Roadmap to Lecture 0
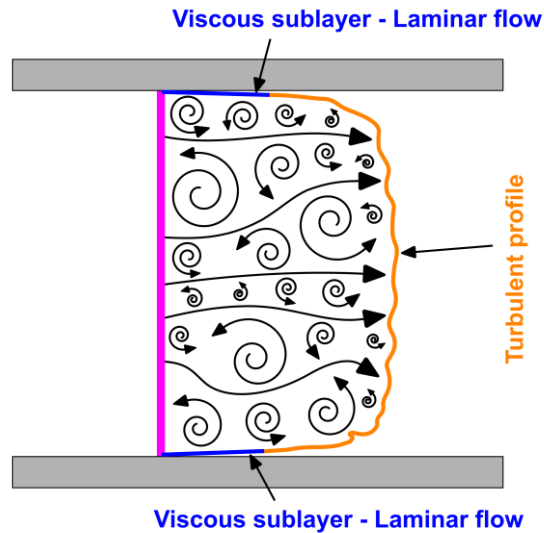
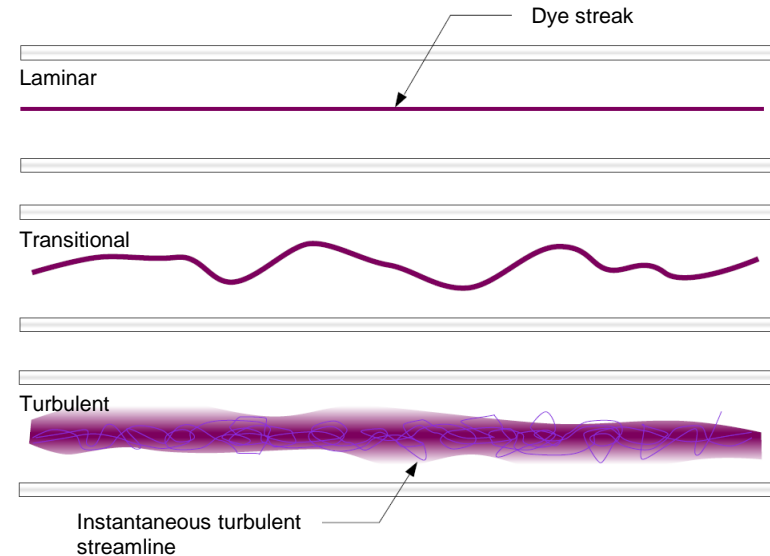1. ~~Quick review of solution methods in CFD~~
2. ~~What is Ansys Fluent? – Executive summary~~
3. **Turbulence in action**

Turbulence modeling – Wall bounded and shear free turbulence


Wall bounded turbulence

Shear free turbulence

- **Turbulent flows can originate at the walls.** When this is the case, we talk about wall bounded turbulence.

- **Turbulent flows can also originate in the absence of walls (or far from walls).** When this is the case, we talk about shear free turbulence (usually jets, heated walls, atmospheric flows).

- But indifferently of the type of turbulence, the turbulent motion has a direct effect on the velocity profiles, wall shear stresses, and mixing of transported quantities (heat transfer rate, species concentration, mass transfer, and so on).

