Aircraft Design

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Lecture - 12
Design Considerations: Aerofoil Selection

Good morning friends. The last lecture we were discussing about gross weight, and then importance of aerofoil, in a generic manner. We also discussed about the speeds required for let us say ensuring maximum rate of climb or under fly at a minimum power. And we have trying to discuss in a generic manner how the aerofoil will play an important role.

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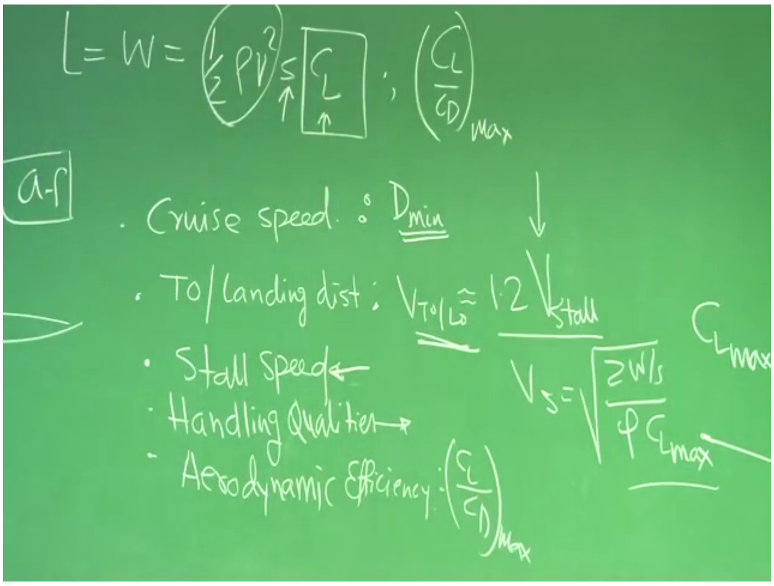

We need not debate much on this point regarding the importance of aerofoil, because after all lift which has to be equal to weight for the cruise is given as half rho V square s C L. This is a dynamic pressure. This is the wing area and this is the C L what we are talking about. Also we know as a designer we should not only thing in terms of C L, it should thing in terms of C L by C D, because C L will also induce drag which we know is called induced drag. So, when I am selecting an aerofoil, I should not only take in terms of C L, but also that you see what is the C L by C D, maximum I get and under what conditions and at under what speed.

So, if I try to summarize as far as airfoil selection is concerned loosely I can say I need to know what is the cruise speed, I am going to fly the machine, I need to know takeoff, and landing distance required, and also stall speed I will explain all these term, then handling qualities and aerodynamic efficiency. Why cruise speed should be back of our mind in selecting the aerofoil, because finally, the designer I want that should fly with drag minimum. Also I should know that if the cruise speed a low subsonic then there is a drag characteristics which is differently when I try to design an airplane for high subsonic speeds on a near transonic speed, or near supersonic speed that is how the aerofoil shape is likely to be different.

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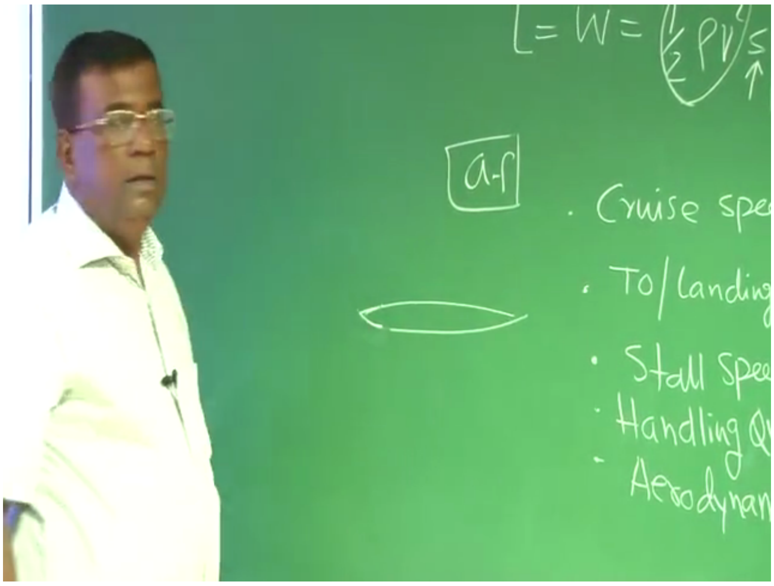

For example, for a supersonic speed, you want the nose part to as pointed as possible, provided you can manage it structurally right. Takeoff and landing why this is important because you know takeoff and landing that speed takeoff or landing roughly is1.2 times V stall.

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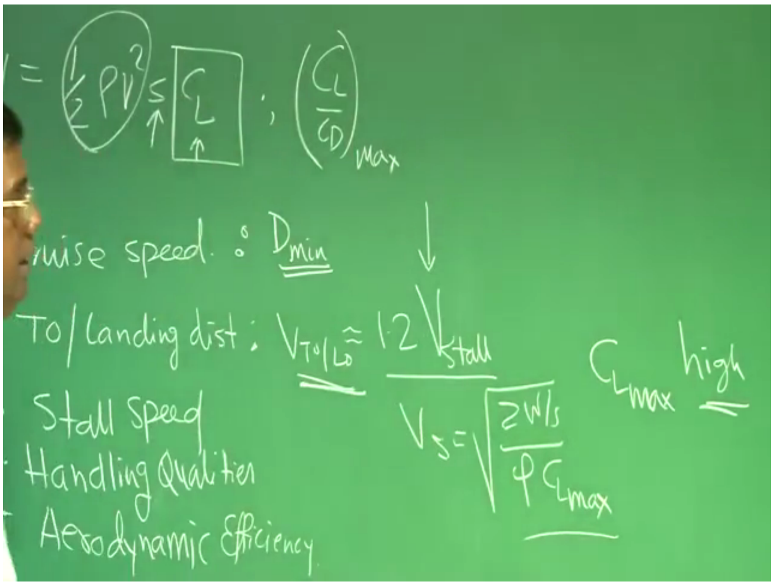

And V stall is 2 W by s by rho C L max. If I want V takeoff and V landing to be lower, then I should ensure the V stall to be lower. During takeoff and landing what indirectly means is for other thing will constant C L max should be high. The C L max could be high could be possible if you select any aerofoil, instead of this if you select an aerofoil your C L max is high.

