Compressible fluid dynamics pdf

Fluid dynamics is the study of the movement of fluids, including their interactions as two fluids come into contact with each other. In this context, the term "fluid" refers to either liquid or gases. It is a macroscopic, statistical approach to analyzing these interactions at a large scale, viewing the fluids as a continuum of matter and generally ignoring the fact that the liquid or gas is composed of individual atoms. Fluid dynamics is one of the two main branches of fluid mechanics, with the other branch being fluid statics, the study of fluids at rest. (Perhaps not surprisingly, fluid statics may be thought of as a bit less exciting most of the time than fluid dynamics.) Every discipline involves concepts that are crucial to understanding how it operates. Here are some of the main ones that you'll come across when trying to understand fluid dynamics. The fluid concepts that apply in fluid statics also come into play when studying fluid that is in motion. Pretty much the earliest concept in fluid mechanics is that of buoyancy, discovered in ancient Greece by Archimedes. As fluids flow, the density and pressure of the fluids are also crucial to understanding how they will interact. The viscosity determines how resistant the liquid is to change, so is also essential in studying the movement of the liquid. Here are some of the variables that come up in these analyses: Bulk viscosity: μDensity: ρKinematic viscosity: $\nu = \mu / \rho$ Since fluid dynamics involves the study of the motion of fluid, one of the first concepts that must be understood is how physicists quantify that movement. The term that physicists use to describe the physical properties of the movement of liquid is flow. Flow describes a wide range of fluid movement, such blowing through the air, flowing through a pipe, or running along a surface. The flow of a fluid is classified in a variety of different ways, based upon the various properties of the flow. If the movement of fluid does not change over time, it is considered a steady flow. This is determined by a situation where all properties of the flow remain constant with respect to time or alternately can be talked about by saying that the time-derivatives of the flow field vanish. (Check out calculus for more about understanding derivatives.) A steady-state flow is even less time-dependent because all of the fluid properties (not just the flow properties) remain constant at every point within the fluid. So if you had a steady flow, but the properties of the fluid itself changed at some point (possibly because of a barrier causing time-dependent ripples in some parts of the fluid), then you would have a steady flow that is not a steady-state flow. All steady-state flows are examples of steady flows, though. A current flowing at a constant rate through a straight pipe would be an example of a steady-state flow (and also a steady flow). If the flow itself has properties that change over time, then it is called an unsteady flow or a transient flow. Rain flowing into a gutter during a storm is an example of unsteady flow. As a general rule, steady flows make for easier problems to deal with than unsteady flows, which is what one would expect given that the time-dependent changes to the flow don't have to be taken into account, and things that change over time are typically going to make things more complicated. A smooth flow of liquid is said to have laminar flow. Flow that contains seemingly chaotic, non-linear motion is said to have turbulent flow. By definition, a turbulent flow is a type of unsteady flow. Both types of flows may contain eddies, vortices, and various types of recirculation, though the more of such behaviors that exist the more likely the flow is to be classified as turbulent. The distinction between whether a flow is laminar or turbulent is usually related to the Reynolds number (Re). The Reynolds number was first calculated in 1951 by physicist George Gabriel Stokes, but it is named after the 19th-century scientist Osborne Reynolds. The Reynolds number is dependent not only on the specifics of the fluid itself but also on the conditions of its flow, derived as the ratio of inertial forces to viscous forces in the following way: Re = Inertial force / Viscous forces $Re = (\rho V dV/dx) / (\mu d2V/dx2)$ The term dV/dx is the gradient of the velocity (or first derivative of the velocity), which is proportional to the velocity (V) divided by L, representing a scale of length, resulting in $dV/dx = V/L$. The second derivative is such that $d2V/dx2 = V/L2$. Substituting these in for the first and second derivatives results in: $Re = (\rho V V/L) / (\mu V/L2)$ $Re = (\rho V L) / \mu$ You can also divide through by the length scale L, resulting in a Reynolds number per foot, designated as $Re f = V / \nu$. A low Reynolds number indicates smooth, laminar flow. A high Reynolds number indicates a flow that is going to demonstrate eddies and vortices and will generally be more turbulent. Pipe flow represents a flow that is in contact with rigid boundaries on all sides, such as water moving through a pipe (hence the name "pipe flow") or air moving through