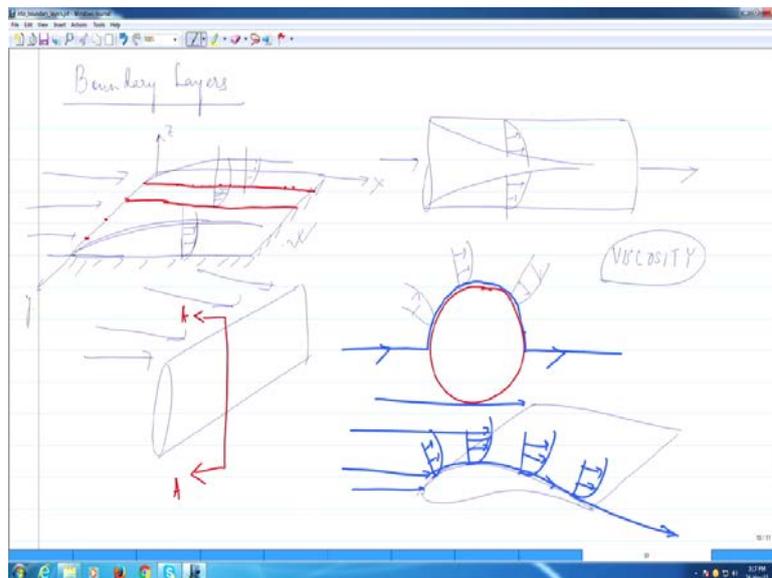


**Introduction to Boundary Layers**  
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**Module – 03**  
**Lecture – 03**  
**Concept of a Boundary Layer (BL)-I**

Hi, welcome to the third module. So, what we going to start talking about is basically Boundary Layers. So, ISPE, you have really heard about the boundary layers that the word itself is not like completely unknown to you. If you know then let us, this kind of view sets and try and understand what that means and every time you talk about the boundary layer we kind of always going back to your flat plate, flat plate, flat plate. Fine, we also look at boundary layers, but boundary layers could form at various places.

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So, basically what we are starting out to do today is Boundary Layers and why at all is this important? Why is this important to even studying? So, say you have a flat plate, every time we draw a flat plate we kind of draw at in this fashion, but what exactly we are talking about is that the plate is actually a plate like this. You know this is the flat plate and you have say fluid coming in over there, but every time so you could actually

say that, this the z axis, this is the x axis and this is the y axis and then we draw of things like this.

So, every time we say draw a boundary layer, you can draw a boundary layers like that, you drawn a nice stuff like that and then you say, this is the velocity profile. So, what basically you are looking at, so every time you draw something like that, you should remember that you are basically looking at particular section on this flat plate along y. So, what do you mean by that? So, essentially what I mean is that I could have several sections along this y. So, if I have were to say, look at this point, so this line, this section or it could be say this section or this section.

So, then at all these section one would like to know the behavior of the boundary layers. How would that look like and how would the velocity profile look like, somewhere here? Essentially, what we are saying that as we progressively move along the y direction there are various sections at which there is a boundary layers. So, I guess when you look at the picture that you see in the books, so basically you are looking at a say a 2 d boundary layer. So, where you kind of a either you are not talking about at all or you basically saying that you see the same thing as you move along, you see this particular picture, this kind of a velocity profile will not change if you move along y, that is what you are assuming you do not know that actually.

Of course, you go along x. There is a change in the velocity profile. So this is again what you see, but then boundary layers could have flow through a pipe. So, you have a flow through a pipe, so you have flow coming in and flow goes out. You have boundary layers forming like that and you have boundary layers forming like that. So this you know along the walls, so you could have boundary layers there as well.

