Introduction to Flight
Professor Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology, Bombay
Introduction to Aerofoils and Aerofoil Nomenclature
Lecture no. 05.1

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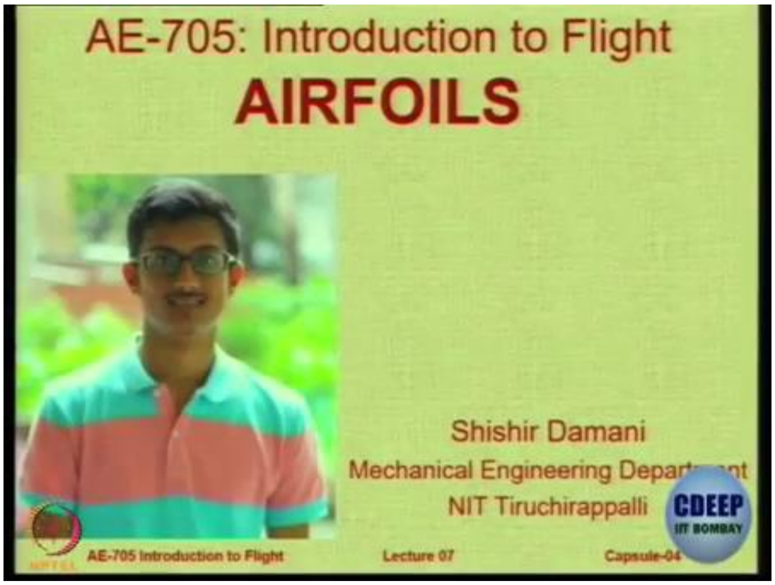

Today, we start the fourth capsule of this course, in which the first lecture, the seventh lecture is on aerofoils or airfoils. This particular content has been essentially credit by Shishir Damani, a summer intern who came and worked during this summer.

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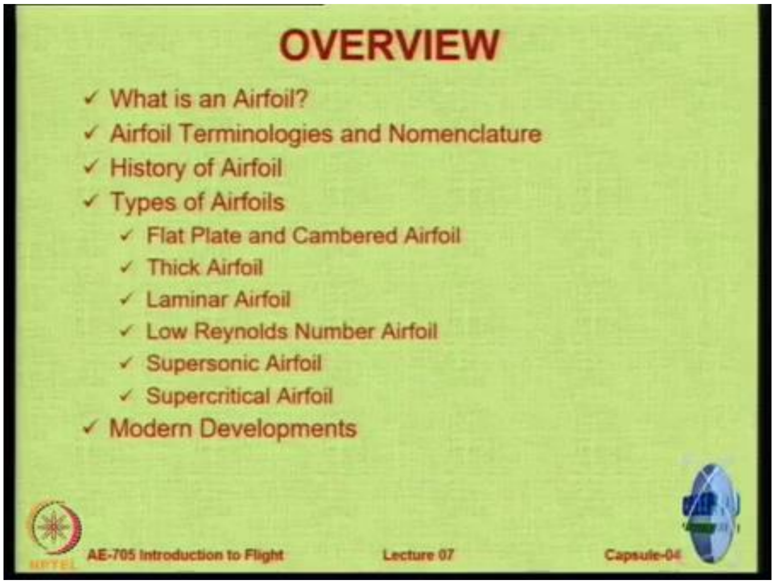

Let us first have a very quick overview on what we are going to see in this lecture. First of all we will understand what an aerofoil is? Although, many of us know about it, but still we will go for a formal introduction to airfoil.

Then we look at the terminologies and nomenclature for a typical airfoil. We look at some historical information about how airfoils came about and how they were developed and then we move on to bulk of the lecture which will be on the various types of airfoil. So, there is a list of aerofoils mentioned there, we will look at each category and try to understand the features and requirements of each of these type and finally we look at some modern development towards the end.

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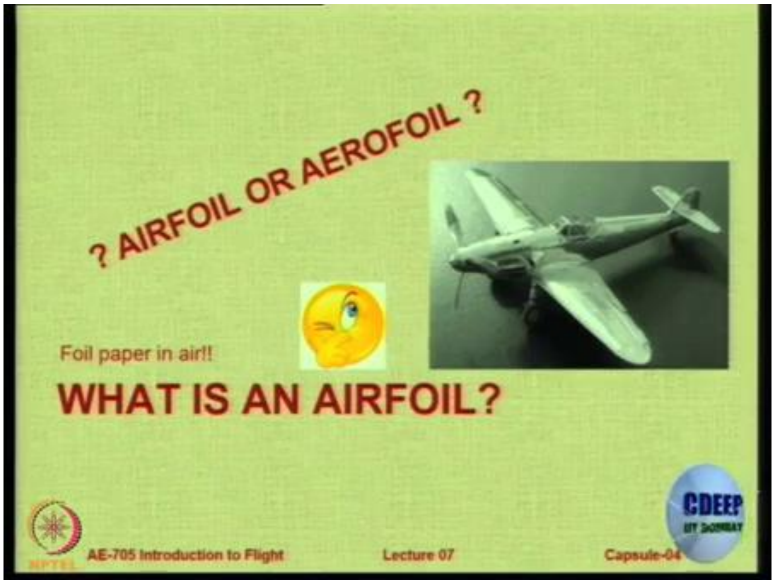

So what is an airfoil? Is basically a shape or a profile but then are there are two spellings for airfoil. Some people call it aerofoil, some call it airfoil. The difference between the two is only the British English and the American English. In the American English, we say airfoil and in the British English we say aerofoil. They are the same. Alright!

