High Speed Flow Visualization using Shadowgraph and Schlieren Technique

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AE351A: Experiments in Aerospace Engineering

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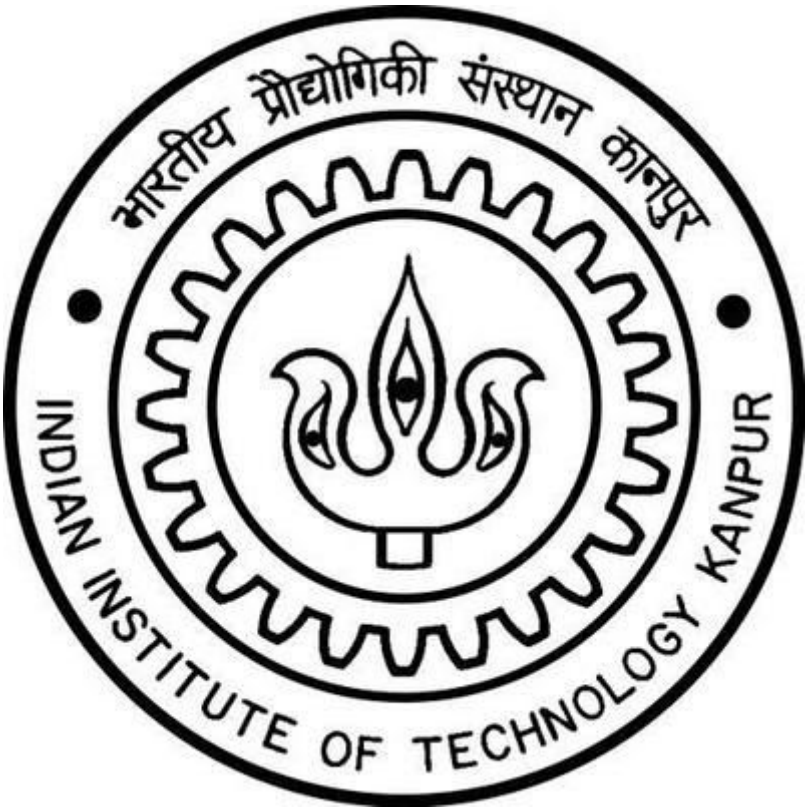


OBJECTIVE

The objective of the experiment is to study shock pattern and determine flow Mach Number using:

1. Schlieren Technique
2. Shadowgraph Technique

INTRODUCTION AND THEORY

SHOCKS

Shocks are the region of abrupt pressure gradient caused by objects moving at a speed greater than the speed of sound of that medium. When an object moves faster than the information can propagate into the medium (i.e., speed of sound 340 m/s), then the fluid near the object has no time to adjust its properties to the coming disturbance before the disturbance arrives. Therefore, the fluid properties like density, pressure, temperature, flow velocity, Mach number, entropy, etc. change abruptly in a thin region called the shock. Width of these region are about 200 nm.