There is flow pass a cylinder. Again, if I will draw a cylinder this way, the fluid basically comes in this, this way. So, if I would take a section again, so I go along this and I take a section. This section is basically I cut through the cylinder. So what I will basically see is just a circle, which is similar to here. And then when I see that, I have say flow moving in like that, then this is a steam light. So, maybe I am doing this. Similarly, I have drawn on half of it, so you could do that. When the flow comes in there, you will see boundary

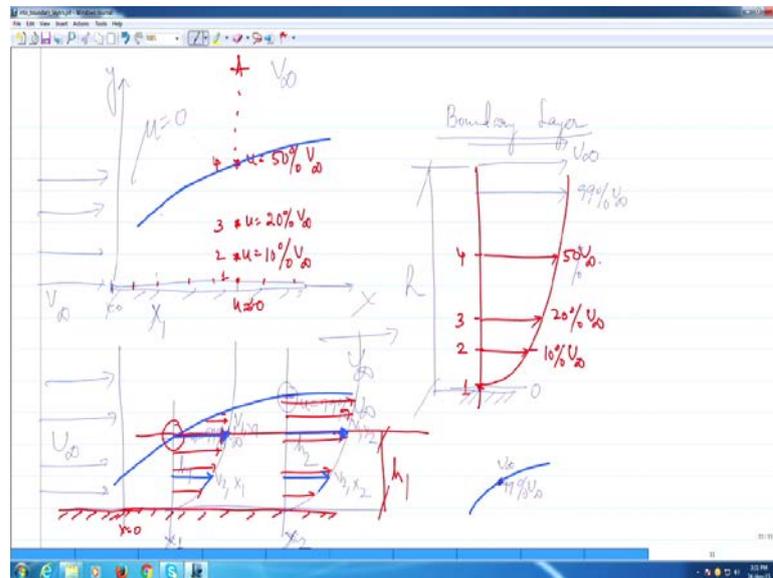
layers forming here is well. Boundary layers are everywhere. Then of course, you have the shape which I deal with most because this is what I kind of research on. So this is your airfoil, this is 2 d. Again, you could think of this of flat plate.

So this basically, the section here we have to change. This is different from the flat plate that we talked about here. This is different in the sense; the section is in airfoil shape. So, here two, as flow moves in like that. This is a cambered airfoils it will cause lift even when the angle of a track is 0, because of the shape. So than you know flow moves in this way and so and so forth this is a particular stream line. Here also the flow which is closes to the body would stick to it as you move away from it, it will flow a pass and so and so forth. So you could draw velocity profiles in this fashion in this way.

These are the velocity profiles you could draw. And again, here too you could draw velocity profiles, so here too you could draw velocity profiles, see if I am right. So basically, these are boundary layers. Again, what exactly is the concept, what is this thing that it sticks to it so on and so forth? How does this problem crop up? Now, this was basically Frontals theory. Frontals theory that the effect the reason we have the boundary layers is one of the effects of considering a fluid with viscosity. So, viscosity is a key term here, which we kind of discuss the little bit in detail probably in the first modules. The viscosity is basically causes retardation on you known fluid which is moving. So, that is what which basically it pulls the layer of the fluid which is closest to, it pulls in the reverse direction to what it is actually flowing. And this pull decreases as you go away from the plates or form the surface on which it is moving.

So, viscosity however is a property of the fluid itself. Unlike friction, please remember that unlike friction where the surface property it is a surface and that depends on it. It depends on the weight because friction is equal to friction of forces is coefficient of friction into the normal force. Here however, the viscosity itself is a property of the fluid. So, it is the property of the fluid by which basically it is following and that is what causes the layer which is closes to the surfaces stick to it, and then progressively as we move away from it, the layers are more freely moving, let us put it that way. They are not been pulled back so much.

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So, essentially if I would have for example, in any one of this say again I am going to draw this 2 d plate, so now we can look at the this stuff constantly. This is my plate and I have incoming flow something like that and say this is my x and this is the y direction. Now, the thing is so obviously this effect of the viscosity is the maximum when you are closest to this and the farther we move away it decreases. So, you heard of this. Now the thing is that a by definition, what exactly is a boundary layer? So basically, it is that layer of fluid that outside layer, this is  $V_\infty$  so very far of away from here, it is  $V_\infty$ .

If you are closest to the plate here, must probably your velocity is going to be; less put it this way velocity is going to be nearly 0 this. As you move further say if you are here may be if I would write the velocity in terms of, this is the free stream velocity, this is what it would have continued with the flow, but then it encountered the flat plate. Then this could be say 10 percent of the  $V_\infty$ . Then keep moving further, so maybe this is say 20 percent of that. If I keep moving even further say 50 percent of  $V_\infty$  and so on. And then you could take several sections along this and do the same thing. So this is what exactly what you draw in terms of a velocity profile.