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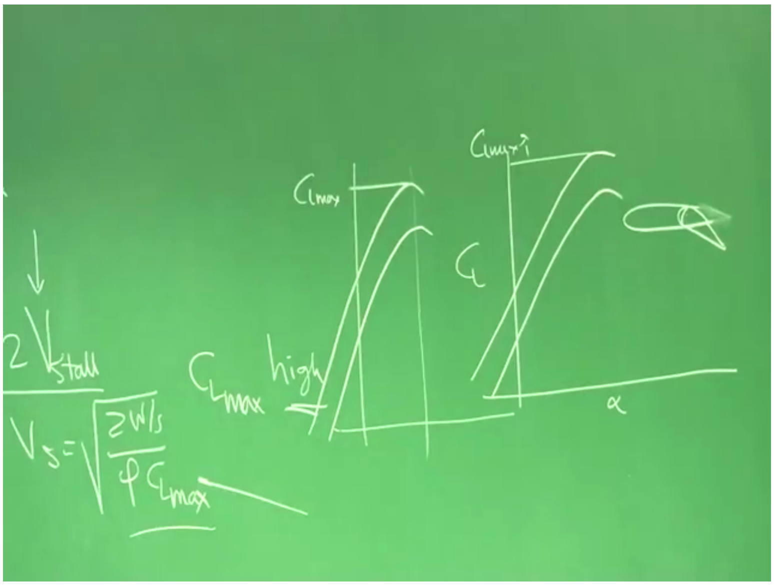

So, for the beginning you have a aerofoil selected which you will have C L max high, but you understand the moment I look for C L max high, I am mentally prepared to be penalty in terms of drag, even the stall angle may reduce. So, to overcome that you will find people use flaps. We look we will come to that. So, this is basic aerofoil and then you put the flap, flap down that is if this is a basic aerofoil, I put flap down some degrees 10 20 30 degrees and ensure that the C L max is enhanced. So, that is where when we have selecting an aerofoil, I also keep in mind takeoff a landing distance because if V takeoff when V landing distance speeds are less and for a given thrust to weight ratio the takeoff and landing distance also will be less right stall speed you understand.

When I am selecting an aerofoil, I would like to know what is the V stall. I will always like V stall to be as low as possible, but it should not be lesser than the amount it should not be. So, less that it becomes too sensitive to wind and the environment conditions, but yes stall speed depends on C L max inversely. So, when I select an aerofoil, I try to see C L max to be as high as possible. Handling qualities via handling qualities because the performance of the airplane near the stall is a very important parameter for the pilot to have in smooth handling or better a good handling qualities.

So, again in handling qualities you find somehow the stall angle.

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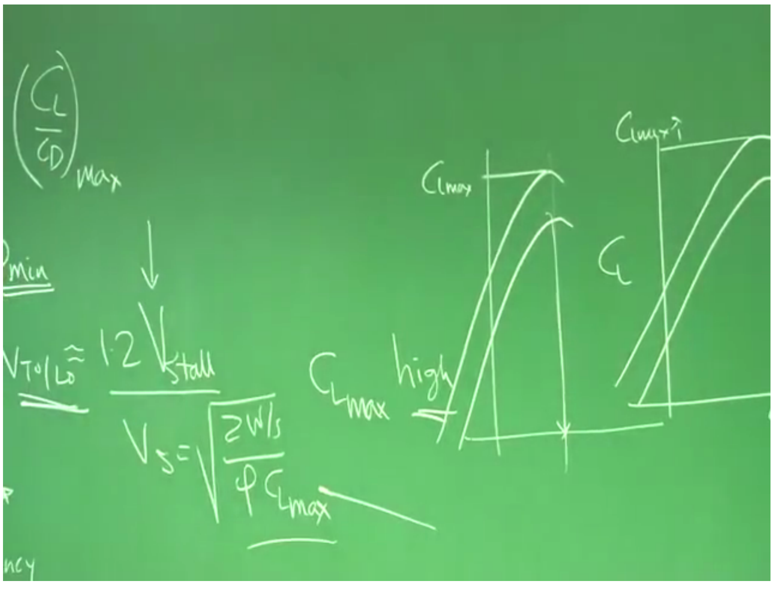

This angle plays an important role. So, I need to look for an aerofoil which generally has higher stall angle. And of course, aerodynamic efficiency which we have talked about I will look for in aerofoil where C L by C D max is what I look for, it should be higher one maybe 13, 14, 15 within stall (Refer Time: 07:14) much higher right. If this is from the aerofoil side, what I look for in a design, when I translate this aerofoil into wing right there is a another important parameter which you should clearly understand with a direct implication.

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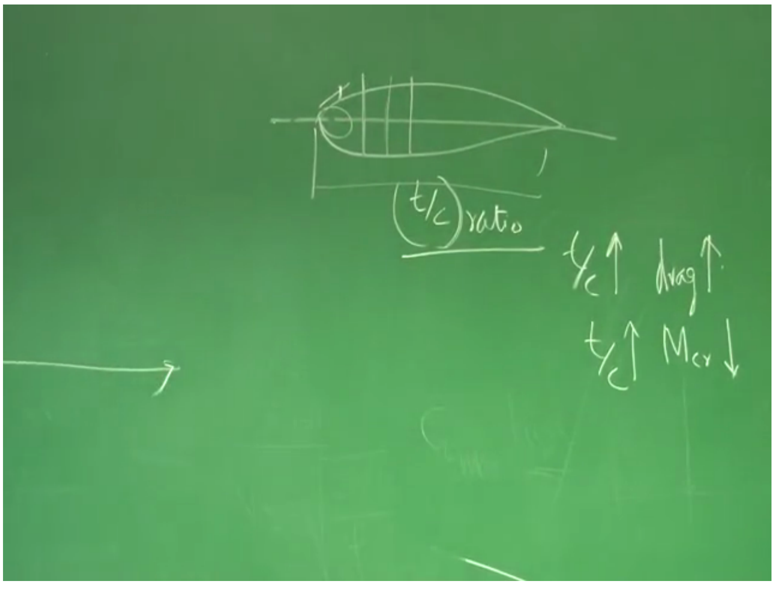

If I draw an aerofoil, this distance you could find thickness to chord ratio. This also plays an important role. If you see that if t by c is large then the flow will accelerate here faster than aerofoil having t by c less, the t by c large gives me an advantage for a given chord, I got larger volume in the wing, where I can store fuel I can store other components, but the point is as I increase t by c the drag may also increase. So, I have to be careful if I increase t by c the end critical may reduce. So, if I increase t by c, these are all generic statement if the t by c m critical may reduce. So, t by c will play the important role.

And as a designer without thinking of big aerodynamics, if you see if this t by c is large and the flow accelerate faster than decelerates. Then there could be a region where there is a high adverse pressure gradient, and flow may separate in a manner, which you do not like. The flow may not exist as a laminar flow if you are designing a laminar flow aerofoil, the flow will become turbulent sooner than you are desiring. So, t by c also will play an important role now you can understand, when I am generating data for different types of aerofoil which you have to use the database, we used to call NACA aerofoil nowadays of course, you have a customized aerofoil.

But if you see when the data were generated data will be generated in such a manner that it will give you thickness to chord distribution the leading edge radius, it will tell what is the speed for which C L by C D is maximum. What will be C L max I can achieve, all those parameters will be given. As a parameters to select which aerofoil you want. So, I will just go back to the NACA aerofoil era, and explain you some nomenclature to understand, what is the aerofoil and what are it is special features. So, that we can select aerofoil based on those nomenclature.

Before I go for the nomenclature which is purely mechanical thing, but where the designers should know how important it is for us to understand the database via those nomenclature before I go to that.