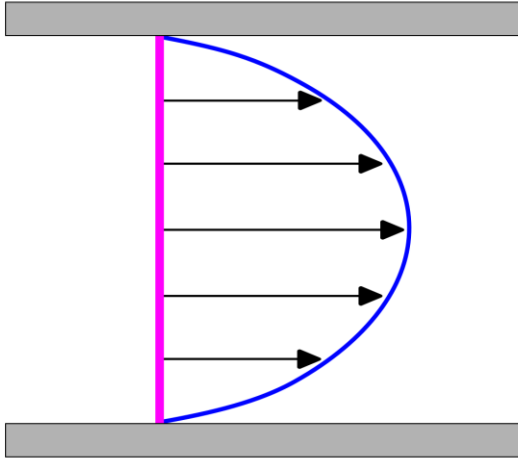## Turbulence modeling – Wall bounded and shear free turbulence
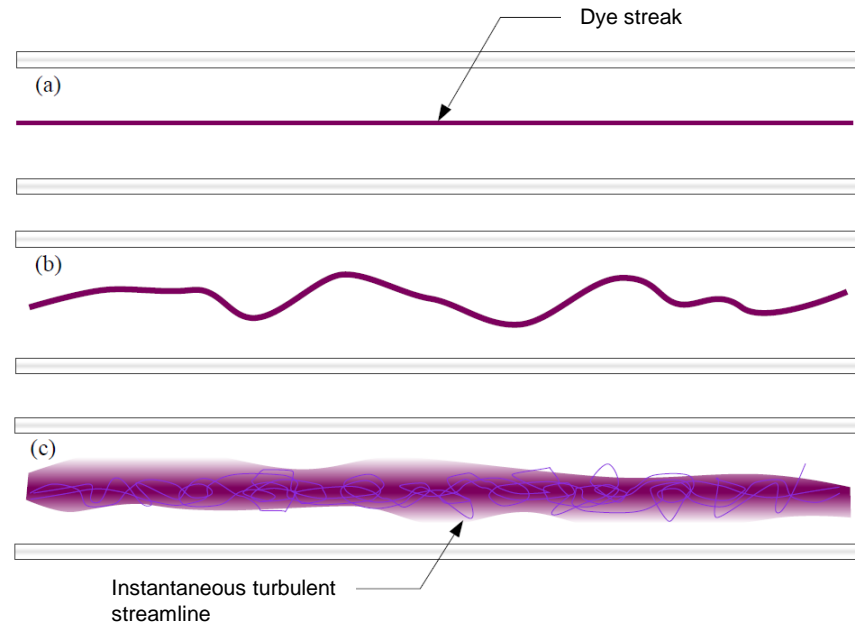
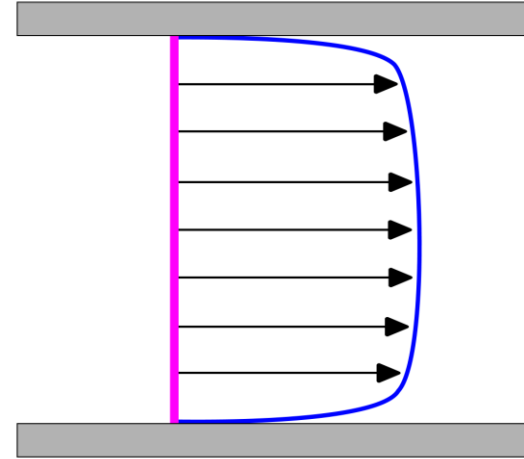Flow in a pipe. (a) Laminar, (b) Transitional, (c) Turbulent

- Turbulence has a direct effect on the velocity profiles and mixing of transported quantities.
    - **Case (a)** correspond to a laminar flow, where the dye can mix with the main flow only via molecular diffusion, this kind of mixing can take very long times.
    - **Case (b)** shows a transitional state where the dye streak becomes wavy, but the main flow still is laminar.
    - **Case (c)** shows the turbulent state, where the dye streak changes direction erratically, and the dye has mixed significantly with the main flow due to the velocity fluctuations.
- This image give us an idea of what happens at the core if the flow, but what about the walls?

3

Turbulence in action

Turbulence modeling – Wall bounded and shear free turbulence
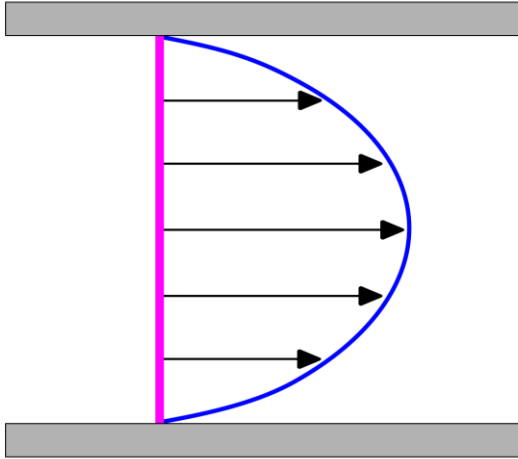
Laminar flow in a pipe
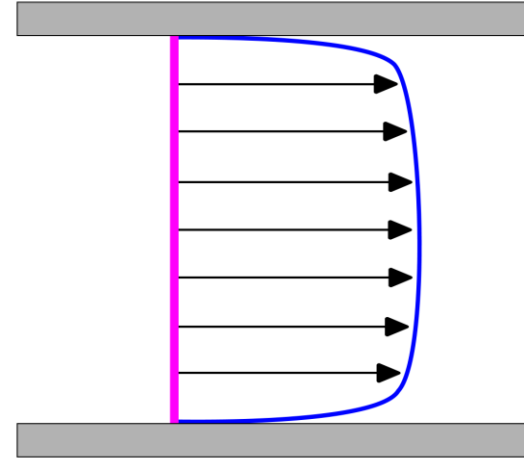
Turbulent flow in a pipe

