Introduction to Boundary Layers

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Module - 01
Lecture - 09
Concept of wall friction

Hi, welcome. So, what we are going to talk about in the next two modules is about Skin Friction Drag. I think one of the reasons, why we are studying boundary layers and it effects as we started out saying is that, it causes drag and we need to quantify that, how much given a certain size of the surface on which fluid is moving, what kind of drag that can cause and I think, we use some results of boundary layers series directly without going it derivation of it, skin friction coefficient for a laminar boundary layer.

We use formulae and use the problem to kind of solve that. We are going to sort of just learn a little more about that and very interesting way of calculating the drag and if you have access to very simple facilities anywhere, you can actually set up an experiment and do this yourself and it can be quite interesting. So, we will just try to understand, what we mean by drag and a little more about that.

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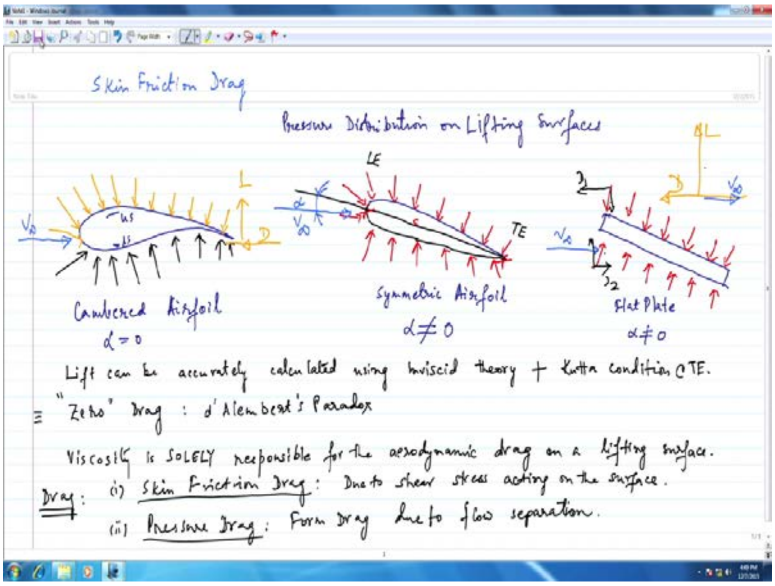

So, what is basically we are going to talk about is, let us write that down saying, what we are going to talk about is essentially Skin Friction Drag. This is what we sort of started out saying, what we will do. Now, for example, I am going to draw a couple of scenarios. Now, look at this scenario. Let us look at this, I am going to draw that little differently, then I am going to have another scenario, which is like that and yet another scenario, which is like this. This is a little more, thick than I would like it to be. So now, these are basically 3 cases, what we are going to look at is and what we basically have here is there, I have fluid moving this way, this is the free stream in all the 3 cases. What I can do here is for example, draw the pressure distribution. I have a pressure distribution like that, what about the pressure distribution here, something like that and similarly, there is a certain pressure distribution this way, something like that.

So, basically this is the pressure distribution. Let us say, if I want to write this, this is pressure distribution, this is very important here. I am going to say, this is basically on lifting surfaces. Now, this one you can see here, this is actually cambered airfoil and as you can see, the angle of attack is actually 0, this is going to lift because there is a differential pressure distribution on the upper surface and the lower surfaces. This is the upper surface, this is the lower surface. This is a symmetric airfoil and here, angle of attack is not seen. There is a certain angle of attack, how do we calculate the angle of attack? Well, I think that is basics but I will still talk about that here, let me come to that. So, symmetric airfoil, this is alpha is not 0 and this is essentially a flat plate and here too alpha is not 0. Now, of these 3 basically, the symmetric airfoil in the flat plate will not lift without an angle of attack.

In this particular case, it does have an angle of attack, the cambered airfoil. However, due to shape as you can see is different from this airfoil. It will lift even at 0 degrees because due to a shape, the differential pressure is created. So, what do we mean by angle of attack? What we are going to do is just join the shortest points between this is the leading edge. So, this is essentially the leading edge and this is the trailing edge and if I join that, if I join, basically the leading edge and I need to get a straight line here. Now, I need to get a straight line. So, this line which joins basically, the leading edge to the trailing edge, just this bit. This is the chord length, that is the chord and the angle of this chord length makes with free stream basically, gives you the angle of attack. So, if I were to take that off here and say this, then this is your free stream, then this is your angle of attack.

