Fluid and Particle Mechanics
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Lecture - 69
Laminar and Turbulent Boundary Layer

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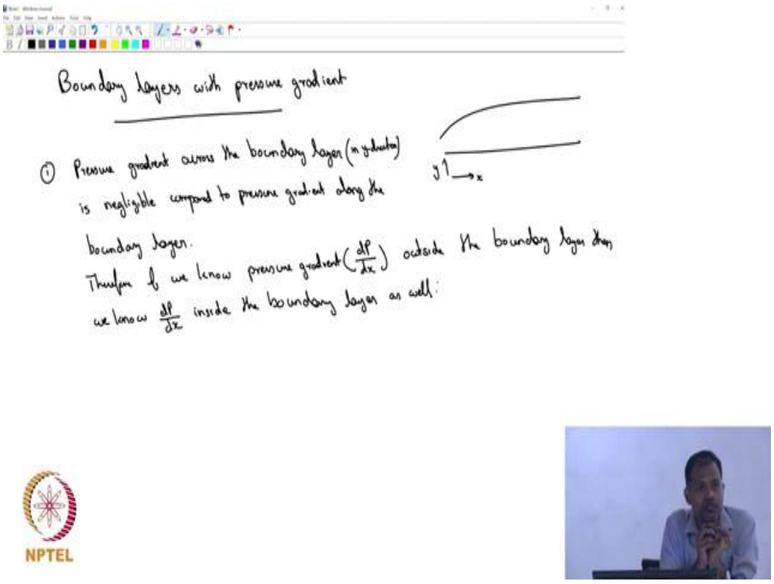

So, if you look at the facts that we talked about, one of the things that we talked about was that, so if you have you know let us say boundary layer and this is x-direction that is y-direction, then I said pressure gradient across the boundary layer. So, across the boundary layer meaning in y-direction is negligible compared to pressure gradient along the boundary layer.

So, this is one of the things that we said in the last class. And therefore I argued that if therefore if we know pressure gradient which is you know dp by dx outside the boundary layer, then we know dp by dx inside the boundary layer as well ok. So, knowing the pressure gradient outside the boundary layer essentially helps us to determine what is the pressure gradient inside the boundary layer, so that is one of the things that we learned.

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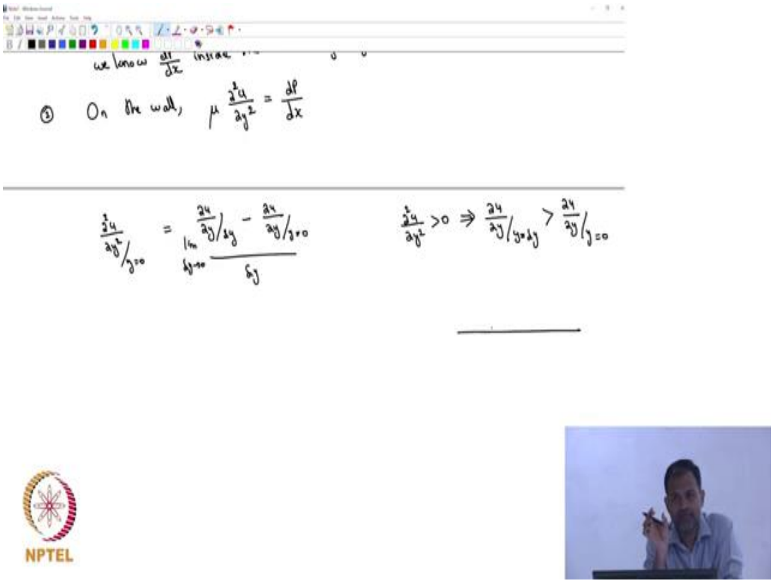

And then I also argued that on the wall the governing equation essentially simplifies to d square u by d dou square u by dou y square is equal to dp by dx so on the wall. And therefore knowing the pressure gradient outside the boundary layer helps us to determine, how does the you know second derivative of velocity change on the wall ok. What is the second derivative of velocity on the wall and that basically helps helped us to plot the velocity profiles.

So, just to go through it once again I am interested in calculating the second derivative of velocity. So, dou square u by dou y square at y is equal to 0, I can write it as dou u by dou y at let us say delta y minus dou u by dou y at y is equal to 0 by delta y in the limit delta y tending to 0 is my definition of second derivative of velocity. And if I say dou square u by dou y square is greater than 0 that automatically implies that dou u by dou y at y is equal to delta y should be larger than dou u by dou y at y is equal to 0. So, that would mean that my velocity profile it is, I have to say that if it is at 0 the slope is smaller above the slope is larger. So, it has to be that or this.

Student: First.

First one, I did not do the different colors. So, remember your that is here u that is your y ok. So, if dou u by dou y is large, basically this is this it has to be of that form right. So, it has to be that.

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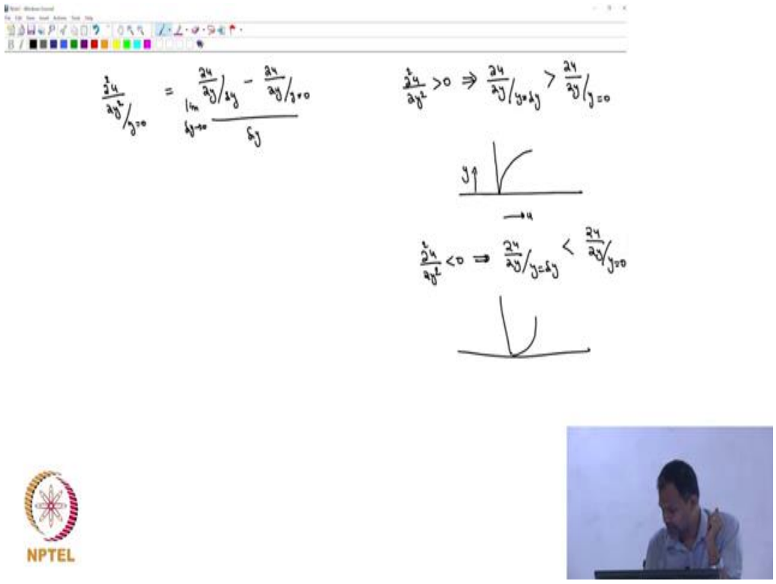

And if dou square u by dou y square is less than 0 that would imply that dou u by dou y at y is equal to delta y should be smaller than dou u by dou y at y is equal to 0 and that would happen if my profile actually has a opposite curvature. And therefore, we talked about few different situations.