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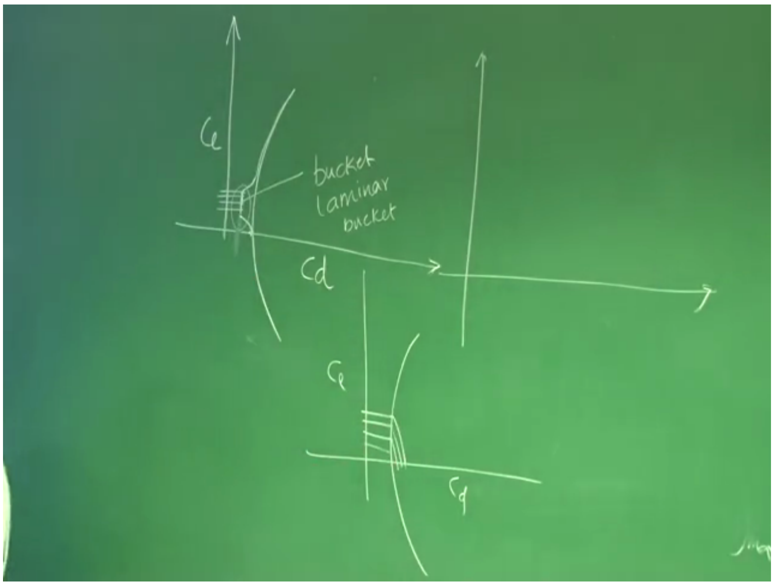

Let me also explain you, if you recall most of the drag polar C L and C D of an aerofoil take bit is out of a shape, and we say this is the minimum C D. Now the point is we will find latest aerofoil, which have been used their shape not only looks like this, it may be something like this then rows like this. And there is a bucket oh sorry, there is a bucket this is a bucket formation typically this sort of aerofoil where C L by C D shows a bucket recall it laminar bucket.

Then the importance is this, if you see in this region, even if there the increase in C L there is hardly an increase in C D, but if you see the other type of aerofoil where it is something like this, and this is C L and this is C D, if there is increase in C L the C D will go on increasing right here it is this. So, the designer I will prefer a laminar bucket type aerofoil. So, that even if I am changing C L because of different operational requirement I do not give too much of drag penalty, but please understand this is typically a laminar aerofoil. And nomenclature wise will find there are 6 C D aerofoil mostly.

But there is an issue with laminar bucket type of aerofoil is that if there is a slight imperfection in the construction, even if I you find some insect material dead material is there the flow immediately becomes turbulent right, but there is a trend that mostly people will be using 6 series or derivative of 6 series or customized 6 series aerofoil, which for 7 series x series all those things the idea would be what is the most radius I am looking for, what is the point where I am finding out that the C p pressure coefficient is becoming 0. It is not necessary that pressure coefficient is 0 only at t by c maximum location. Because C p is 0 pressure coefficient 0 is the important parameter, because then I know where from the adverse pressure gradient will start acting or pressure gradient variation how it will act, which will be responsible for flow separation right.

With this background, let us come back to that nomenclature part. I will not talk about all the nomenclatures available, but few one and it expected that you read books and really understand, why these nomenclatures and how much a designer can take information from those nomenclature. I am adding few more designers perspective before you go for the nomenclature. Specially to get a feel how thickness ratio, will implicate in terms of flow separation, on an aerofoil in a very generic manner. And I am referring a text from Ramos book you can read Ramos book.

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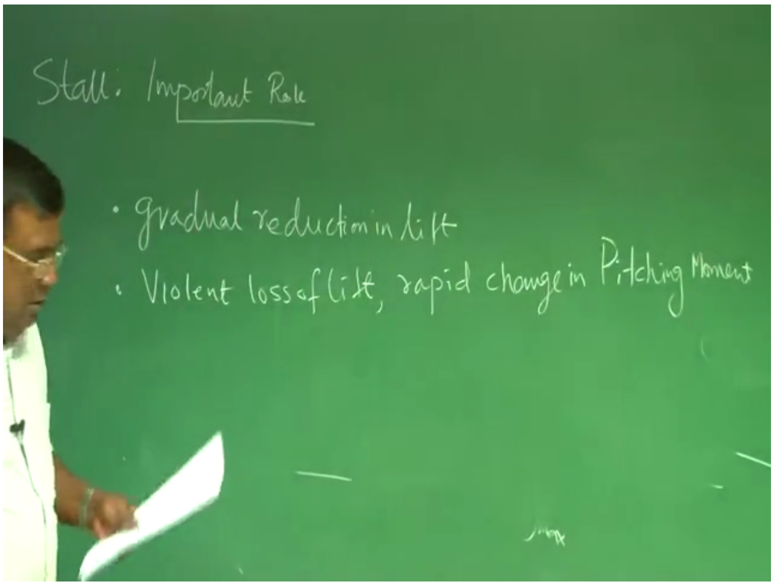

So, I give a heading as stall. And I say important role. You will find some aerofoil will show gradual reduction in lift and some aerofoil will show violent, loss of lift, and rapid change in pitching moment. For example, if you take cambered aerofoil wings, this is a cambered aerofoil wing if you see this diagram, if C L max will be more, but it will have large Cmac negative, that is if I just throw it that will turns in to go down like this right. So, there in Ramos perception, he has explained 3 types of stalls, very wonderful summary of he explains, and I thought it must be shared.

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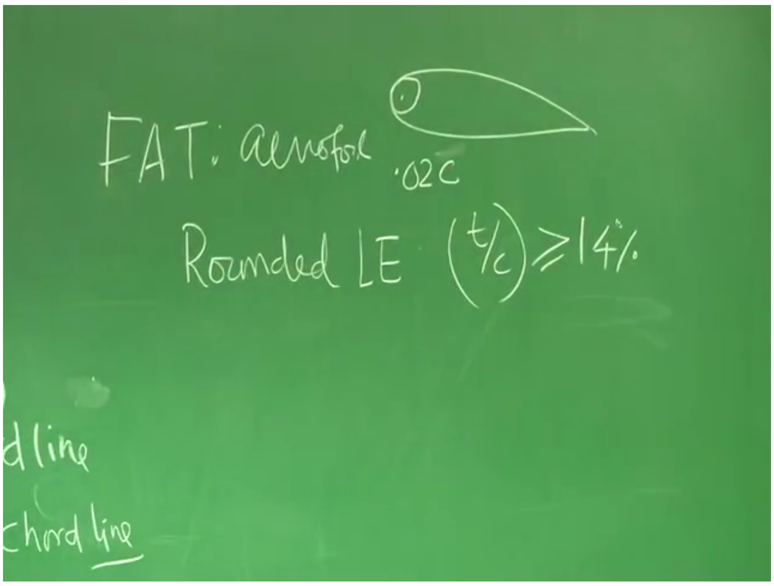

One he talks about fat aerofoil. That is rounded what is the characteristics, rounded leading edge, that is if I draw an aerofoil this leading edge is rounded. I get (Refer Time: 16:52). And t by c thickness to chord ratio is greater than equal to 14 percent. It may be cursing me why suddenly he is talking about t by c, what is t by c ratio. So, I have not mentioned anything about how aerofoil looks like, what are their chambered line, how to select how to choose and how to see when a cambered line.

