Gas Dynamics
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Module - 19
Lecture - 48
High Speed Flow Visualization

Hello, everyone welcome back we were looking at some images of shocks and expansion fans and shadow graphs last class you want to go into details of the setup today I gave you the basic setup yesterday now I will just give you a little more detail of it and how it works. So, that you can start using it better and then I will show you some specific differences if you change the setup slightly that will go over today the simpler setup is our shadow graphs setup which is just I have some lamp I am putting one lens in front of it. Typically they put a reflector behind it you collect more light and you focus it to a point you put a pinhole there

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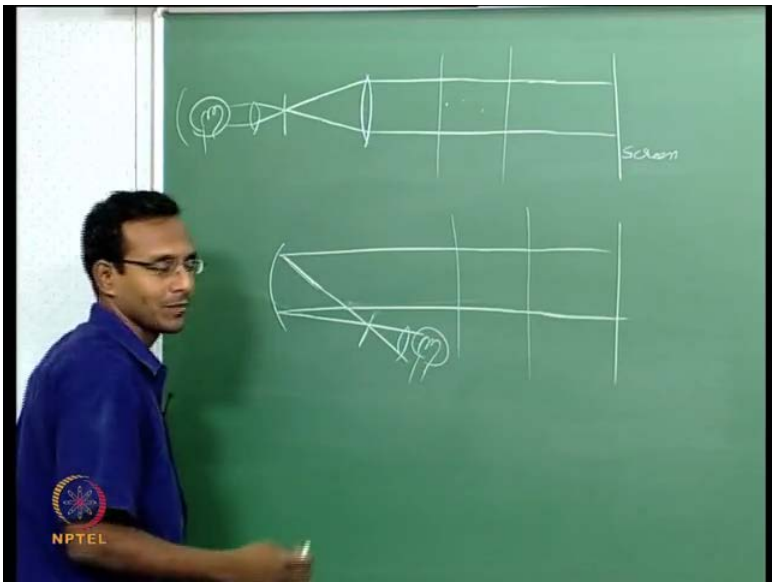

This becomes my point source now from here I can have a lens space setup which will send a parallel beam like this and whatever I need to do in the middle say my test section is somewhere here and whatever is the density gradient inside that will be changing the flow field after some distance I will put my screen this is my density variation region this is my test section that is one case.

Or I can have a modified setup which will be I will draw it the other way. Now I can have my light source bulb etcetera here pinhole and then I can have a reflecting mirror concave mirror which will make the beam parallel. Assume its parallel currently I am not drawing parallel lines and this parallel beam now I can again use for some test section. After some distance I will put a screen depending on how far I put the screen that will decide the deflection if I put it too far it may not look very good if I put it too close the deflection will be too small.

So, there is some intermediate distance we will put typically that comes with experience after sometime one or two pictures you take you will just know where to put typically. It will be of 1 foot or 2 feet away from your flow system that will work reasonably well. After that if you want more clarity you can adjust it this way that way you get better pictures this is simple enough setup this is how you create your parallel beam of light right either using a mirror or using a lens?

So, from now on when I draw setup I will not draw this part I will just assume there is parallel beam of light coming somehow you can use either this setup or that setup actually I will go back and draw with mirror setup once more anyway.

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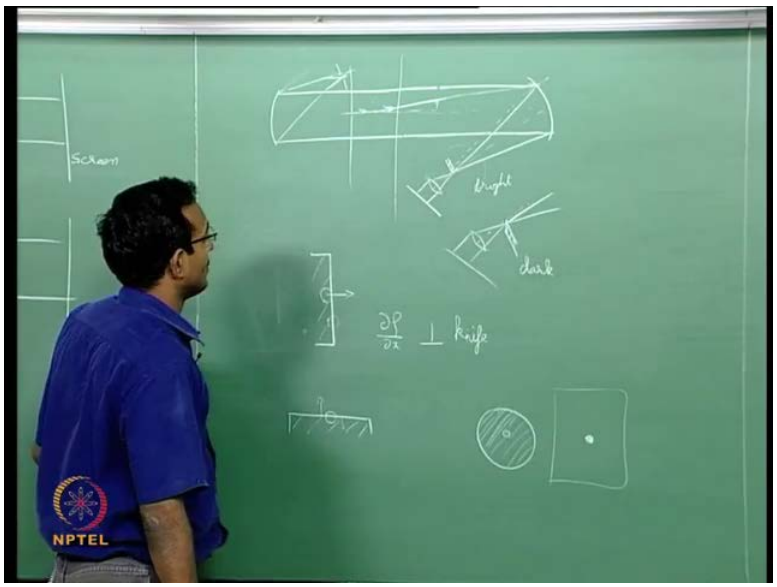

So, parallel beam of light coming from this mirror if I think about, setup I will have my test section somewhere. And then I am going to have a mirror and then, I am going to have some setup like this, is one way of looking at the setup I am assuming of course,

you know that there is the other section which is having a pinhole and producing lamp and pinhole everything from that side producing a parallel beam of light here. What matters for me is, only this side this is my collection side. Now, I am having instead of having just one mirror and a screen here, which becomes my Shadow graph setup now I am having that parallel beam going through another mirror focusing to a point and then it is after that point is imaged onto a screen with a lens here that focused point all the light coming from here is going to this point that point is expanded into this screen using a lens that is a final mechanism.