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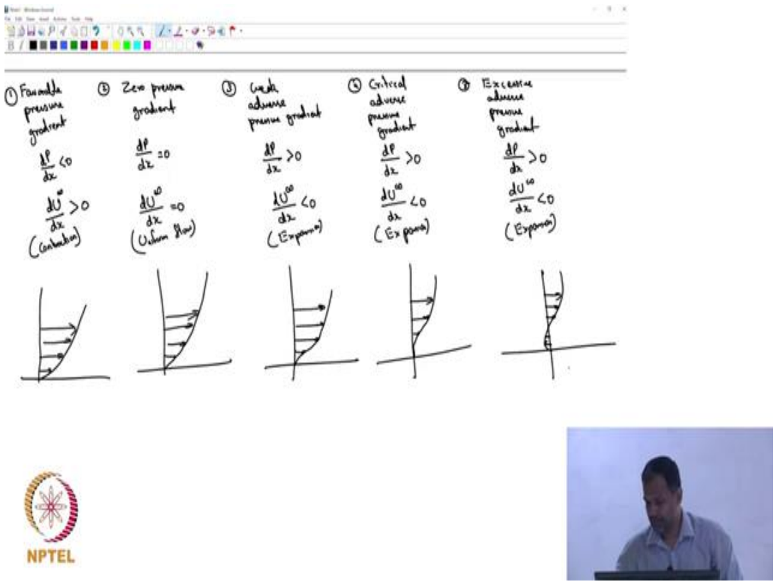

I talked about favorable pressure gradient.

It is velocity profile no. So, how do you draw velocity profile? That is your u, that is your r or y or anything.

Did I do it wrong. So, let us look at the first case we have dou u by dou y should be correct dou u by. So, this is my y is equal to 0. Here my slope is smaller, there my slope is larger, because if there is a small change in y, u changes not here correct, this is ok. So, we have a favorable pressure gradient. Second was 0 pressure gradient; third one was weak adverse pressure gradient; fourth critical. So, I did not put all the names I think yesterday pressure gradient by excessive adverse pressure gradient.

So, favorable pressure gradient has to be in the direction in which dp by dx is less than 0; this is dp by dx is 0; this is dp by dx is greater than 0. This is dp by dx greater than 0; this is dp by dx greater than 0. And therefore, d u infinity by dx should be greater than 0; d u infinity by dx is 0; d u infinity by dx is less than 0; d u infinity by dx is less than 0; d u infinity by dx is less than 0.

So, in the first case, where u infinity is increasing with x that is like a contraction, this is just uniform flow. This is like an expansion; this also like an expansion and this also like an expansion that the amount of divergence should be larger and larger as you go to the right. And therefore, we said the flow profile here should be like that, here till increase her like a straight line. And then smoothly join with U infinity, here you should have a difference different curvature.

So, it has to be like, like that or you could actually have it almost like that and you could have it like that. So, in a contraction flow sticks to the wall in an expansion on the surface, you could have flow going the other way. So, this was the story that we had at in the last class. Any questions on that again? So, what I am going to do today is, I am just going to show you how do you see these things in the experiments.

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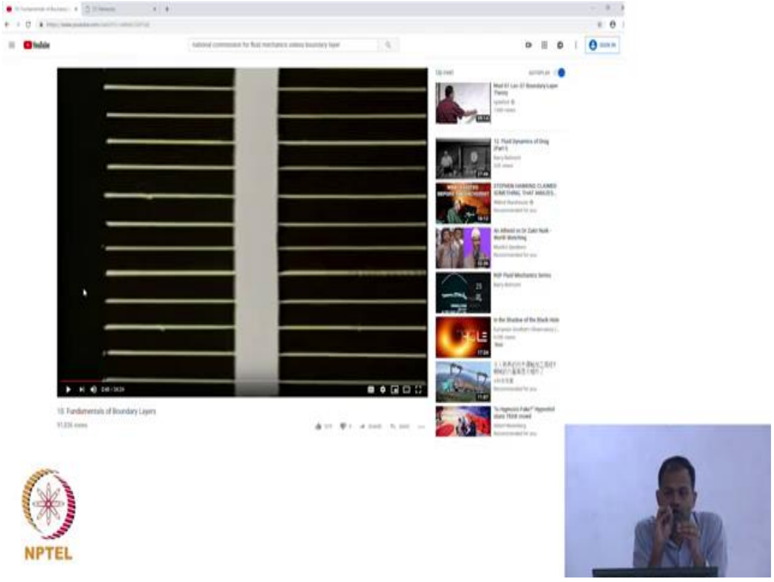

So, what they are going to do is that you know they are basically going to have look at both contracting, expanding as well as uniform flow and to see the flow they have actually put hydrogen bubbles into the fluid flow ok. So, this hydrogen bubbles are extremely small, they just get carried ok, they just go passively with the flow, but you can see it whatever you going to see white are actually concentrated our hydrogen bubbles ok. So, that is the way they visualize it.

