Introduction to Flight
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology Bombay
Lec 28
Coefficient of Lift and Coefficient of Pressure

There are some coefficients. Now, the lift that you generate on a body, it is not just a function of velocity and curvature there are many many more things ok..

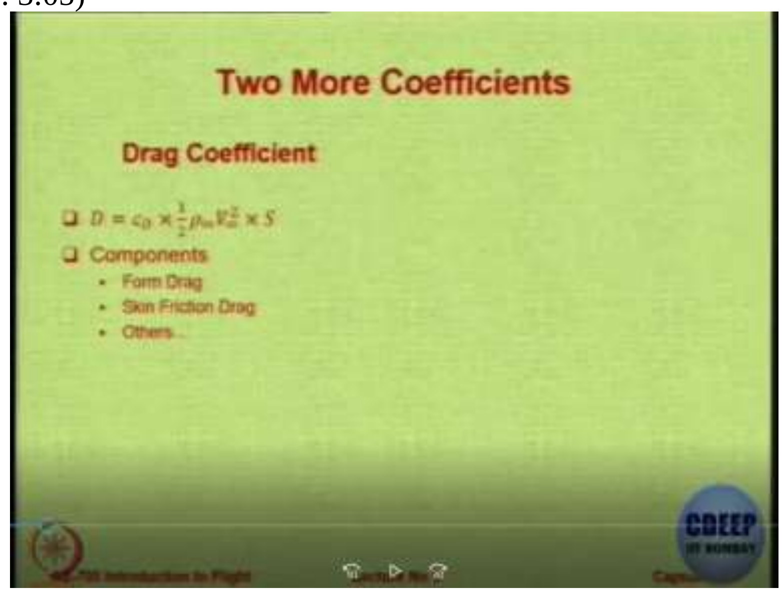
(Refer Slide Time: 00:24)

For example, it depends upon the shape because different shapes are going to create different streamline and curvature. It depends upon angle of attack because the angle of attack also will create a difference in the curvature. It depends upon the viscosity because viscosity is the property of the fluid that will affect the friction acting on the body. Compressibility because that will affect on the transfer of momentum between the fluid ok, then area, freestream velocity, and density, all these things and many more will affect the amount of lift generated. So, therefore what we do is to take care of all the important things. What we want is a simple equation that will capture the essence and to do that we basically have this equation which says that the lift is a function of the density of the fluid, the velocity, the area, and there is a coefficient called C_L or the lift coefficient which simply relates the numerical value of lift with the parameters like area, velocity, and density that directly affect the amount of lift created.

So, in let us say there are two fluids, one with density ρ_0, one with density ρ_1, everything else remaining same. The lift generated will be more if ρ_1 is more than ρ_0 ok. So that is why similarly the velocity, same body at different velocity will generate different amount of lift so that is the reason why. So intuitively we know that the force will be proportional to ρ_∞, V_∞^2, and area. Now, area in this case is the area on which the flow is actually attached or working, ok

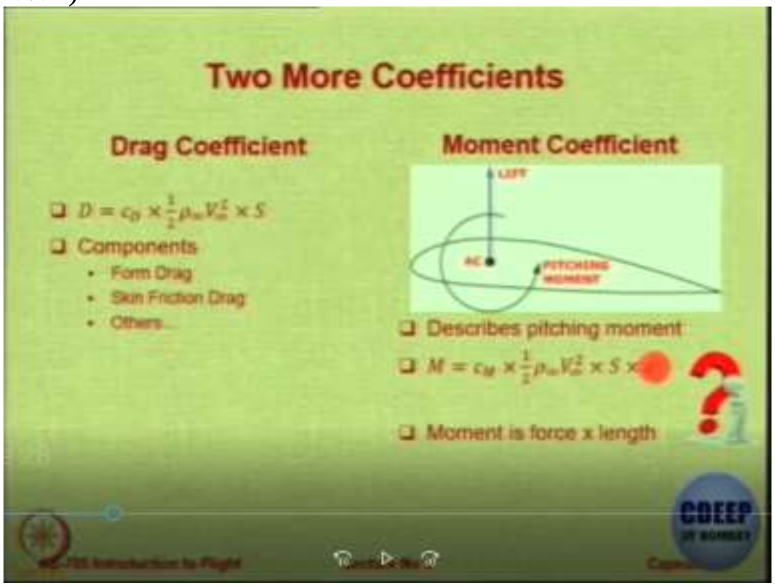
So if there is a situation where the area is such that some area is not playing any part in the lift generation then on that area we do not have to, we cannot count that area because that area is not exposed or not being affected, is not transferring its momentum, it is not playing a role. So the lift coefficient is non-dimensional, it is a coefficient. It captures all almost all dependencies, not all but almost all dependencies and you determine that experimentally ok.