Now, depending on this lens I can magnify or maybe zoom small amounts inside with this lens. Now, this is one way of doing the setup this is not enough I will tell you one more I need to put a knife edge here I need to put a knife edge now we will talk about, the nice edge a little more this is the basic idea of shear layer setup. Now, if I am interested in actually I do not need to have the lens here all the time also even without the lens in the system can work if you have the lens here, I can zoom in a little better I can have required regions alone zoomed in a little better.

Now, if I have this parallel beam of light deflected instead of going straight it is deflected say I have this situation now we are supposed to be looking for that here right. So, how will I see it if it is getting deflected upward there now, what should happen it is going to go out there it is going to see a different angle right. If, I look at the local region normal it is going to reflect inward right this dotted line will be my reflection of this one ray deflected ray of light from that curved mirror at that local region. You know, how a mirror works right local normal incident ray that angles should be equal to the other angle and it will come out to be something like this, what happens is because deflected it that way this light deflected inward.

Now, because of this knife edge is going to be blocking the light that was deflected if it gets blocked this way. Now, I will not be seeing that light on the screen more than that there will be a hole here, in that original direction which is coming through the lens on to the screen that point will have a hole because, that light was deflected and it is blocked by the knife edge right.

So, because of this I am going to see a dark region at the location where, there was a density jump that is the idea we told that setup is sensitive to d rho by d x right if x is this

way d rho by d x perpendicular to direction of propagation of light d rho by d x this way. So, if it is deflected and I put a knife edge like this then it is going to be blocking the light what if I do the same thing I will just draw this picture again here.

If, I put my knife edge the other way. Now, what will happen now the deflected light definitely comes through, but there was already some other light at that location right this is not going to its original spot it is going to go to some other spot right. So, that location already had some light. Now, it is becoming brighter that region becomes brighter. So, I am going to look at that region now.

Now, I should know one more thing depending on how I put my knife edge I can either, cut of this focal point all the light at the focal point or I do not cut anything at all in this particular situation. If, I am interested in getting dark lines where there is density difference then, I will not cut of the full spot the focal spot I will cut off only the deflected light when I go from this side typically the deflected light will come through bright I do not want the background also to be bright.

So, I will cut off the focal spot fully and I will allow the deflected light alone to go through the knife edge will block the whole region this particular thing where, the background is always bright and the shock or the density difference is dark that particular thing is called bright shear layer this will be bright setup and this will be a dark shear layer the dark background versus bright background will be the difference for this based on the background I am naming this dark and bright shear layer.

Now one more thing I need to think about say I have a density difference inside here it is still perpendicular to the propagation of light direction, but it is this way in and out of the board direction if that is the case what happens to the light it is going to be deflected let us say out of the board or into the board I will pick out of the board. Now, what will happen that mirror is going to make this dotted line thing coming out of the board or, but I have a two d knife edge I said it is like a blade which is a lined like edge if it is a two d knife edge it is not going to see any difference it is having only density difference in out of plane direction, but it is not moving this way or this way.

So, it will not see any difference which means the deflected light will not make any difference in my image what does that mean my shear layer setup is sensitive to density gradients only perpendicular to my knife edge. If, I have my knife edge like this I will

draw a fresh one if, I have a knife edge like this and I am going to say my focal spot is something like this, and this whole thing is blocked this is what dark or bright I am blocking all the focal spot blocking all the focal spot is dark. So, only the light that is deflected this direction will be visible only that will be visible everything else will be dark if I had this particular setup then that will be bright if the light deflection is that way what if I have density gradient opposite here? the light deflection is the other way for the same setup that will also be dark.

If I want both the deflections to be seen one as bright other as dark I will block this focal spot halfway I will pick a focal spot something like this it will give half intensity background will be half intensity and wherever there is this way deflection that will be bright wherever there is this way deflection that will be darker. Now, I can see both depending on what I want as, my final output I can choose where my knife edge is with respect to the focal spot that is the idea.

Now I will tell you again one more thing we said that if there is out of plane deflection or the deflection from this happens to be up and down then the knife edge does not make any differentiation across that right if there was light here, it now goes up does not matter for the knife edge it does not cut-off anything.

So, the light still goes to the screen. So, we would not see much difference in the image except when it is going this way or this way. So, I am going to say if my density gradient if it is perpendicular to my knife edge then only it is sensitive this is very important. Now, I can choose my density gradients which, I want to see in my flow I can specifically choose some particular specific knife edge orientation then it will be sensitive to only that direction.

So, if I put the same thing focal spot with the horizontal knife edge like this, now if the beam is deflected upwards then that will be bright if it is deflected downward that will be dark I can have this condition also depending on. What I want I can choose, these settings that is the good thing about, choosing a knife edge there are special situations where people choose different knife edges there are situations where people will say I want only radial gradients how will I pick my knife edge.

Now, I will choose a circular knife edge I can either have a big disk with a hole and my focal spot is going only through this if, that is the case if it is going higher radius it will

be cut-off right that is the possibility this is my knife metal. That is the possibility or people use the opposite I have a transparent glass piece with an opaque circle if my focal spot is inside this any deflection out higher radius will allow the light through right this is the opposite of it I can choose this or this also if I am interested in radial gradients alone these are the special methods that people can think about using this is also available for shear layer if I want only radial gradients I can go for this. The next thing I can go for is color(Refer Time: 14:18) but before that I will just go and show you what the pictures look like no before that I will show you what the length setup looks like with this.