So, first let us look at. So, this is; so, this thick band that you are seeing that is a whole lot of hydrogen bubbles that has been inserted and there is a fluid flow from left to the right. So, you see that the band is moving ok. And as the band moves, they will put a white solid plate. So, the fluid will go above the plate and then you then the moment the fluid is going on the plate you should see the formation of the boundary layer. So, that is the idea, so no, so there.

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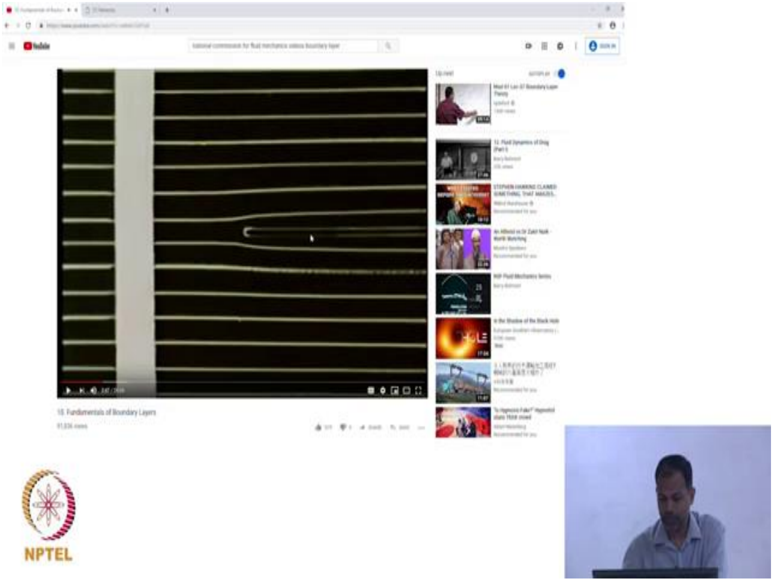

So, that is the solid plate there you go.

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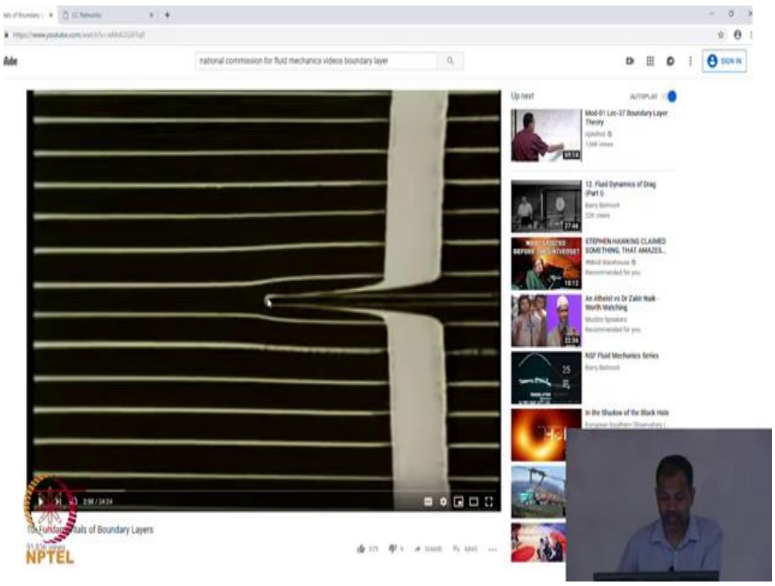

So, you see the this basically the fluid near the plate is getting accelerated and then you start seeing this growth of boundary layer. You will see a few more times and you can see as boundary layer the thickness grows as you go downstream ok.

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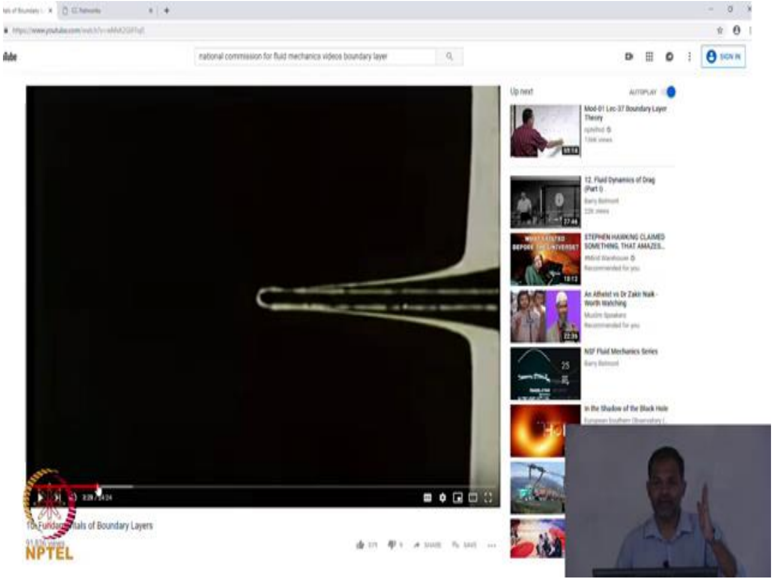

Now, what they do is, you have this, they will actually move the camera along with the band ok. So, then you can see much more downstream, you can see that now, maybe they are short, they are.