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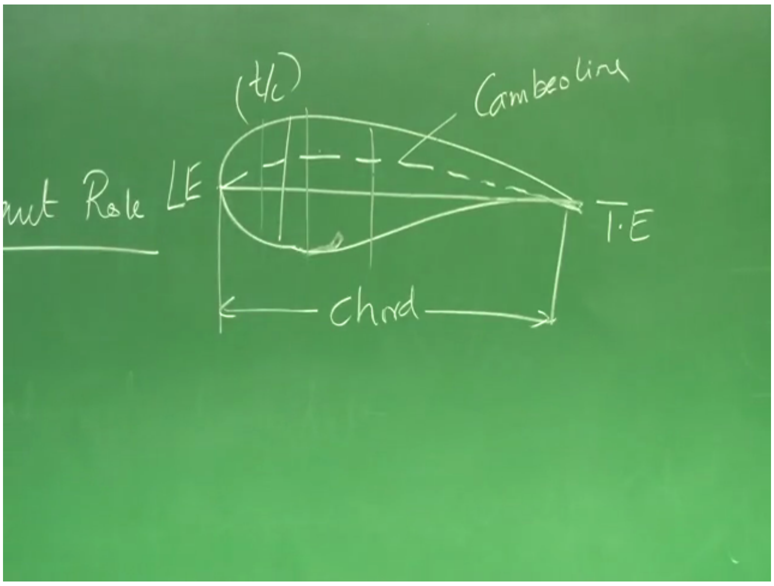

So, let me do that for you, which I presume you are all knowing this because you have done already 2 process. This is a leading edge and the trailing edge and this distance with chord. So, what is camber then if I for completion I will write then explain you what is camber I am in particular to write exactly what is we accepted by everyone, but you could see that.

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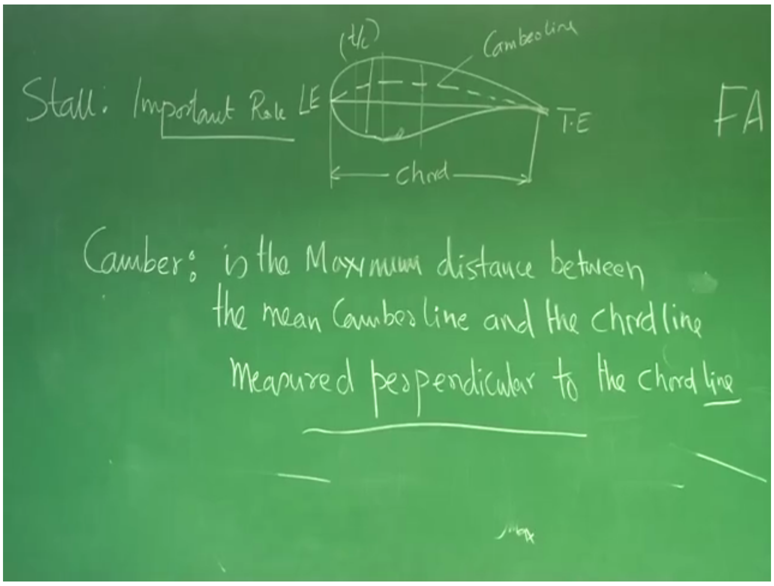

So, if you have commonsense, you can find out what is camber, I need not all these follow this definition. So, is the maximum distance between the mean camber line and the chord line, this is important measured perpendicular to the chord line. This is important, the here which are the chord line is horizontal here.

So, we are talking about the maximum distance between the main camber line civil camber line, and the chord line, chord lined measured perpendicular to the chord line. So, that is what is the camber, that is this is the chord line, this is the camber, this is the camber, this is the camber, this is the camber. It is possible that the chord line is something like this and mean camber line is something like this, and I take the mean position.

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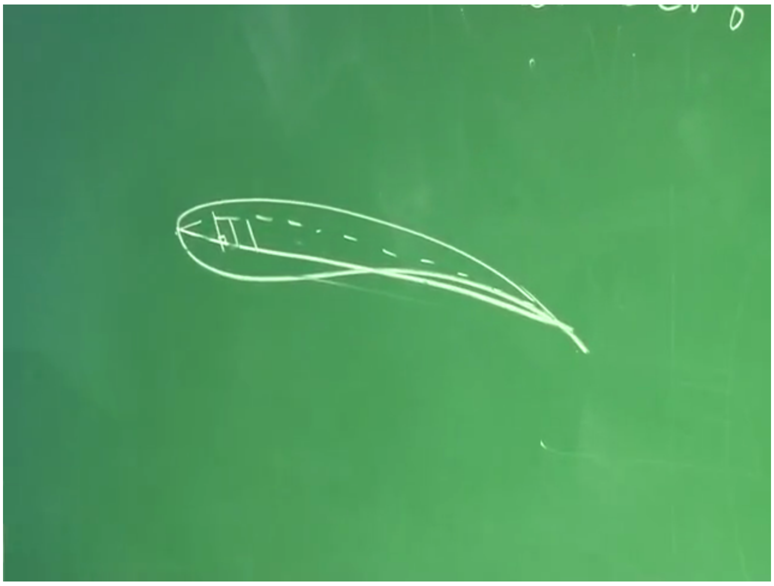

So, that time I will say the camber I have to draw a perpendicular the chord line. So, that will become the camber right. This would be clear in your mind.

Then leading edge radius. So, I was talking here mostly we will find this is point 0 times C bar, or C bar r this is a C bar chord 2 percent of chord around that. So, now, you know this nomenclature now I feel to talk about a mechanical name that nomenclature.

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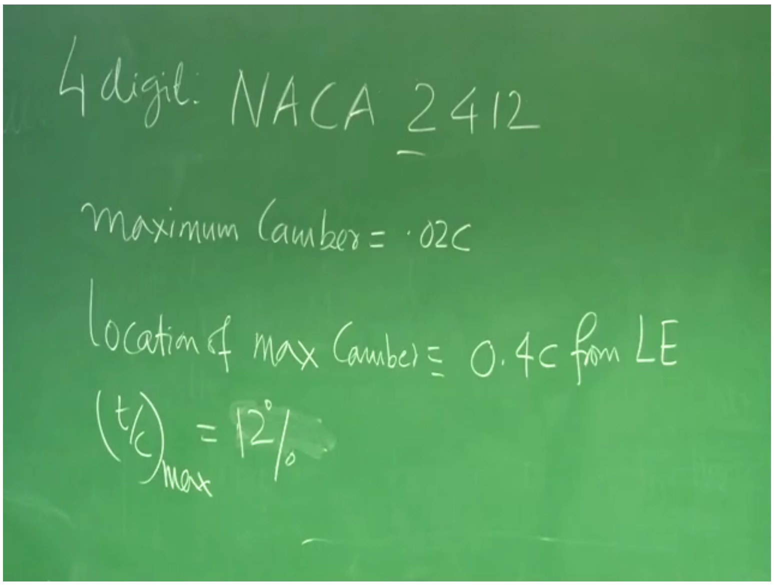

And start with 4 digit nomenclature this is NACA, let us say NACA 2 4 1 2. What is the information you will get from here, is that is maximum camber, maximum camber is 0.02 C. This is this one.

What is this 4 signifies, that location of location of maximum camber is 0.4 C from leading edge right, C is the chord. And this 12 that is t by c maximum is 0 0.1 2 C or t by c is 12 percent (Refer Time: 22:48) t by c max is 12 percent. So, once you see a NACA 4 digit nomenclature, immediately from this number you could easily find out what are the information.