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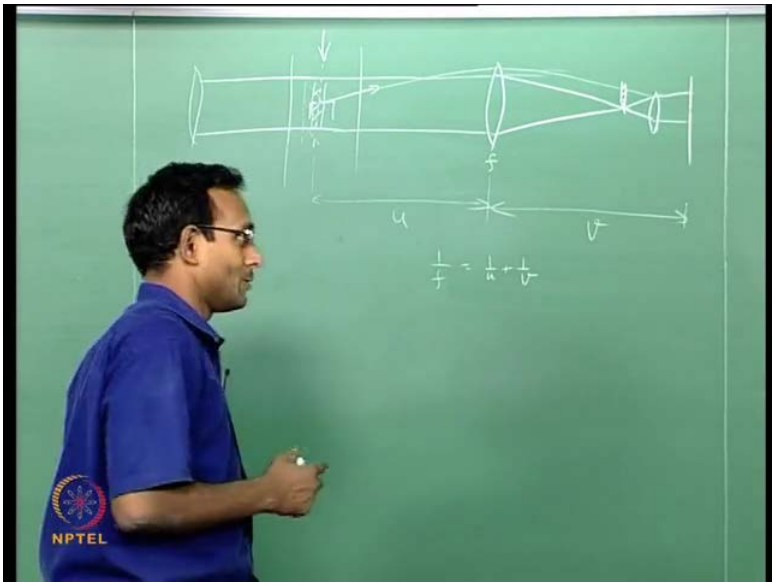

I have drawn it once before, I will just say parallel beam of light coming from a lens in this case I have my test section I am having my knife edge I am, zooming into the correct screen size whatever and I will put my knife edge in this place depending on what I want I will put my knife edge either fully in or half in or nothing inside at all or whatever, different positions I want I can choose.

Now, what should be the location of my screen? I have to think about that because now let us say I want to think about density gradients only in this particular plane of imaging then I have to think about a point on this if it is deflecting light it is as if it is a light source think about the light source from here it is as if it is a pinhole kept at that point this lens sees this pinhole light coming it is going to send it to some particular focal

length right it will obey that lens formula 1 by u plus 1 by v is 1 by f that formula from high school it is going to go use that particular formula there if I call this distance as u and some distance this is v and this is lens focal length is f I am going to use that simple lens formula 1 by u plus 1 by v is 1 by f.

Now, based on this If I do not have the 3rd lens I can talk about it very easily the screen location should be such that 1 by u plus 1 by v is equal to 1 by f that should be the location of the screen for this plane imaging whatever I am getting in(Refer Time: 16:12) is corresponding to only one plane of course, people who are interested in photography will immediately know that that has a focal plane thickness etcetera we will ignore that for now it is not exactly one plane it is a small band of planes that is what it is really, but if I am doing a two d experiment I am not going to have a full very wide model from one wall to the other wall I have some width in my test section in this case if it is 20 mm wide I will make my focal plane thickness of the order of 10 mm. So, I am sitting inside only I will not be sensitive to other regions that is something I can think about if I have say my model is like this flow is coming this way.

So, it is going to form let us say it is a wedge and the shock is coming out of the board flow is coming this way if that is the case if my focal plane thickness is only up to here. Then I am going to see only one shock nothing else if the same thing if my focal plane thickness is this wide then, I will be in trouble am going to see this curved shocks on the side also which we do not want to see typically.

So, I have to adjust my lens positions accordingly anyway that is a special thing too much detail into may be it is not needed for you people for this course, but screen location is a particular location where if I put an object here which is a light source that should be imaged on the screen exactly if I have another lens also it should be imaging that particular point on the screen that should be, the location cannot be any other location that is very important out there.

So, you have to think about that in theorem shadow graph there is nothing like that I can put the screen anywhere, along the parallel beam of light it is anyway parallel beam nothing much is going to be affected there will be a small effect. But I will ignore that for now for this class it is going to go this way and go to that screen there that is typically the way is going to be.

So, when you are setting up a setup we will put this lens after that we will put the screen farther away from this knife edge location that is after the focal length and then. Now, you are going to say I will adjust this length and this length such that whatever plane I want should be imaged on the screen. So, basically I am controlling my u and v such that it will match this f this formula should be obeyed that is what I need to do if I do that now I will tell you one special trick to check whether your theorem is correct.

If it is if your screen position is wrong if you remove your Knife edge and you have your flow the shock shadow graph will be visible. It will be a shadow graph if you do not have a knife edge it becomes a shadow graph if your screen is wrong if your screen is perfectly placed for shear layer alignment that is this formula is valid exactly for your lengths where arrangement then you will not see any change on the screen due to density differences inside. Only that particular location will be a picture you can go and prove that that is correct some other time, but if you do a good shearim image then you will find that you will not see a shadow graph at that plane if you remove your Knife edge.