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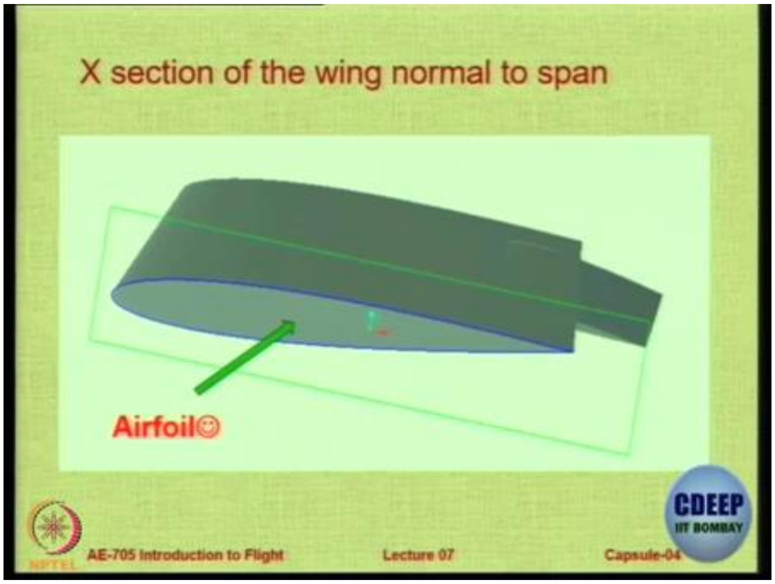

So basically an airfoil is a cross section of the wing which is normal to the span. The span of the wing is essentially the lateral length of the aircraft so the distance from one tip to the other tip is called as the wing span and if you take a cross section normal to that, now the span can also be like this, sweep forward or like this sweep back. Whatever be the case if you take a cross section perpendicular or normal to the span you get a shape, that shape is called as a airfoil and there are different types of shapes which are, different airfoils which are prevalent.

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Let us look at the terminology. The meaning of the word terminology is description of various elements, various features and what they are called. What are their names because we will use these names and it is important that everybody understands what these names mean. So for that we have short video clip.

