II.2 Classification of fluid flows

The motion, or *flow*[(xxix)], of a fluid can be characterized according to several criteria, either purely geometrical (Sec. II.2.1), kinematic (Sec. II.2.2), or of a more physical nature (Sec. II.2.3), i.e. taking into account the physical properties of the flowing fluid.

II.2.1 Geometrical criteria

In the general case, the quantities characterizing the properties of a fluid flow will depend on time as well as on three spatial coordinates.

For some more or less idealized models of actual flows, it may turn out that only two spatial coordinates play a role, in which case one talks of a *two-dimensional flow*. An example is the flow of air around the wing of an airplane, which in first approximation is "infinitely" long compared to its transverse profile: the (important!) effects at the ends of the wing, which introduce the dependence on the spatial dimension along the wing, may be left aside in a first approach, then considered in a second, more detailed step.

In some cases, e.g. for fluid flows in pipes, one may even assume that the properties only depend on a single spatial coordinate, so that the flow is *one-dimensional*. In that approximation, the physical local quantities are actually often replaced by their average value over the cross section of the pipe.

On a different level, one also distinguishes between *internal* und *external* fluid flows, according to whether the fluid is enclosed inside solid walls—e.g. in a pipe—or flowing around a body—e.g. around an airplane wing.

II.2.2 Kinematic criteria

The notions of *uniform*—i.e. independent of position—and *steady*—independent of time—motions were already introduced at the end of Sec. I.3.3. Accordingly, there are *non-uniform* and *unsteady* fluids flows.

If the vorticity vector $\vec{\omega}(t,\vec{r})$ vanishes at every point $\vec{r}$ of a flowing fluid, then the corresponding motion is referred to as an *irrotational flow*[(xxx)] or, for reasons that will be clarified in Sec. ???, *potential flow*. The opposite case is that of a *rotational flow*.[(xxxi)]

According to whether the flow velocity v is smaller or larger than the (local) speed of sound c_s, one talks of *subsonic* or *supersonic* motion[(xxxii)], corresponding respectively to a dimensionless *Mach number*[(e)]

$$\boxed{\mathrm{Ma} \equiv \frac{\mathsf{v}}{c_s}} \tag{II.15}$$

smaller or larger than 1.

When the fluid flows in layers that do not mix with each other, so that the streamlines remain parallel, the flow is referred to as *laminar*. In the opposite case the flow is *turbulent*.

II.2.3 Physical criteria

All fluids are compressible, more or less according to the substance and its thermodynamic state. Nevertheless, this compressibility is sometimes irrelevant for a given motion, in which case it may fruitful to consider that the fluid flow is *incompressible*, which as was seen in § II.1.3 a technically means that its volume expansion rate vanishes, $\vec{\nabla}\cdot\vec{\mathsf{v}} = 0$. In the opposite case ($\vec{\nabla}\cdot\vec{\mathsf{v}} \neq 0$), the flow is said to be *compressible*. It is however important to realize that the statement is more a kinematic one, than really reflecting the thermodynamic compressibility of the fluid.

[(xxix)] *Strömung* [(xxx)] *wirbelfreie Strömung* [(xxxi)] *Wirbelströmung* [(xxxii)] *Unterschall-* bzw. *Überschallströmung*

[(e)] E. Mach, 1838–1916

In practice, flows are compressible in regions where the fluid velocity is "large", namely where the Mach number (II.15) is not much smaller than 1, i.e. roughly speaking Ma $\gtrsim 0.2$.

In an analogous manner, one speaks of viscous resp. non-viscous flows to express the fact that the fluid under consideration is modeled as viscous resp. inviscid—which leads to different equations of motion—, irrespective of the fact that every fluid has a non-zero viscosity.

Other thermodynamic criteria are also used to characterize possible fluid motions: isothermal flows—i.e. in which the temperature is uniform and remains constant—, isentropic flows—i.e. without production of entropy—, and so on.

Bibliography for Chapter II

- National Committee for Fluid Mechanics films & film notes on *Deformation of Continuous Media*;
- Faber [1] Chapter 2.4.
- Feynman [8, 9] Chapter 39–1
- Guyon *et al.* [2] Chapters 3.1, 3.2