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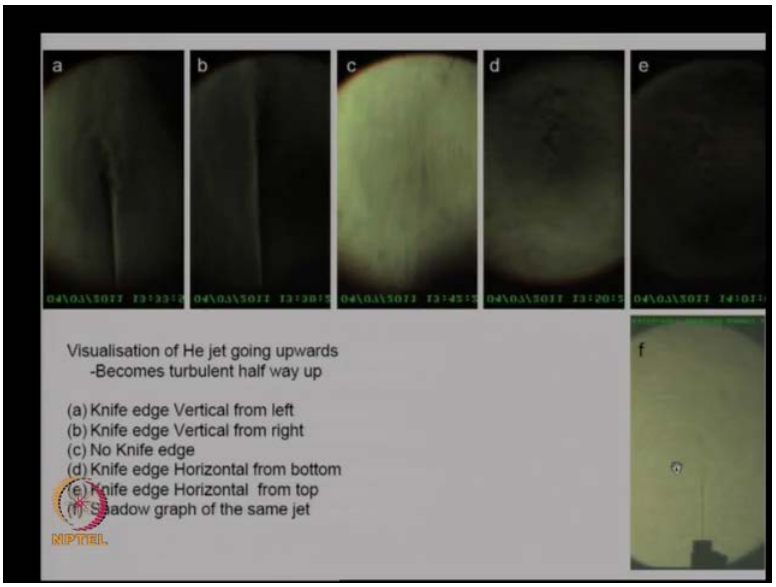

We will see pictures now from some experiments we did in the lab we will go to the screens. What I am showing here are some set of pictures where let us, go to the board once then we will come back to it. I am creating a jet from a tube which is closed at the end and a tiny hole at the centre I am creating a jet of helium in air helium is coming through this and air is present outside.

So, there is a big density difference because of molecular weight difference the same temperature and pressure. So, there is going to be a density difference. So, it is going to send out a straight jet we are sending flow rates low enough that is laminar and after sometime. Due, to length it becomes turbulent and it starts doing this kind of thing this is what you should be seeing in our pictures.

Now, why will this give you a shearim setup because helium is low molecular weight density is lower because of that if I draw a cross section here and draw the density profile it is going to look like this density versus distance will look something like this, for this jet if the same thing is replaced by c o 2 inside here it will be heavier than air. So, it will go up and come down I have chosen to use helium in our experiments there is all.

So, now I have a density gradient in my flow it is not a shock or an expansion fan it is something else I am having two different gradients now we will go to the screen again the first have labeled them a b c d e f I am showing here what it is Knife edge Vertical from left that is shown in here Knife edge Vertical from the right is shown here now I have to decide what is left what is right will go back to let us say you just look at me here this is the beam of light coming and this is the jet of helium coming up from here for the beam if I am the beam and I am coming I am the light I am coming this way if the light knife edge comes from here I call it Knife edge from the right if it is from this side I call it Knife edge from the left from the top and from the bottom that is what I mean by this now we will go back to the screen now this thing will make more sense for you.

1st one is Knife edge from the left 2nd one is Knife edge from the right 3rd one is no Knife edge, but I am still having the helium jet going here still there is helium jet going in this picture next am going for by the way in all these cases helium jet is supposed be going up from here and from here it becomes turbulent and goes out like this that is what you are having now here also there is a jet, but you cannot see it that says my shearim setup was good and you are seeing these small lines there here and there they are due to scratches in the lenses and mirrors etcetera we will ignore that for now this two pictures are having horizontal knife edge.

I am again showing you from the bottom and from the top horizontal knife edge cutting from the top and cutting from the bottom the last one is a Shadow graph image these are the various items. Let us 1st start with this f we will 1st start with this f if you look at just

this picture I am seeing if you look close enough you can see that there is one dark region enveloped both sides by some slightly brighter region on each side and then it goes back to the regular intensity all the way around now we will go to the board and draw that particular profile of density of intensity versus x if I plot what I am seeing there is up down up down this is what I am seeing there is some regular intensity it is higher goes below comes back higher then goes to what is outside this is what I am seeing there we will keep this picture now we will go to shearim images again going to screen.

I will look at the very 1st one a this is for the case where it is Knife edge is coming from the left if you look at this picture I want you to concentrate on this section alone 1st if you look at this section alone if I take a crosssection here I am seeing that there is some intensity of light here it is getting darker brighter and then coming back to original intensity as this if I draw that profile here I will go back to this board that profile is going to look like something like this its sum value going down going up coming back to neutral this is what I am having this is one case.

Now, we will go to the screen again and look at case b if I look at case b Knife edge coming from the other side this is coming from the right what we are seeing here is this side and this side are almost same intensity as I go from here to here it becomes brighter darker and then becomes uniform this is the inverted profile of this that is the other profile I will draw it offset from this picture that is going to look like this. This is the other case you are having now we will go to of course, I already talked about c which is I am still having a jet here, but it is not visible because I am having setup with Knife edge alone missing if I go to this picture d there is no intensity variation here there is no intensity variation along here, at all there is something happening in this region alone in this region alone you are having some variation we will come back to it the same thing here this is from the top and again here there is no variation.

In both these cases my Knife edge is parallel the Knife edge line is parallel to my density gradient direction because, of that the density is varying this way if I go from here to here. I will see a density variation, but my knife edge is along this line which means the light is deflected along that line. So, light will not be cut off in anyway and because of that I am not going to see any variation in intensity in any in these cases that is why you are not seeing anything in these two pictures.

Now, we will go to this board again we will look at what will happen to a jet when it goes out farther typically it becomes turbulent after sometime and you will start seeing this shear layer setup. So, you will start seeing this kind of it may not be very clear like this, unless it is very nice slow flow this is faster than that you may not get this nice mushroom like cloud, but you will see some such shapes due to this vorticity here, air has entered into here.