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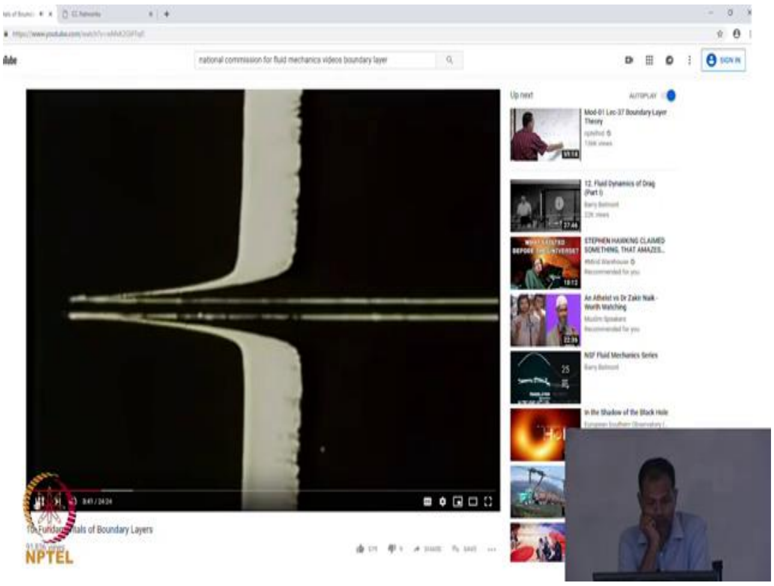

So, they are moving along with that and you can see the growth in the boundary layer now right ok.

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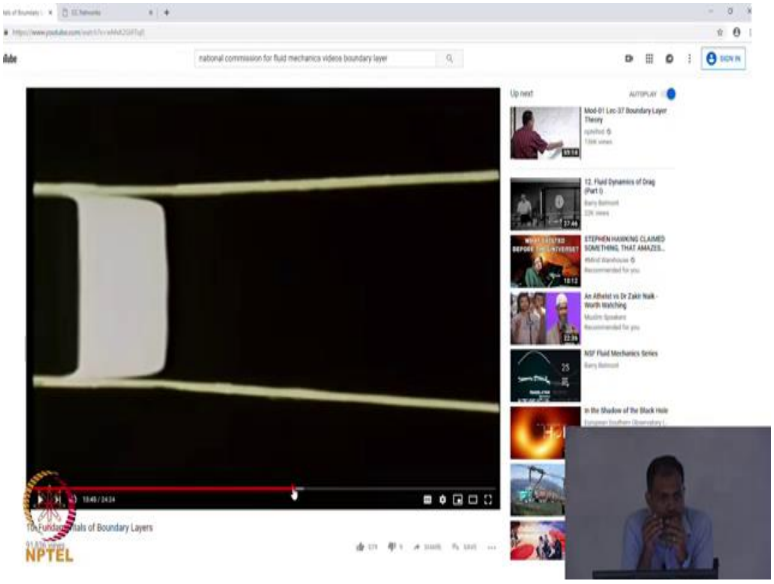

So, now what they have done is, they are actually going to take a diverging channel. So, we remember we said in a diverging channel is where you basically have a you can expect to see a separation, so that is what they want to demonstrate. So, you can see that this channel is slightly diverging ok. So, slightly diverging is going to generate a big adverse pressure gradient.

So, there will not be any separation, but as you will see that as divergence increases, you will see the fluid flow separating. So, here this is going to be without. So, you can see the boundary layer here ok. So, this black region is basically the representation of boundary layer, the boundary layer grows, but nothing special happens.

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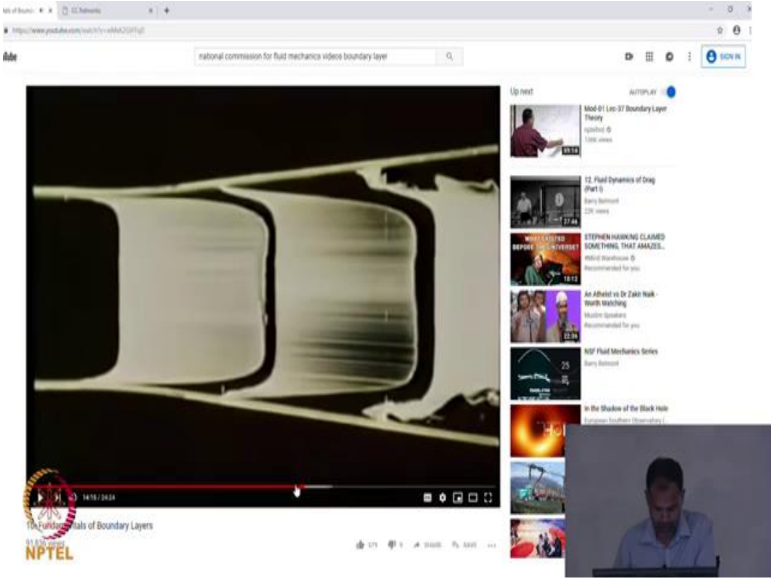

Now, taking a bigger diverge more diverging channel.

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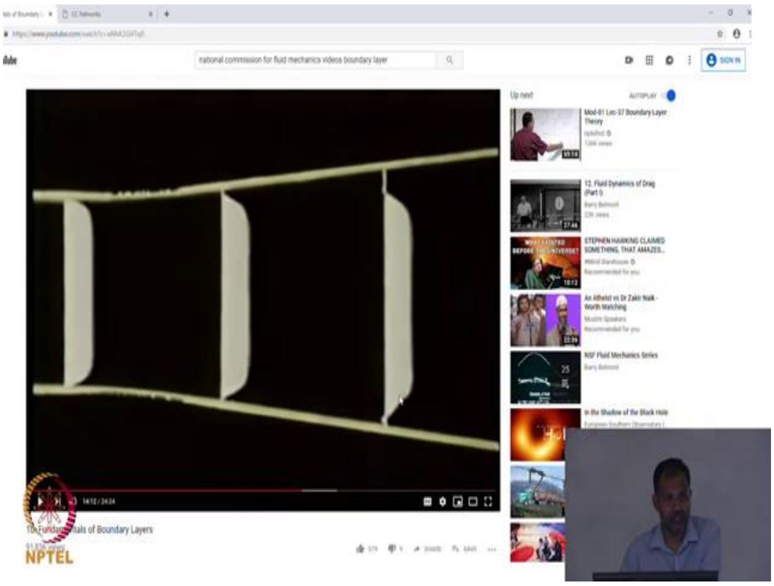

So, they are in so this is a band of you know hydrogen bubbles that has been inserted. So, here this is like you know more or less uniform, then you can see a bit further this downstream and this is a bit more downstream ok.

