FLOW IN DUCTS

There is no general analysis of fluid motion. The reason for this is that very complex changes occur in fluid behavior at moderate Reynolds Numbers. At this introductory level Reynolds number is considered to be the primary parameter affecting transition from laminar to turbulent flow.

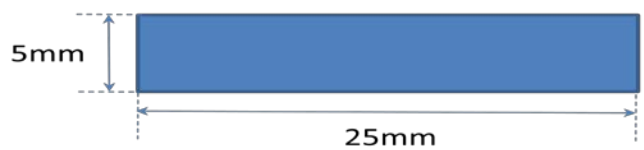
$$\mathrm{Re} = \frac{\rho V L}{\mu}$$

Where V is the average stream velocity, ρ is the fluid density, μ is the fluid dynamic viscosity, and L is the characteristic length.

We use water in the Interactive Experiment. At 20°C, the density and dynamic viscosity for water are $998 kg/m^3$ and $1.003x10^{-3} Ns/m^2$, respectively. In non circular ducts, as we have in our Interactive Experiment, Hydraulic Diameter can be used for L.

$$\text{Hydraulic Diameter} = \frac{4 \text{ x Area}}{\text{Wetted Perimeter}}$$

The value of Hydraulic diameter in our experiment is constant. Based on the following dimensions of the duct in the Interactive Experiment:



The hydraulic diameter is 8.33mm.

The following approximate ranges occur for flow in ducts [2]:

$0 < Re < 1$	:	highly viscous laminar, "creeping" motion
$1 < Re < 10^2$	:	laminar, strong Reynolds number dependence
$10^2 < Re < 10^3$	:	laminar, boundary layer theory useful
$10^3 < Re < 10^4$	:	transition to turbulence
$10^4 < Re < 10^6$	:	turbulent, moderate Reynolds number dependence
$10^6 < Re < \infty$	:	turbulent, slight Reynolds number dependence

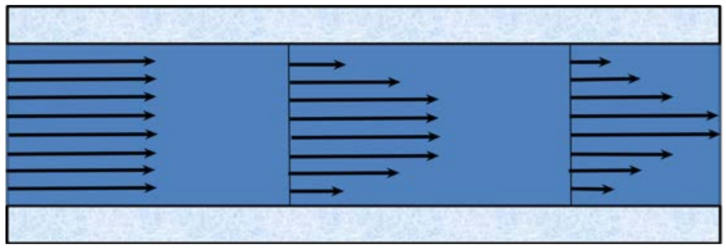
These values of Reynolds number a good indication of the flow regimes, but the values can vary with surface roughness, flow geometry, and inlet flow stream fluctuations.

The flow in our Interactive Experiment is considered to be internal flow because the fluid is constrained by the bounding walls. The viscous boundary layers grow downstream of the entrance to the duct. This results in the retardation of the axial flow at the wall and acceleration of the center fluid so that the incompressible continuity law is satisfied.

The incompressible continuity law states that:

$$Q = \int u \, dA = \text{Constant}$$

Where Q is the flow rate, A is the cross sectional area and u is the velocity.



The parabolic velocity profile, as shown on the far right side of the sketch above, is theoretically reached only after an infinite distance[1]. It is usual to regard this point at which the maximum velocity is only 1% different from the final value[1].

In the Interactive Experiment we are able to study flow not only in straight ducts but also flow over obstructions by inserting various flow models. One flow model studies the effect of reduction in flow area on the flow. The effect can be explained by considering the Bernoulli's equation:

$$\frac{P}{\rho g} + \frac{u^2}{2g} + z = \text{Constant}$$

Where, P is pressure and z is height.

Bernoulli's equation only applies to frictionless (inviscid), steady and constant density flows. Bernoulli's relation is generally true only for a single streamline. We are assuming that you studied the Streamlines notes, in Flowex™.

Our Interactive Experiment is horizontal and so there is no significant gravitational effect on the flow. We can, therefore, eliminate z from the Bernoulli's equation. If we consider the flow in a converging duct, continuity tells us that as the area gets smaller the flow speed increases. Also Bernoulli's equation tells us that as the speed increases pressure must decrease.

References:

1. "Mechanics of Fluids," B. S. Massey, Chapman & Hall, ISBN 0 412 34280 4
2. "Fluid Mechanics," Frank M. White, McGraw-Hill Book Company, ISBN 0 07 069673X