(Refer Slide Time: 3:05)



Now, there are two more coefficients which are important. The first one is drag coefficient and this drag coefficient is very similar to lift coefficient. Only thing is we call it, we use the coefficient C_d, C_d instead of C_L. Now, this depends on many many things ok. There is something called as a form drag, skin friction drag, other drag components. We will discuss this in detail in the next chapter when we look at the drag estimation. Drag estimation is a very important part and by the way, after we do the next exercise then you will be now in a position to attempt the assignment number 2 which is the mid sem assignment about which I will talk after I finish the next lecture.

(Refer Slide Time: 3:52)



So, there is also a moment coefficient because the forces acting on the body are not going to act at only one specific point, they are acting all over the body because the entire body is going to be immersed. The whole body is immersed in the fluid ok so, whenever you have a body which is exposed to fluid, apart from the forces of lift and drag which act on it and the weight because of its own mass, there is also a moment which is acting on this body and this moment is called as a pitching moment because this is the one that makes the nose go up or down.

So the pitching moment is also defined by a coefficient called C_m or the pitching moment coefficient and it relates the moment with $\frac{1}{2}\rho V^2 S$ but now the problem is that there is something called c there and that c is introduced because moment is a quantity which is force into length, not just force. Lift is a force, drag is a force but moment is force into length so you need a length dimension. So we choose some characteristic length and that characteristic length c is normally the chord length for an aerofoil ok.

So the chord length is added otherwise the units will become dimensional. So to make a moment coefficient non-dimensional we, all this is convention ok this is not physics. For example, how did this half come into picture? Why should D be equal to $\frac{1}{2}\rho V^2 S C_d$, why not $\rho V^2 S C_d$? Can anybody answer this question? Why do we have this half there? Nobody knows this.

What do you think?

Student: Even if we do not have half it is fine, there will be no change in C_d

Professor: Exactly that is one thing, you could define a new C_d called C_d' which is equal to twice C_d. As you can say D is equal to $\rho V^2 S C_d'$. But there must be a reason why people have put this half. Why not one-third, why not one-fourth? Yes.

Student: Maybe because $\frac{1}{2}\rho V^2$ is a dynamic pressure.

Professor: That is right, that is exactly right that is very right because $\frac{1}{2}\rho V^2$is dynamic pressure and this relates to dynamic pressure. It is a functiona of dynamic pressure. So people have said let us put $\frac{1}{2}\rho V^2$so that we can call it as drag is equal to Cd into dynamic pressure into area that is the reason. It is just for convenience but as long you are clear and I am clear that we are using Cd of the formula half Rho V square S we are both on the same page. Tell me Rho infinity any doubt what it is? No, it is density of the surrounding fluid. V infinity any doubt, no, it is velocity of the body but which velocity, it is the relative velocity. It could be ambient velocity if the body is stationery, it could be velocity of the body if the air is stationary or it could be a relative velocity correct.

What about S? What is the area S? Which area? Please answer this question. Which area is this S? yeah.

Student: I am Vinay. It is any reference area, it can be the wing area, it can be any reference quantity used by the wing area.

Professor: When you say wing area, is it the top and bottom.

Student: No, it is the projected area.

Professor: So, is it projected area in top view or bottom view.

