Introduction To Boundary Layers

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Module - 04
Lecture - 32
BL separation with pressure- gradient-I

Hi everyone. So, let us move on a little bit into the study of boundary layers and I think this is one of my favorite topics too. And even a scheme of things, I think students talk about boundless separation quite a lot. Would I find fascinating about this you know, this set of a topic is how we kind of mix and match the physics with the math. On one hand we understand the physics a little bit and we also do the math along with it and look at the geometry and that gives us so much information and is very simple math you know, and in the sense that we look at the calculus and that gives us a lot of information about the boundary layer.

So, let us see what we are talking about and hopefully this, all of this makes some sense. Now, clearly when we talk about separation we go and talk about boundary layers with pressure gradient. So, let us see what I am going to right now start with it, there is Boundary Layers with Pressure Gradient.

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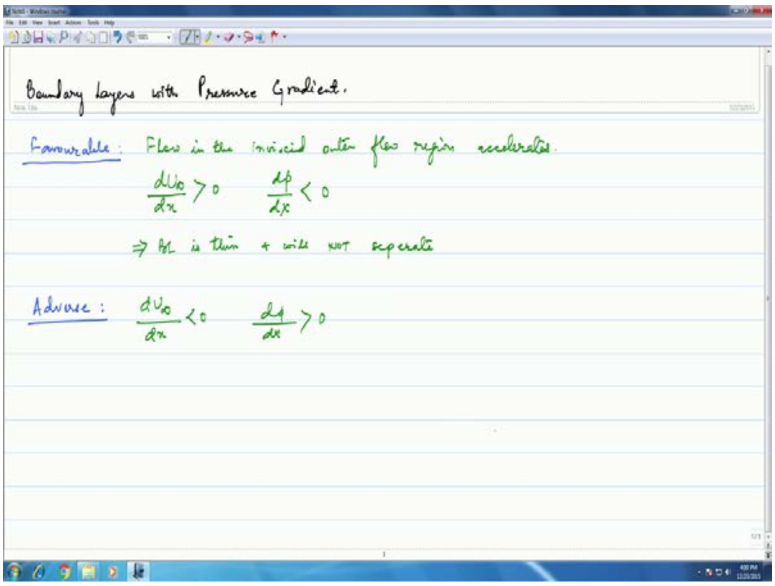

So, let say this is with pressure gradient. Now, what do we instead of mean by; so of course, you heard of this you know favorable pressure gradient and as at the pressure gradient. So, what do we mean by that? Now, favorable; when do we have a favorable pressure gradient? We have favorable pressure gradient, right. One basically you know, the flow in the outer flow region accelerates. So, this happens when flow in the inviscid outer flow region accelerates, which means that how I write that down mathematically. It accelerates, which means that du infinity dx is greater than 0, which means that the velocity is increasing as we go along x which causing a corresponding depending pressure.

Now, the reason we call this favorable because in this case the boundary layer is thin and it will not separate under these conditions and this also means that this also implies that boundary layer is thin and will not separate.

On the other hand, when I say adverse; so the flow is basically decelerating so that it is this, right? Let us look at a few you know, let us look at a few plots and see if. So now, for example, let us draw a few things and see what we get. I am going to draw a couple of things, which we can just think. Now, if you have you know, you should be able to recognize this.