- Turbulence has a direct effect on the velocity profiles and mixing of transported quantities.
    - In the **laminar case**, the velocity gradient close to the walls is small (therefore the shear stresses are lower).
    - The **turbulent case** shows two regions.
        - One thin region close to the walls with very large velocity gradients (hence large shear stresses).
        - Another region far from the wall where the velocity profile is nearly uniform.
    - The larger the velocity gradient close to the walls, the larger the wall shear stresses will be.

Turbulence modeling – Wall bounded and shear free turbulence

Laminar flow in a pipe

Turbulent flow in a pipe

- Turbulence has a direct effect on the velocity profiles and mixing of transported quantities.
  - In a laminar flow or in the viscous sub-layer*, the wall shear stress τ_{wall} can be approximated as follows,

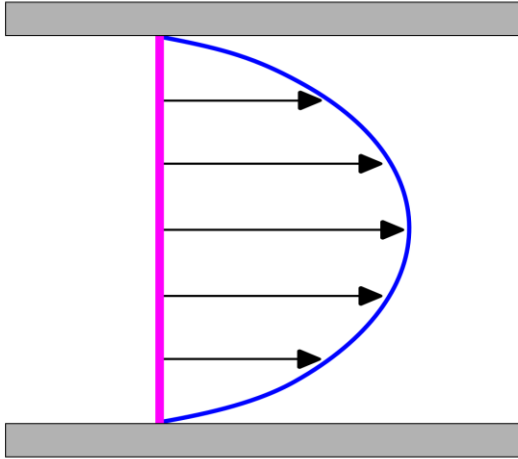$$\tau_{wall} = \mu \frac{\partial u}{\partial y}$$

Note:
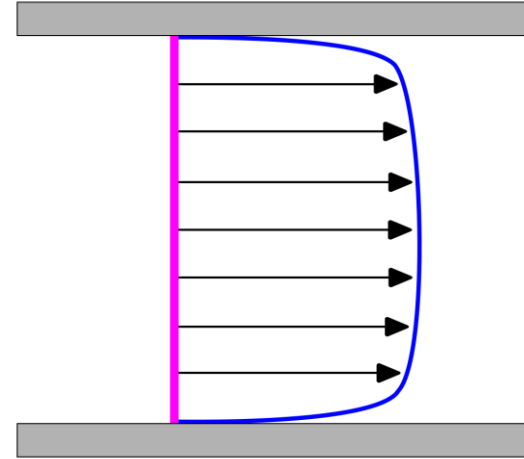This approximation is valid for 2D boundary layers

* The viscous sub-layer is the region of the turbulent boundary layer very close to the wall where the flow is laminar.

Turbulence modeling – Wall bounded and shear free turbulence

Laminar flow in a pipe

Turbulent flow in a pipe

- Turbulence has a direct effect on the velocity profiles and mixing of transported quantities.
  - In a turbulent flow, the wall shear stress τ_{wall} cannot be approximated using the same relation as for laminar flows.
  - We need to add a correction to take into account the effects of the increased mixing, randomness, or agitation of turbulence flows.

