Shadowgraph and Schlieren Techniques

Another set of flow visualization techniques is based on the property that the refractive index of a fluid can vary with the local fluid temperature. These come in various levels of sophistication, the commonest being shadowgraph and Schlieren techniques.

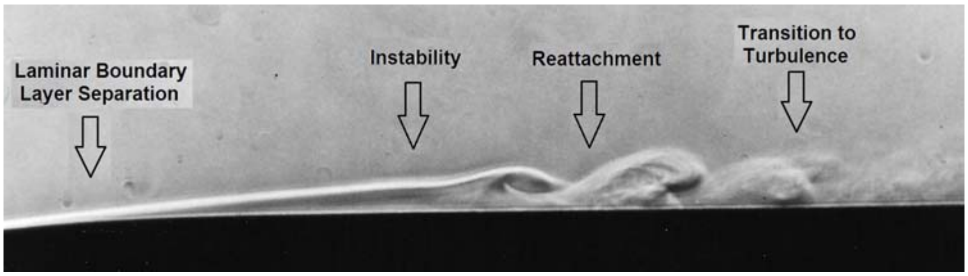

Figure 1: Shadowgraph photograph taken by V. Arakeri of the development of the boundary layer flow on the surface of an object in a water tunnel. The flow is from the left to the right.

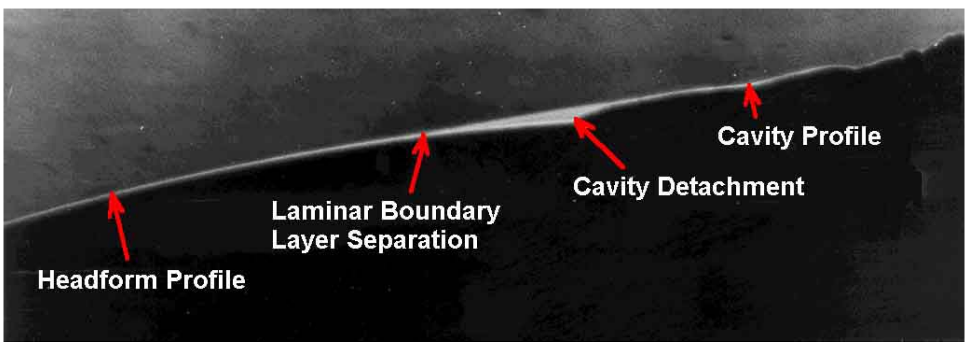

Figure 2: Shadowgraph of the boundary layer on a body in a water tunnel with cavitation separation.

The shadowgraph is the simplest form of optical system suitable for observing a flow exhibiting variations of the fluid density. In principle, the system does not need any optical component except a light source and a recording plane onto which to project the shadow of the varying density field (Figure 1). A shadow effect is generated because a light ray is refractively deflected so that the position on the recording plane where the undeflected ray would arrive now remains dark. At the same time the position where the deflected ray arrives appears brighter than the undisturbed environment. A visible pattern of variations of the illumination (contrast) is thereby produced in the recording plane. From an analysis of the optics of the shadow effect [see, e.g., Merzkirch (1981,1987)], it follows that the visible signal depends on the second derivative of the refractive index of the fluid. Therefore, the shadowgraph as an optical diagnostic technique is sensitive to changes of the second derivative of the fluid density.

It is evident that the shadowgraph is not a method suitable for quantitative measurement of the fluid density. Owing to its simplicity, however, the shadowgraph is a convenient method of obtaining a quick survey of a flow in which the density changes in the described way. This applies particularly to compressible gas flows with shock waves that can be considered as alterations of the gas density with an extremely intense change in curvature of the density profile, i.e., a change of the respective second derivative. The observation of shock waves in gases by means of shadowgraphy goes back to the 19th century when these flow phenomena were discovered by means of this optical technique.

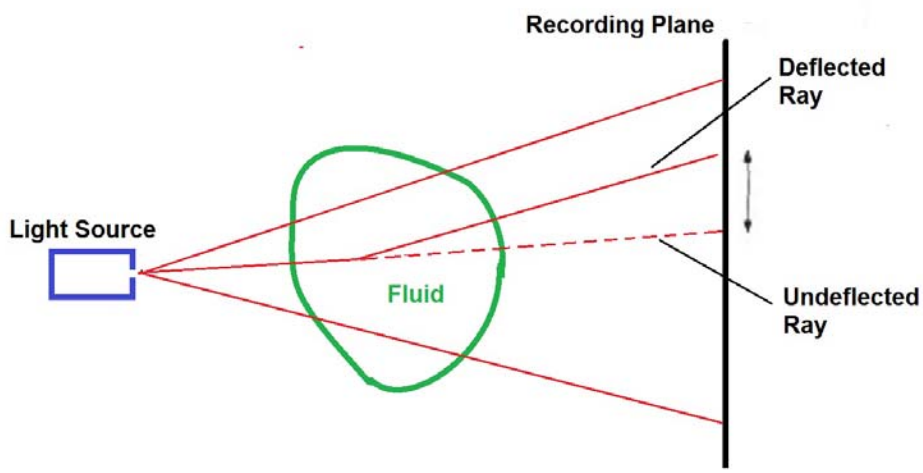

Figure 3: Setup for shadowgraph without optical components.

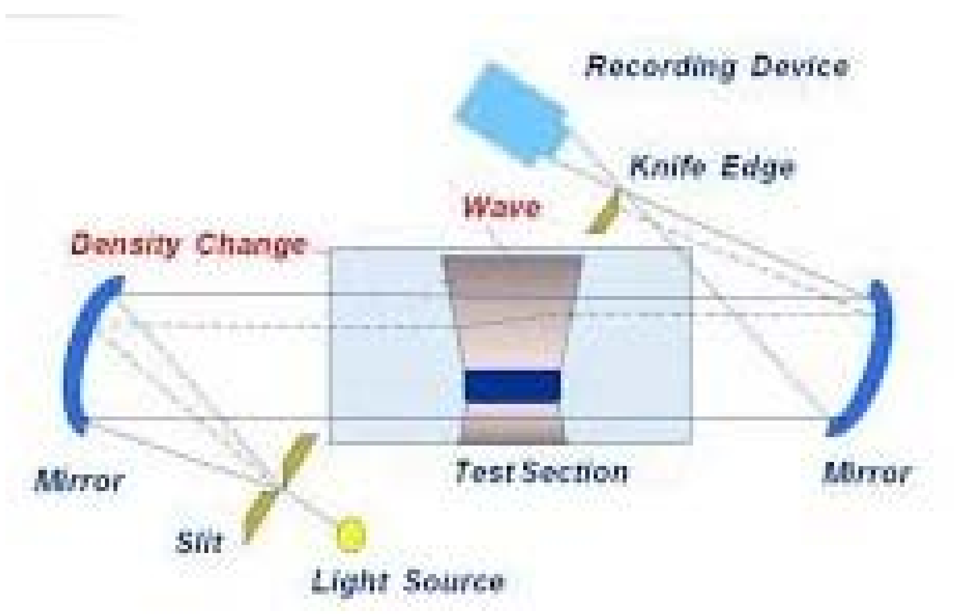

Figure 4: Setup for Schlieren optical system.