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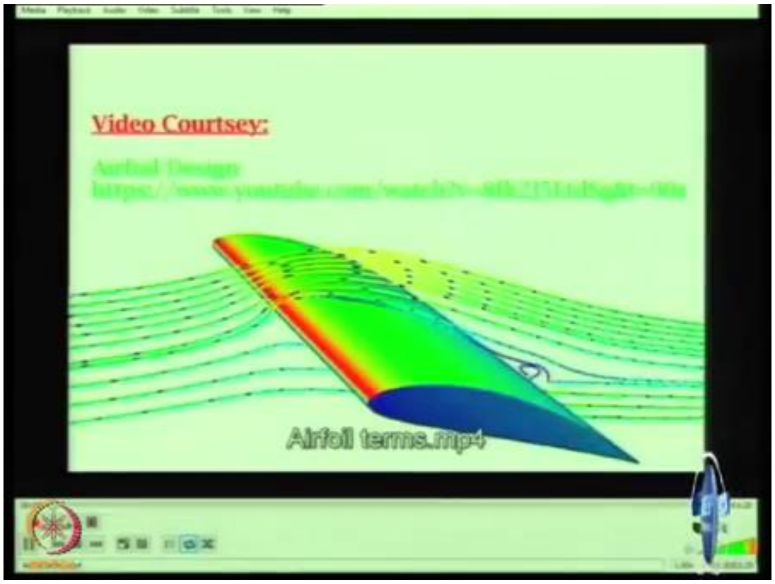
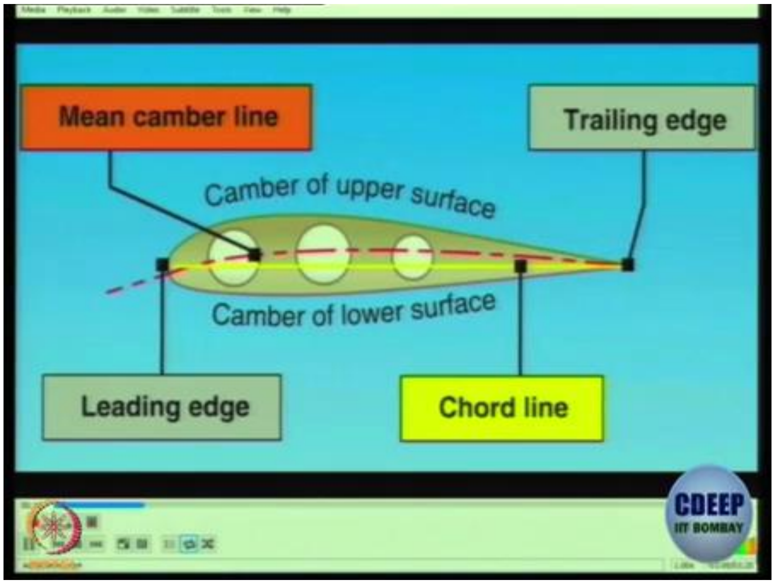
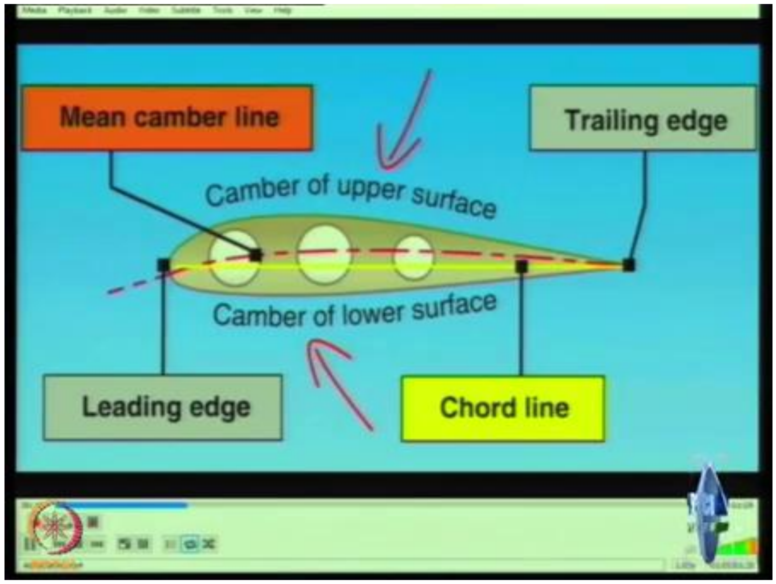
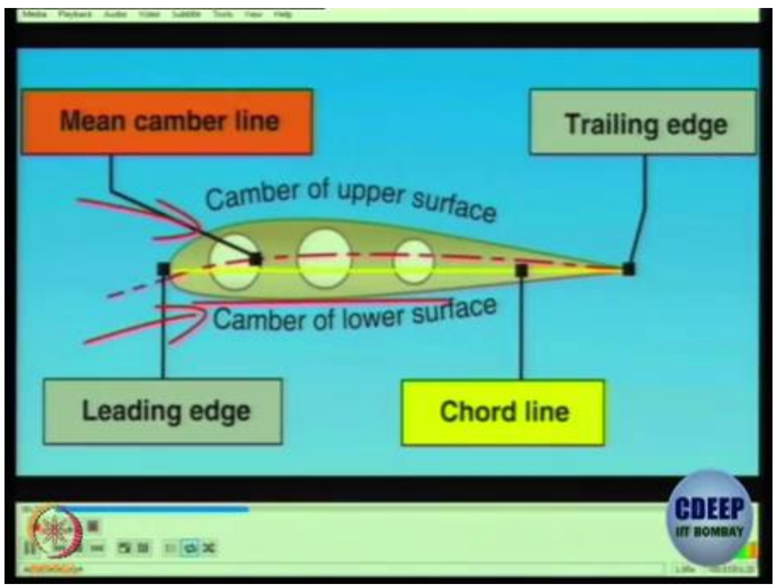





