Laminar Boundary Layer Theory

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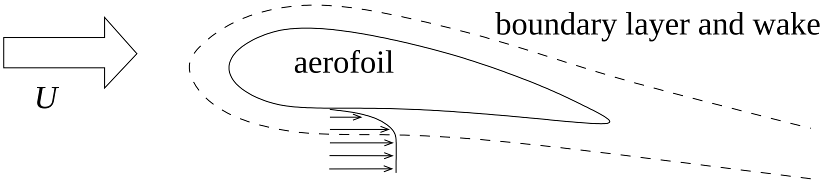
Abstract

This is a course in the theory of the thin boundary layer that forms when fluid flows past a solid body at high Reynolds number.

Section 1: The basic equations of fluid dynamics. We start by deriving the basic equations of viscous fluid flow. Most of the material in this section should be revision (but I've assumed no prior knowledge, in case it isn't).

Section 2: Introducing the boundary layer. Using the equations derived in Section 1, we consider the relative importance of inertial and viscous forces in a fluid. This is expressed by a dimensionless quantity called the Reynolds number. We consider flow past a solid obstacle at high Reynolds number, and give simple arguments to show that a thin boundary layer must form, over which the fluid velocity decreases precipitously from its bulk flow value to zero ("no slip") at the solid surface.



Section 3: The boundary layer equations. Here we put the qualitative discussion of Section 2 on a more formal footing by deriving the equations to be used in the analysis of various boundary layer phenomena in section 4.

Section 4: Exact solutions of the boundary layer equations. We start with the simplest exact solution of the equations derived in Section 3: the boundary layer that forms when fluid flows past a flat plate at zero angle of incidence. Using this example, we motivate the existence of self-similar solutions to the boundary layer equations and apply this idea to more general flow geometries. We discuss flow round blunt obstacles and show that the boundary layer can often separate from the surface, causing a turbulent wake that leads to large drag. We discuss techniques for eliminating this undesirable phenomenon, such as the careful streamlining of aerofoils. Finally, we apply boundary layer theory to fluid jets.

Section 5: Compressible flows. In sections 1 to 4 we made the simplifying assumption that the fluid is incompressible. We now discuss the conditions under which this assumption breaks down, and present the equations necessary to describe the way in which the thermodynamics of compression interacts with the mechanics of flow.