Turbulence modeling is about how to approximate/model this term

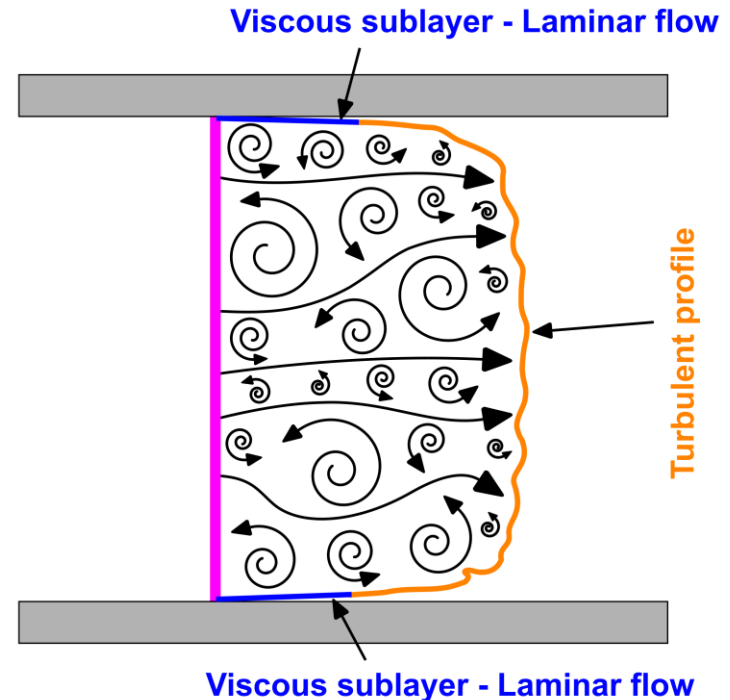$$\tau_{wall} = \mu \frac{\partial u}{\partial y} + \boxed{\tau^R}$$

Note:
This approximation is valid for 2D boundary layers and where $\tau^R = \overline{u'v'}$

Turbulence modeling – Wall bounded and shear free turbulence
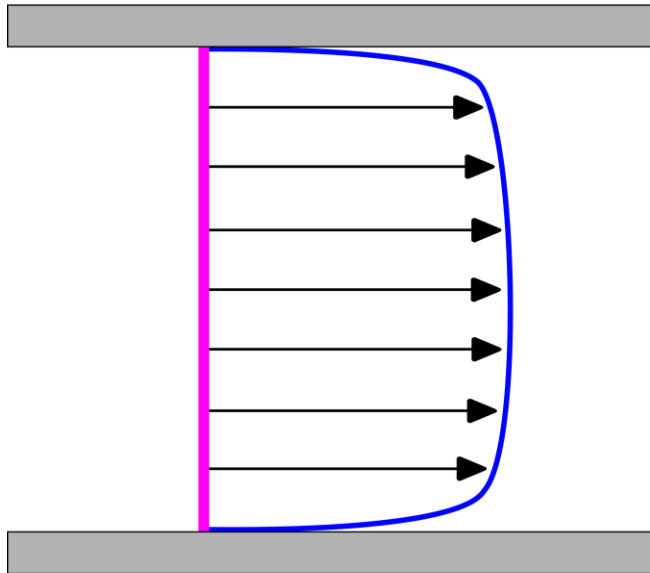
Averaged turbulent flow

Instantaneous turbulent flow

- In the left figure, the velocity profile has been averaged.
- In reality, the velocity profile fluctuates in time (right figure).
- The thin region close to the walls has very large velocity gradients and is laminar.
- Far from the flows, the flow becomes turbulent.
- Turbulence increases the wall shear stresses and enhances mixing.

On the Reynolds number

- It is well known that the Reynolds number characterizes if the flow is laminar or turbulent.

- So before doing a simulation or experiment, check if the flow is turbulent.

- The Reynolds number is defined as follows,

Convective effects $\longrightarrow$

Viscous effects $\longrightarrow$

$$Re_L = \frac{\rho U L}{\mu} = \frac{U L}{\nu}$$

$$\nu = \frac{\mu}{\rho}$$

- Where U is a characteristic velocity, *e.g.*, free-stream velocity.

- And L is representative length scale, *e.g.*, length, height, diameter, etc.

Turbulence in action

On the Reynolds number

- Turbulent flow occurs at large Reynolds number.

    - For external flows,

$$Re_x \geq 500000 \qquad \text{Around slender/streamlined bodies (surfaces)}$$

$$Re_d \geq 20000 \qquad \text{Around an obstacle (bluff bodies)}$$

    - For internal flows,

$$Re_{d_h} \geq 2300$$

- Notice that other factors such as free-stream turbulence, surface conditions, surface roughness and other disturbances, may cause transition to turbulence at lower Reynolds number.

- Turbulent and laminar flows have very different behaviors.

- Turbulent motion has a direct effect on the velocity profiles, wall shear stresses, and mixing of transported quantities (heat transfer rate, species concentration, mass transfer, and so on).