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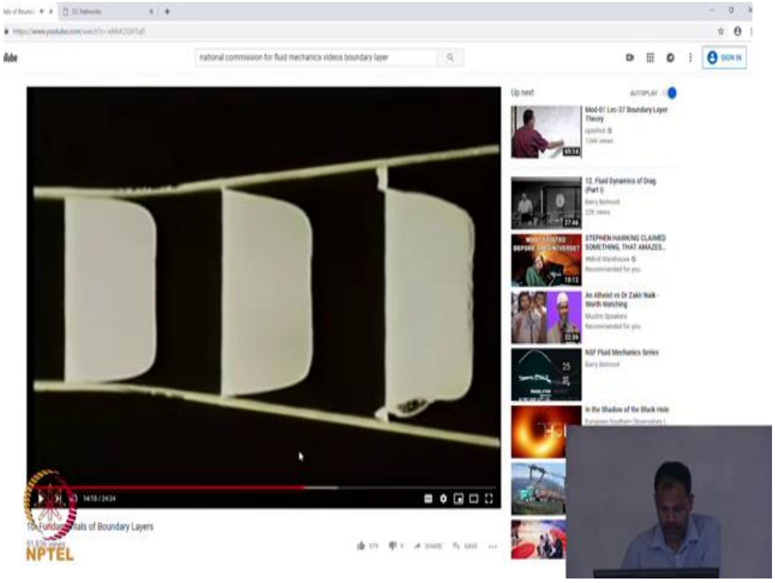

And you can see that here because of because this is diverging, the pressure the velocity is decreasing that would mean the pressure is increasing. And we know that the pressure gradient outside is going to determine what is going to happen on the wall and the fluid is actually flowing in the opposite direction.

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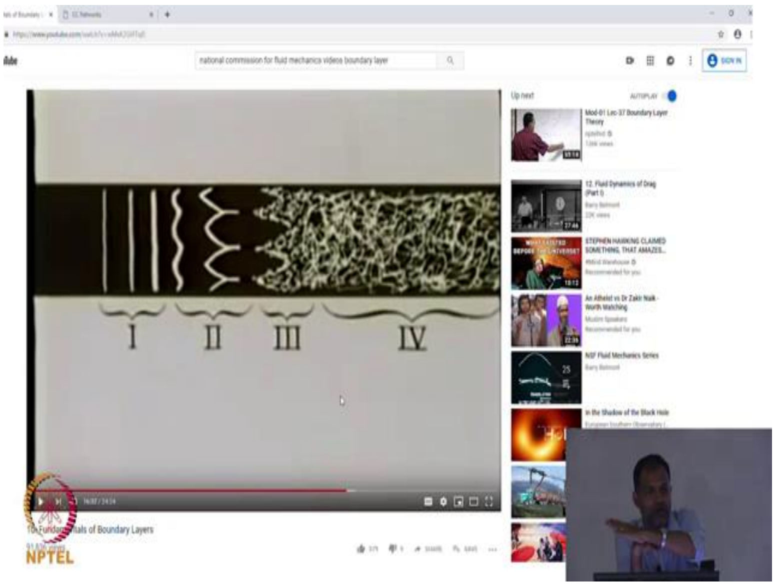

So, I said in the boundary layer ok, so as soon as the boundary layer starts, it will be a laminar boundary layer. And beyond a point, it will transition into turbulent boundary layer ok. You can also see that. So, in this particular case, we are not going to do it on a wall.

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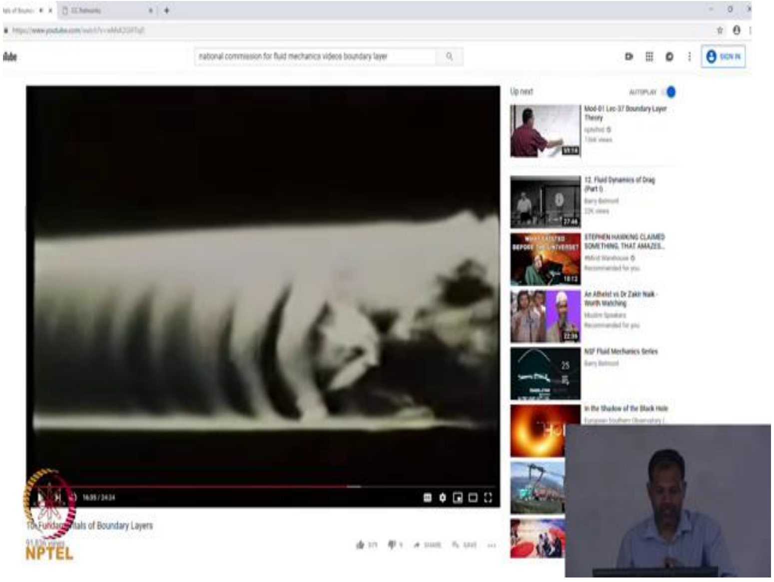

So, there they actually have a pipe ok, and they and there is a fluid that is coming from the left side and it is flowing on top of the pipe ok. So, it is a round thing. And therefore, a boundary layer grows on top of the pipe and there they have actually characterized. So, on the leftmost, you have a laminar boundary layer. And then what you see is some kind of a waves and so on that essentially represents transition and here much further downstream it basically turns into turbulent boundary layer.