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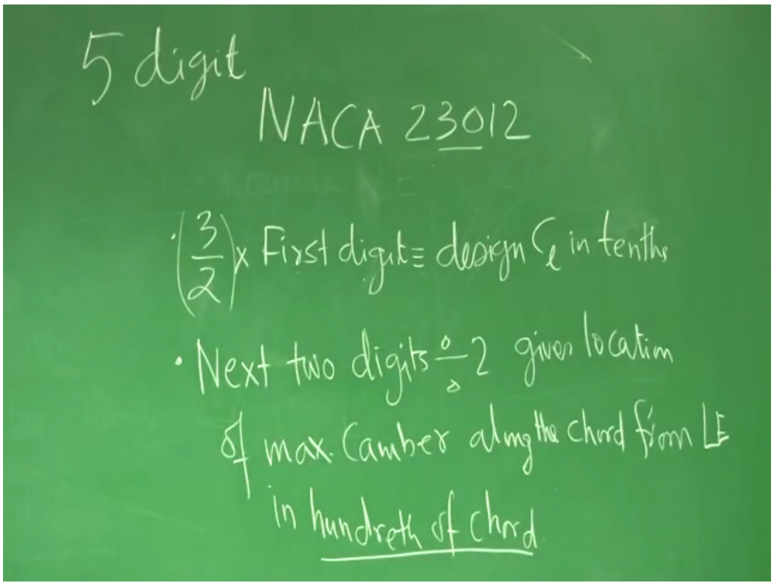

You are getting after 4 digit nomenclature, now we are discussing about 5 digit nomenclature. You will find NACA 23012. How to read that the guideline or the direction is how to read this is the 3 by 2 multiply by first digit is will give you design C L in tenth.

3 by 2 first digit is 2. So, 3 it will be 0.3. What is the next 2 digit? How do I take information from that? You say next 2 digit is divided by 2 is that gives me the location of maximum camber along the chord line from leading edge in hundredth of the chord right. Is not a big philosophical statement right? If you just follow it let us see if I try to understand this NACA 23012 what other information we get. Let us say 5 digit is NACA 23012 and for the first statement 3 by 2 into 2 because it is 2 is the first digit this gives me three, but in tenth it is telling. So, 0.3 is the design C L right.

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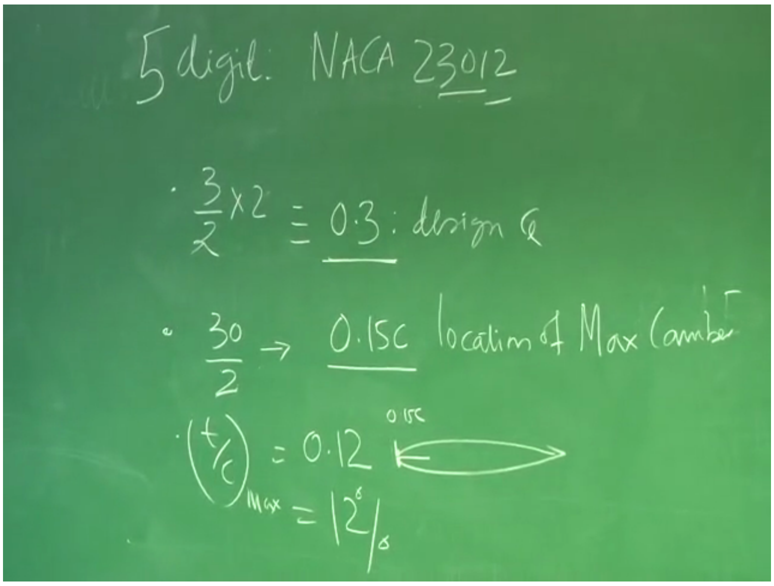

Second one is next 2 digit divided by 2 next 2 digit is 30. So, 30 divided by 2 will be fifteen, but it says maximum camber along chord line from leading it in hundredth of the chord. So, 15 divided by hundred is 0.15 c. So, tells me that if I move from the leading edge here and at 0.15 C the camber will be maximum and of course, last 2 digit tells me t by c maximum which is 12 percent right, which is also we say 12 percent divide sequence. So, this is what an information we get from a nomenclature which is 5 digit nomenclature.

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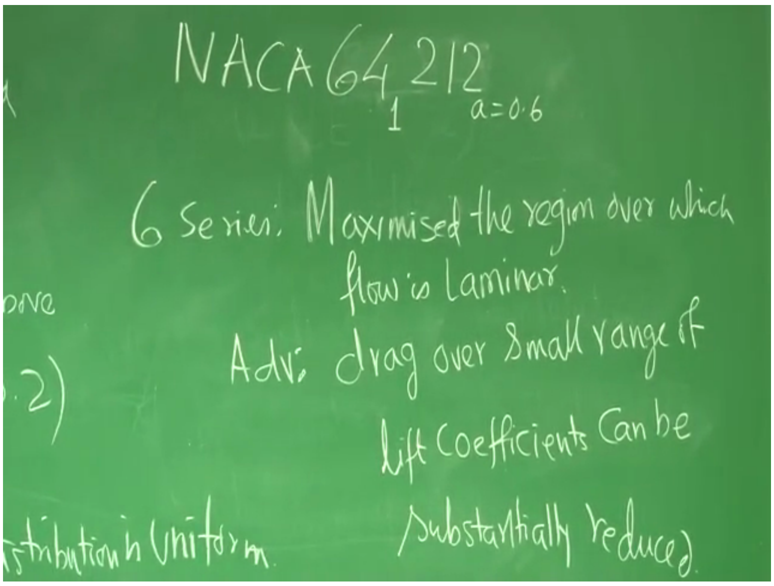

After 5 digit nomenclature or 5 series nomenclature, we are talking about 6 series nomenclature the 6 series.

When you talk about you should be mentally prepared that we are now going into a laminar type of aerofoil. I just give an example NACA 641212 at a equal to 0.6. What does it mean? The 6 is a series designation for the nomenclature. And if you understand that for a 6 aerofoil, has been designed to maximize the region over which the flow is laminar. Advantage the drag over small region of lift coefficient can be substantially reduced because you know laminar will give in this drag, but I have been telling you the word of caution the manufacture will becomes a challenge on a very particular and maintenance of the surface of the wing is also very important. In fact, if I take cleanliness of the surface that is also a challenge on one has to a particular about it the slight impurities asks foreign limit sitting on the wing may turn the flowing to a turbulent flowing right. So, that was all about 6.