Now, what am I going to see a complex flow field with a cross-section here looking like if I take this cross section it is air into air density here it is helium density here air density helium density like that it is going to go up-and-down in intensity if, I have a Knife edge that is vertical then any change this way will be picked up right we told if Knife edge is vertical then perpendicular to that any change will be observed.

So, you should be seeing this kind of picture in the cases where Knife edge is going from the left or Knife edge is going from the right in both of them you should see what will happen if the knife edge is coming from the top or from the bottom? If that is the case you will still see this region because there is a line like this across which there is density jump there is a density gradient in this direction. Now, which will have a component downward also.

So, that is perpendicular to my Knife edge. So, I will see this region, but when I go here density gradient is only along this direction. So, if I put a Knife edge like this the light just moves sidewise nothing goes wrong. So, you should be able to see this vortex structure even in the images Horizontal knife edge and Horizontal knife edge top and bottom cases.

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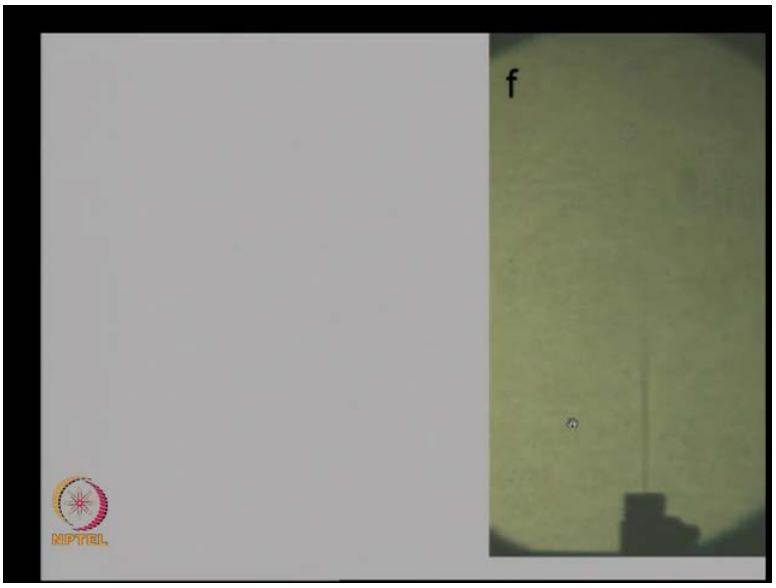

Now, we will go and check whether you are seeing that, intensity on computer is better than this, but anyways you can see this region here, having some structures it is having some kind of structure in this region. And if you look, at similar picture here wherever it is bright that region will be dark here. It is just opposite the front of the vortex is one color here; it is the opposite color in here. That is the idea of this which basically says that the density deflected upward is blocked versus not blocked in one of these pictures that is the idea in this. So, depending on what flow and what you want to see you can choose different systems. When I go in this shadow graph picture again if, I go for this laminar section I am seeing good density when I go out here, the same turbulent region is present here also, but since the changes are too drastic the and the shadow graph tends to the 2nd derivative the intensity the value of the 2nd derivative is very small that it is not able to pick up that light here. Unless my light intensity surrounding is extremely small and my camera is very sensitive to that light it may not be very easy to pick up in shadow graph fine density changes. Good density changes like, a shock very easy to pick up in a shadow graph, but not these very small changes this is what I wanted to talk about, in versus shadow graph comparison we will go back to the board.

Now we will look at this, and we want to make sense out of this picture I have drawn from here. How can I get this particular profile either the top one or the bottom one from this picture how will I get it? If I take derivative of this we told already that it you should know the answer already right. If I take dou rho by dou x versus x what is this here

gradient is 0 for longtime, and then suddenly gradient is going negative and then it is 0 at this bottom and then it is again positive coming back to 0. So, what should I see I am going to see something like let us, say this is my 0 it is going to go negative positive 0 this is what I will see that is the picture I am having for 1 of the knife edge cases.

In the other knife edge cases I am having negative of this. Why is it negative of this? Now, my knife is direction is opposite. So, what is supposed to be seen is now cut off what is supposed to be cut off is now seen. So, it is as if my axis is now going the other way then, it will look like it is going up and coming down as x increases if my axis is going the other direction. That is all it is those are the two cases here, shadow graph we said it was sensitive to 2nd derivative is derivative of this again once more what will we see derivative of this it is 0 here and then this slope is going negative that is it is becoming more negative and then it becomes 0, it becomes positive, become 0, becomes negative becomes 0.

So, if I draw this thing it is going to look like, it will look something like this I have, made it wider ideally it should be these are the points that are supposed to be corresponding to each other. I have drawn it wider actually this area should be shrunk a little bit more inside this are the points that are supposed to be corresponding to each other. If you look at this picture is somewhat similar to what I have there of course, I have the inverse of it that is all, but this is the idea and may be it should be minus dou rho square dou square rho by dou x square then it will match that is your shadow graph picture this is what we just saw. If I give different density gradient like this, I am going to get pictures like this.