So, this is what the boundary layer would look like. If you I mean if you basically put lots of you know let us say something that you can visualize you will see how smooth the laminar region is and how things basically turn to turbulent as the boundary layer undergoes transition. So, this is the laminar turbulent transition in a boundary layer.

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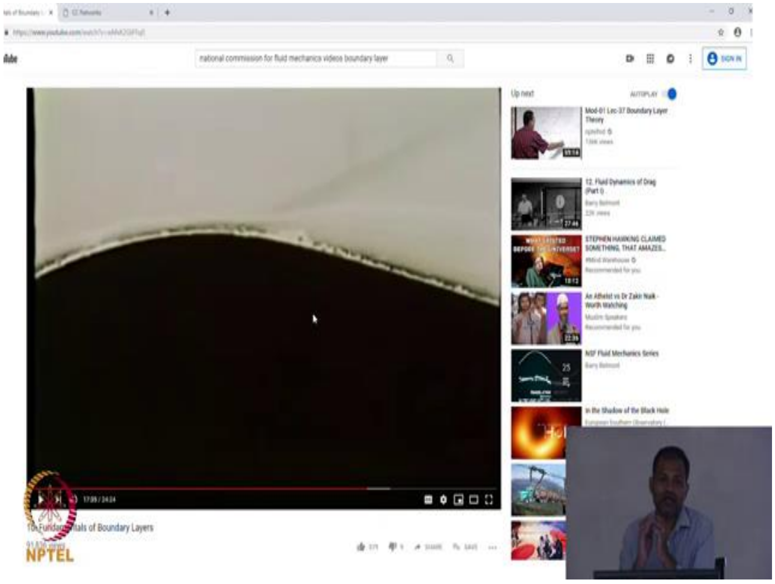

Now, something that I did not tell yet ok, we really did not distinguish laminar boundary layer versus turbulent boundary layer. So, and we talked also about the separation in the boundary layer. So, what happens is that the turbulent boundary layer, so turbulent boundary layer would mean larger Reynolds number right and larger and Reynolds number is basically a representation of larger inertia.

So, if they are in turbulent boundary layer, therefore, separation occurs at a later point not as easily as in a laminar boundary layer. So, in laminar boundary layer, the fluid might you know get separated, so this region that I am talking about ok. While if you are looking at a turbulent flow, the separation is expected is you know there is less chance for separation because it is more inertial, therefore, it will have a tendency to actually stick to the wall and go ok, so that is called a delayed separation. So, in turbulent boundary layer use you are less likely to see the separation than in laminar boundary layer if you were to do a comparison. So, this can also be seen and that is what is going to be demonstrated.

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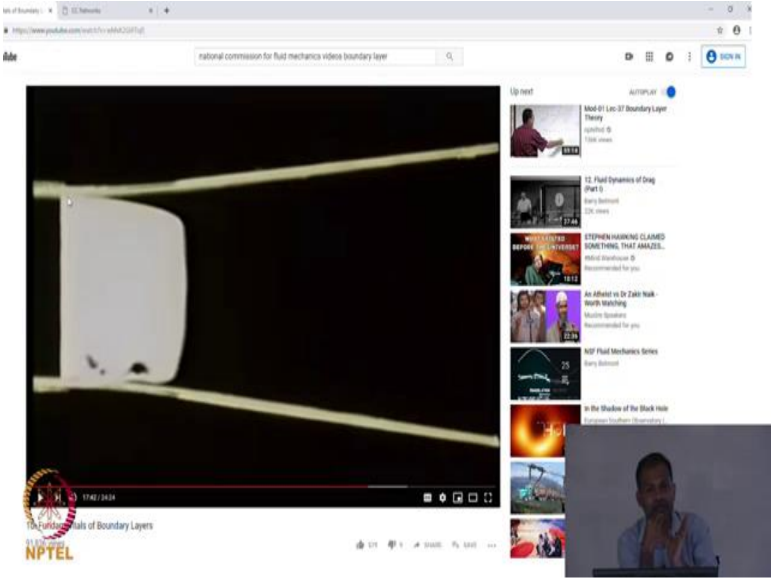

Note this there. So, here you have a same diverging channel. And I forgot on one of the side they will have. So, what they do is that, so it is the same channel and then the fluid is coming on the top it is just smooth pipe; at the bottom they will introduced a little bit of roughness ok. They basically will put a wire ok. And then what happens is that the flow will basically be trip to turbulence because you see some you know disturbance. So, it was trying to maintain the laminar flow, but you have given some disturbance. So, the fluid flow will turn turbulent. So, this is a nice case in which the top, you will have laminar turbulent layer; at the bottom, you will have a turbulent boundary layer ok.