Student: Sir, same.

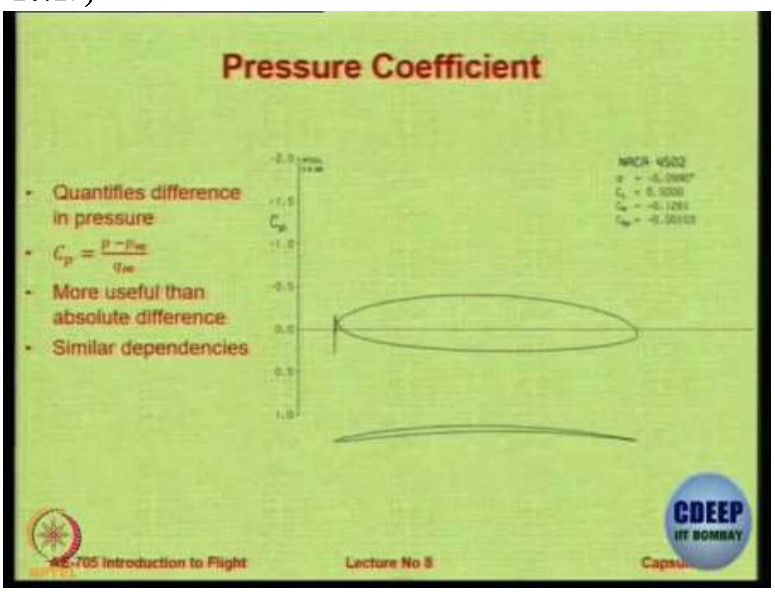
Professor: If you look at only the wing I can understand but if you are looking at the aircraft now there could be some difference. So, what I am saying is you are right, it is a reference area. So this reference area one has to be clear. So when I say Cd is so much you should be clear that this half has to be used, you should be clear that the density is this density, this velocity and you should be clear that I have given you Cd assuming the area to be this area. In normal unless otherwise stated this area S is considered to be the projected area in the top view ok, not the area along the curvature, not the area of top plus bottom. Area in the top view, projected top view, yes Sohrab you have a question.

Student: Sir, with the change in angle of attack, the projected area would change do we consider that.

Professor: That is a thing that is also an important thing as in the change in the angle of attack the projected area may change so we do not. So we do not consider when you define this S we do not consider the change in the projected area that can happen because of change in angle of attack. So, as long as all of us are clear so I can say it is the projected area in the top view at 0 angle of attack whatever it is, in the top view of the aircraft or the airfoil as shown on the paper.

So as long as you and me are on the same page we will not make any mistake. This is the area where there are, this is an interesting part this is the area where there are maximum confusions and maximum errors in calculations. I will explain to you when I will come to one particular example ok. Pressure coefficient basically quantifies the difference in pressure. Question is what is important to us ok.

(Refer Slide Time: 10:17)

