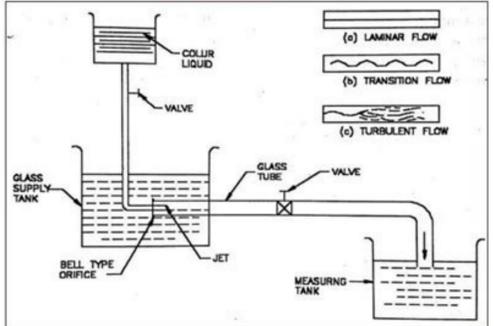


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New Post Editor Dimensionless quantity in fluid mechanics The plume from this candle flame goes from laminar to turbulent. The Reynolds number can be used to predict where this transition will take place. Turbulent (left) and laminar (right) flow of tap water from a faucet. A vortex street around a cylinder. This can occur around cylinders and spheres, for any fluid, cylinder size and fluid speed, provided that it has a Reynolds number between roughly 40 and 1000.[1] George Stokes introduced Reynolds numbers. Osborne Reynolds popularised the concept. The Reynolds number (Re) helps predict flow patterns in different fluid flow situations. At low Reynolds numbers, flows tend to be dominated by laminar (sheet-like) flow, while at high Reynolds numbers flows tend to be turbulent. The turbulence results from differences in the fluid's speed and direction, which may sometimes intersect or even move counter to the overall direction of the flow (eddy currents). These eddy currents begin to churn the flow, using up energy in the process, which for liquids increases the chances of cavitation. Reynolds numbers are an important dimensionless quantity in fluid mechanics. The Reynolds number has wide applications, ranging from liquid flow in a pipe to the passage of air over an aircraft wing. It is used to predict the transition from laminar to turbulent flow, and is used in the scaling of similar but different-sized flow situations, such as between an aircraft model in a wind tunnel and the full size version. The predictions of the onset of turbulence and the ability to calculate scaling effects can be used to help predict fluid behaviour on a larger scale, such as in local or global air or water movement and thereby the associated meteorological and climatological effects. The concept was introduced by George Stokes in 1851,[2] but the Reynolds number was named by Arnold Sommerfeld in 1908[3] after Osborne Reynolds (1842-1912), who popularized its use in 1883.[4][5] Definition The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities. A region where these forces change behavior is known as a boundary layer, such as the bounding surface in the interior of a pipe. A similar effect is created by the introduction of a stream of high-velocity fluid into a low-velocity fluid, such as the hot gases emitted from a flame in air. This relative movement generates fluid friction, which is a factor in developing turbulent flow. Counteracting this effect is the viscosity of the fluid, which tends to inhibit turbulence. The Reynolds number quantifies the relative importance of these two types of forces for given flow conditions, and is a guide to when turbulent flow will occur in a particular situation.[6] This ability to predict the onset of turbulent flow is an important design tool for equipment such as piping systems or aircraft wings, but the Reynolds number is also used in scaling of fluid dynamics problems, and is used to determine dynamic similitude between two different cases of fluid flow, such as between a model aircraft, and its full-size version. Such scaling is not linear and the application of Reynolds numbers to both situations allows scaling factors to be developed. With respect to laminar and turbulent flow regimes: laminar flow occurs at low Reynolds numbers, where viscous forces are dominant, and is characterized by smooth, constant fluid motion; turbulent flow occurs at high Reynolds numbers and is dominated by inertial forces, which tend to produce chaotic eddies, vortices and other flow instabilities.[7] The Reynolds number is defined as[3] $Re = \frac{\rho u L}{\mu}$ where: ρ is the density of the fluid (SI units: kg/m³) u is the flow speed (m/s) L is a characteristic linear dimension (m) (see the below sections of this article for examples) μ is the dynamic viscosity of the fluid (Pa·s or N·s/m² or kg/(m·s)) ν is the kinematic viscosity of the fluid (m²/s). The Brzina equation The Reynolds number can be defined for several different situations where a fluid is in relative motion to a surface.[n 1] These definitions generally include the fluid properties of density and viscosity, plus a velocity and a characteristic length or characteristic dimension (L in the above equation). This dimension is a matter of convention - for example radius and diameter are equally valid to describe spheres or circles, but one is chosen by convention. For aircraft or ships, the length or width can be used. For flow in a pipe, or for a sphere moving in a fluid, the internal diameter is generally used today. Other shapes such as rectangular pipes or non-spherical objects have an equivalent diameter defined. For fluids of variable density such as compressible gases or fluids of variable viscosity such as non-Newtonian fluids, special rules apply. The velocity may also be a matter of convention in some circumstances, notably stirred vessels. In practice, matching the Reynolds number is not on its own sufficient to guarantee similitude. Fluid flow is generally chaotic, and very small changes to shape and surface roughness of bounding surfaces can result in very different flows. Nevertheless, Reynolds numbers are a very important guide and are widely used. History Osborne Reynolds's apparatus of 1883 demonstrating the onset of turbulent flow. The apparatus is still at the University of Manchester. Diagram from Reynolds's 1883 paper showing onset of turbulent flow. Osborne Reynolds famously studied the conditions in which the flow of fluids in pipes transitioned from laminar flow to turbulent flow. In his 1883 paper Reynolds described the transition from laminar to turbulent flow in a classic experiment in which he examined the behaviour of water flow under different flow velocities using a small stream of dyed water introduced into the centre of clear water flow in a larger pipe. The larger pipe was glass so the behaviour of the layer of the dyed stream could be observed. At the end of this pipe there was a flow control valve used to vary the water velocity inside the tube. When the velocity was low, the dyed layer remained distinct through the entire length of the large tube. When the velocity was increased, the layer