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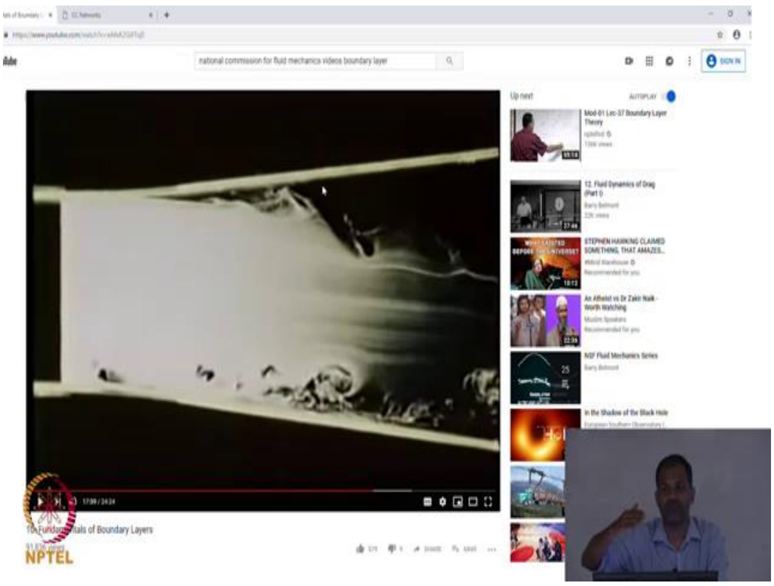

So, this is laminar to turbulent, I mean in top and bottom, it is different. And you can see that turbulent boundary layer sort of sticks to the wall much further downstream than the laminar boundary layer ok. So, the top you can see separation the fluid flow is going the other way so basically this already so see the white is coming from the left. So, if it was occupying the full region that would mean that it was a unidirectional kind of flow ok, but it is not. All this region it is actually occupied by the black, that means, that the fluid flow is basically coming in a different way.

So, this black region should be thought of as region that are separated from the main stream right ok. So, if you were to see what is there in the black you will see the flow in the opposite direction as we saw earlier. While in turbulent you can see that the fluid flow is almost sticking to the wall much further downstream ok. Therefore, turbulent boundary layer sticks to the wall much more than the laminar boundary layer.

Yes, you mean the video or the what I said? So, what I am trying to say is the turbulent boundary layer turbulence basically corresponds to larger inertia. So, the fluid that is going to come basically have the tendency to maintain that velocity ok. So, instead of having an opposite velocity, it would have a tendency to go with the same velocity ok. So, therefore, turbulent boundary layer the chances of separation is less compared to laminar boundary layer. So, this will we can do this comparison if you have the same Reynolds number and you can still get laminar and turbulent.

So, that is the case here. You have the same Reynolds number the fluid flow can actually be laminar or turbulent. If the fluid flow is turbulent, then the fluid flow will not that will not separate from the wall, it will have it will go with you know in the same direction as it was coming well the laminar might separate. So, upside you have laminar flow, it is separating, but downside you see it is turbulent, so it is trying to stick to the wall black color. So, everywhere it is fluid, the white region indicates the fluid that is coming from the left.

So, wherever you are seeing white, you should imagine that is the fluid actually that is incoming right. So, the black region is the one then it has not come from there. So, it has come from somewhere else. So, it must represent regions either stagnant or it flow it fluid flow from the other side.

No, that is the region of the boundary layer now or actually that is the region in which they know. So, this is the wall; this is the wall. See this is the wall and this is the wall these two white are walls it is a diverging channel. So, 99 percentage greater than 99 percentage would be this region. This region will be boundary layer; this region will also be boundary layer ok.

Now, this region you are not seeing any white fluid means that the fluid here has not come from the left side, either it was just stuck there or it would have come from the right side right. See here whatever is entering is coming as a white fluid, so if it was all going it should have occupied the entire channel.

So, fluid has a velocity smaller than 99 percent is both up there and down there right ok. So, now, what I am saying is that look here the fluid has already reached white color. So, the fluid has not reached here, the white fluid has not reach here. You expect that the white fluid will come and occupy the entire region.

If boundary layer was not there. So, here there is boundary layer. So, the fluid is the white fluid is going to come at a slower, oh, I see what you are saying. So, it is going to come at a slower velocity. Now, look here, so this region it has already reached white right, but here it has not come white ok, so that means, that the fluid even though it was a slower region this region has already turned white and therefore, we would expect this region also to turn white.

No, so, yes, this is fluctuating velocity field, but the fluid that the main velocity is still in the x-direction. So, the fact that you have gotten the white fluid here would mean that the fluid has reached here, the incoming fluid. Similarly, you would have expected the incoming fluid to reach here also, but it has not ok. In fact, it has not because if you look at this, this entire region there is a black color. So, in this entire region, it is because the fluid flow is separated. So, look here. So, this entire region is still occupied by the white, so that is all incoming fluid. But this region is not incoming fluid ok, so that means, the laminar flow has already separated, well turbulent flow has not separated yet.

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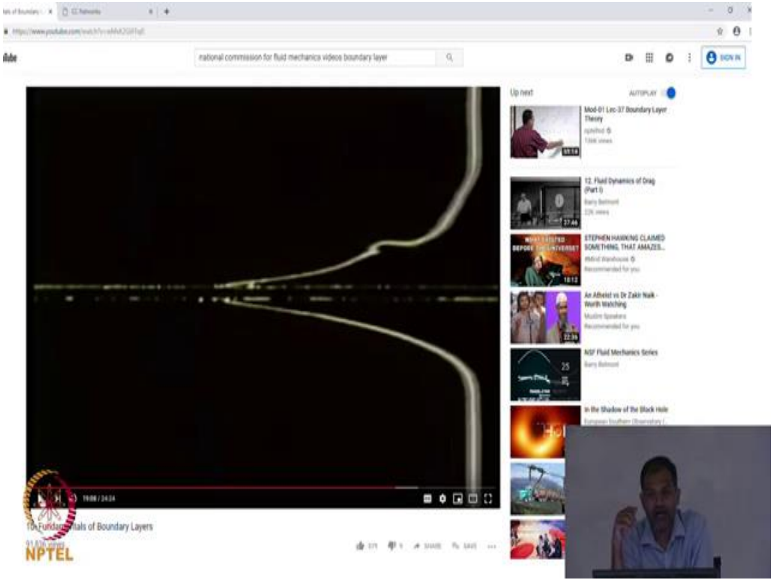

They will draw a little bit of velocity profiles ok. So, you can see how here also they have done the same thing. You have a plate above they have made it turbulent; below it is laminar ok. So, laminar you can see that a boundary layer and it will be all fluctuating velocity field. We will draw more. They show you a few snapshots of various profiles. So, this is the effect of the fluctuations in the velocity field in a turbulent flow ok, but on an average it would look something. So, they will plot an average also is like images put on top of each other.