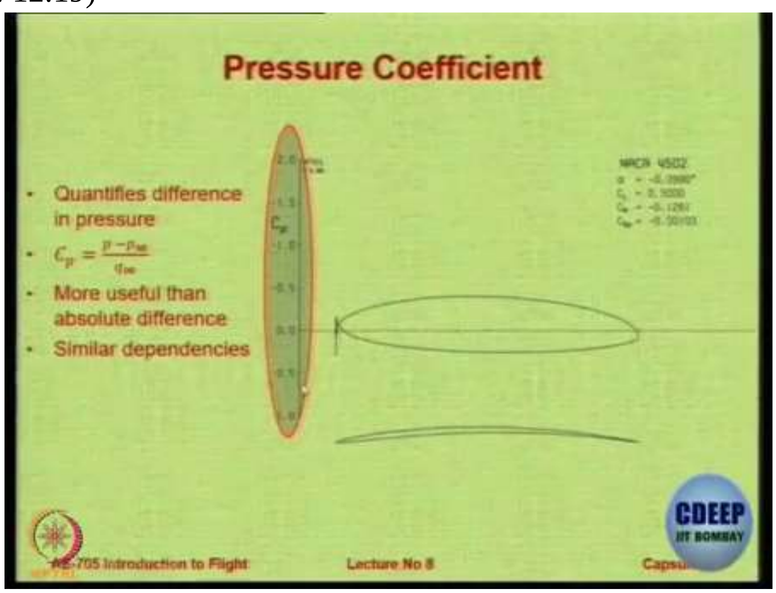


So, what is pressure coefficient? It is basically the local pressure at any point in the flow field minus the pressure of the free stream far away from the body that is P infinity divided by q infinity this is dynamic pressure half Rho V infinity square. In fact this value Cp is more useful than the absolute difference because you might say what we need is the absolute difference in the pressure acting at every part of the body, above and below take any part of the body above and below there is a pressure difference give me that, I will multiply by the local area and give you the net force. It turns out that the value of pressure coefficient at any point is more important for us. I will show you why and the dependencies are very similar.

So, this is one example, this is the NACA forces. I hope all of you have read about NACA airfoil by now because I mentioned last time that NACA family is a known family is there in all textbooks, so many sources so I hope you know that 4502 means something ok. This is the 2 percent thick aerofoil and it is you can say it is a very thin 2 percent is very less and it also has some kind of a camber.

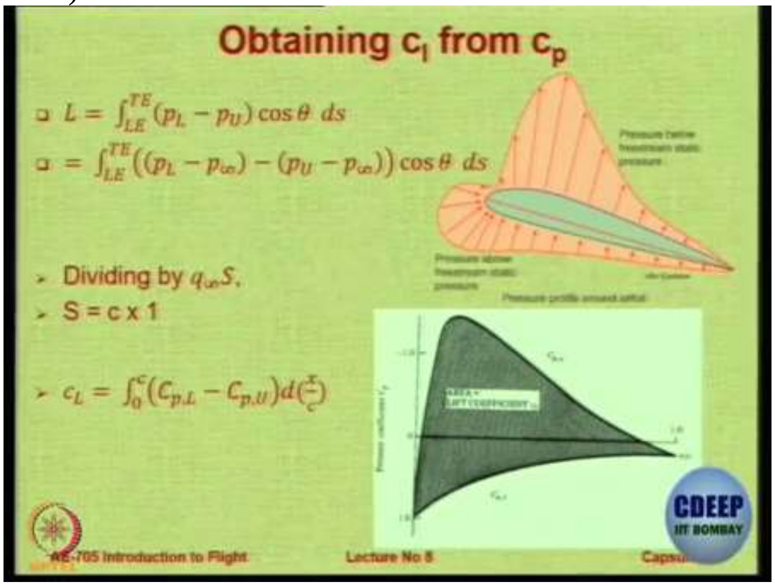
So if you plot Cp versus X by c versus the ratio of location upon chord, you get a distribution as shown here. So one of these, now notice interesting observation is that the scale is inverted ok. Normally, above 0 we put negative value and below 0 we put positive value ok, this is the convention again you need not follow this convention. But when you look at the Cp curve, you make some conclusion, my request to you will be look at the scale first and if the scale is different from what you are used to, you have to invert the image in your mind because many conclusions you will draw by looking at the shape of the Cp curve.

(Refer Slide Time: 12:19)



So, now tell me what happens if the value of Cp is equal to 1, + 1. What does it mean? Let start with 0 first. So when Cp is 0 it means that p is equal to p infinity correct, so that means on this aerofoil somewhere at this portion ahead of the tip you notice that Cp is 0. There are actually two curves here there is one curve which is like this and then like this and the other one is I think like this ok there are two curves here. This is the pressure Cp plot for the upper surface and the lower surface, so we have to draw some conclusions

(Refer slide time: 13:02)