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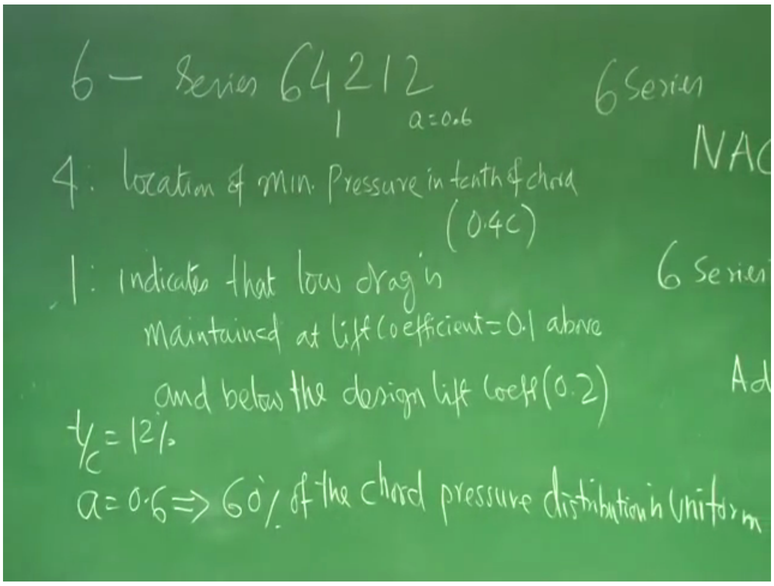

Now, the next one is 4, 4 tells you location of minimum pressure in tenth of chord that is if this is the wing airfoil. And as you know there will be accelerations of the low pressure drop.

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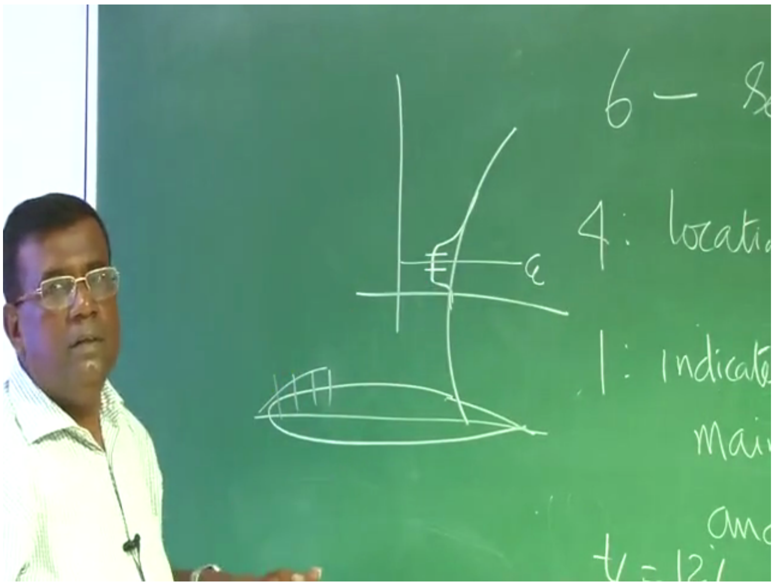

And then will be a point where which correspond to the minimum pressure point. And that is being explained here that at 0.4 C from the leading edge will have a point where the pressure coefficient will be minimum. What is that 1 indicates? 1 indicates that low drag is maintained at a lift coefficient equal to 0.1 above and below that design lift coefficient 0.2, where from this 0.2 came this is from here the next is 2. So, 0.2 is the design lift coefficient you know from here and this one tells you that 0.1 or above by 0.1 below 0.2 we will have the drag coefficient or the drag lower correct.

So, we say indicates that low drag is maintained, as well as I was mentioning for a 6 series or a laminate of aerofoil there is a laminar bucket right that is being talked about. This will if I further clarify this. And this is your laminar bucket. If this is the design C L with 0.1 I hope of 0.1 down, will have low drag configuration right. So, this is also important because you will as a designing to know all the time you are not going to fly a design C L. So, what I goes of conditions and whether your aerofoil is optimally selected or not. So, that helps you in this t by c is 12, here is the max is 12 percent and also a equal to 0.6, this is also additional information you get from a 6 series nomenclature.

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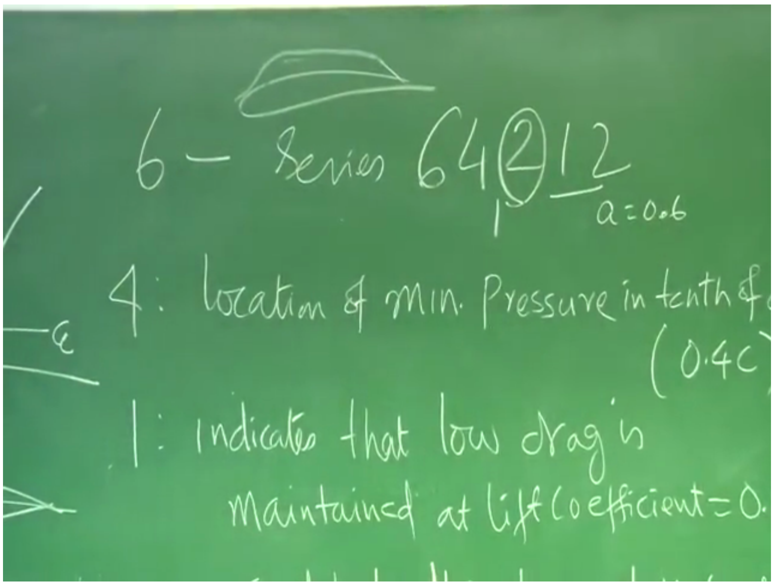

It tells you 60 percent of the chord over 60 percent of the cord this is over 60 percent of the chord the pressure distribution is uniform goes like is not that sharply is not falling. So, it will be over 60 percent of the chord the pressure distribution will be uniform. That is also important when you talk about minimizing drag or flow separation stall and all those things we will be very clear when I talk about supercritical airfoil. These are the steps towards you know defining a supercritical airfoil as well you see that this is very important a equal to 0.660 percent of chord distribution is uniform. I started with Ramones perception about aerofoil as a designer. I started some point then I went back to remembering this I am again coming back. And please appreciate what a designer should have.

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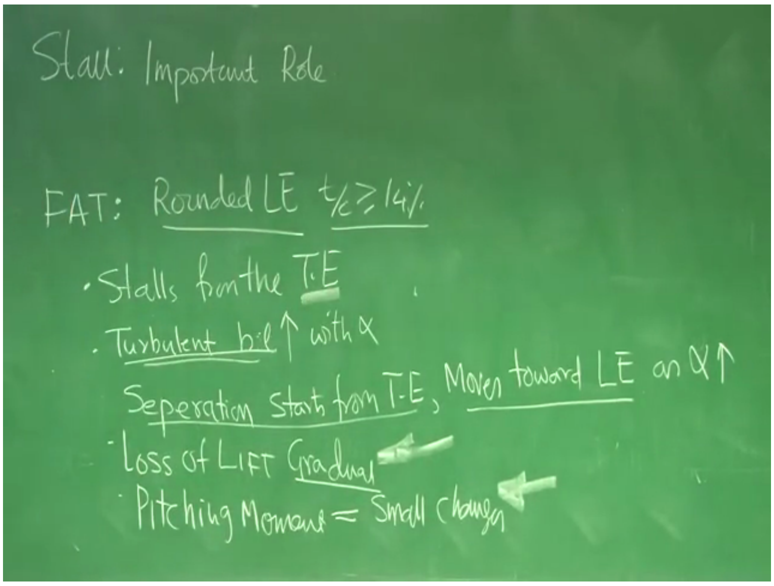

All these nomenclatures are fine theory is fine, but as a designer how do you perceive things. He characterized the aerofoil as fat aerofoil thin aerofoil very thin aerofoil. So, fat aerofoil what is his message to us is, typically aerofoil rounded leading edge and t by c greater than equal to 14 percent. And what we will see such aerofoil near the stall it is important we are discussing about stall and how an aerofoil should have characteristics near the stall because that is going to decide the handling qualities which is very important design parameter says for a fat aerofoil. So, your rounded leading edge t by c greater than 14 percent such aerofoil stalls from the trailing edge then turbulent boundary layer falls.