That is what I am seeing here, and in here I can choose either I get this intensity variation or this intensity variation, depending on what kind of knife edge I use. We also saw that, I can use radial knife edge slant knife edge whatever I feel like. I can choose special cases where I want to have knife edge at an angle instead of horizontal or vertical I can put it at an angle and say I want density gradient only perpendicular to this direction that also can be done. In special cases people want to do special experiments they can do that also. Now, once you understand this can I do something more with my knife edge more than radial knife edge etcetera that is the next stage.

And now, I am going to give you a color shade set up which is, I will go back to this picture no I have the lens picture here. I do not like this lens picture here I will draw it again fresh I am having some lamp.

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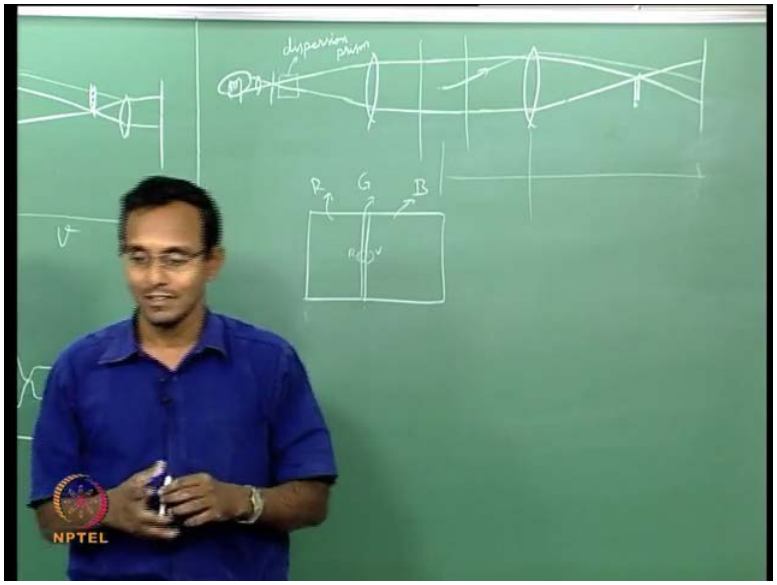

There is a lens and it is focusing there is a pinhole immediately after that I put some optic here; I am using a dispersion prism. What will it do? It will separate out the colors. If it is separating out the colors I am going to have, this expanding beam I am assuming the initial lamp is not monochromatic it is having several wavelengths and. So, when it comes out here it is going to be separating out say one end will be the highest deflected will be violet right, I do not remember right now I think highest deflected is violet. So, violet will go more down and red will go less down etcetera, we are going to have that full spectrum of things coming here.

Now, if I think about putting my regular lens of and make a (Refer Time: 34:58) parallel beam out of this, what I am going to have is a whole bunch of parallel beams next to each other. The topmost one will be the red one and then there is this reverse of vibgyor the whole thing will be there, violet will be the bottom most and then whole bunch of parallel beams. Because of this, now if I put my test section here. I have some density gradient and then I am going to complete my set up and I will draw the simplest one I will put just a screen no lens to zoom in or out and I put a knife edge.

Let us say, I put just a simple knife edge regular knife edge the metallic knife edge let us say I put. If I put something like this if, my density if my light is such that it is going up and I have cut out all the light if I if my density the variation is such that, the light here is deflected up and I have adjusted my screen such that this one by u one by f all that is satisfied then.

I am going to have that light alone going there and coming there. Right now, which one has before that I have to tell you one more if I think about all these parallel beams coming with slight offset in each other. What will their focuses be on this knife edge? There will also be slightly offset one from the other, red will be the topmost then there will be next one orange, green, and then there is blue, and violet etcetera and the whole thing will be sitting here like this. They are not going to be very much off they are going to use a prism which is not going to split them very much I want to split it very slightly.

Now, because of this if I have a deflected light then the very 1st thing to go up above the knife will be the topmost focal point thing. That will be your red in this particular case, we said that red is the topmost in our system. Because of that I will see red colour light if it is deflected up. What if it is deflected down? Nothing will be seen we will just see dark. Because there is no light going through, all the light are getting cut-off by this knife edge nothing will be seen. That is one way of doing (Refer Time: 37:11). Now, I want to make it sensitive in both directions what will I do? I will put a knife edge which is sensitive to wavelength. So, what I am going to do is I will create a glass plate which has 3 parts this region allows green, this region allows blue only, this region allows red only. If I create such a knife edge really it is a knife edge for different wavelengths if you think about it, only the center region will allow green other two regions will not allow green. This region will allow red for red light, this left line is my knife edge only on this side red will be passed that side red will be blocked. So, it is a knife edge coming from the right for red. For blue its knife edge coming from the left, and for green knife edge coming from both sides any deflection will be cut off no deflection it will go through straight.

I will put my focal spot somewhere here, if I do that now of course, you should know that it is not single focal spot it is a whole bunch of focal spots red on this side and violet on this side. The whole thing sitting here, vibgyor reverse sitting here. I am going to put this knife edge rotate it and put it there in that place. If I do that if it is deflected up, then

red will be allowed if it is deflected down, that is the other side then blue will be allowed. So, now, I can see sensitive to both sides. If I now, say that deflected up is a shock deflected down is an expansion then I will see, shocks has red color expansion has blue color. So, that is the advantage of using a color (Refer Time: 34:58) directly I am going to get picture if it is not deflected.

