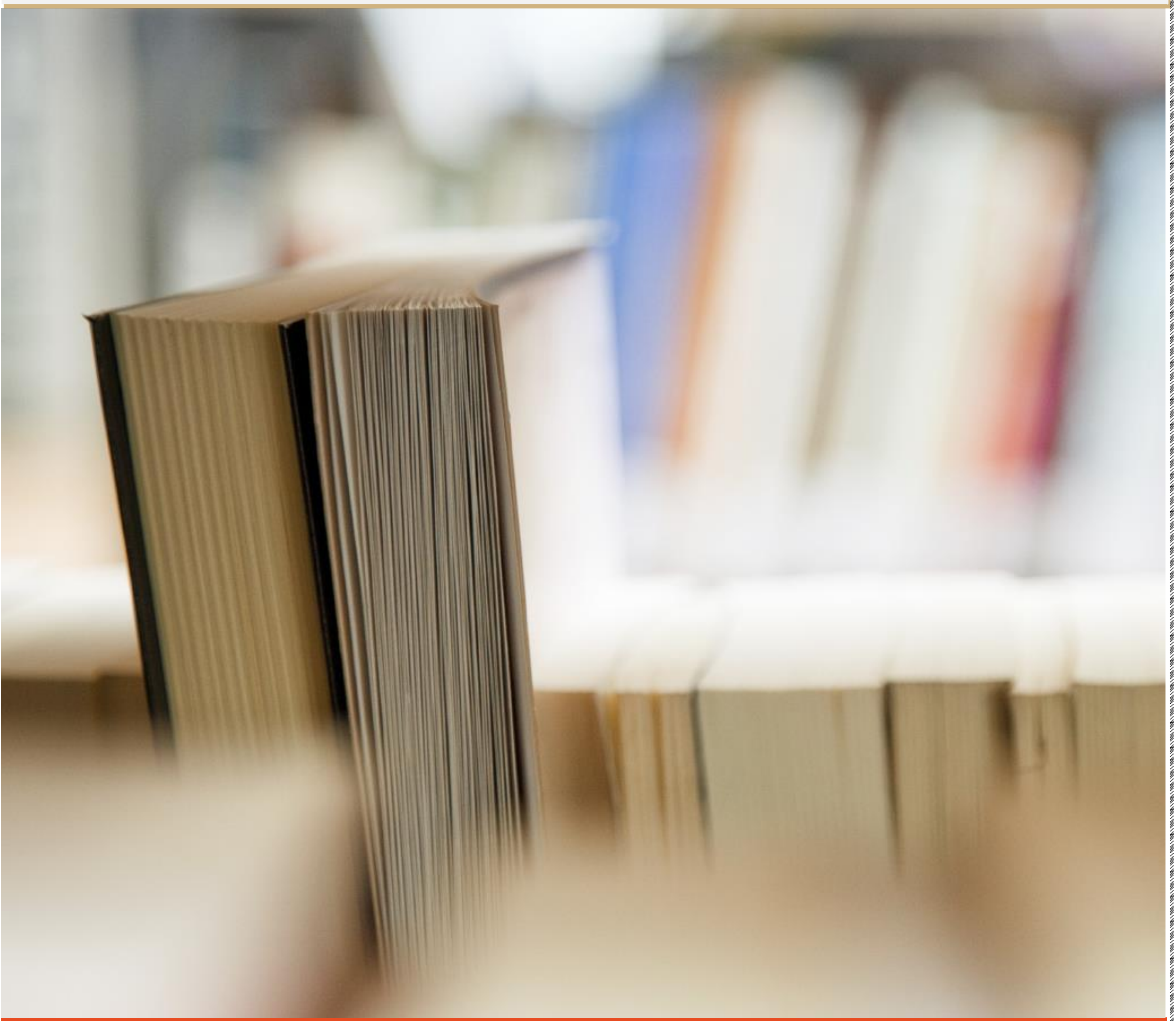
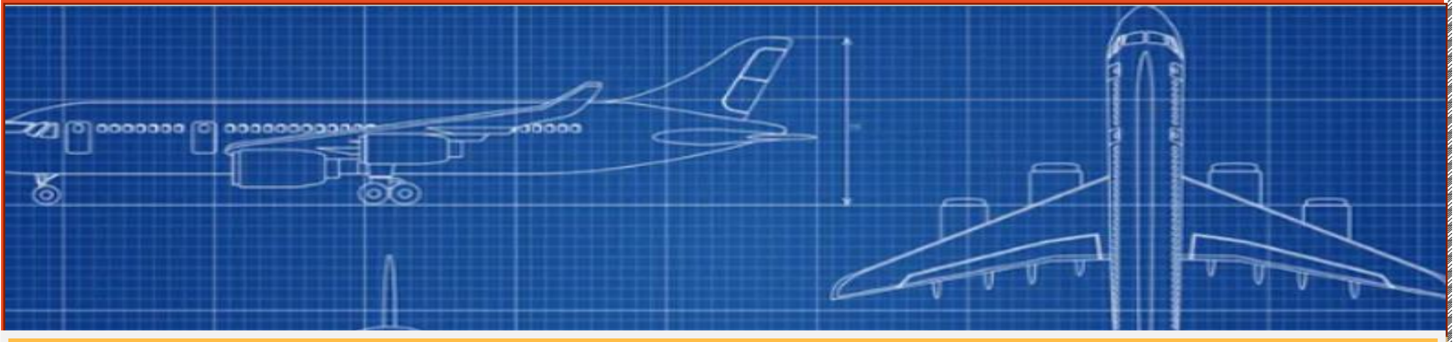