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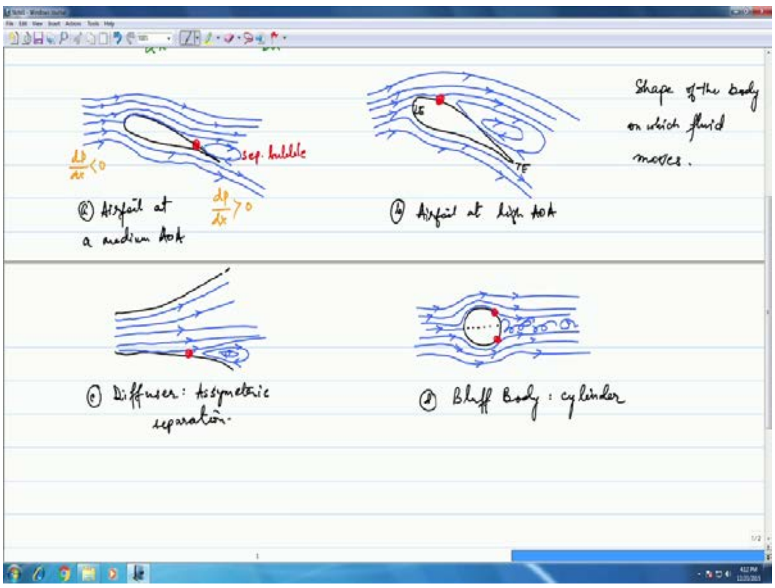

So, I have an airfoil and let me, then I also have something like this, this, this. Now, if do that, this so I have a streamline and say that, separates. So then I have streamlines which go this way, my line should be little more straight; something like this. So, you have got this, right? So, basically this is kind of moving, this is in a clockwise sense if you see this. That is the separation bubble actually, that is a separation bubble. So, you have got these streamlines here. Now similarly, you have this. So, you can very much say that something. Let us draw this first, so we got this and well let me draw this slightly better this is kind of let us say I am going to draw it this way kind of exhausterating that; this I am kind of exhausterating this.

So, these are essentially my streamlines. This is now, this is a type of flow then again we will have for example in here, this; this is basically you know differential, the walls are behaving differently. So, these are also streamlines. And then again, this is a region where I am going to just set of draw it like that, that is basically the region of you know turbulent flow and these are all nice streamlines.

So, now let us do this here, let us call this a, this is b, this is c, this is d. As you can see that you know, let me just set of point out a few things. Now between a and b, these are both airfoils. Now, what you can see is. So, try to know the difference between the 2 flows out here. Now of course, we have you know this bubble which is, this is a separation bubble. So, these are a separation bubble.

Now, when we have the flow which comes in here, now dp dx; so, dp dx is less than 0. dp dx is less than 0 flow is accelerating, so the here dp dx is actually favorable pressure gradient, but once it comes here you know, here on this side dp dx is now greater than 0 you know, and that basically causes the separation point and if you look here we could say that this is around the place where it is separating, so say somewhere around here. So, that is the separation point. So, that is the separation point.

Similarly, if you see here this is around the point where it you know separates. Here, this is around the point where it gets separates here. These are the 2 point locations where it separates, flow separation and these are the separation bubbles. So, this is a separation bubble and this is a separation point, again this is the separation point. Therefore, this is essentially airfoil, at a medium or sort of you know moderate angle of attack; say around 5 or 6 degrees, 5 or 6 degrees.

Airfoil, here the airfoil is at a medium angle of attack. Here it is at high angle of attack; here it is at angle of attack; so, airfoil at high angle of attack, right? So, you can see the difference here when it is at angle of attack you see the separation point it move towards the leading edge. So, this is the leading edge, this is the trailing edge. So, in this case that moves up and this is more towards the trailing edge here and also in this case you have a larger bubble you know, you have a smaller bubble here. So, that is basically the difference in that will definitely affect the performance of the 2 airfoils of the given conditions. So, that is that.

Then c is essentially, if there is wall it is a diffuser as you can see and what you see here is asymmetric. So, it is asymmetric separation; it is asymmetric separation. And this of course is a; and you can see that what happens here you know this is like the top, this is the top wall. It is kind of guiding the flow, it is kind of guiding the flow and the bottom wall actually seems to leave the flow you know and therefore, it separates only at the bottom causing this again separation bubble, that as you can see here. Now in this case also, this is a bluff body you know which is a cylinder. So, here too as you can see the surface around this surface, so the flow kind of surface around these two points both on top you know, if you were to draw the diameter. So, two you know separation points look at on the opposite sides of the slow of the diameter.

