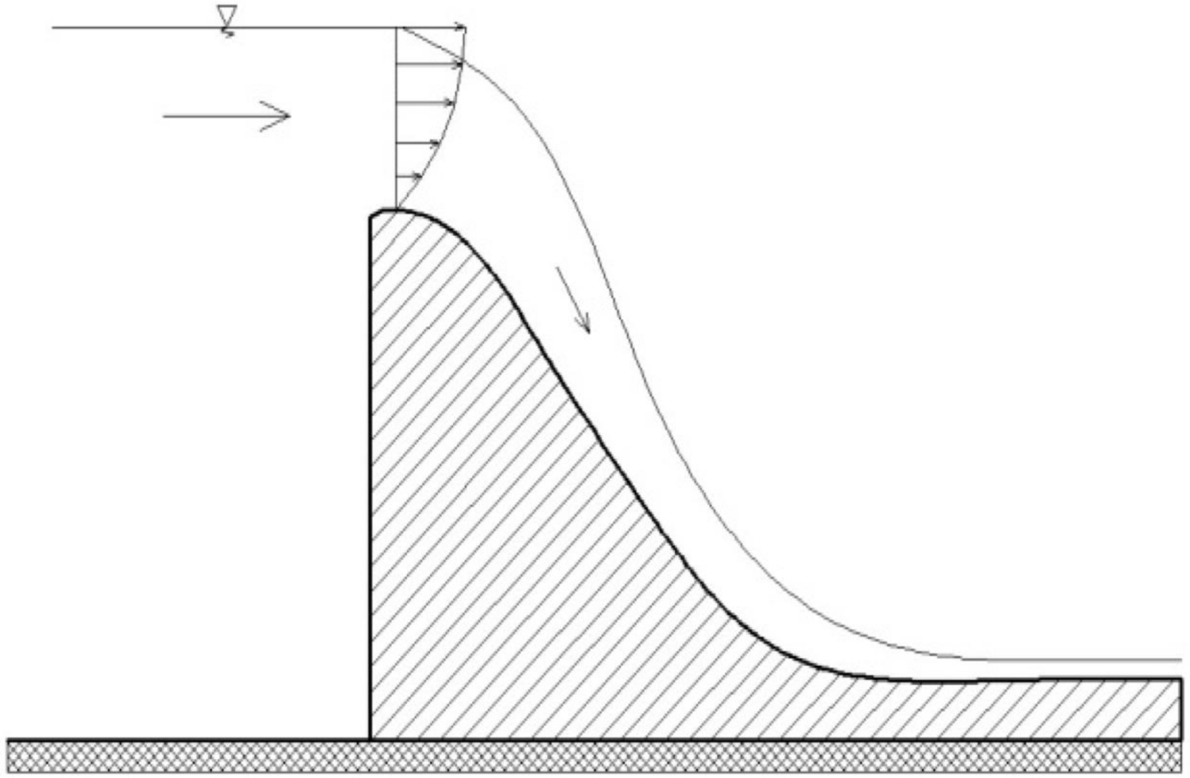
Two dimensional (2-D) flow:

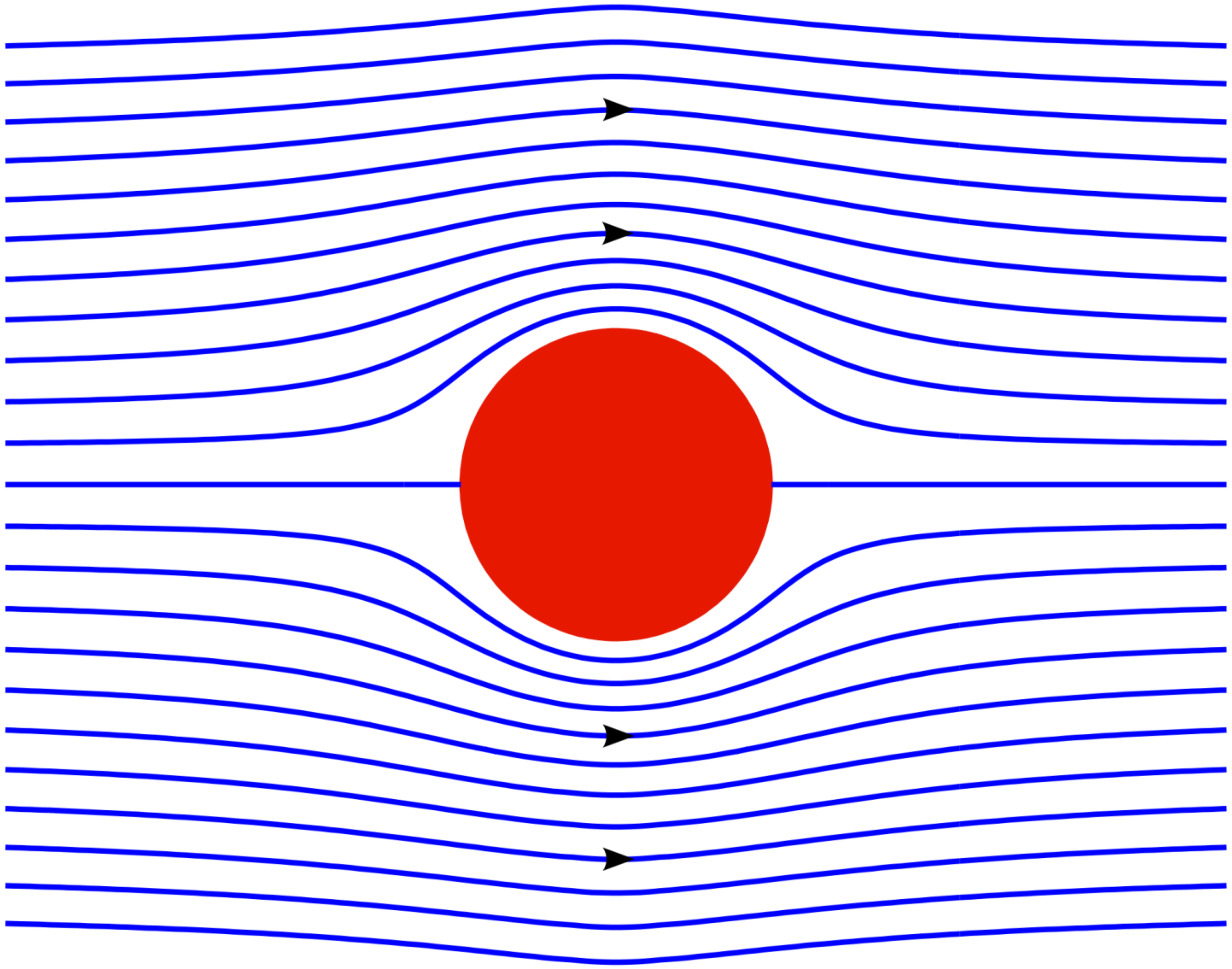
If there is variation in flow characteristics in two directions and the characteristic remain the same and do not vary in the 3rd direction, the flow is known as ***two dimensional flow.***

Because of this, 2-D flows are called planar flows.

The nature of flow observed at every plane Parallel to the flow plane produced by this kind of flow remains the same.

Flows above sluice gates of dams and flow around cylinder having infinitely long length placed in a flow as an obstacle can be taken as examples of 2-D flows.