So, if I where to draw just this section, let me call this section as A, I would draw straight line and then this is the point, if I were to call this as say 1, 2, 3, 4 at the point here. So

this is point 1, so this is point 2, this is point 3, this is point 4 and this here it is 10 percent  $U_\infty$ , if you see. And then you that, this is 20 percent  $U_\infty$  and this is 50 percent  $U_\infty$ . So, you do that the several of this section and then connect these points, and that is when you get what you typically know as your boundary layers, that is when you get this, this kind of a plot.

Now usually what you know, you know what you are aware of, is that this velocity is 99 percent of  $U_\infty$ , so 99 percent of  $u_\infty$ . So, that is basically aware of looking at it. You are basically saying that there is almost recovered, going from 0 here which is at the plate, so here it is 0. It has recovered, it has slowly the velocity increases as we go away from the plate and it is almost nearly equal to the free stream and after this there is no retardation and it is usual free stream. So, that in convention of sense is essentially the boundary layer. Where it is basically the distance, it is this distance, by this distance; I am going to call it just age for now. This distance after which by which time or by which distance it recovers almost its complete velocity because the way you look at that is that the free stream comes in and if you are close to the plate it is 0. It comes in with the viscosity  $U_\infty$  but it becomes 0 here. So you retarded and it becomes 0 here.

So, it recovers this  $U_\infty$  with distance age. It recovers it is completely by the time only at a distance age. This is in the convention of sense is basically your boundary layer. And therefore, it would be fare to say that if I would draw here, if this is my boundary layer so I could say that the effect of viscosity is not 0 here and here it is. This it is outside of the boundary layers, basically here is nothing but free stream. So, at every you can see therefore, that at when  $x$  is small closer to this edge, which is a leading edge of the plate, so at this  $x$  it takes a smaller height to recover the entire of free stream velocity, is not it? Even given by the look of this when you have boundary layer like that, at a smaller distance  $x$  from this leading edge we can this is  $x$  is 0 here, at this say  $x$  1.

You need this edge. So, let us erase this page or let me drawn another one. I am going to drawn another one. So, here you have you plate somewhere and here  $x$  is 0 and let us say this is your boundary layer. I am considering this bit as  $x$  is 0. If I do that, then if you see I am going to take two sections, one section here and one section here. So, by definition we say the height which is required to recover the entire of free stream velocity. This is

what it came in with, which is say  $U_\infty$ . At say  $x$  location say this is  $x_1$  and this is  $x_2$ , it needs  $h_1$  and this needs  $h_2$ . So, what you basically see is that  $h_1$  is the distance and the velocity here is 99 percent of  $U_\infty$ . So, if I want to do a close up of this little point here and I come here. So then what you basically see is that this is your boundary layer so then see at this point which is see just inside if you get this, just inside of this if 99 percent of  $U_\infty$  and just outside of that if  $U_\infty$ . So this is your  $0.99 U_\infty$ .

That is how we can look at that. So that is what this means. Essentially, at  $x_1$  we need a height  $h_1$  so that I recover the entire free stream velocity and at a height  $h_2$  at the further distance, at further distance I need a height  $h_2$  to recover because again here the velocity is 99 percent of  $U_\infty$ . Therefore, if you are further down along  $x$  direction you need a larger height to recover the free stream velocity. Therefore, now the question arises that how will the velocity profile look like.