So, this is essentially you know the picture which kind of looks like. So, you have you know accelerating flow which comes and the reason you see all of this you know, the reason you see this as you can see is that you know that point would draw all this is to driven the point that there is essentially an effect of the shape. So, shape of the object or shape of the surface, shape of the; or say body, shape of the body is important. So, shape of the body on which fluid moves, shape of the body on which the fluid moves. So, you can see that the separation point, the type of separation, the size of the separation bubble will depend on the shape of the body itself. So, that is what I am trying to show here.

Now, let us now try like I said you know we will just try to do couple of; will try to do some mathematics and see if we can get more information from this space. Now, you can see here that now depending on whatever value, whatever is the body one is using now at the wall.

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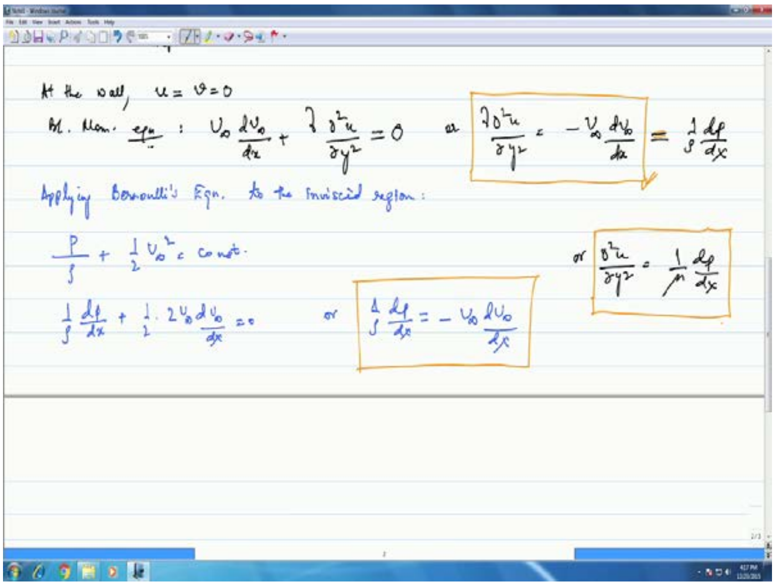

At the wall, the velocity is 0. Now from the boundary layer momentum equation, what we get is del 2 u del y 2 is equal to 0. Or we can basically say that well you know, so from here we can write, from here we can write nu del 2 u del y 2 is minus u infinity d infinity dx. Now, this is something that regarding this.

Now, what we should do is we will be applying Bernoulli's equation, Inviscid region. Now, what we will do is we will apply Bernoulli's equation to the inviscid region and if I do that, and that I can do, right? Bernoulli equation is applicable in the inviscid region which is outside of the boundary layer; if I apply that what I will get is this p by rho. So, if I differentiate this, if I differentiate this and see if I differentiate this. So, what I will get is 1 by rho plus half 2 u infinity is equal to 0 or basically, 1 by rho dp dx is equal to minus infinity, so this is it.

Then, if you look at this thing that we just did. So, nu del 2 u del y 2 is equal to minus u infinity this thing. So, therefore, from here we can also write that this is equal to this or this is also equal to minus u infinity is also equal to 1 by rho dp dx. Or we can also write here, so or we can also write that del 2 u del y 2 is equal to 1 by mu. It is 1 by mu dp dx, is that, right?

Now, this is interesting part. So this is basically what? We took the momentum equation and then we applied the Bernoulli's equation in the outer inviscid boundary layer and we are able to get these relationships. Let us see how we can use these relationships, to give us some idea about the boundary layer velocity profiles and what it means in terms of separation. We are talking about separation, how is you know simple expressions like this going to help us, understand that. Let us see.