Similarly, you can explain yourself for the flat plate. Now, basically the 3 pictures that I have drawn here, all of these three things will be able to cause lift, which is great and primarily, now the next question you should be asking or thinking about that, which will cause more lift? Or which will cause less lift? How much will each of these lift? I going to use symmetric airfoil, whether a cambered air foil, whether a flat plate, so which one will lift more, will that is something which will be given by, when we quantify the lift and how do we do that because what we do is, we integrate the pressure over the surface and take its component in the lift direction. So, I will come to what the lift direction means in a bit.

Basically, the lift direction essentially is direction, which is perpendicular to v infinity. In this particular case, if I were to do that. So, here in this, for this cambered airfoil, my lift direction will be, this is going to be lift and this is going be drag. So, drag direction that always acts opposite to the free stream and in this particular case also the lift interacts in this particular case because this is my V infinity is horizontal for all these 3 cases as we can see. Therefore, the directions for the lift and drag, this is lift and this is drag because this is your V infinity. Therefore, basically you can see that, we not talking about any sort of boundary layers or friction or anything like that. So, lift can be calculated fairly accurately using inviscid theory along with kutta condition at the trailing edge. So, if I would write that, lift can be accurately calculated using inviscid theory plus along with kutta condition at the trailing edge.

Now, I am not going to explain too much about the kutta condition that is beyond the scope of this course. Let me just say that, what the kutta condition basically means, it basically enforces numerically the fact that the flow leaves the trailing edge smoothly. So, if I would basically draw the stream line pass, this is going to leave it smoothly. So, basically, otherwise there was a possibility that you would have a different value of the circulation on the top, on the bottom surfaces, you would want that. So, the kutta condition is basically that enforces that the flow leaves smoothly at the trailing edge. So, I am going to leave it that. Therefore, lift can be accurately calculated. However, if you want to predict drag using the same theory, it results in 0 drags, that is because if you do the integration, if you think about it on a close surface like this. So, the components kind of, cancel out and let me see if I can sort of draw this.

For example, I think you should be able to sort of do that yourself. For example, if you look at this flat plate and I am looking at these two arrows here. So, this is arrow 1 and this is arrow 2, I want to draw the components. So, one component is going to be like that, another component is going to be like this. So, basically components with respect to this access system that you are looking at in the lift direction and drag direction, let us split there by, so that in this case, if you see, if I take the components which is like that. Now, if I do this, now what you will see is that in this particular case say, it is this say, D1 and this is D2, now if I do a summation like this, these will cancel each other out and also it basically indicates pressure direction. Therefore, if I use this principle, where I can accurately calculate the lift from inviscid theory, it does not necessarily result in any drag; it actually results in 0 drag.

If I use basically, inviscid theory, it results in 0 drag and this is not possible, anything like this by now, we talked about boundary layers for sometimes now. That it is not, it is physical impossibility and therefore, this is what is commonly known as the Alembert's Paradox. After the show, Alembert is a French scientist. Now however, this paragraph immediately goes if you are going to use viscid theory, in the sense when you do not ignore the boundary layer, when you do not ignore viscosity. So, if you take viscosity into account, this paradox is completely gone and therefore, one can really say that viscosity is solely responsible for the entire aerodynamic drag on a lifting surface. If I were to write that viscosity is solely responsible for the aerodynamic drag on a lifting surface.

Now, then again this has to parts to it, let me write that. So, therefore, this drag I am going to classify this little bit. It has the drag, again it has 2 parts, there is a skin friction drag and this is due to the shear stress acting on them. So, this skin friction drag again, this is due to shear stress acting on the surface and the other is basically pressure drag and this is also called form drag and this is due to the pressure you created during flow separation. So, this is also called form drag right due to flow separation. So, basically we are looking at 2 types, we have described this, it is skin friction drag and pressure drag.