Turbulence in action

Turbulent flows videos
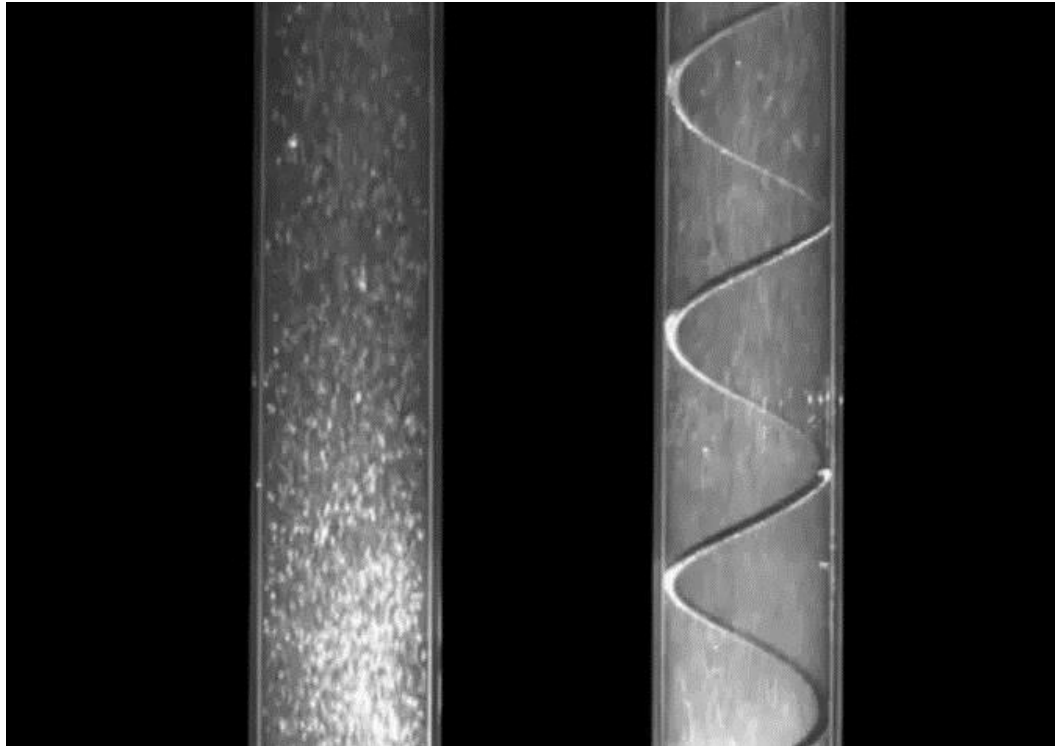
Laminar-Turbulent flow in a pipe
Smooth vs corrugated tube