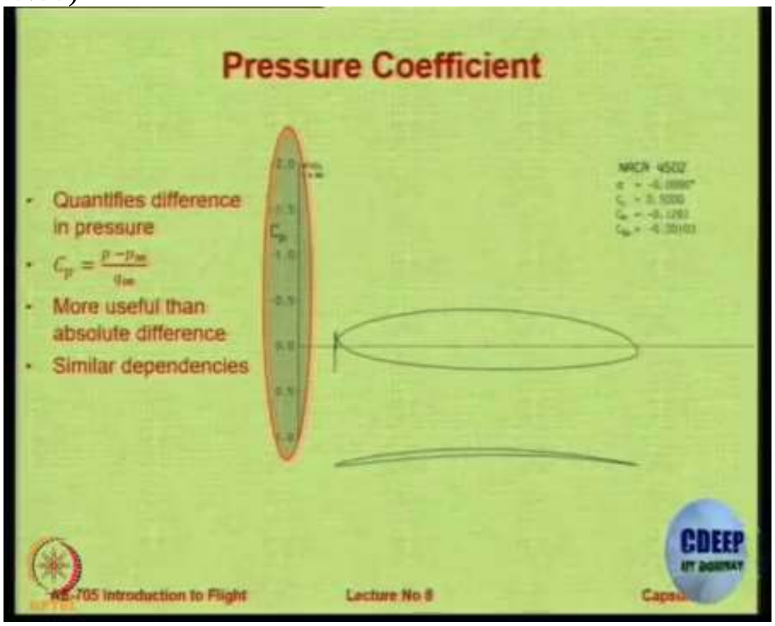


Let us see why? How can you obtain the Cl from Cp and also Cd from Cp? So, basically what you have plotted here is the pressure distribution. This is the pressure below free stream on top and pressure on the bottom ok, so we have plotted a pressure around the aerofoil. So here pressure is, so, if you want to calculate the lift what you do is from the leading edge to the trailing edge you have to just integrate the difference in the pressure between the lower and the upper surface and this Cos Theta ds is basically to take care of the shape as you go around the body ok so this is the method to do it.

So, I can replace Pl by Pl minus P infinity and PU by PU + P infinity so I can get Pl minus P infinity and PU minus P infinity. If I divided by Q infinity, yes and I take S as equal to the chord length into unit dimension because notice that lift acts on an area, not on the line. So we are assuming unit span so the depth of this foil is 1 unity, the length is c, so the area is c into 1. So with that interestingly you will get Cl will be integration from 0 to c of Cp lower minus Cp upper into d X by C, where X by C is the fractional location of the point along the chord.

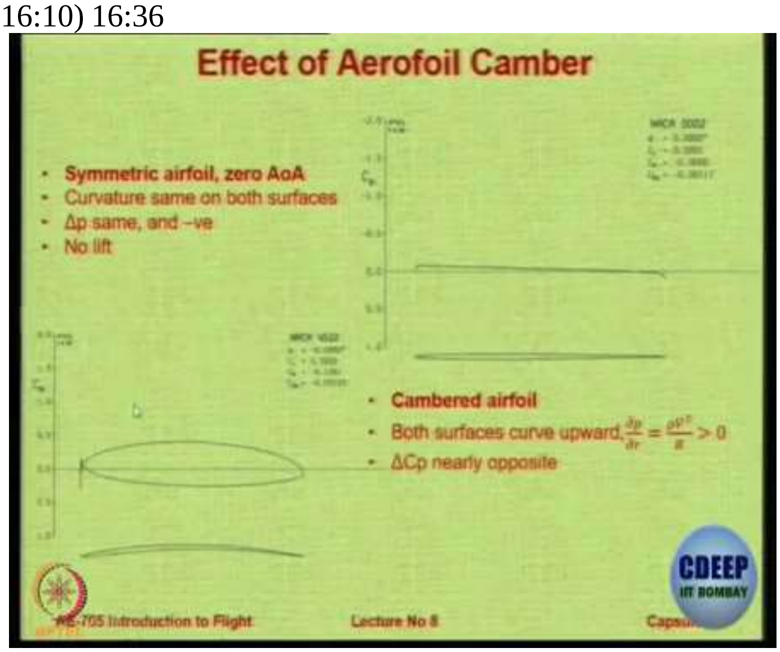
X by C is equal to 0 at leading edge, x by C is equal to half at midpoint, x by C equal to 1 at the trailing edge ok. So basically this is what you do, you plot, so this is the pressure varation, so from here it goes down to 1 and then it goes like this. This is C p of lower surface you go from here right up to this value and then come down. This is C p at the upper surface. So if you just calculate the area between these two that area will be the lift coefficient Ok. So, basically larger the gap between the pressure distribution on the upper and the lower surface, larger will be the Cl that is why this particular graph is very interesting.