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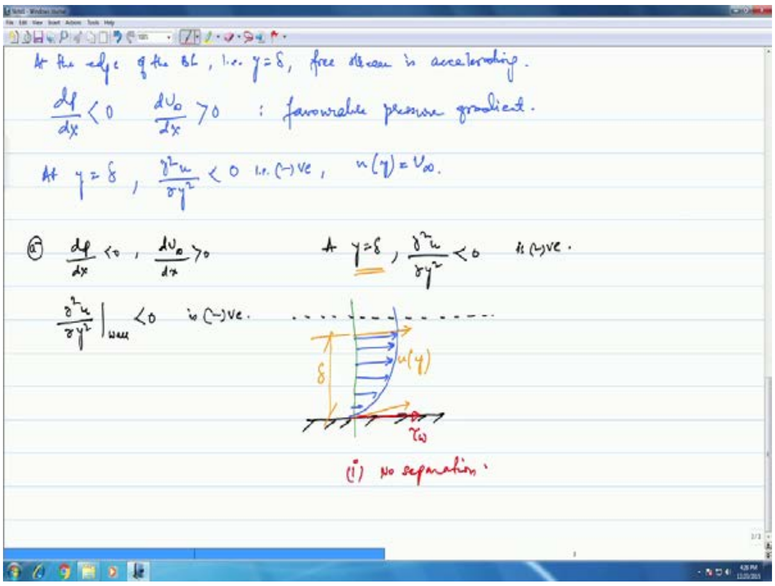

Now, you see at the edge of the boundary layer, at the edge of the boundary layer that is the free stream is accelerating, which means that is this, this which essentially is nothing but it is a favorable pressure gradient. So, essentially this is nothing but it is a favorable pressure gradient. Now, favorable pressure gradient and if you see this expression here del 2 y, if you see this expression here del 2 u del y 2 is equal to 1 by mu dp dx. dp dx therefore, now at y is equal to delta if you see from their expression, is negative, is this, right? So, delta 2 u del y 2 is also negative and this is negative, that is negative and u here is this.

Now, what we will now do is basically look at you know cases like this. So, what we will do is, so we are going to look at how you know these terms how these terms. So, what we have here is the, is an expression for the second derivative of the velocity into the boundary layer in the x direction, in the flow direction let say in terms of both the free stream velocity and the pressure, and how this is going to help us, understand the separation.

So now, let us say case one; so I am going to look at case one. Now here, what we have is therefore, say for dp dx is less than 0 and du infinity dx is 0. Now then, from this at the wall this means del 2 u del y 2 at the wall is less than 0. So, del 2 u del y 2 at the wall is less than 0 that is y del 2 u del y 2 is less than 0 because dp dx is negative. So, I come with the 0, it is negative. So, when I have that, so is negative. And, as we said here that at y is equal to delta, del 2 u del y 2 is anyway negative, is always negative. So, I would like to explain that a little, and then y del 2 u del y 2 is negative. You can actually do that yourself, I will kind of help you do that a little bit.

So now, what we are basically saying that there is a curve there is a certain curve, so which say something like this. So, I have a wall and I have a certain free stream, I have a certain free stream and what I see is that del 2 u at del y 2 is actually 0. So, if I have to sort of draw this a point. So, if del 2 u del y 2 is actually 0. So, which is almost something like this, something like that, so almost 0 and what actually it is negative, sorry not 0. So, del 2 u del y 2, that is actually negative. So, that is what we mean by that. And what is at the wall, so basically we also have at the wall like not at the wall, at the boundary layer. So, there also it is negative. So, it is both these slopes are basically in the negative. So, then I have another you know slope like that which is say another negative.

So, in this particular case if we had to have a profile, it would be something like this which is not much different from what we have been seeing, I got these a little. So, what I mean by that? This is not nothing but a velocity profile; now this is the case we get a velocity profile essentially like this and like we have done earlier. So, this is u y this is u y and also this is a negative slope at the wall and this is negative slope at the free stream at the edge of the boundary layer as well. So, you could say that this is essentially boundary layer.

And of course, we will have the wall shear stress acting here as well. So, we talk about that little bit later on. So, we will have the wall shear stress here, so that this is something this is called, this is a. Let us call this pressure as say "1". So, in this particular case when you have something like this there is no separation.

So, I will kind of stop here and continue to this into the next module and elaborate and take you know go for the down actually and we will see how would that does in terms of separation.

Thanks.