Mean camber line
Trailing edge
Camber of upper surface
Camber of lower surface
Leading edge
Chord line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CDEEP
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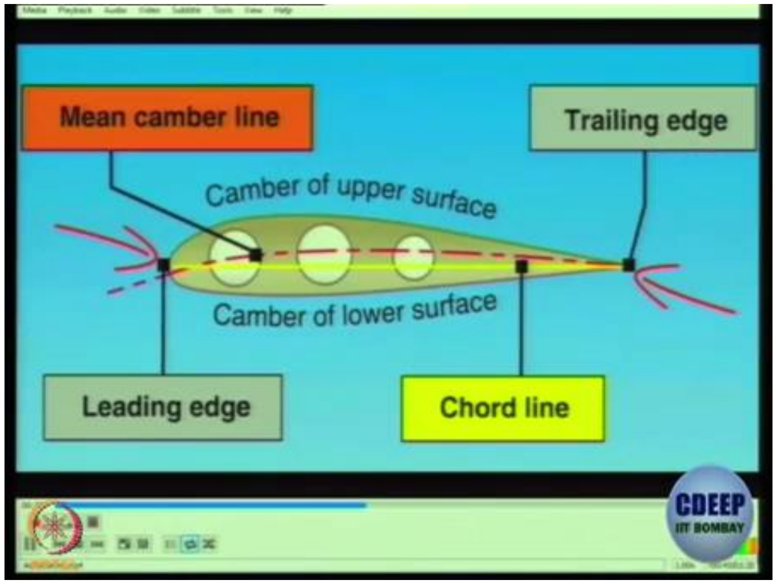
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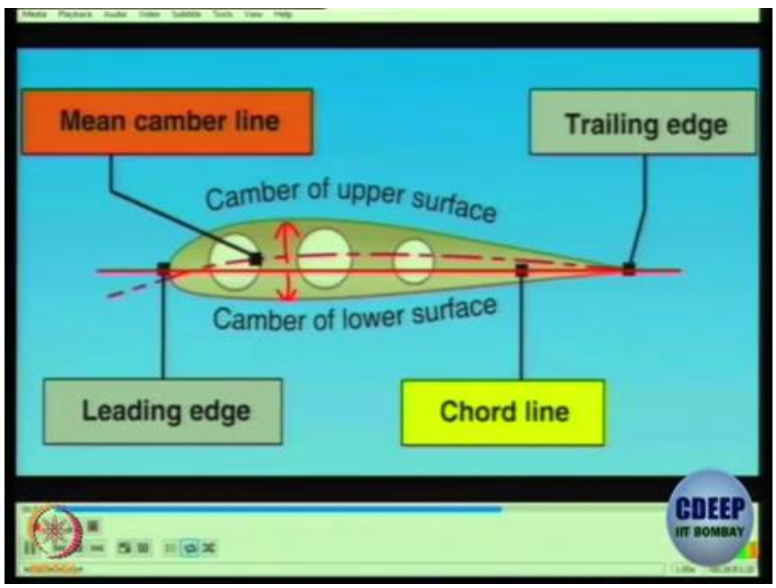
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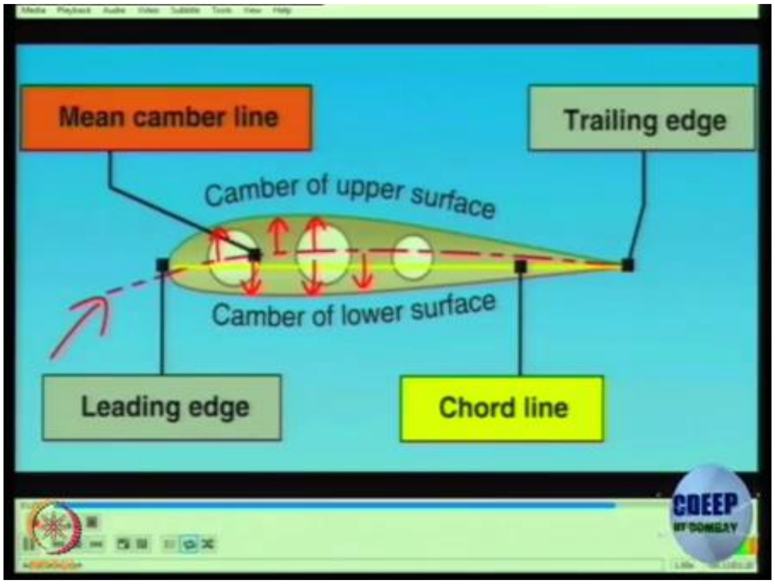

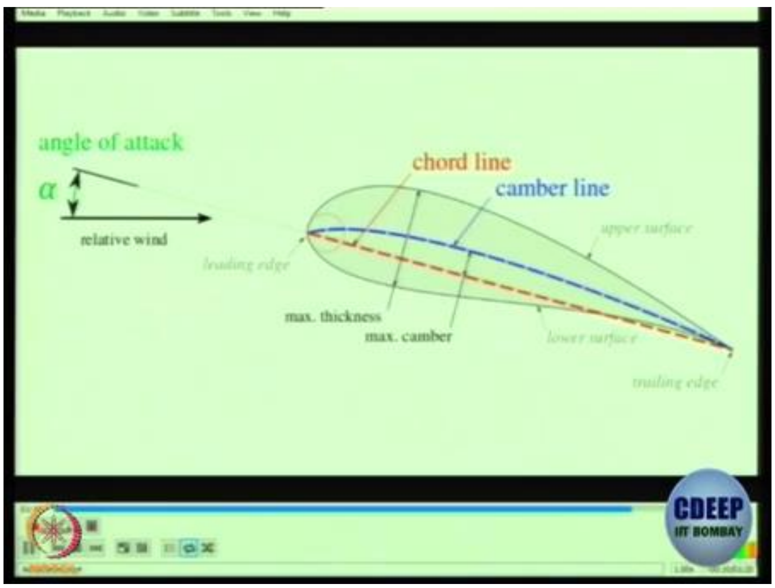

Video presentation: A typical airfoil such as a wing from the side, several design characteristics become obvious, we can see that there is a difference in the curvatures or camber of the upper and lower surfaces of the wing. The camber of the upper surface is more pronounced than that of the lower surface which is usually somewhere flat. The two ends of the airfoil profile also differ in appearance.

The end which faces fluid inside blade is called the leading edge and is rounded the other end is called the trailing edge is narrow and tapered towards the rear. The chord line is the reference line drawn from the center of the leading edge straight through the wing to the trailing edge. The distance from this chord line to the upper and lower surfaces of the wing shows the magnitude of the upper and lower camber at any point.

Another reference line drawn from the leading edge to the trailing edge is the mean camber line. This mean line is equidistant at all points from the upper and lower surfaces.

Professor: I will pause it here so that it can give you some time to look at the various nomenclature items. You have an upper surface and a lower surface. We have a leading edge and a trailing edge.