FLOW VISUALIZATION

DEDICATED TO ALL GATE AE ASPIRANTS



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FLOW VISUALIZATION

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Flow Visualization Techniques

Aerodynamicists use wind tunnels to test models of proposed aircraft and engine components. During a test, the model is placed in the test section of the tunnel and air is made to flow past the model.

In some wind tunnel tests, the ***aerodynamic forces*** on the model are measured. In some wind tunnel tests, flow ***visualization techniques*** are used to provide diagnostic information about the flow around the model.

Optical methods

1. Shadow method
2. Schlieren method (parallel or focused)
3. Interferometry (classical, holographic)
4. Electronic speckle interferometry and shearography
5. Holographic and Laser Doppler anemometry

Special methods

1. Energy adding
2. Refractometry
3. Laser light sheet
4. Particle Image Velocimetry

The interferometer is an optical method best suited to qualitative determination of the density field of high-speed flows. Several types of interferometer are used for the measurement of the refractive index, but the instrument most widely used for density measurements in wind tunnels is Mach–Zehnder interferometer.

From the wave theory of light we hav $c = f\lambda$

where c is the velocity of propagation of light, f is its frequency, and λ is its wavelength

we know that when light travels through a gas the velocity of propagation is affected by the physical properties of the gas. The velocity of light in a given medium is related to the velocity of light in a vacuum through the index of refraction *n*, defined as

$$\frac{c_{\text{vac}}}{c_{\text{gas}}} = n$$

The value of refractive index *n* is 1.0003 for air and 1.5 for glass.

The Gladstone–Dale empirical equation relates the refractive index *n* to the density of the medium as

$$\frac{n-1}{\rho} = K$$

where K is the Gladstone–Dale constant for the given gas and ρ is the gas density.

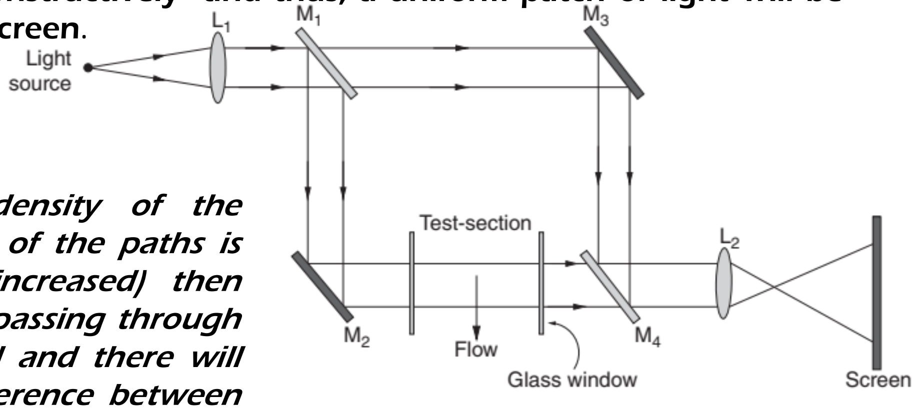
Formation of Interference Patterns

Figure shows the essential features of the *Mach–Zehnder interferometer*, schematically. Light from the source is made to pass through lens L1, which renders the light parallel. The parallel beam of light leaving the lens passes through a monochromatic filter.