Video credit: https://www.youtube.com/watch?v=WG-YCpAGgQQ

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Turbulent flows videos

Reynolds' dye experiment
Various types of flow - Laminar-Transitional-Turbulent

Video credit: https://www.youtube.com/watch?v=ontHCuI6eB4
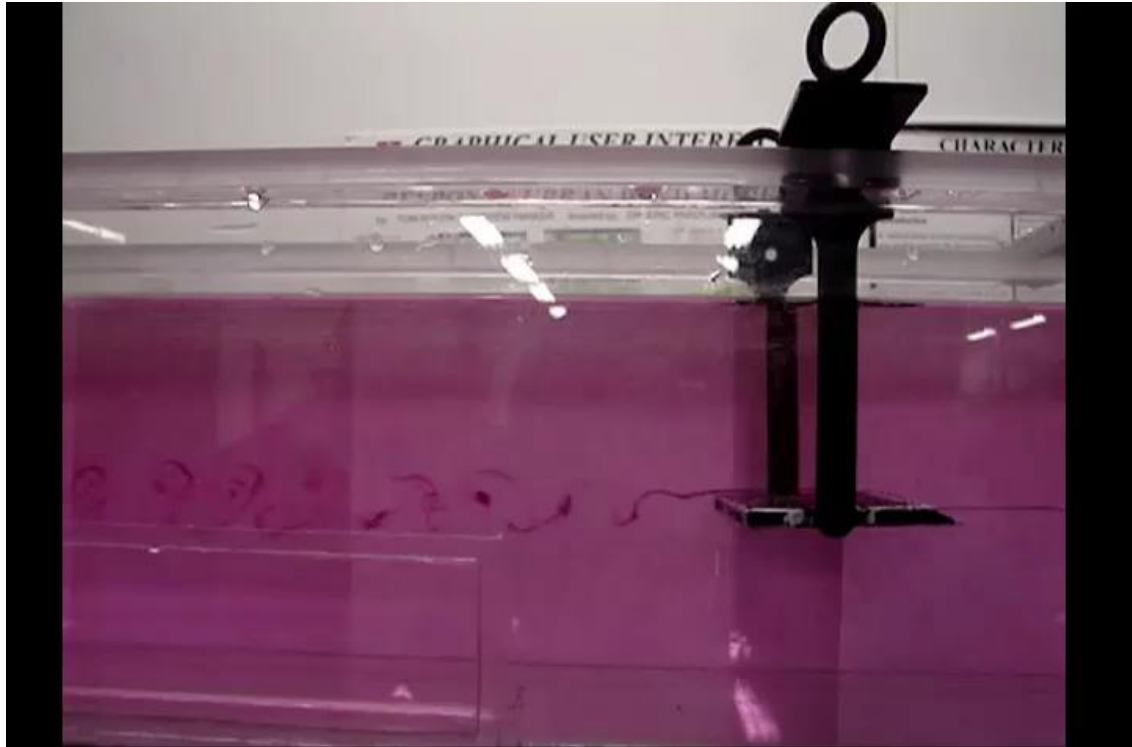
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Turbulent flows videos

Laminar-Turbulent vortex shedding

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Turbulence in action

Turbulent flows videos

Flow over a flat plate
Attached and separated boundary layer

Video credit: https://www.youtube.com/watch?v=zsO5BQA_CZk

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Turbulent flows videos

Turbulent boundary layer on a flat plate

Video credit: https://www.youtube.com/watch?v=e1TbkLIDWys
arXiv: https://arxiv.org/abs/1210.3881

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Turbulence in action

Turbulent flows videos
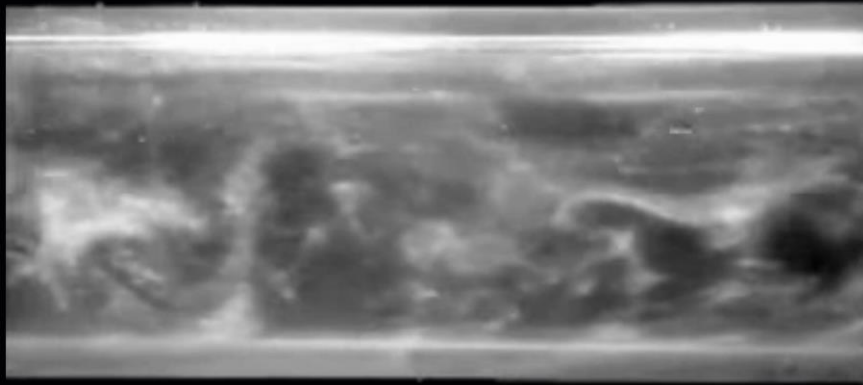
Turbulent flow in a pipe
www.wolfdynamics.com/training/turbulence/video-pipe1.gif