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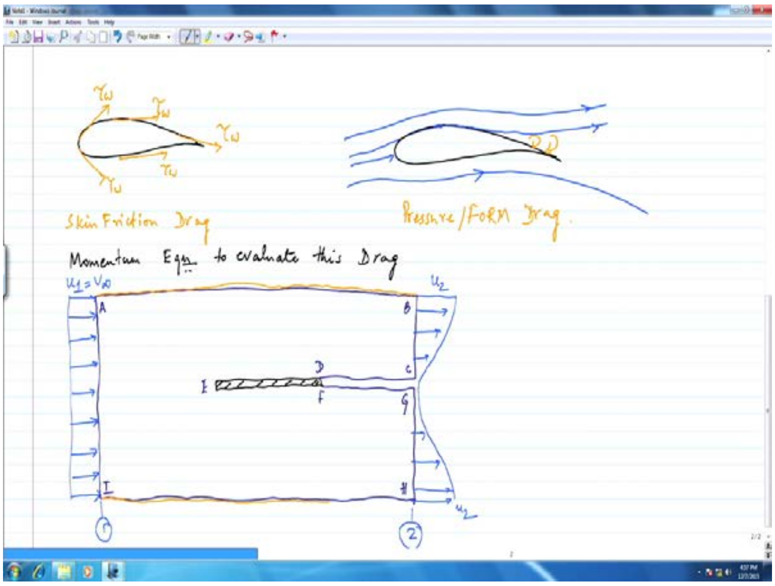

So, let me just sort of explain that a little bit. What I mean is, I have got this surface this is say int f for. So, how does that look like, we know that. This is your valgus stress, we have been doing this and that basically is acting along the surface. So, then we have got some, valgus stress again here on both surfaces and so on so forth, you got the idea. So, basically this is valgus stress and this is what causes skin friction drag. This you can think of this as basically flow dragging itself. You know because dragging itself on the solid surface, because the flow is basically trying to move and the solid surface trying to pull it back. So, the flow drags itself that is what is basically, it is kind of a forcing itself on the surface and that is basically this skin friction drag.

On the other hand, let say you have this again and now you have flow that is not to be inside. So, this is a separated stream line. So, you got stuff which is going on a top, these are stream lines. So, then there is set of back flow of the pressure, etcetera. Now, this is results in what we just discussed as pressure or form drag. Now, what we basically going to do now, our job is that we would like to quantify given the size and shape of some body, we would like to quantify that, we would like to find out how much you stress on? How much pressure of form drag? What is going on the cause? Now, there is very simple and very interesting method.

What we going to do basically, we are going to use the momentum equation. We are going to use the momentum equation to evaluate this drag. So, how are we going to do that? Well, what we going to do is, let me draw this, I am going to draw a control volume using actually momentum equation app. This is actually application of the momentum equation and we are going to draw control volume around a flat plate. Basically, we are going to try and understand a flat plate.

Now, let us look at a flat plate, let this be the flat plate and then I am going to draw. So, this is somewhere here and this is somewhere here and these are the 2 locations, I am going to confine a boundary somewhere. So, this is the boundary that I am looking at and so essentially now, this one, these are almost going to be straight lines and you see that I have two gaps here, which is about; I am taking the gap. Now, this is going to be a straight line, please bear with me, I am drawing in sort of this but it is going to be straight line. Now, this is the thing, let me first, now I am going to call this as A, B, C, D, E, F, G, H, I.

So, this is my control falling and what I am going to do now is going to draw the velocity profile at the inlet and the outlet. So, by this time you know, this kind of inlet this is AI's inlet and the edge is outlet. So, here is nothing. So, there is free stream which comes in, I got that. So, this is my velocity profile and I am going to call this, essentially this is the let me say this is U1 and that is equal to the free stream. Let me say that this section is essentially, 1 and this section is essentially, 2 and the free stream and the velocity profile here would look something like that.

We know that already, something like that and let us call this is U2. Now, AB and I edge or each I would have. These are like really far away from the body and this line is basically a line which is just sort of inside the stream line, just inside the stream line in the sense there is a stream line, which is just outside of it. Similarly, at the bottom, this boundary is just inside the stream line. So, therefore, this is a stream line far from the body, where is basically free stream pressure. So, what we will do is, we can stop here and continue with this in the next module.

Thank you.