broke up at a given point and diffused throughout the fluid's cross-section. The point at which this happened was the transition point from laminar to turbulent flow. From these experiments came the dimensionless Reynolds number for dynamic similarity—the ratio of inertial forces to viscous forces. Reynolds also proposed what is now known as the Reynolds averaging of turbulent flows, where quantities such as velocity are expressed as the sum of mean and fluctuating components. Such averaging allows for 'bulk' description of turbulent flow, for example using the Reynolds-averaged Navier-Stokes equations. Flow in a pipe For flow in a pipe or tube, the Reynolds number is generally defined as[8] $Re = \frac{\rho u D_H \nu}{\mu}$ where D_H is the hydraulic diameter of the pipe (the inside diameter if the pipe is circular) (m), Q is the volumetric flow rate (m³/s), A is the pipe's cross-sectional area ($A = \pi D^2/4$) (m²), u is the mean velocity of the fluid (m/s), μ (mu) is the dynamic viscosity of the fluid (Pa·s = N·s/m² = kg/(m·s)), ν (nu) is the kinematic viscosity ($\nu = \mu/\rho$) (m²/s), ρ (rho) is the density of the fluid (kg/m³), W is the mass flowrate of the fluid (kg/s). For shapes such as squares, rectangular or annular ducts where the height and width are comparable, the characteristic dimension for internal-flow situations is taken to be the hydraulic diameter, D_H , defined as $D_H = 4A/P$, where A is the cross-sectional area, and P is the wetted perimeter. The wetted perimeter for a channel is the total perimeter of all channel walls that are in contact with the flow.[9] This means that the length of the channel exposed to air is not included in the wetted perimeter. For a circular pipe, the hydraulic diameter is exactly equal to the inside pipe diameter: $D_H = D$. For an annular duct, such as the outer channel in a tube-in-tube heat exchanger, the hydraulic diameter can be shown algebraically to reduce to $D_{H,annulus} = D_o - D_i$, where D_o is the outside diameter of the outer pipe, D_i is the inside diameter of the inner pipe. For calculation involving flow in non-circular ducts, the hydraulic diameter can be substituted for the diameter of a circular duct, with reasonable accuracy, if the aspect ratio AR of the duct cross-section remains in the range $1/4 < AR < 4$. [10] Laminar-turbulent transition Main article: Laminar-turbulent transition In boundary layer flow over a flat plate, experiments confirm that, after a certain length of flow, a laminar boundary layer will become unstable and turbulent. This instability occurs across different scales and with different fluids, usually when $Re_x = 5 \times 10^5$, [11] where x is the distance from the leading edge of the flat plate, and the flow velocity is the freestream velocity of the fluid outside the boundary layer. For flow in a pipe of diameter D , experimental observations show that for "fully developed" laminar flow occurs when $Re_D < 2300$ and turbulent flow occurs when $Re_D > 2900$. [12][13] At the lower end of this range, a continuous turbulent-flow will form, but only at a very long distance from the inlet of the pipe. The flow in between will begin to transition from laminar to turbulent and then back to laminar at irregular intervals, called intermittent flow. This is due to the different speeds and conditions of the fluid in different areas of the pipe's cross-section, depending on other factors such as pipe roughness and flow uniformity. Laminar flow tends to dominate in the fast-moving center of the pipe while slower-moving turbulent flow dominates near the wall. As the Reynolds number increases, the continuous turbulent-flow moves closer to the inlet and the intermittency in between increases, until the flow becomes fully turbulent at $Re_D > 2900$. [12] This result is generalized to non-circular channels using the hydraulic diameter, allowing a transition Reynolds number to be calculated for other shapes of channel. [12] These transition Reynolds numbers are also called critical Reynolds numbers, and were studied by Osborne Reynolds around 1895. [5] The critical Reynolds number is different for every geometry. [14] Flow in a wide duct For a fluid moving between two plane parallel surfaces—where the width is much greater than the space between the plates—then the characteristic dimension is equal to the distance between the plates. [15] This is consistent with the annular duct and rectangular duct cases above taken to a limiting aspect ratio. Flow in an open channel For flow of liquid with a free surface, the hydraulic radius must be determined. This is the cross-sectional area of the channel divided by the wetted perimeter. For a semi-circular channel, the hydraulic radius is the cross-sectional area divided by the wetted perimeter. Some texts then use a characteristic dimension that is four times the hydraulic radius, chosen because it gives the same value of Re for the onset of turbulence as in pipe flow. [16] while others use the hydraulic radius as the characteristic length-scale with consequently different values of Re for transition and turbulent flow. Flow around airfoils Reynolds numbers are used in airfoil design to (among other things) manage "scale effect" when computing/comparing characteristics (a tiny wing, scaled to be huge, will perform differently). [17] Fluid dynamicists define the chord Reynolds number R like this: $R = Vc/\nu$, where V is the flight speed, c is the chord length, and ν is the kinematic viscosity of the fluid in which the air foil operates, which is 1.460×10^{-5} m²/s for the atmosphere at sea level. [18] In some special studies a characteristic length other than chord may be used; rare is the "span Reynolds number", which is not to be confused with span wise stations on a wing, where chord is still used. [19] Object in a fluid The high viscosity of honey results in perfectly laminar flow when poured from a bucket, while the low surface tension allows it to remain sheet-like even after reaching the fluid below. Analogous to turbulence, when the flow meets resistance it slows and begins oscillating back and forth, piling upon itself. The Reynolds number for an object moving in a fluid, called the particle Reynolds number

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