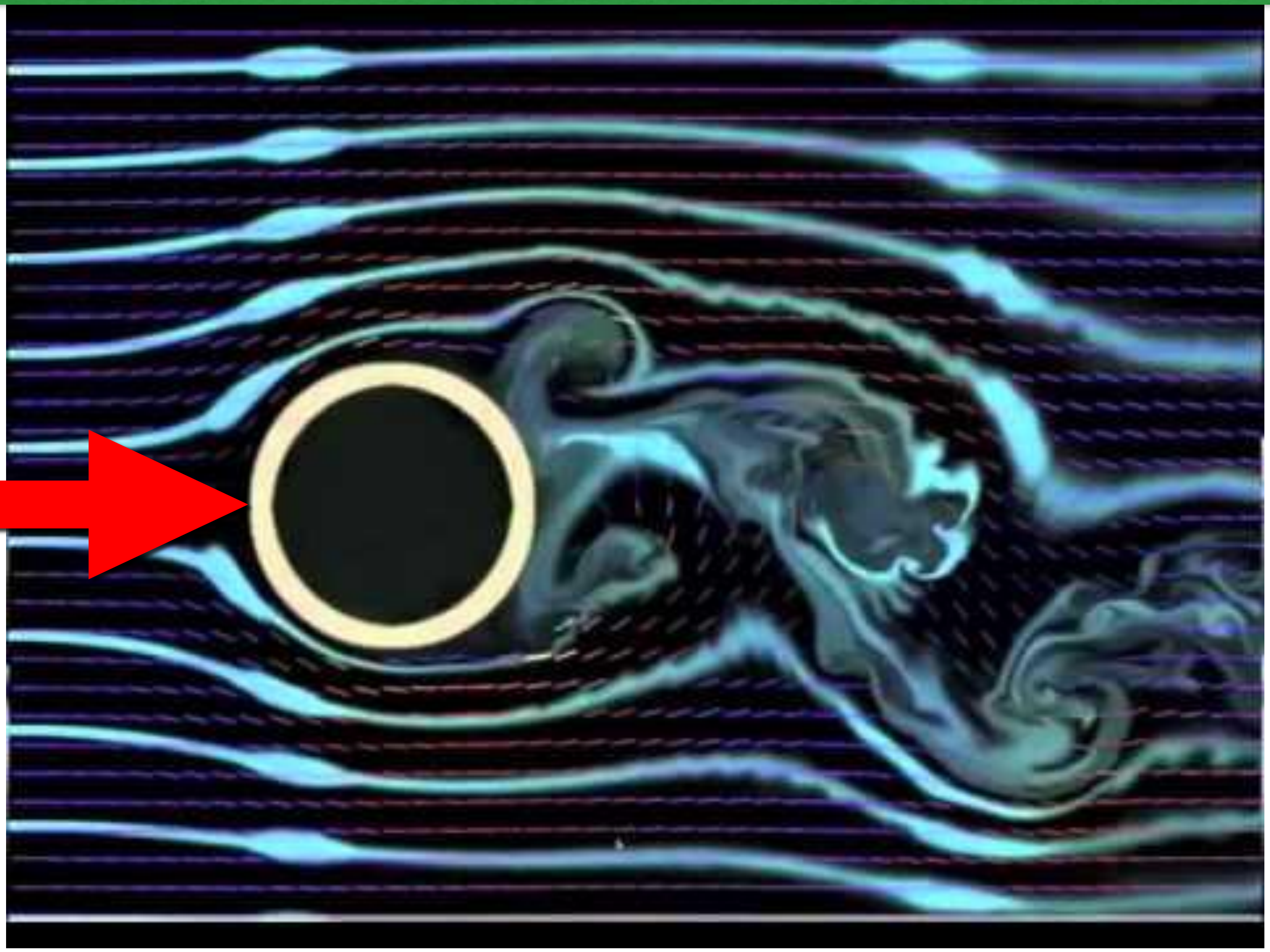




Three dimensional (3-D) flow:

A flow chose characteristics vary in three directions which are perpendicular to each other is termed as ***<u>three dimensional flow.</u>***