The leading edge is a one that is facing the oncoming wind. There is a line, a theoretical line, a straight line joining the leading edge and the trailing edge and as you can see that line can actually go outside the airfoil such as in the rear bottom portion of this one. That is why we say it is a reference line and that is called as a chord, but you can also draw a line which is the blue line in this figure and that blue line is equidistant from the top and the bottom surface all along the length of the aerofoil.

So the vertical distance above the camber line to the top surface and the distance from the camber line to the bottom surface at the same location is going to be the same. So this particular line is called as the mean camber or the camber line. And the maximum camber is the maximum distance between the camber line, the blue line in this figure and the chord line, the red dotted line in this figure and there will be one specific place at which this maximum camber will be located, that is a very important point. It is called as the point of location of maximum camber.

So as we move this point forward and backward the aerofoil characteristics will change, the behavior of the aerofoil will change. Further, you can also, from the from the chord line, you can actually go perpendicular to the chord line along the length of the aerofoil. But now in this case for example, the distance between the chord line and the top surface and the chord line and the bottom surface at the same point, it may not be the same. For instance, we can see that in this case, in most cases, the distance from the chord line to the top surface is more than that from the chord line to the bottom surface. So this total distance is called as the thickness. The thickness will also become maximum at some point.

That maximum thickness expressed as a percentage of the chord length is called as the thickness of the aerofoil. 15 percent, 18 percent, 20 percent and again the location of that maximum thickness may not be the same as the location of the maximum chord, that also plays a very important role in the behavior but not all aerofoils have to be like this. This is a typical aerofoil, but today we will see some very interesting and very different aerofoils about which mostly we do not see in textbooks.

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So, I will once again repeat that, the students who are attending this course. You were expected to be going through the corresponding chapter that I am covering in the class from the main reference book by Anderson. You are supposed to do that as a self-study. You are supposed to read it yourself and in the classroom we are going to try to reinforce some of the important points and also look at points which may not be explained and of course as you all know there are student teams who are going to do the assignment on gathering more information on the topics which I cover in the class with more detail and adding it as their assignment.

So, this is a three level process of learning. The first one is what you hear in the class and then it is uploaded, the second one is what is there in the textbook which is a self-study and the third one is through the self-study folder that I upload for each capsule and finally at the end of the course we will have content available, very soon I am going to upload the assignments which other students have given.

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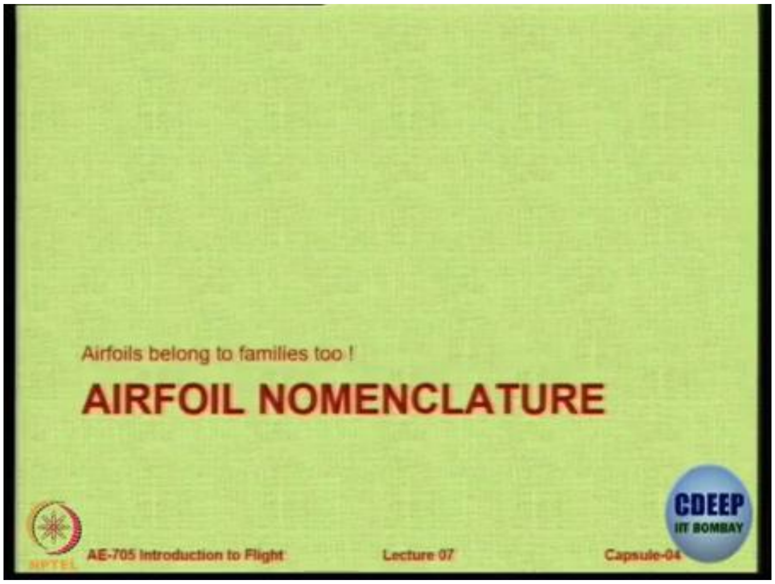

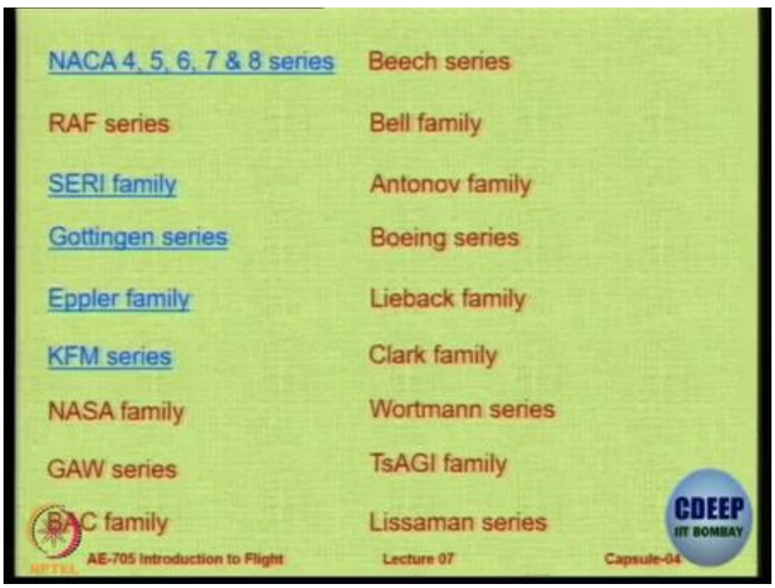

So let us see, just like we all have families aerofoils also belong to particular families. Some families of aerofoils are very well known, for example, we have all heard about this NACA series, there is a NACA 4 family, there is a NACA 5 family, 6 family, 7, 8, etc. etcetera. But there are many other families about which perhaps you may not know and this is not the exhaustive list there could be other families of aerofoils which may be there and whichever team gets this assignment they would be requested to go and locate the detail about those families, new families or maybe elaborate on the families which are mentioned here but not explain.