an air duct. Open-channel flow describes flow in other situations where there is at least one free surface that is not in contact with a rigid boundary. (In technical terms, the free surface has 0 parallel sheer stress.) Cases of open-channel flow include water moving through a river, floods, water flowing during rain, tidal currents, and irrigation canals. In these cases, the surface of the flowing water, where the water is in contact with the air, represents the "free surface" of the flow. Flows in a pipe are driven by either pressure or gravity, but flows in open-channel situations are driven solely by gravity. City water systems often use water towers to take advantage of this, so that the elevation difference of the water in the tower (the hydrodynamic head) creates a pressure differential, which is then adjusted with mechanical pumps to get water to the locations in the system where they are needed. Gases are generally treated as compressible fluids because the volume that contains them can be reduced. An air duct can be reduced by half the size and still carry the same amount of gas at the same rate. Even as the gas flows through the air duct, some regions will have higher densities than other regions. As a general rule, being incompressible means that the density of any region of the fluid does not change as a function of time as it moves through the flow. Liquids can also be compressed, of course, but there's more of a limitation on the amount of compression that can be made. For this reason, liquids are typically modeled as if they were incompressible. Bernoulli's principle is another key element of fluid dynamics, published in Daniel Bernoulli's 1738 book Hydrodynamica. Simply put, it relates the increase of speed in a liquid to a decrease in pressure or potential energy. For incompressible fluids, this can be described using what is known as Bernoulli's equation: $(v2/2) + gz + p/\rho = constant$ Where g is the acceleration due to gravity, ρ is the pressure throughout the liquid, v is the fluid flow speed at a given point, z is the elevation at that point, and p is the pressure at that point. Because this is constant within a fluid, this means that these equations can relate any two points, 1 and 2, with the following equation: $(v12/2) + gz1 + p1/\rho = (v22/2) + gz2 + p2/\rho$ The relationship between pressure and potential energy of a liquid based on elevation is also related through Pascal's Law. Two-thirds of the Earth's surface is water and the planet is surrounded by layers of atmosphere, so we are literally surrounded at all times by fluids ... almost always in motion. Thinking about it for a bit, this makes it pretty obvious that there would be a lot of interactions of moving fluids for us to study and understand scientifically. That's where fluid dynamics comes in, of course, so there's no shortage of fields that apply concepts from fluid dynamics. This list is not at all exhaustive, but provides a good overview of ways in which fluid dynamics show up in the study of physics across a range of specializations: Oceanography, Meteorology, & Climate Science - Since the atmosphere is modeled as fluids, the study of atmospheric science and ocean currents, crucial for understanding and predicting weather patterns and climate trends, relies heavily on fluid dynamics. Aeronautics - The physics of fluid dynamics involves studying the flow of air to create drag and lift, which in turn generate the forces that allow heavier-than-air flight. Geology & Geophysics - Plate tectonics involves studying the motion of the heated matter within the liquid core of the Earth. Hematology & Hemodynamics - The biological study of blood includes the study of its circulation through blood vessels, and the blood circulation can be modeled using the methods of fluid dynamics. Plasma Physics - Though neither a liquid nor a gas, plasma often behaves in ways that are similar to fluids, so can also be modeled using fluid dynamics. Astrophysics & Cosmology - The process of stellar evolution involves the change of stars over time, which can be understood by studying how the plasma that composes the stars flows and interacts within the star over time. Traffic Analysis - Perhaps one of the most surprising applications of fluid dynamics is in understanding the movement of traffic, both vehicular and pedestrian traffic. In areas where the traffic is sufficiently dense, the whole body of traffic can be treated as a single entity that behaves in ways that are roughly similar enough to the flow of a fluid. Fluid dynamics is also sometimes referred at as hydrodynamics, although this is more of a historical term. Throughout the twentieth century, the phrase "fluid dynamics" became much more commonly used. Technically, it would be more appropriate to say that hydrodynamics is when fluid dynamics is applied to liquids in motion and aerodynamics is when fluid dynamics is applied to gases in motion. However, in practice, specialized topics such as hydrodynamic stability and magnetohydrodynamics use the "hydro-" prefix even when they are applying those concepts to the motion of gases.

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