Boundary becomes very turbulent as angle of attack increases and the flow separation starts from trailing edge and moves towards leading it as alpha is increased, the loss of lift is gradual this is very important. And pitching moment changes are small. Understand this loss of lift is gradual, and pitching moment changes is small changes. It starts stalling from the trailing edge. And boundary layer becomes turbulent as you increase the angle of attack.

which has direct implication on the drag point right.

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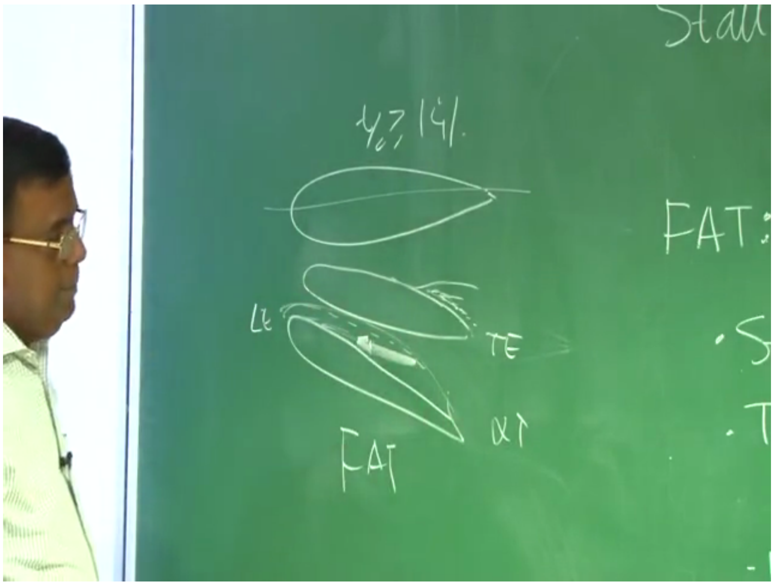

If I try to draw this if this is an aerofoil, to a t by c is greater than 14 percent. If I translate those observation it says stalls from the trailing edge. So, separation is stalls from the trailing edge as I increase angle of attack, this stalling or the separation moves towards the leading edge. And finally, hold flow separates. And in that process loss of lift will be gradual and pitching moment changes will be smaller. This is the perception of Ramon when he talks about fact, which are rounded in the leading in aerofoil with t by c greater than 14 percent.

If you are designer you will find how useful are these observation. Similarly he has talked about thinner aerofoil let me talk about thinner aerofoil, after that fat aerofoil.

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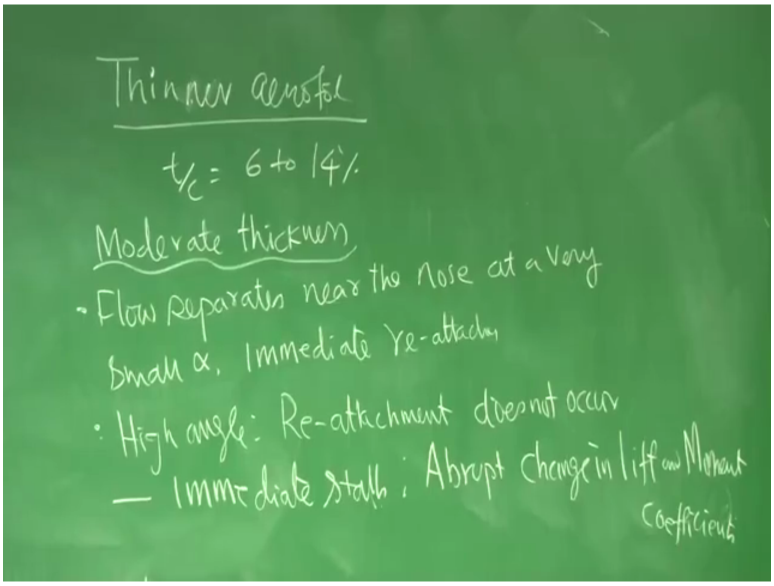

Let us also see the thinner aerofoil as far as Ramones perception is typically the t by c between 6 to 14 percent around 9 ,10 will be we talked about thinner airfoil. And those are as a design the designers language we call it moderate thickness. What is a moderate thickness means that to 9 percent 10 percent like that the moment that going be on 12 to a caution is no more a moderate fitness?

What is the beauty of those aerofoil? The flow separates near the nose at a very small angle of attack, very small angle of attack flow separate, but at small angle we have separates, but reattaches, but as we will increase the angle of attack there is no reattachment, and suddenly the flow stalls or the flow separates and there is abrupt change in C L and pitching moment that is what one designer should be very clear.

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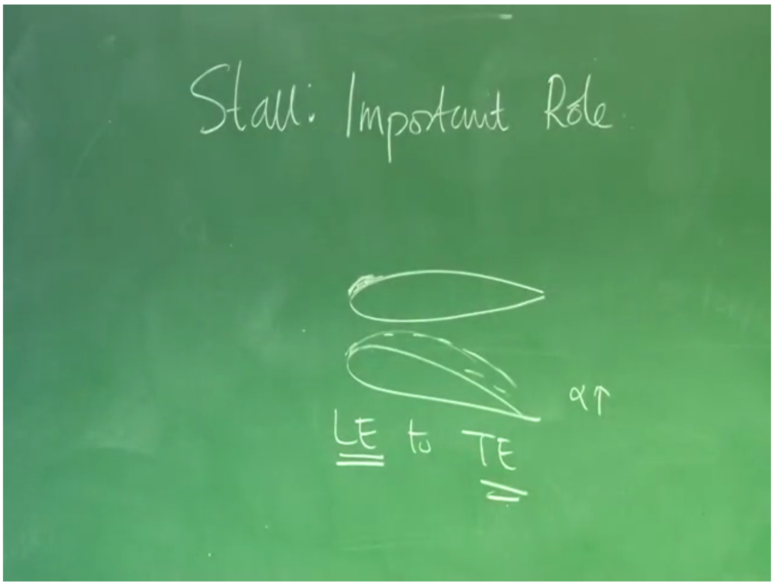

If we have working with this type of aerofoil depending upon what flight regime you are flying what angle of attack you are flying. So, typically if I repeat that small angle of attack then we separation, but it reattaches, but as angle of attack is increased, there is no need of attachment and suddenly you will find the hole flow will separate, very abruptly the flow separates, but this happens from leading edge to trailing edge. This is important the flow separation starts from leading edge to trailing edge. Unlike for fat aerofoil it was from trailing edge to leading edge. So, the lift loss was gradual, but here it starts from leading edge. So, naturally the leading edge portion is the portion where the leave generation is most efficient if that part stalls the naturally the lift stall will be very abrupt, and naturally when the abrupt change in lift coefficient and pitching movement coefficient.