So because of limited time we will look at only a few families. Obviously, I will not look at the NACA family because every textbook, every website, every source describes the NACA series. So we will not touch that. We will just tell you that you look at this textbook, there is a chapter 5.20 on historical note and there these families are explained quite beautifully. We will look at some new families or families about which you do not know.

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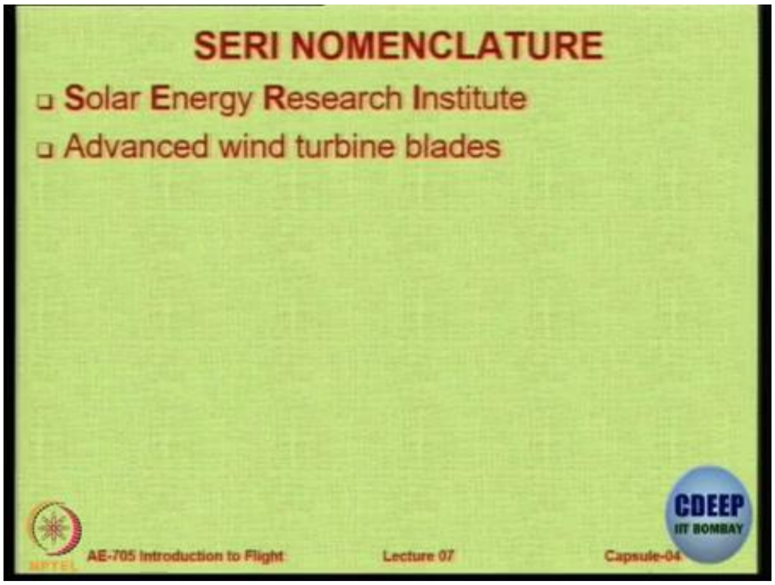

Does anybody know about the SERI nomenclature or the SERI family? Do you know what is SERI? Solar energy research institute. So these are aerofoils which have been developed specially for solar energy. So, this is a agency that looks at alternative power generation systems, alternative systems and they have classified special aerofoils for wind turbine blades. So for a wind turbine, the purpose of a wind turbine is different from a wing. The purpose of the rotor of a wind turbine is to extract energy from the ambient air even at low speeds.

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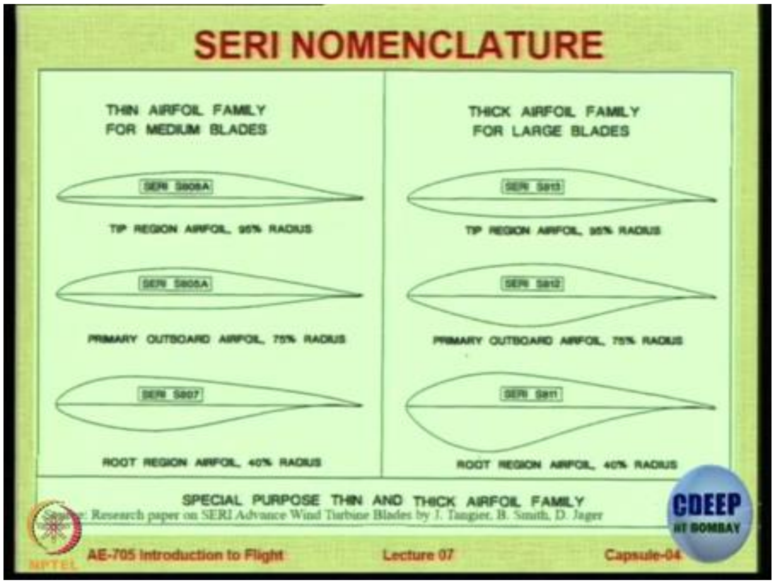

And also to ensure that as the speed changes we do not get too much of variation. So these aerofoils have been, have been designed based on these requirements in mind. So, you have a thin aerofoil family and a thick aerofoil family. The thin aerofoil family is used for the medium blades or small size blades which are going to rotate.

The large blades are going to go, going to rotate, and when they rotate because of their size, their span, they will generate a lot of power, so there they have gone for thick aerofoil families.