I made it such that it looks green. So, because of that now, just looking at the picture itself I can tell my density mapping wherever, the density is climbing up high density gradient mapping wherever it is density gradient positive I am going to see in this particular system whatever I told shocks are red I said. So, wherever it is red I am going to say there is a shock, wherever it is blue going to say there is expansion, wherever it is green not much of density variation. I can tell that based on just this kind of setup.

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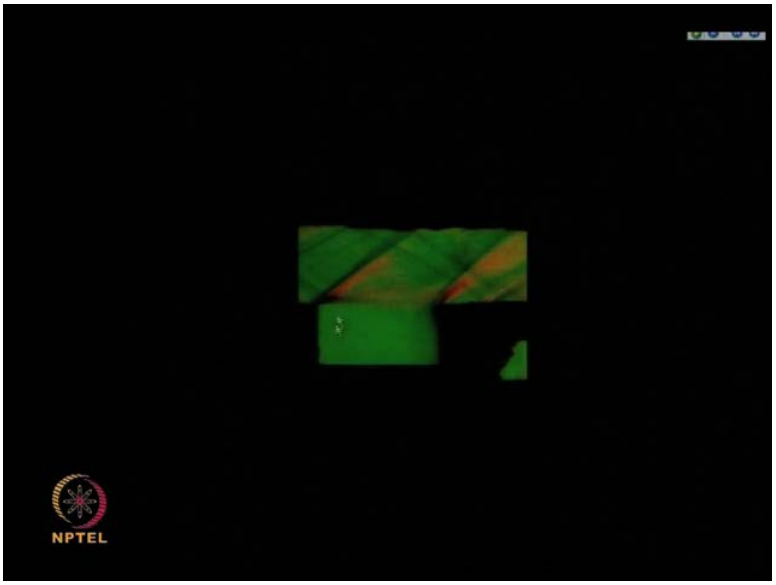

Now, I will show you one picture like that, taken from our lab. Here we have done the experiment, but with only a simple knife edge not with the color knife edge. It is just a plain metallic blade as for knife edge. So, what we are seeing here is wherever it is expansion it is red in colour wherever it is a shock there is no blue knife edge. So, it just becomes dark. That is what you are seeing here it just wherever it is dark I am going to say the dark spots are knife edge this particular case is supersonic flow with top wall straight bottom wall having a small cavity and then it is going straight.

This particular case where you are going to see that, there is a flow injected in here because of that you are going to have a shock followed by expansion in this region and then there is a shear layer formed in here which is going to hit this corner it is going to create shock expansion etcetera, alternating in this corner. That is too much of details for you in supersonic flow here, but you can see that there is a shock coming from the nozzle to the test section joining point and that goes here, it comes back this way this bump like things here are glue holding atop wall to the side glass wall and glue is blocking all the light.

That is what you are seeing here, araldite glue where you have seen there that is what you are seeing here this goes up comes down from the wall bounces off again here, that whole thing is dark saying that that is a shock wherever it is red it is expansion. We have set the knife edge such that expansion will be seen as red that is what is currently being done this is your colour set up. Now, there is only one more setup for density variation based measurements flow visualization which I have not shown you which is interference based interferometer. Interferometer again has the same beginning setup I want parallel beam of light. So, ideally I should keep this.

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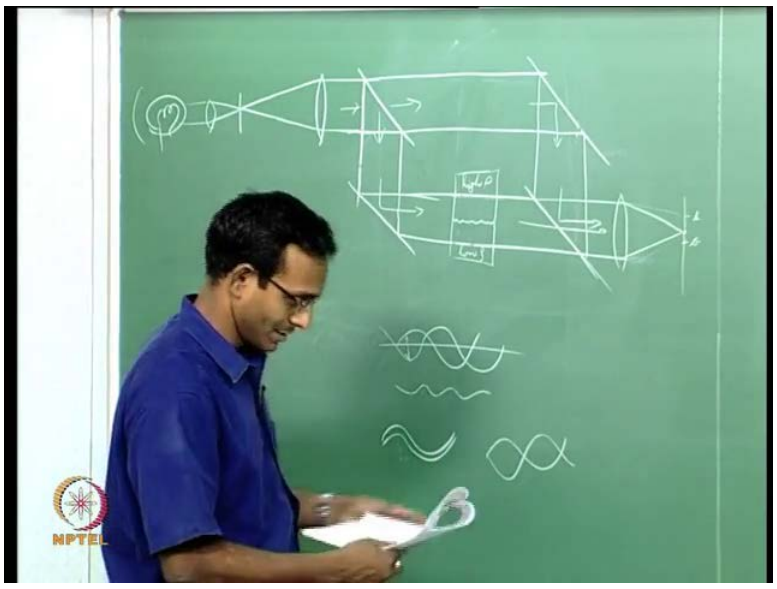

Now, what I will do is I will put a beam splitter I have put the beam splitter the wrong way right, I want the beam splitter the other way which is going to reflect 50 percent of the light and allows 50 percent of the light. Now whatever, is going there I will put a

mirror reflect it again, actually I have to reflect correctly and here we will put another mirror reflect it, and I will put a beam combiner which is again a beam splitter just working the reverse way it is going to allow all the light that is going this way and whatever, light is coming this will be reflected and it is going that way. This is my setup light directions are like this, basically what I have done is have created a parallel beam of light I made it go through to rectangular side paths. One is going this way and the other is going this way. If I make all the arrangements nice, then I am going to say that this path length is exactly same as this path length. You have to make sure that it is. So, otherwise your experiment will not be good I already told you setting up interferometer is more difficult. So, you have to make sure that your path lengths are equal and at the end I am going to put it back onto a screen. Now what I am going to do is? I will put my test section in this region in one of the paths.