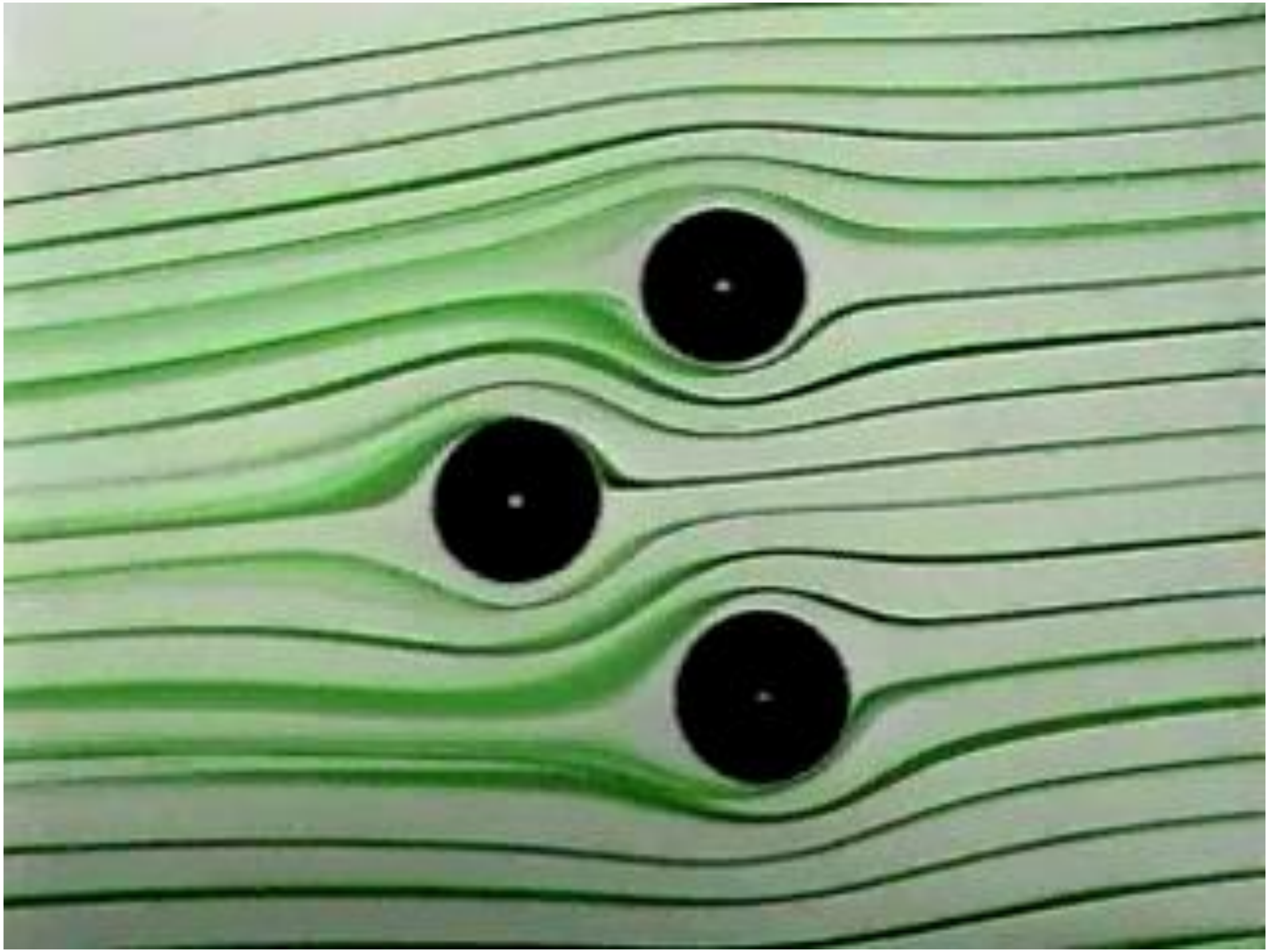
<u>Sphere</u>



A flow around an object whose dimensions change in <u>three</u> ***<u>directions</u>*** *(for example: a* ***<u>sphere</u>****) is an example of such a flow.*

In general,
there is 1 velocity component in 1-D flows,
there are two velocity components in 2-D flow
and
three velocity components in 3-D flows.

Streamlines created by injecting dye into water flowing steadily around a series of cylinders reveal the complex flow pattern around the cylinders



Three-dimensional, unsteady conditions. The flow past an airplane wing provides an example of these phenomena.

Thanks to

Abdusselam Altunkaynak for his lecture notes

http://www.meted.ucar.edu/hydro/basic_int/routing/media/flash/uniform_non_uniform.swf

Munson, Young and Okiishi's Fundamentals of Fluid Mechanics, 8th Edition

Fluid Mechanics: Fundamentals and Applications
by Çengel & Cimbala

https://en.wikipedia.org/wiki/D%27Alembert%27s_paradox