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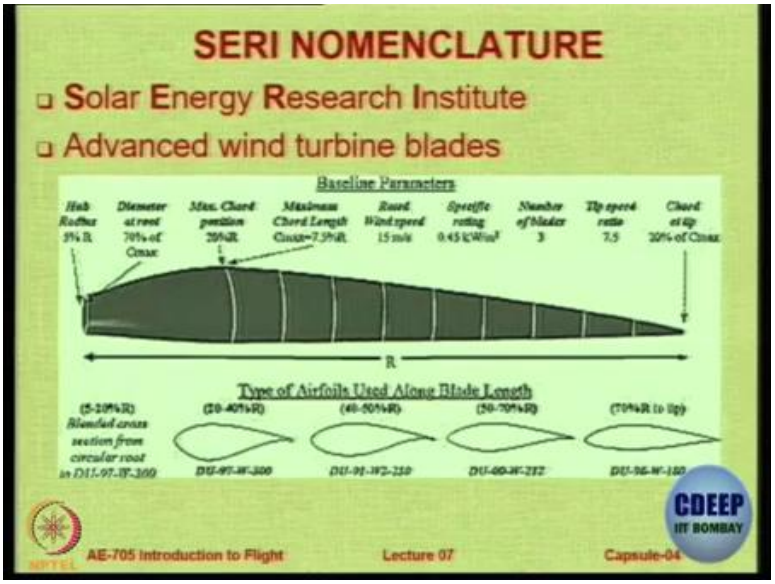

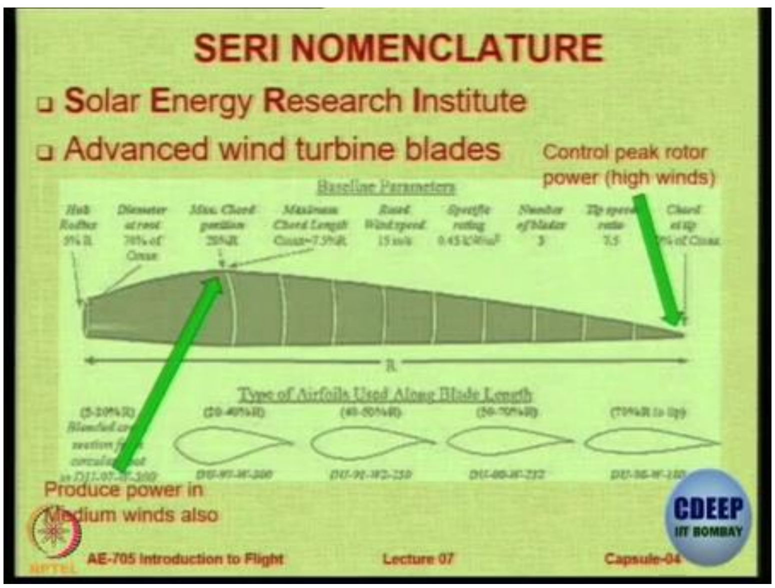

So, more details will be available later on. I just want you to understand what are the characteristic features provided in these particular aerofoil? So for example, you have locations in the front or near the root where you would like to have power produced even at lower winds or medium winds. So the cross section at the location near the hub belongs to a particular type as well as at the tips you are very far away from the root anyway and by virtue of 2 pi r effect, the rotation effect itself you are generating power.

So we would like to control the peak power that is produced by the rotor. So there, there are different types of aerofoils. So as you can see there are thicker aerofoils towards the root and thinner aerofoils towards the tip. So using various SERI family members along the span you can custom design a blade for a turbine and this is a huge area of research and in our department also we have some of my colleagues who specialize in design of wind turbine blades as well as in the fabrication and testing.

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Right. I want to also introduce you to a very interesting family which is popular with people who do aeromodelling. They are called as Kline Fogleman aerofoils based on the person who suggested. So, they were devised around fifty years ago and they are interestingly aerofoils with steps. We are all conditioned to understand that aerofoils should be smooth but here we have intentionally provided steps, one step or two steps. So we need to understand what these are and there is a very nice video which shows the aerodynamics of these aerofoils.

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Professor: Can we increase the audio please.

Video: Which is a utility aerofoil very popular on scratch filled planes. This airfoil is known to have a higher stall resistance than a conventional airfoil. Some speculations on the mechanisms behind this airfoil suggest that a small trapped vortex forms behind this step which somehow increases the lift being generated.

Professor: Somewhere here.

Video: As seen in this test, the area behind the steps forms a pocket of air which appears to be stationary with no vortex present. When the airfoil stalls and airfoil separation occurs, the pocket quickly disintegrates. At the lower angles of tap we can see a significant amount of turbulence being created in the wake far more than observed with a regular airfoil.

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Professor: So, this is a very special aerofoil series mostly designed for model aircraft. They will have a very poor lift to drag ratio because drag will be quite high and lift is going to be where it will be less but, as I heard and also you must have heard these aerofoils are much better at higher angle of attacks. They are able to withstand and the reason for that is the mechanism of creation of a vortex bubble in the region behind the step. So these are very common for remotely controlled plane although we have not seen many aircraft flying with these kind of a aerofoils but if you look on the internet if you look at forums which talk about RC planes apparently these are very easy to make.

It is like layering up material. Balsa slabs can be simply layered and stuck with little bit of rounding, so it is very easy to make.