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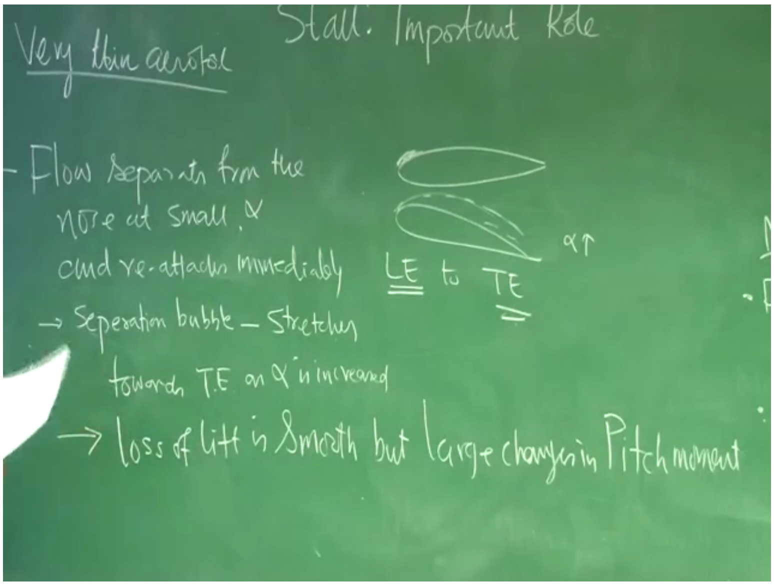

So, that is the story when you are working for a moderate thickness aerofoil which your nomenclature as thinner aerofoil. Then last one which I want to share with you is a very thin aerofoil, very thin aerofoil again. It is Ramones perception. So, I am says flow separates, from the nose at small angle at small alpha and reattaches. Immediately this is fine, if I say separation bubble stretches towards trailing edge as alpha increased.

If I try to see the similarity between what we talking about thinner and very thin airfoil, here you will absorb loss of lift is smooth, but large changes in pitching moment. That is the difference is very thin aerofoil (Refer Time: 36:52) 3 percent 4 percent 2 by C, if I close separate from nose at small angle of attack and reattaches same separation bubble stretches. So, it is something like this.

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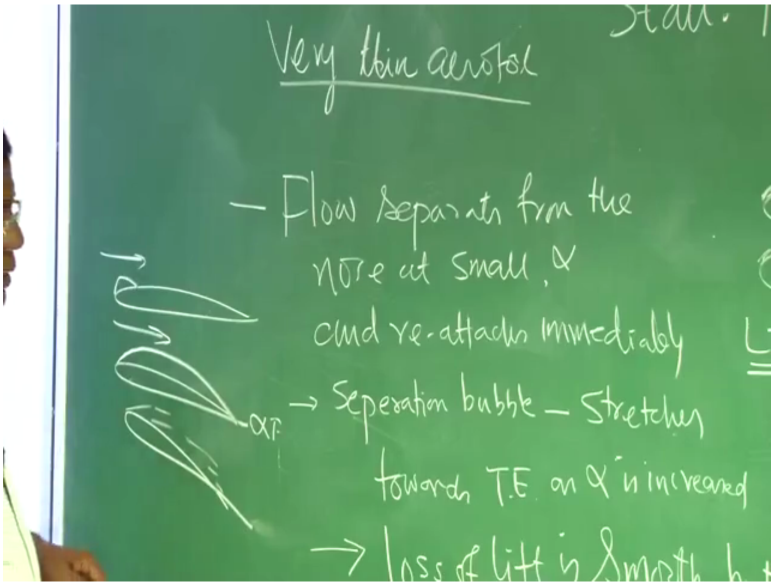

If this is thin there is a separation bubble, now as I am give angle of attack the separation bubble goes over this and then further if I increase an angle of attack this whole supreme bubble abreacts.

Movement is from leading edge the trailing edge. So, there is a separation bubble stretches towards the trailing edge as alpha will increased, and there is a separation here observation is loss of lift it smooth, but large change in pitching moment. So, this is what the perception of our knowledge base shared by Ramon. As a designer you need to see this re service the aerodynamic characteristics of different aerofoil right. And you sit within aero dynamists and talk to him what does it mean how do I customize my aerofoil. So, that this thing does not happen or these things should happen right. So, that is why there is a constant introduction with aero dynamists where a designer looks for the particular type of performance.

For example, if he is designing an airplane or the unmanned aerial vehicle of around class 6, 700 kg wait speed is not high. So, it is proud to experience large angle of attack if there is a vertical aboard guest. So, designer will ask the aero dynamists can you give me an aerofoil which has a very good stall characteristics. Designer may not be satisfied with whatever aerofoil are available even customized aerofoil characteristics the designers may not be happy about it there is a limit to which an aerofoil shape can be configured.

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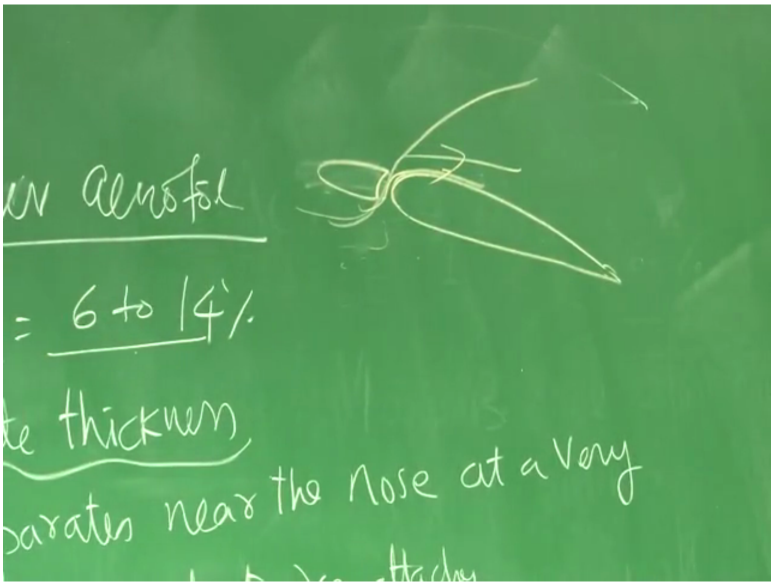

But then designer will not sit idle, that is what I am telling you what a designer how a designer at different from and persons will do analysis even designer. What it will do this is the maximum stall angle you are able to give to this aerofoil. So, I will put a split aerofoil here, the split aerofoil that here on as use that. So, what will happen if is this was not there, this was having stall angle let us say 12, 13 degrees the moment you put a split aerofoil then if you see that the air goes from here and comes out like this and it pushes the stall the stall angle increases right.

The important thing is how do you contour this part. So, that the air coming we should not go like it should come and follow the path that is where the million dollar design winter testing CFDs is set a play ground right. So, whatever I am trying to give you I am sharing few knowledge base of designers few from analysts who are analytical person and also trying to give you example how you are not an aero dynamist you are not a structural man you are a designer right, and you have to be smart just being bright will not make a good designer a designer has to be sufficiently bright, and more importantly he should be smart as well are you prepared for that or not we will learn from this courses. And I can guarantee you that we will become all smarter.

Thank you very much.