The light wave passes through two paths (1–2–4 and 1–3–4) before falling on the screen, as shown in the figure. The light rays from the source are divided into two beams by the half-silvered mirror M1. The two beams, after passing through two different paths (the lengths of paths being the same), recombine at lens L2 and are projected onto the screen.

- The difference between the two rays is that one (1–3–4) has traveled through room air while the other (1–2–4) has traveled through the test-section.

- When there is no flow through the test-section, the two rays having passed through identical paths are in phase with each other and recombine constructively and thus, a uniform patch of light will be seen on the screen.

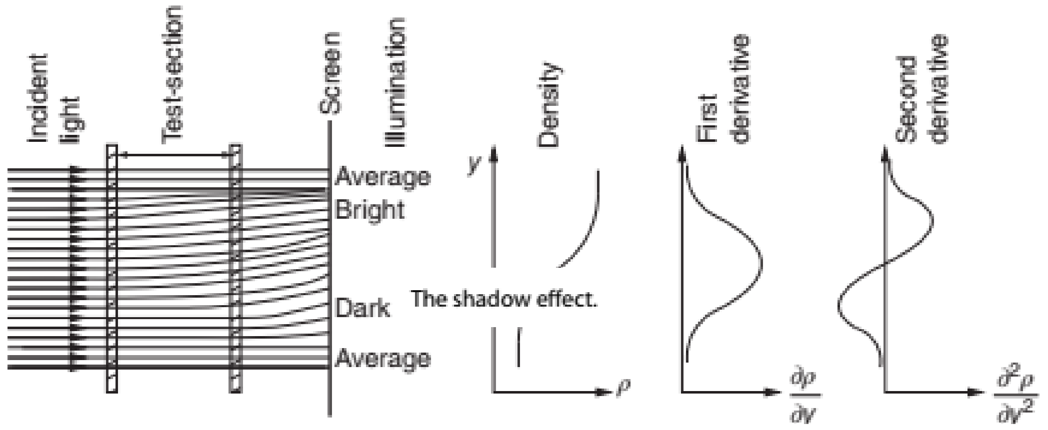


Now, *if the density of the medium of one of the paths is changed (say increased) then the light beam passing through will be retarded and there will be a phase difference between the two beams.*

When the magnitude of the phase difference is equal to $\lambda/2$, the two rays interfere with each other giving rise to a dark spot on the screen.

Hence, if there is a considerable difference in the density, the picture on the screen will consist of dark and white bands, the phase difference between the consecutive dark bands being equal to unity.

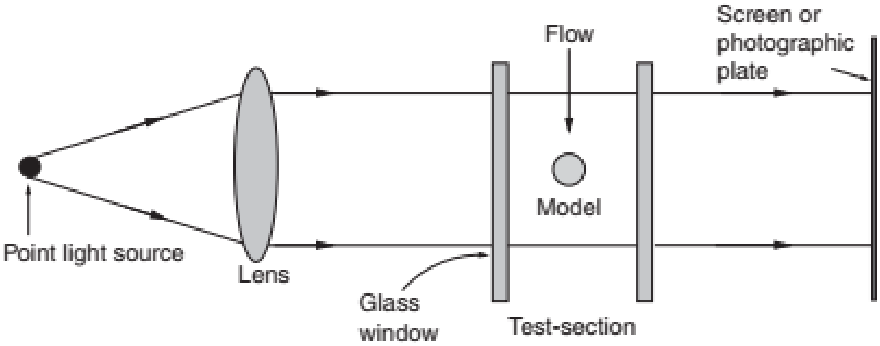
- **If the screen is placed at a position close to the test-section, the effect of ray deflection will be visible. This effect, termed the *shadow effect***
- **The shadowgraph arrangement depends on the change in the light intensity arising from beam displacement from its original path.**
- **When passing through the test field under investigation, the individual light rays are refracted and bent out of their original path.**
- **The rays traversing the region that has no gradient are not deflected, whereas the rays traversing the region that has non zero gradients are bent up**



The shadow effect.

- On the screen there are bright zones, where the rays crowd closer, and dark zones, where the rays diverge. At places where the spacing between the rays is unchanged, the illumination is normal even though there has been refraction.