SCHLIEREN SYSTEM

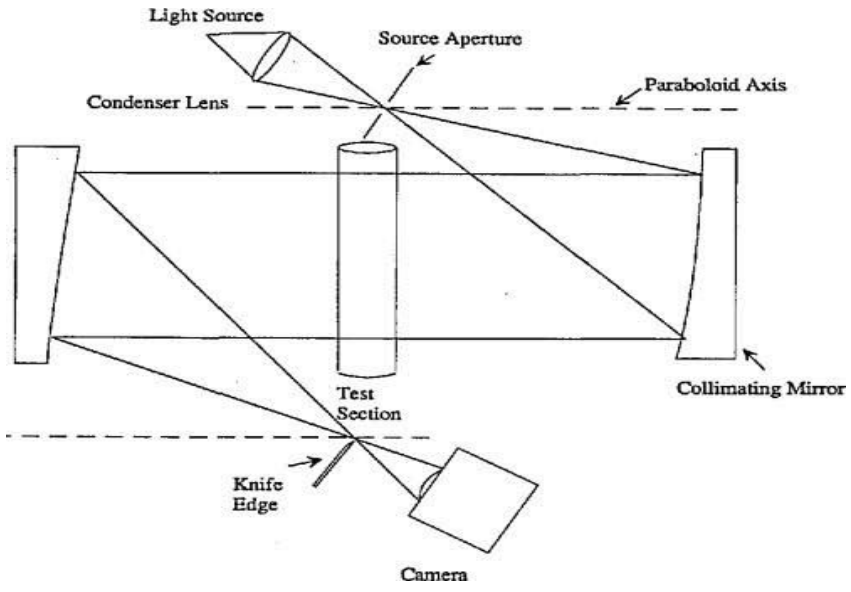
Schlieren System is a system that help visuals flow with varying density (1st derivative of density) that cannot be seen directly by human eye. It consists of a point source whose size is precisely set because larger size would cause diffusion and smaller size would not provide enough intensity to form a clear image. Rays from lens are made parallel and directed towards the test section using a condenser lens. These parallel rays are reflected towards the test section using a collimating mirror. The flow which we want to visualise lies In the test section. Parallel Rays passing through test section get slightly bent (due to refraction) in different direction. Then rays from test section get reflected and converged from another concave mirror to a knife edge. It cut approximately half of the coming rays which results in decreased intensity. And then rays are projected on a screen to see the image. Due to varying density, rays are continuously bending in different directions. Some rays which were previously blocked by knife edge gets unblocked and some unblocked rays get blocked due to bending which forms darker and brighter region on the screen.

SHADOWGRAPH SYSTEM

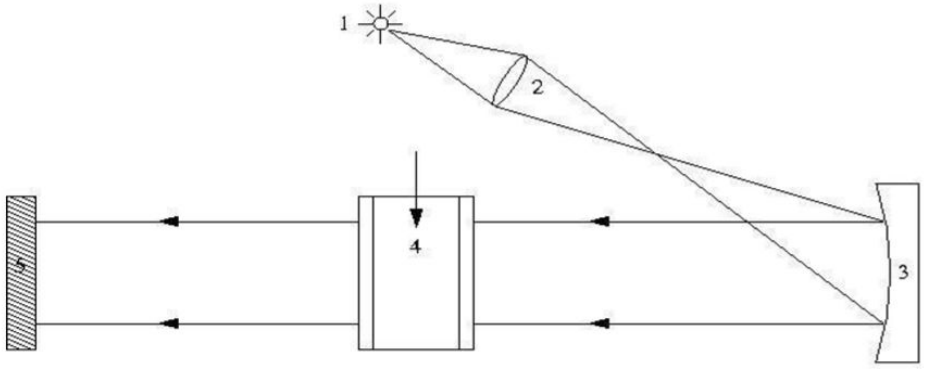
Shadowgraph System has almost similar mechanism as that of Schlieren System. Shadowgraph system shows variation of gradient of density (2nd derivative of density). Shadowgraph also starts with a point source of appropriate size. Rays from the source get reflected and becomes parallel from a condenser lens which are then reflected by a collimating mirror towards a test section. Flow that is to be visualised is in the test section. Rays will get slightly bent due to refraction. Till here the system is same as Schlieren System. But now the rays from test section is directly projected on a screen. This is more simple system than Schlieren System.

EQUIPMENTS

Light Source (a 5W Laser), Condenser Lens, Collimating Mirror, Test Section, two Concave Mirror (200 mm diameter and thickness of the mirror glass about 25 mm), Screen (a plain white sheet) and a good camera.



SCHLIEREN SYSTEM



SHADOWGRAPH

PROCEDURE

Light Source was switched on, the mirrors were adjusted to the appropriate position, a conical body was placed in the test section and the supersonic flow was allowed to pass through the test section and the image formed on the screen was observed.