Laminar flow in a pipe
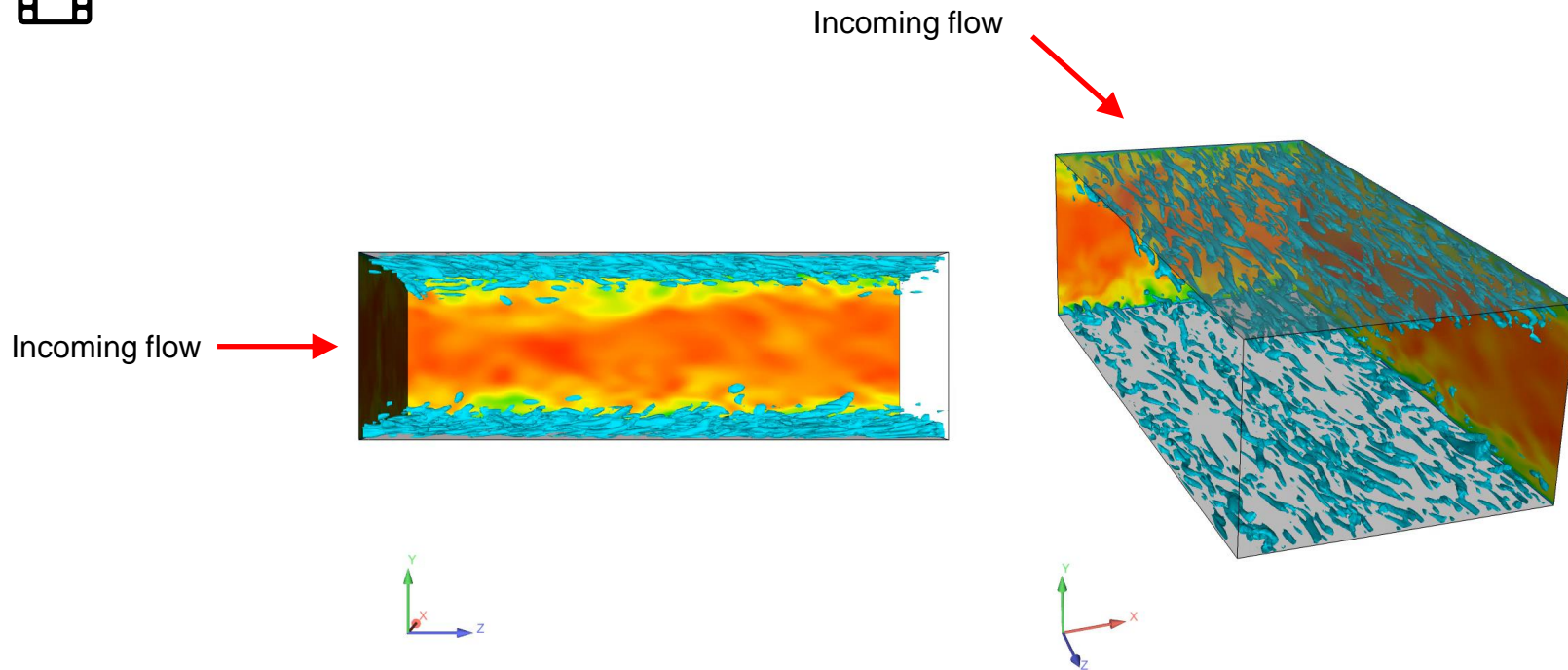www.wolfdynamics.com/training/turbulence/video-pipe2.gif

Turbulent flows simulations

Incoming flow

Incoming flow

Wall bounded flow – Channel flow

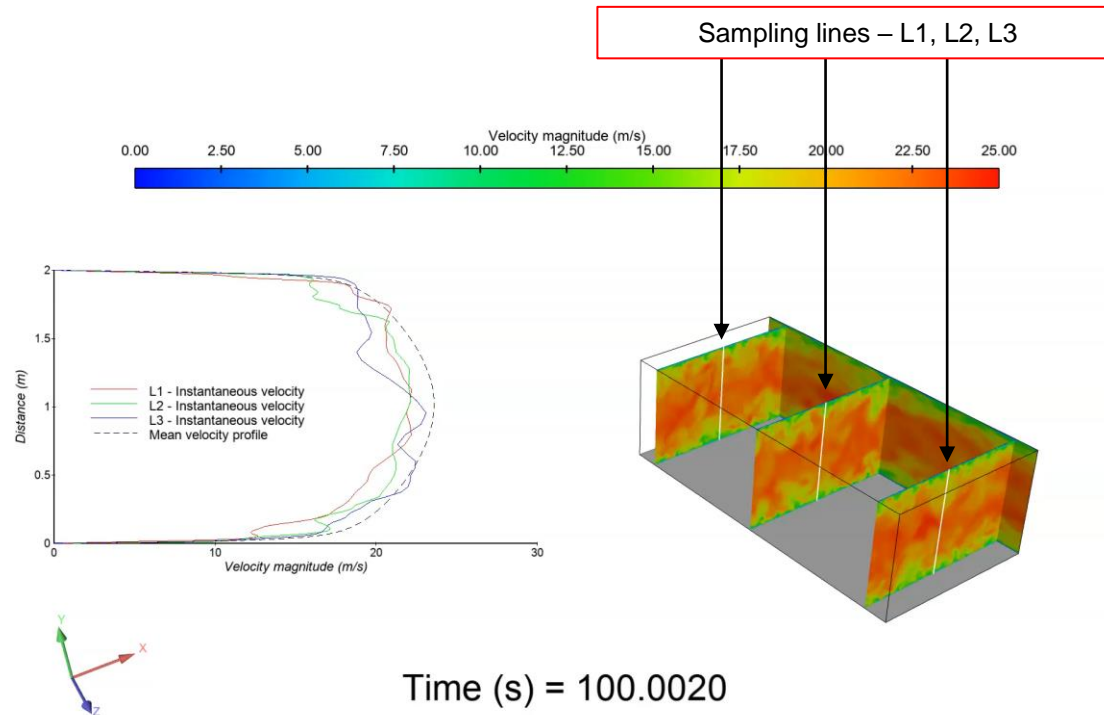**Video credit:** http://www.wolfdynamics.com/training/turbulence/channel1.mp4