(Refer slide time: 15:35)



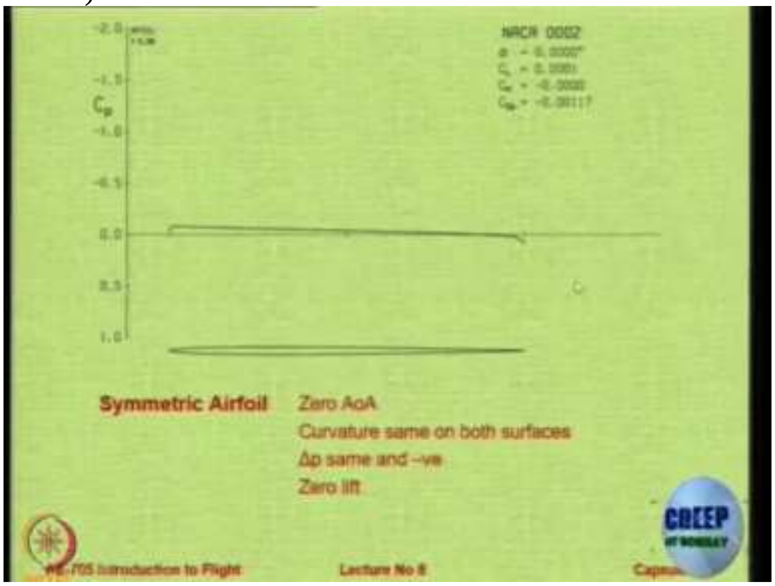
It just show you that if here is some net area between the two that means there is some lift as you can see Cl value is 0.5 ok, so if you plot can it be possible there is a no lift, yeah so we can plot and I am saying that Anderson chapter 5 has got more details. You are supposed to refer to it about the Cp methodology.

(Refer slide time: 16:10) 16:36



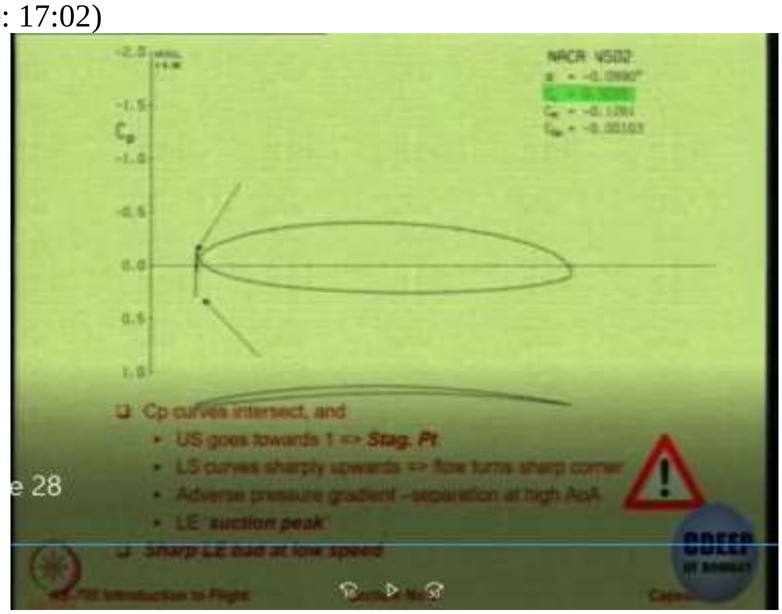
Last thing we will see is the effect of airfoil camber and effect of thickness. So, you can see here, there is some net area although very small therefore the value of Cl is non-zero 0.0001. So this is a symmetric aerofoil with zero angle of attack ok actually speaking you should have 0 lift, but due to some numerical error or very small value, there is some very small value of Cl. If this is a cambered airfoil as I show you last time in a better way.