If there, is a density variation in here in one of them alone, what will happen now if there is a density gradient only in one of them? Then this particular line alone this light will see higher density gas to go through, higher density corresponds to higher refractive index right, we said glass stone del formula last class higher density means higher refractive index, higher refractive index means slower speed.

So, it is not going to cover this distance in the same time as what this does same distance. So, initially whatever face I had say I pick a particular peak that is going to be split into two, there is a peak of a wave of going this way, there is a peak of a wave of going this way, by the time this wave comes and reaches here. This wave would have come reached and gone past the top one. Because of that there is going to be a phase difference between these two light paths.

And when they meet and come together and go into these lines to form a focus point, it will not have the original intensity what is expected when there is no density change. Since they are not interfering the regular way, it is as if I have a wave like this and there is another wave coming like this, and what I am going to say is the summation of these two waves that will come out to be see this point is negative this point is positive, but less. So, I will get slightly lesser value here, it is going to do something like this I will get some other wave finally. I am not drawing it exactly for this picture just drawing something looking close to this. You can exactly find out what the shape should be add two sine waves you know sign a plus sign b it will give you, something to do with

cosines right, you can get to that point we would not do that here. But, you are going to get bright dark regions here, suddenly which was not initially present.

So, I am going to form fringes in my flow, I am going to form bright dark fringes in my flow if there is a density variation. What if my density variation in such that? The 1st peak is shifted by one full wavelength when it reaches the next one. When it reaches here, then there will be interfering nicely positive interference right, both are having same thing they will just add up nicely they are not cancelling each other they are just adding up.

So, intensities will add up which means that region will be bright. If I had a situation where, my densities are such that they are having this complete opposite case. Then I will not have any light at this location, if the density is like this. Now, if I say my density is low here, high here, and it is varying linearly from here to here. Now I can think about this last line and the immediate next line they are not going to have the same phase shift between this two sine waves. What are these sine waves? My waves of light electromagnetic waves I am talking about, those waves electric field or magnetic field waves. Those will not interfere the same amount in each of these, because of that the shift between the two peaks will be different if it happens to be this, then it will be very bright let us say we will pick that case it is very bright let us say, this particular point will be focused somewhere here.

And then that will be a bright region and if I say the topmost thing is going to interfere like this, then it will be dark region and that will let say is going to be focused here dark region. Now, I am going to say these all the intermediate regions the intensity should be increasing slowly to the other one that is assuming there is only one full wave length phase shift that need not be the case any integral phase shift will lead to this condition. Phase shift being 0 will lead to this or phase shift being 1 lambda, or 2 lambda, or 3 lambda any n lambda will give you this. Here, any n plus half lambda will give you this. So, I may have a situation where bright dark,I may end up like that, I will have a zebra like pattern there you see picture where it is showing bright dark .You can immediately tell that it is a interferometery picture I will try and get interferometery picture for next class. I have not made a interferometery experiment yet. Once I make we will show it to you. But, if I have a sudden jump in density let us say, I have a shock somewhere inside here in my flow, then what will happen all this region I am saying it is a same low

density no change no fringes it will just be plain one color, other side again plain another color across this is going to be a huge jump in number of fringes that I have gone to cross there is going to be they will typically number the fringes 1, 2, 3, 4, 5, 6 and call it the order of the fringes typically you will find that there are some 7 to 10 fringes jump of course, it depends on what is the focal length you are using what is the path length you are using etcetera. I just generally picked a number 6 to 10 because I have seen pictures that are moving 6 to 10 fringes.

So, I will show you some picture where I can show you the number of fringes shift also if possible. Some such data hopefully I will do the same helium jet. So, that you can compare across different cases it will be nice to see them, but this is your interferometery set up this one is a little more difficult because now you have to make sure that the path lengths are exactly matched the light beams are exactly co-linear they are not exactly co linear you are not going to get the same focal spot for both the beams.

Then the interference will not happen or it will happen with the wrong data point. So, you have to think about, a lot of things once the full interferometer is set up then you finally bring in the test section and put it there. till that time you do not have a test section that is the only way to ensure that there is no fringes. So, the way the people do it is they will make this whole interferometer with a gap for test section. And they will come and put the test section once the interferometer is very well aligned. that is the way they work with the system. In the next class I will show you an interferometer picture I have already shown you a color picture also.

So, hopefully you can make some setups and shadow graph setup shadow graph is the easiest setup. After that we will move on to method of characteristics based calculations of flow fields that is next class is any questions yes

Student: dou square rho by dou x square, what is the peak which point does that peak correspond to dou square rho by dou x square.

Where the peak is is corresponding to wherever is the highest slope? Highest slope change which typically will be at the center because here it is increasing increasing after that it is decreasing so if I draw that region alone in much more detail it is going to look like this slope is 0 here 0 there, but in the middle it went to a highest value and then it came back to 0 value.

So, the highest value is somewhere here, the point of inflection if you know that is where it will be the highest point of inflection is given by third derivative right, yes no third derivative becoming 0 that will be that point you will just get to that point it is your point of inflection that is where you will have the peak in there.