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Turbulent flows simulations

Sampling lines – L1, L2, L3

Time (s) = 100.0020

Wall bounded flow – Channel flow

Video credit: http://www.wolfdynamics.com/training/turbulence/channel2.mp4

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Turbulent flows simulations

Kelvin Helmholtz Clouds
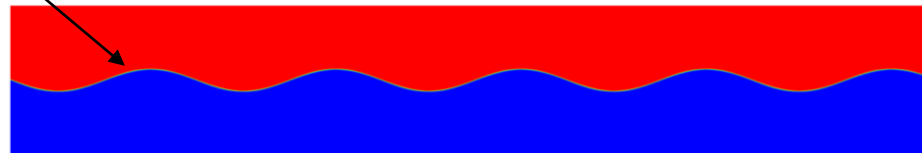Photo credit: **https://www.deviantart.com/yenom/art/Kelvin-Helmholtz-Clouds-5368556**
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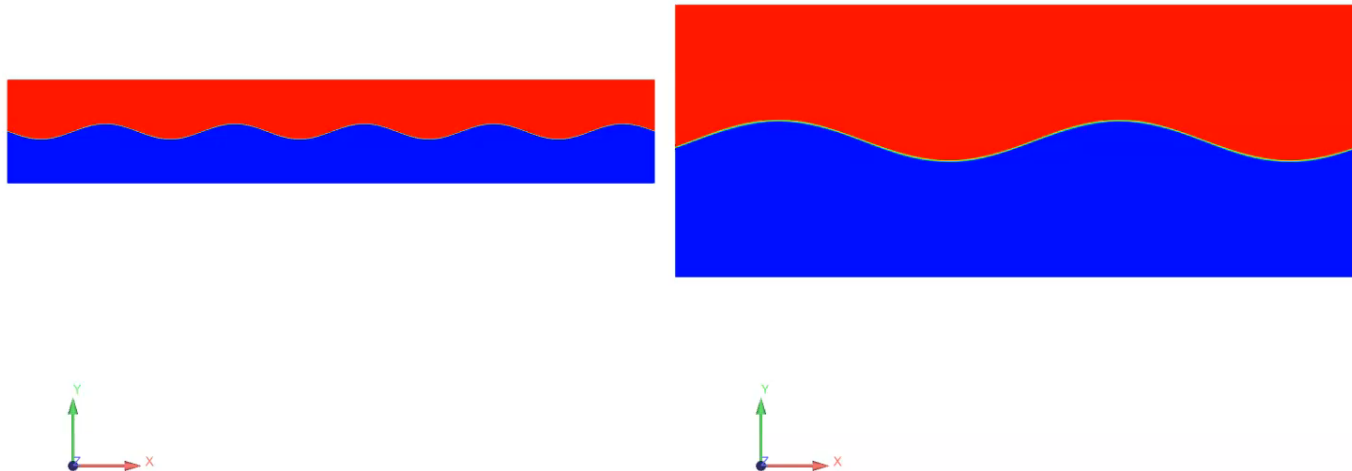
Velocity perturbation

Note:
The top and bottom boundaries are slip walls

Periodic BC

Periodic BC

Shear free flow – Kelvin-Helmholtz instability – Initialization for the numerical simulation

Turbulent flows simulations

Numerical simulation of the Kelvin-Helmholtz instability – Shear free flow

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