(Refer Slide Time: 16:35)



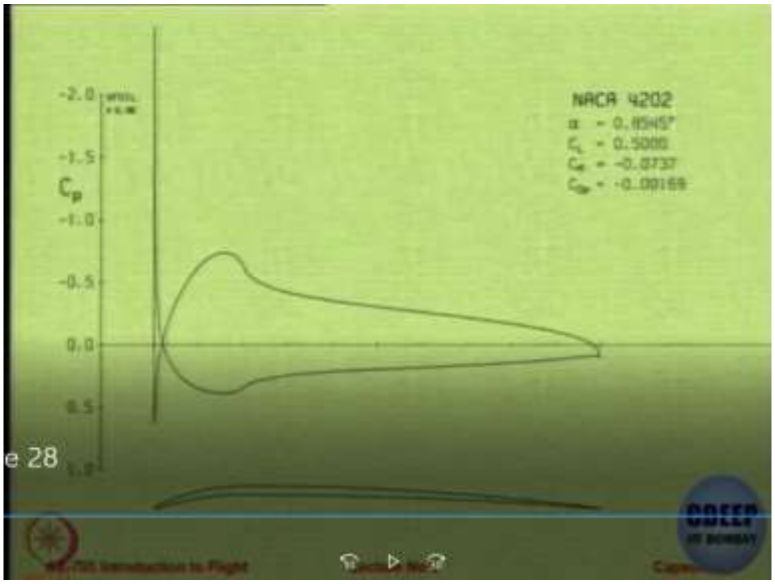
So you can see that the airfoil is symmetric and it is supposed to be 0 angle of attack, so it should have the same on both sides, so therefore, the Cp will be the same, Delta p will be the same and negative and the lift will be 0 but numerical calculations indicate that there is some value, this is because of numerical error ok.

(Refer Slide Time: 17:02)



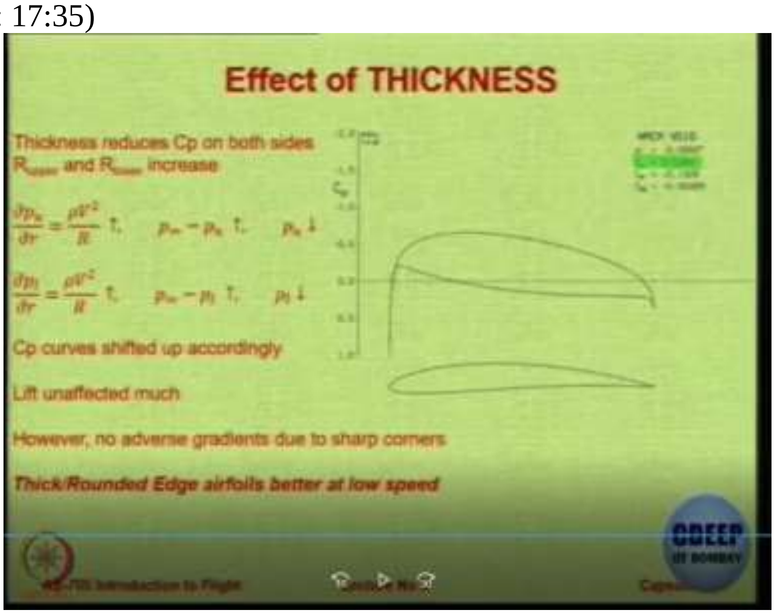
An if you now look at symmetric, cambered airfoil, you will see that the values are there is some finite area and therefore there is some finite lift coefficient.

