Optical Methods for Solid and Fluid Mechanics
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Lecture - 22
Schlieren and Shadowgraphy

Hello and welcome back. Today is a special class. We are going to step into the lab where Naveen and Abhineeth have set up some experiments for you to see. Those experiments will concern Schlieren imaging and particle image velocimetry, experimental setup as well as how to do the post-processing for particle image velocimetry.

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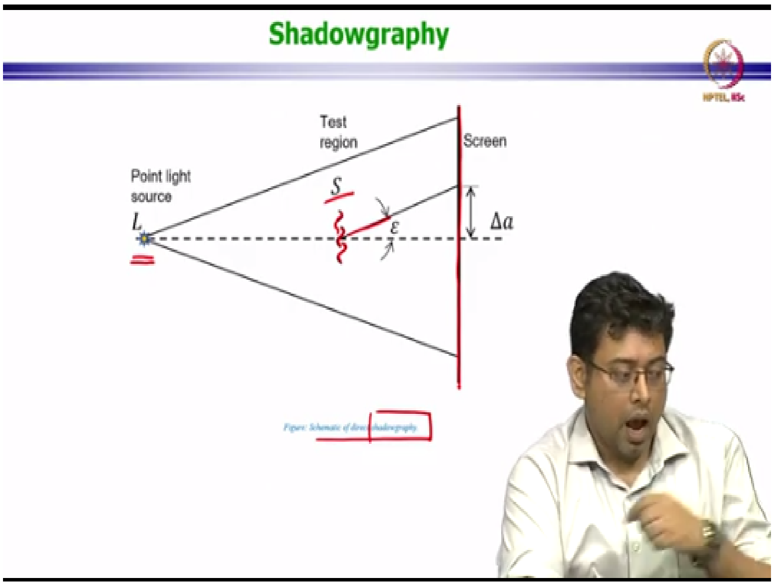

We have been discussing issues of related to shadowgraphy and Schlieren in the last class and I want to go over these two methods just once more and I want to show you a few examples before we actually step into the lab. So in shadowgraphy, this is a very simple setup, schematic, of a shadowgraphy using a point light source. So you have a point light source and you have a Schlieren object here.

Now this entire system is such that these are transparent media, right? So please remember that we are talking about transparent systems. So the differences, this Schlieren object creates is off the refractive index in the system. And these differences are very small compared to the overall background, not very high.

We discussed that also last time, yet the differences even despite the fact they are small, they do affect the passage of light through this. So this ray for example, it shows you a small amount of refraction maybe this is a heated layer of gas that is rising above a slightly colder ambient gas and this refracts the light and it changes its direction. This is obviously a much exaggerated image.

But once it changes the image you have a screen at the end where the image in data can be taken. This point source of light need not be always pointed, it can be an extended source of light as well. In that case, this geometric optics diagrams that will change. But the overall idea remains the same that is the use of a shadow, okay. Much like what happens when a solid body intercepts a solid opaque body intercepts light.

Here also you have a shadow that is cast, but this time, you have the passage of light through the transparent media. It is just that the passage of light is altered just a tiny bit because of the Schlieren object.

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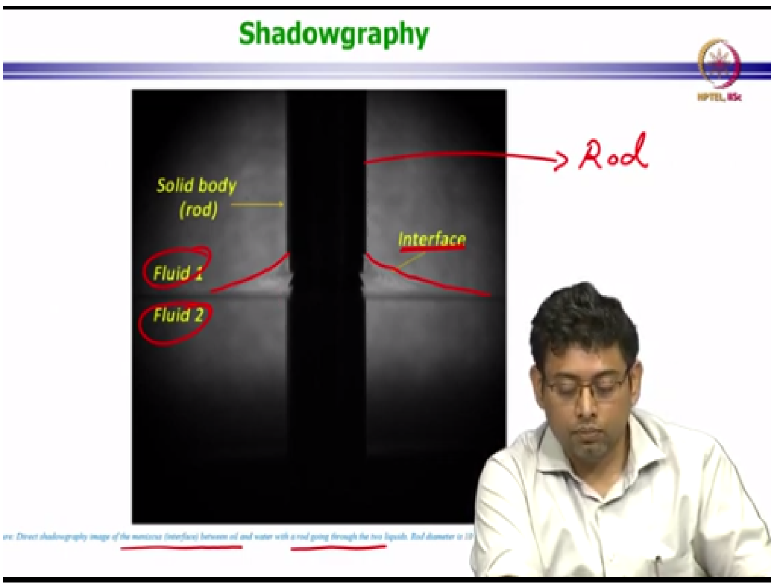

And when you have that, this is an example of a shadowgraphy that we have done in our lab. So this is a direct shadowgraphy image of a meniscus between oil and water. And this is a rod that is going right through the two liquids. The rod diameter is 10 mm just for a sense of the scale. And this is a visualization from our lab actually. And this was being done for understanding a particular phenomena called the rod climbing effect.