- Thus, the shadow effect depends not on the absolute deflection but on the relative deflection of the light rays, that is on the rate at which they converge or diverge on coming out of the test-section. A shadowgraph consists of a light source, a collimating lens, and a viewing screen,

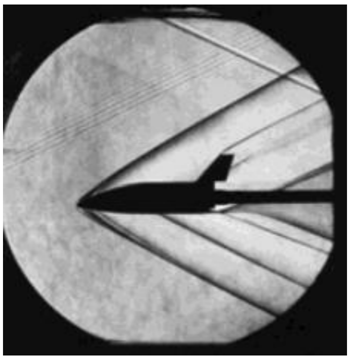


Shadowgraph system

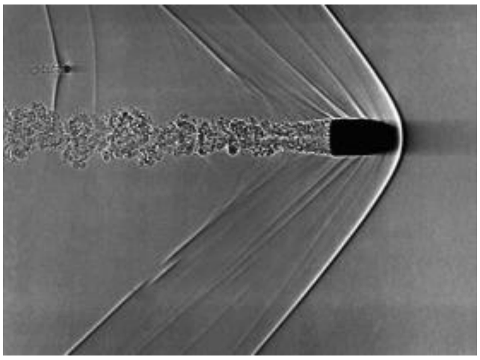
Shadowgraph Systems

Above Figure illustrates the shadowgraph effect using simple geometric ray tracing. Here a plane wave traverses a medium that has a non uniform index of refraction distribution and is allowed to illuminate a screen.

The resulting image on the screen consists of regions where the rays converege and diverge; these appear as light and dark regions respectively.



Schlieren Image



Flow generated by a bullet at supersonic speeds.

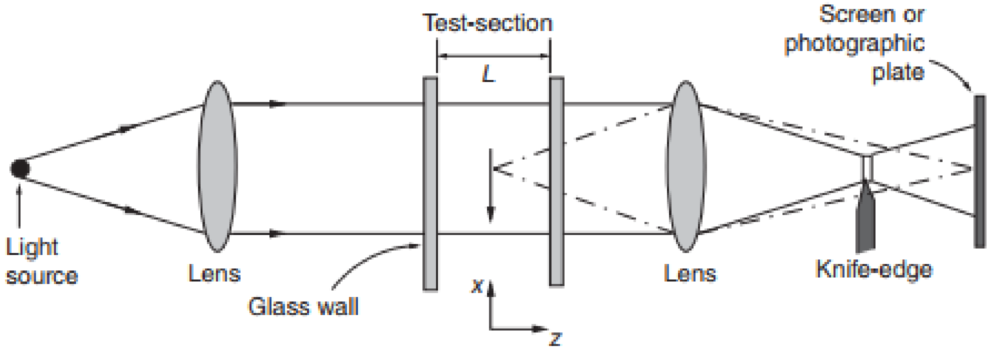
Schlieren Visualization Technique

- One of the older flow visualization technique called ***schlieren photography.*** Schlieren photography is similar to the shadowgraph technique and relies on the the fact that light rays are bent whenever they encounter changes in density of a fluid.

- Schlieren systems are used to visualize the flow away from the surface of an object. The schlieren system shown in this figure uses two concave mirrors on either side of the test section of the wind tunnel.

- A mercury vapor lamp or a spark gap system is used as a bright source of light. The light is passed through a slit which is placed such that the reflected light from the mirror forms parallel rays that pass through the test section.
- On the other side of the tunnel, the parallel rays are collected by another mirror and focused to a point at the knife edge. The rays continue on to a recording device like a video camera.

When flow is taking place through the test-section, the light rays will get deflected, since any light ray passing through a region in which there is a density gradient normal to the light direction will be deflected as though it had passed through a prism.



- i.e. if the medium in the test-section is homogeneous (constant density) the rays from the source will continue in their straight line path. If there is density gradient in the medium, the rays will follow a curved path, *bending toward the region of higher density and away from the region of lower density*.

- Therefore, depending on the orientation of the knife-edge with respect to the density gradient, and on the sign of the density gradient, more or less of the light passing through each part of the test-section will escape the knife-edge and illuminate the screen.

- Thus, *the Schlieren system makes density gradients visible in terms of variations of intensity of illumination*. A photographic plate at the viewing screen records density gradients in the test-section as different shades of gray.

REFERENCES:

1. Anderson, J.D., Modern Compressible Flow:
2. Ethirajan Radhakrishnan, Gas dynamics
3. NPTL