(Refer Slide Time: 17:14)



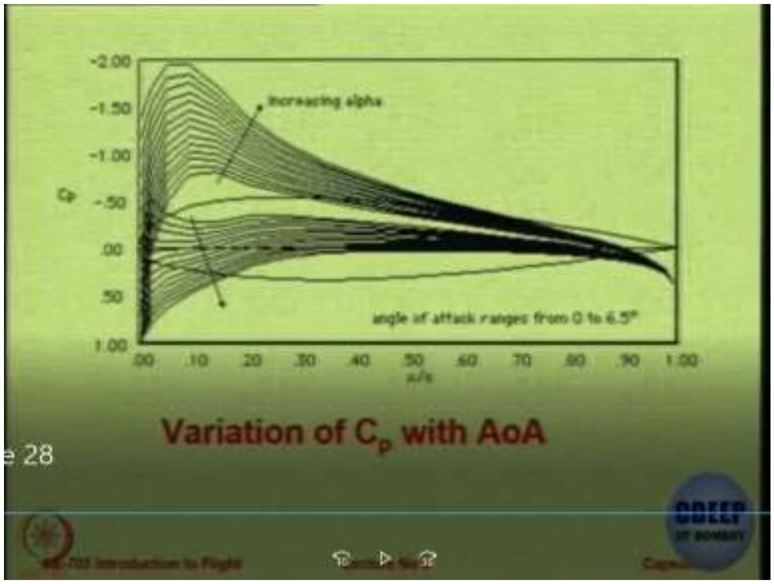
What about this airfoil NACA 4202, this will have some net Cl because there is some non-zero area but you can see that C p is shooting up very high and coming down and here also it is coming up, going down, and then coming down ok.

(Refer Slide Time: 17:35)



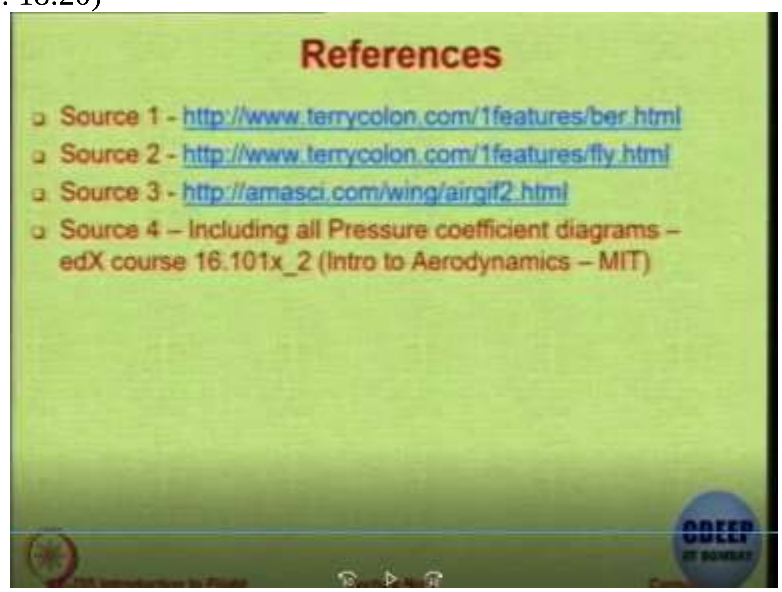
Now, we see the effect of thickness so because of thickness the Cp on both sides will be reduced. So you can notice again same formula is applied once again and you can see that there is going to be a difference in the pressure, so these kind of airfoils are better. And if you plot with angle of attack the variation of the Cp, you will see that the top surface undergoes continuous increase in the pressure coefficient, it can go up to minus 2 and up to 1.

(Refer Slide Time: 17:52)



So can you go more than 1 in Cp? Can you have Cp more than + 1, think about it?

(Refer Slide Time: 18:20)



So, the material for this presentation have come from these sources. I have already mentioned them inside. That is a very interesting edX course by MIT called as Introduction to aerodynamics that explains the various pressure coefficients diagrams and in the next class which will be a tutorial followed by a quiz. I am going to run a software and show you the various pressure distribution curves. So on that note we will stop for the day.