But you can see that there is this there are two fluids. So this is the upper one is the fluid 1, the lower one is the fluid 2. And this is very small amount of difference between, of refractive index between the two. But when you have the meniscus the interface is very clearly visible in this particular case, right? So the interface can be clearly seen.

Deformations of the interface also can be clearly seen during the experiment which does provide qualitative insight into the deformation, right? Now the only problem is this data cannot always be used for quantitative evaluation because in shadowgraphy, the relationship between the image and the object is not always one to one and not always, not always that easily quantifiable.

So that creates a problem. So the image is not always a conjugate of the object and hence, these are not often used for highly quantitative visualizations.

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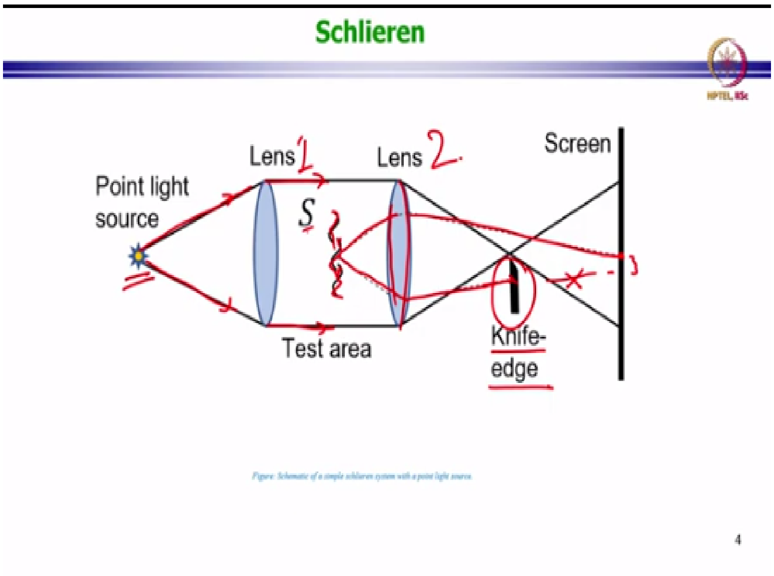

The one that is most popular is called Schlieren. Now in the last class I discussed setup using parabolic mirror setup. I also said it is a Z-type two mirror system. Now it is, that system need not always use a mirror, it can also use a lens. In this case, you will see there is a point source of light. This point source of light is, this light rays are going from here. They are getting collimated by the first lens that it is passing through.

And then you have this Schlieren object here which is creating these small differences in refractive index of the system, again a transparent system. And then you have the second lens in the path. So this is lens 1, and this is lens 2, and a second lens is being used to focus this beam of light to a point. Now what we do is we put some kind of an obstacle, in this case a knife edge.

Usually the knife is actually a knife edge. It can be a razor blade, really a razor blade in that sense. And it is placed in such a way that the path of light through this is altered. So for example, a light ray that is coming here, it is intercepted by this razor blade and does not end up here. So otherwise it would have traveled and that light ray is not able to travel whereas the light ray from the top is able to travel.

And this fact that you are stopping some of the light from traveling creates these small optical differences at the screen and those show up as a difference in typography that we will see difference in grayscale values in the image.

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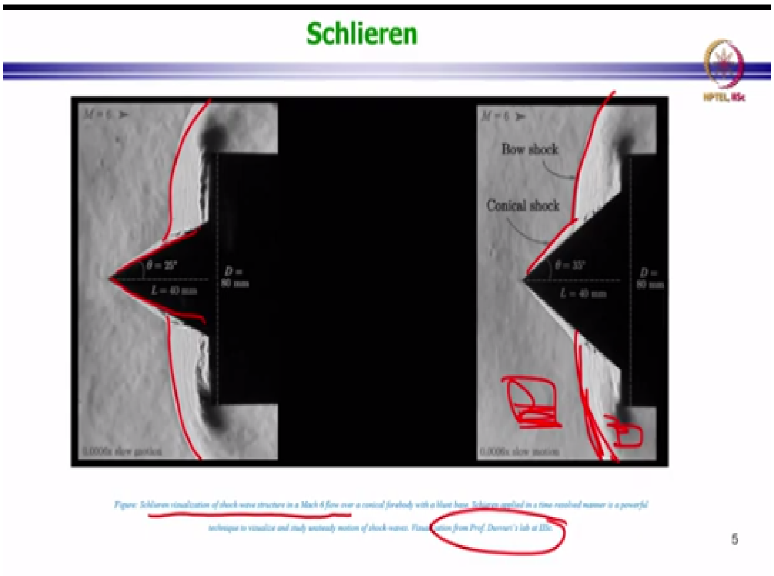