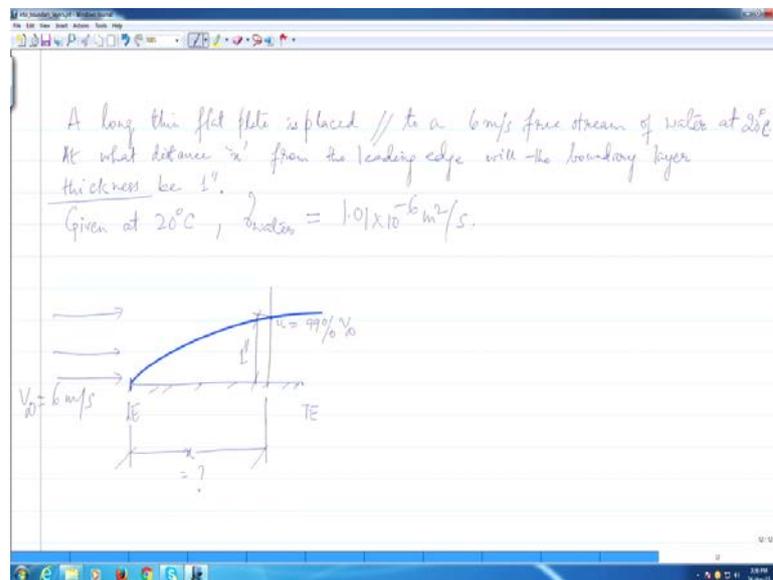
In the sense, I want you to think about this will answer this question later on. I want you to think about this that if I have, let us use this if I have this, so how does this look like. How does the velocity profile look like? What I mean by that, in the sense that if I take say  $h_1$ , it is the same  $h_1$  height and I could take any distance less than  $h_1$  as well I want to know, whether this velocity factor, the velocity say factor here at  $h_1$  at location  $x$  is larger or less than the velocity at the same height  $h_1$  but at  $x_2$ .

Similarly, if I what to take another factor here, another factor here. So, how do these compare? If I would compare say this vector, so velocity vector I am going to call this  $V_{1 \times 1}$ , this is also  $V_1$  but  $x_2$ , this is  $V_{2 \times 1}$ , this is  $V_{2 \times 2}$ . Now the question is, is  $V_{2 \times 2}$  larger than  $V_{2 \times 1}$  or less or equal and what about  $V_{1 \times 2}$  and  $V_{1 \times 1}$  that is the question. So, that is what will try to answer that in a bit.

So that is a little bit about what boundary layers are all about. Essentially, just outside the boundary layers since it has recovered. So, is basically it is potential flow because here you have recovered, in this zone you have recovered the free stream and the effect of viscosity is not dominate. Now this is something that frontal came up with and it was his a kind of almost like intuition that if the viscosity effects are closest to the body then why

do not we sort of do that, we kind of segregate that area. Find out equations which pertain particular to the boundary layer and we will solve those along with other equations which of valid for you know this zone. That was his idea and that is when we come up and found were boundary layer theory. Now before we kind of talked about this let me pause, the problem so that we kind of get some ideas to what exactly we will be doing in terms of trying to study this.

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The problem looks like this. A long simply a thin flat plate is placed parallel, forgive my art work, to a 6 meters per seconds free stream of water at 20 degree centigrade. The question is: At what distance  $x$  right from the leading edge, leading edge is basically the edge which meets the flow first edge will the boundary layer thickness be 1 inch and given at 20 degree centigrade, our viscosity of water is  $1.01 \times 10^{-6}$  meter square per second. You get the problem.

So basically, we have a flat plate. So it is encounters 6 meters per second free steam and. At what distance? So this is the leading edge and this the sterling edge at what distance  $x$  from the leading edge. Therefore, now this is going to have a boundary layer, so now the question is at what distance will the height of the boundary layer be 1 inch. What is this distance? This is equal to what? This is the question. And the height of the boundary

layer is given has 1 inch, which means that at this distance  $x$  one inch away from the plate the velocity is 99 percent of  $V_{\infty}$ , which in this case is seen that it is almost recovered, it is almost 6 meters per second. So this is the question. What exactly is this distance? This is what we are talking about and what is given you is the kinematic viscosity coefficient.

Now, you want to do this. Let us go ahead and you know. What we will try to do is do some math. Let us try to do some math and then we will come back and try to solve this problem. In fact, you will be able to solve this yourself and now that you understand this. So basically, I think that the way the problem is here, what we are trying to pose here is that what you need exactly here, is the relationship of this height of that boundary layer with the displacement, is not it? I think that is what we need here. We will try to find that out. Let us do that in the next module, so we will try to find out that, and also this word called what is the thickness? There are the terminologies which are associated with the boundary layer thickness, displacement thickness, a momentum thickness so on and so forth. So, we will just start understanding those things right in the next module. So that is for now.