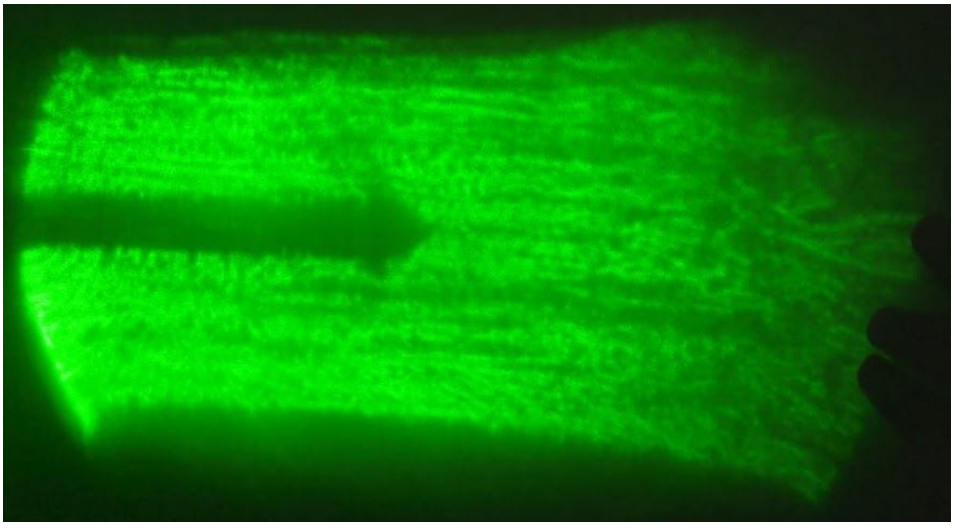
MEASUREMENTS

Full angle of cone: 50º

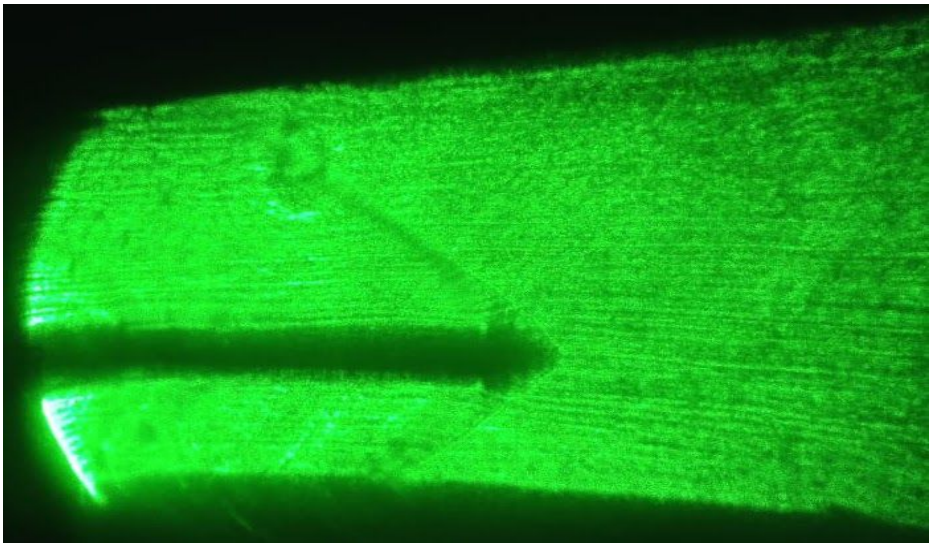
SCHLIEREN OBSERVATIONS:

Image	Angle of attack (α)	β (beta)	App. Stagnation Pressure
IMG1	0º	51.2º	3.4
IMG2	4.5º	40.7º	3.4
IMG3	9.2º	37.1º	3.4

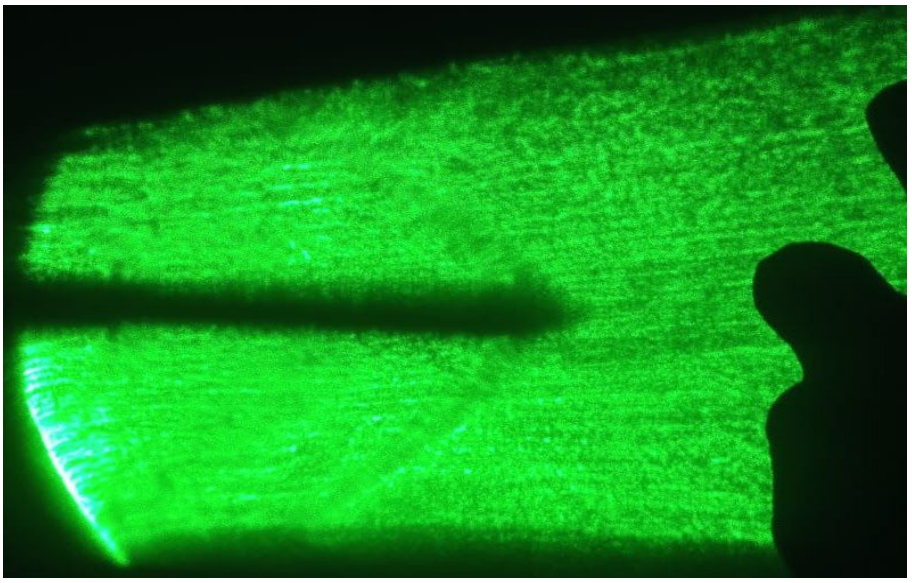
IMG1 ($\alpha = 0$)