Now this is an example. This is not the example that you will see in the lab demonstration, which is why I wanted to show you this. This is a Schlieren visualization of a shockwave in a hypersonic flow over a conical body with a blunt base. Now this visualization comes from Prof. Duvvuri Subrahmanyam’s lab at IISc in the aerospace department.

And you can see this shock wave formation and the bow shock very clearly in the two cases. So here you can see this shock formation, right. So there is a difference in the grayscale images in this background over here and let us say the grayscale here. So the shock wave formation is very clearly seen. What is not, what you do not get is data regarding the velocity field.

So these are not quantitative in the same way that particle image velocimetry is, but you can use data from this to visualize how the shock wave changes, etc., right? So this is that.

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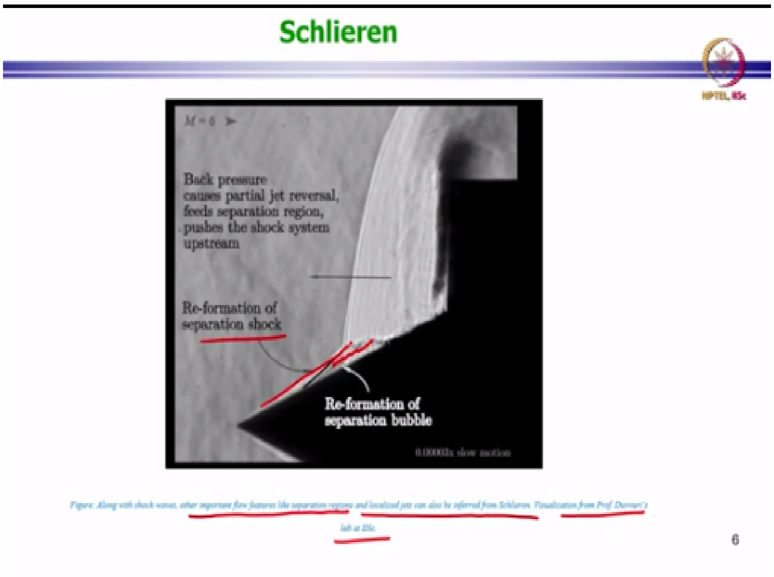

So this is just to illustrate, for example what you can visualize. So for example, important flow features like separation regions and localized jets can be inferred. Again, this image comes from Prof. Duvvuri Subrahmanyam's lab at IISc. So thank you, Prof. Duvvuri for lending us this image. And you can see in this region, you have some reformation of separation of shock, you can see some features.

And somebody who is very well qualified to interpret this can figure out what is really happening in the floor based on some of these images. Once again, you do not get a quantitative Eulerian velocity field in such a case though.

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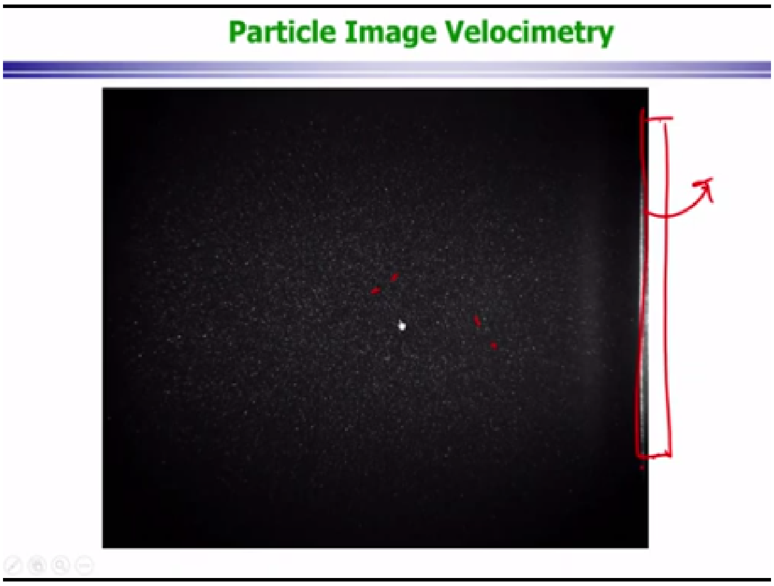