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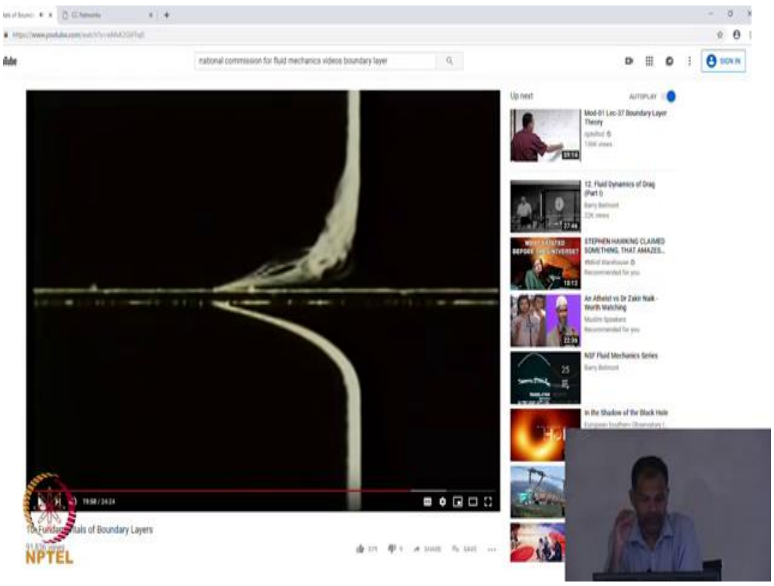

So, they are going to put all the images together of the turbulent, then you can see that there is a nice average ok. So, up as the turbulent boundary layer, bottom is the laminar boundary layer. And you can also see that in the turbulent boundary layer the profile is much flatter than in the laminar boundary layer. So, that is what we had even argued in the case of a pipe flow, till draw a mean profile ok.

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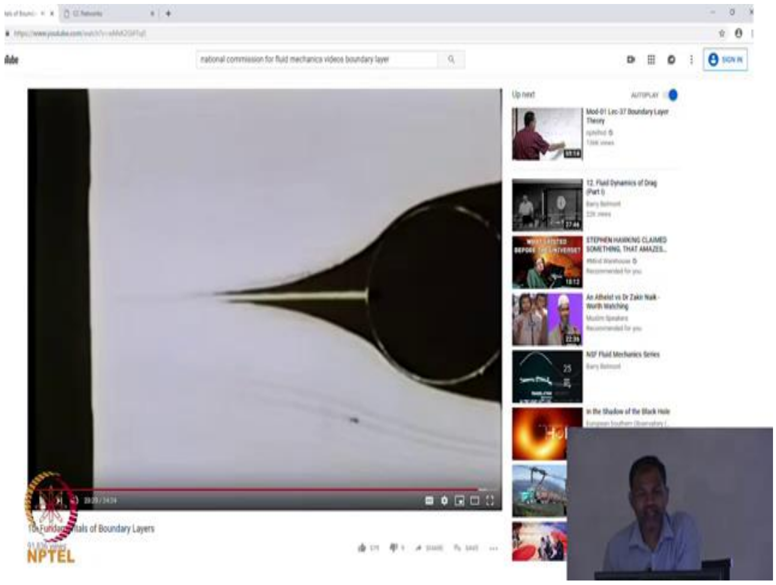

This is not really anything to do with the boundary layer, but I have been telling you about the you know the fluid flow getting separated and so on. So, this last portion actually they show it very nicely in this region, you can see how you know this vortices form other corners ok.

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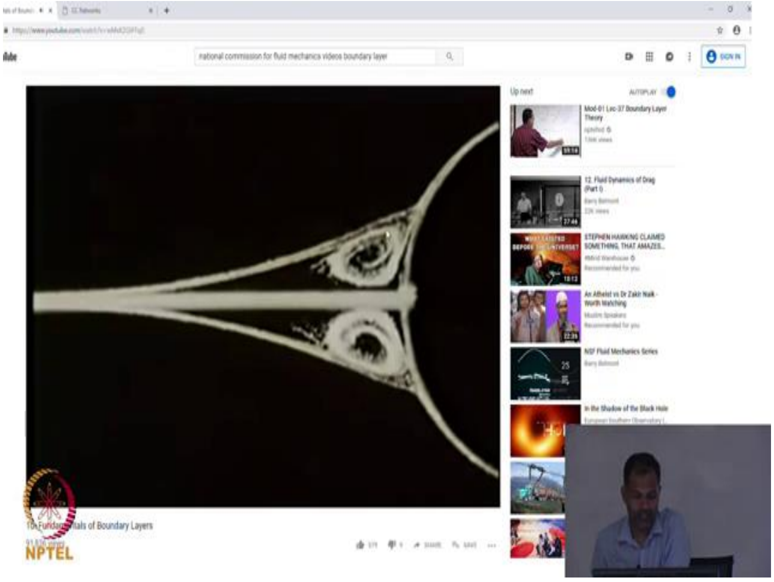

Yes, there is there are two corners up there up there I mean up there and down there and you can see how near the corners the fluid flow is separated and then form this vortices and so on. You can go back and check the video at least the images.