IMG2 ($\alpha = 4.5$)



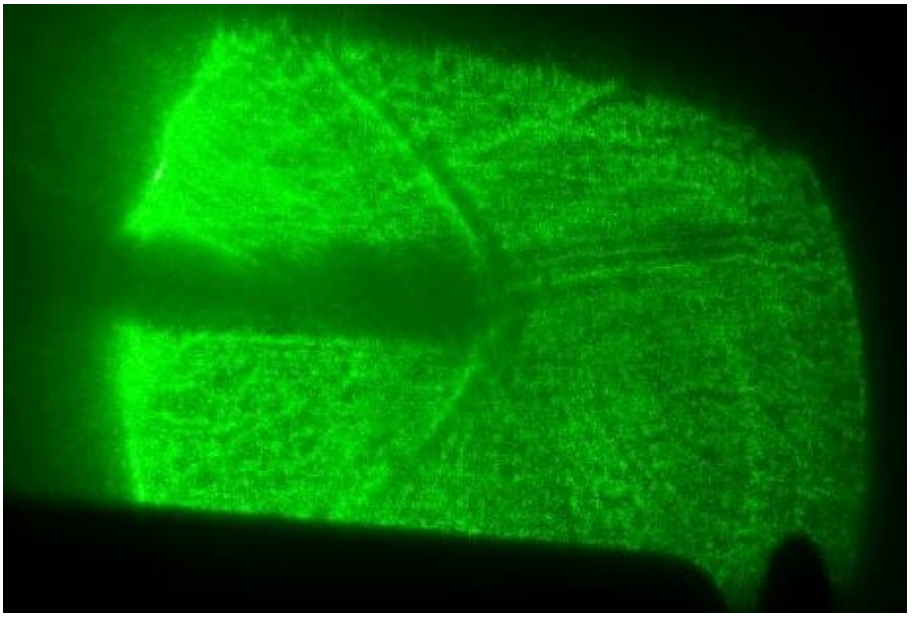
IMG3 (α = 9.2)



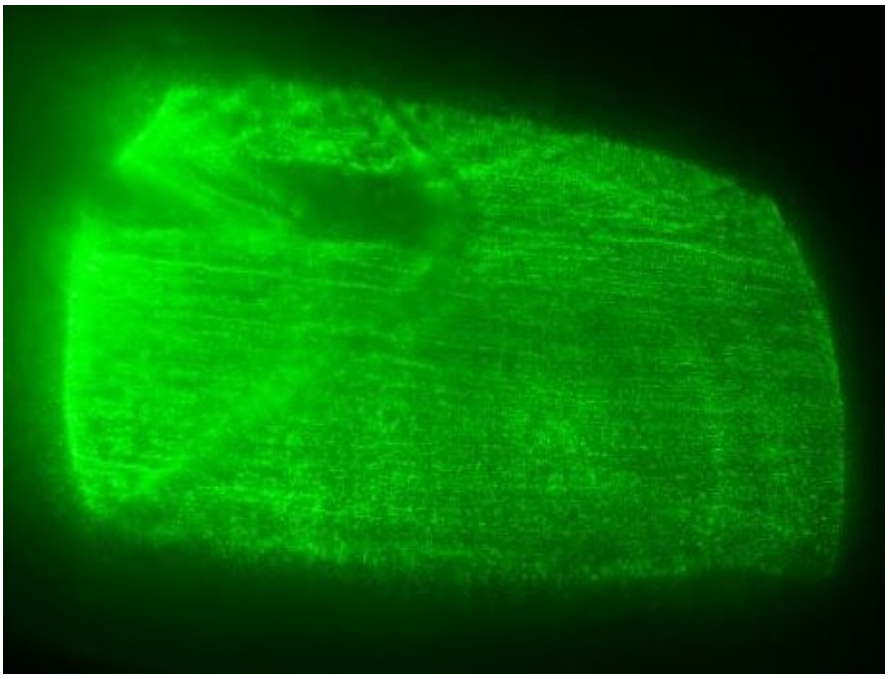
SHADOWGRAPH OBSERVATIONS:

Image	Angle of attack (α)	β (beta)	App. Stagnation Pressure
IMG4	0º	54.3º	3.4
IMG5	4.5º	48.3º	3.4
IMG6	9.2º	37.33º	3.4

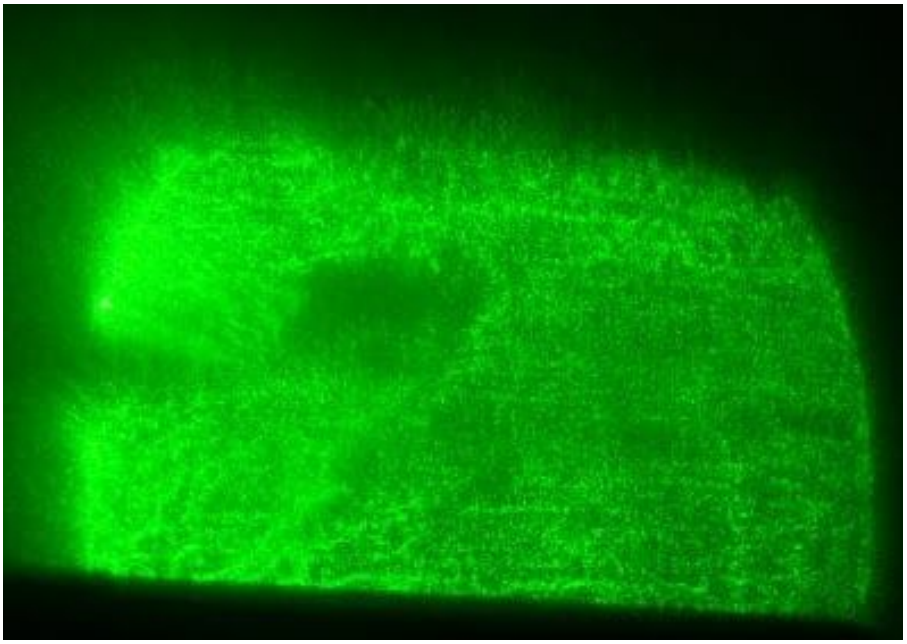
IMG4 (α = 0)



IMG5 (α = 4.5)



IMG6 (α = 9.2)



(Our images are a bit hazy due to humidity on the day of experiment)

RESULTS

SAMPLE CALCULATION

$$\tan\theta = 2\cot(\beta)\frac{(M_1^2\sin^2\beta) - 1}{M_1^2(\gamma + \cos 2\beta) + 2}$$

We know the value of Angle of Attack (α) and then we can find Theta (θ) using the equation $\theta = 25 - \alpha$. And now we can plug the value of θ *and* β in the above equation to find Mach Number (M).

VALUES FROM SCHLIEREN METHOD:

Angle of attack (α)	Theta (θ)	Beta (β)	Mach No
0º	25º	51.2º	2.5
4.5º	21.5º	40.7º	2.7
9.2º	15.8º	37.1º	2.5

VALUES FROM SHADOWGRAPH METHOD:

Angle of attack (α)	Theta (θ)	Beta (β)	Mach No
0º	25º	54.3º	2.4
4.5º	21.5º	43.2	2.6
9.2º	15.8º	33.6º	2.5

CONCLUSION

We learnt how Schlieren and Shadowgraph technique works, how to set them up, differences between them and how to find Mach Number of the flow using these techniques. We also learnt about the formation of shocks and its properties.

PRECAUTIONS

1. Don’t cross the beam while experiment is taking place.
2. Wear the protective headphones during the experiment.
3. Try to keep test section dry, humidity blurs the images.
4. Don’t disturb the mirror after they are setup.
5. Don’t cross the exit flow area, it can hurt you.