Now in the lab visit, what you will see is going to be a significant amount of time being spent on particle image velocimetry. You will see the lab scale demonstration of how Naveen has been able to collect this data. And then he will also show you some of the analysis. I just quickly go over that once and here for example, this is the rod by the way, which this is slightly different example from what he is going to show you.

But in this case, this is also a particle image velocimetry analysis where there is a rotating rod, and there are these glass spheres that are suspended in the flow, and they are being captured through a high speed camera. So we did not use a normal PIV camera, but we just use a high speed imaging and we were able to get slow enough changes between successive frames, so that our analysis can be done.

So once you have a flow-field like this, a video like this. You see it is necessary that the displacements between particles in a image pair will be small in order for you to be able to calculate right.

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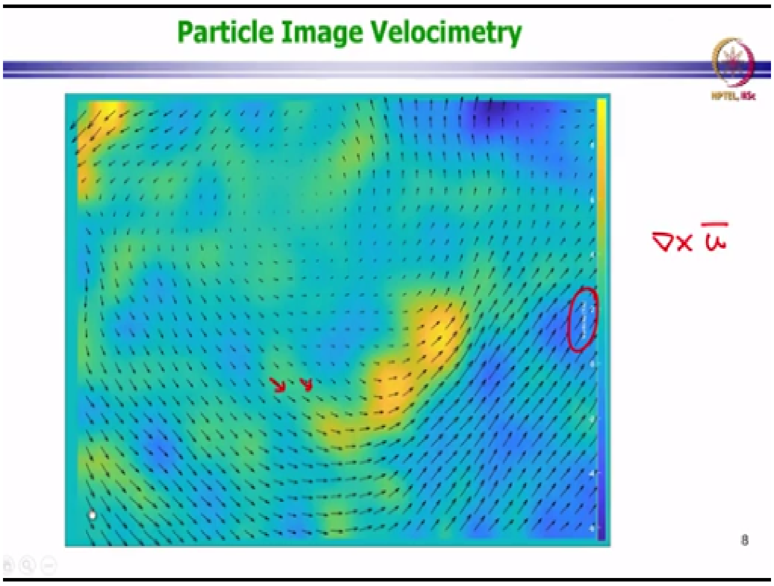

So once you have that, this kind of a proper data, you can use post-processing, which again Naveen is going to show you in a lot of detail, how this post-processing is done. You can get a time-resolved velocity field. So this is a time-resolved velocity field. There is a vorticity. So this, these are the vectors and then the vorticity was also calculated for these cases.

And this vorticity was plotted and that is what is the background. So this is vorticity has been plotted here. And that is, the variation of that is what you saw, with time okay? So with that, what we will do is we will step into the lab and where Abhineeth and Naveen will show you a real life demonstration of these experimental techniques and you will see one possibility of how this is, how these techniques might be implemented.

I want to again caution you once that there is, there can be strong deviations from one experimental case to another, in which case you might need changes in the hardware and the changes in the way data is being collected. It could be change in the camera, it could be a change in one of the optical elements or something else or even maybe the tracer.

So in each experimental case, you have to evaluate your needs properly and I hope we have been able to capture some of the fundamental aspects of flow-field characterization, flow-field visualization and that you now have sufficient knowledge in order to evaluate which of these standard techniques can be used in your particular application and which where you might need alterations.

So wherever you need alterations you should do the relevant calculations yourself and evaluate what exactly is the need. And finally, this sort of data processing is extremely useful for many applications. I mean, the applications in fluid mechanics they are abound.

They go all the way from microscale fluid flow, for example in lab-on-a-chip devices, where some of these visualization techniques are used extensively to much larger scale applications such as aerospace industry, where you might have to look at shocks. That is exactly why I wanted to show you an example from aerospace industry where we saw the hypersonic shockwaves, shock fronts in hypersonic flows.

So the applications of these are tremendous and very varied. And that is why it is very important that you evaluate your own case properly before utilizing or before designing your setup. So with this, I will end and let us go into the lab. So yeah, I will see you soon. Thanks.