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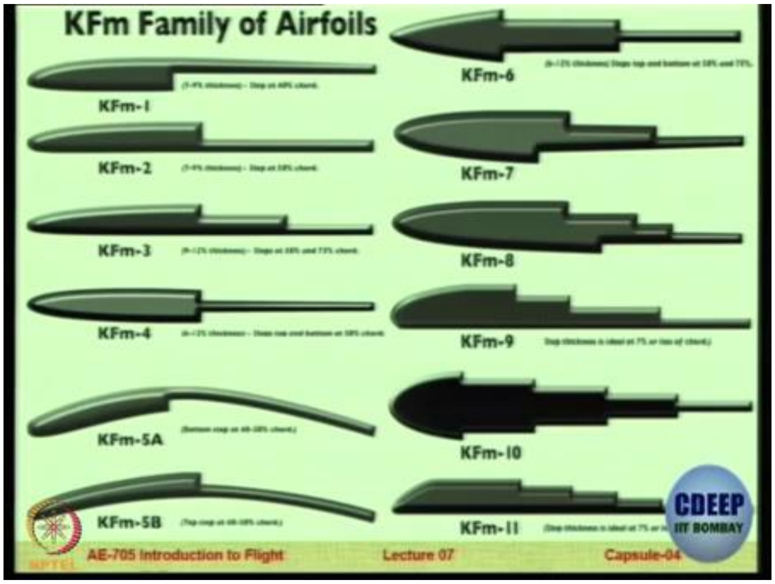

And there are many, many series as you can see there are some which are having two steps on the top, one on the bottom like the KFM 8 series. There are some which have got curvature also. So this is one very interesting series and you have KFM 11 which has got not one but 1, 2, 3, 4 steps on the top surface and the bottom surface is flat.

So, the mechanism of generation of lift and the mechanism, the aerodynamics of this particular (configura), of this particular layout is such that it is helpful in a certain class of aircraft mostly for remotely controlled.

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All right. Let us look at another interesting series called as a Gottingen aerofoils which were created in the university in Germany mainly through wind tunnel testing because in 1910 we did not have CFD available to us so these were very painstakingly developed through minute and very careful wind tunnel testing. So they also have one digit, two digit, three digit numbers. So this is one cross section Gottingen 622 aerofoil.

We observed here that the bottom is almost flat, slight curvature in the front and the top one is having a good curvature. Now what is meant by this one series, one digit, two digit, three digit, so this is something I want you to find out and upload on moodle. So, you are going to search for this kind of aerofoils. You are going to tell us what are these one digit, two digit, three digit numbers and what is the relationship. So for example, Gottingen 622. Does the number 622 mean something? Just like in the NACA series you know that each number means something so do they mean something here, all those details I would like you to upload on moodle page.

Moving on to another family called as the Eppler aerofoil family. Now this is a an aerofoil family which has been designed using mathematics, using what it is called as a conformal transformation or conformal mapping. So what is conformal mapping? Something has to conform or remain the same between the base and the mapped surface.

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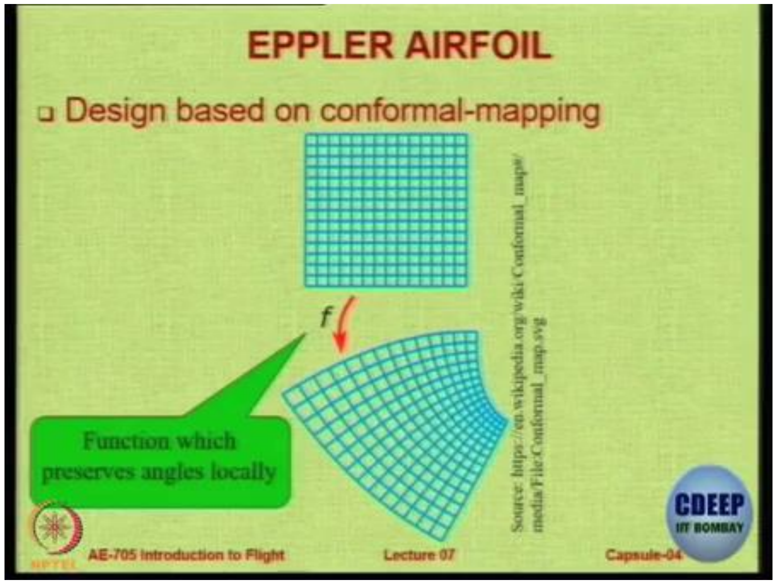

So in this case what we do is we consider a domain which is a simple rectangular domain. Here we see in the top half of the figure. You see a simple grid with perpendicular lines horizontal and vertical, on the bottom same grid has been transformed using a mathematical transformation.

So, Y is equal to A sin theta X is equal to or you know, something like that, some kind of a transformation can be used to create something so each point or each intersection in the bottom grid corresponds to a particular point in the top grid and the transformation happens through a function, f, but notice that the perpendicularity at the junctions is still maintained. To a large extent, the perpendicularity is maintained. So this is the meaning of conformal. So using some mathematical expressions you have a transformation available, but the functions are such that they preserve the local angles.

So using these kind of expressions now when the initial studies of aerodynamics started there was a huge contribution by mathematicians so when we were students, for example, there used to be a subject called as wing theory and this, there used to be joukowski aerofoils and some other aerofoil which are very theoretical. Practically, you do not see these aerofoils exactly. Because, for example, if you take a classical transformation you will find that a joukowski aerofoil has got a cusp at the trailing edge, it is very difficult to make a cusp at a trailing edge in a practical aerofoil.

So these are theoretical aerofoils but they were suggested or purposed by mathematicians to do a analytical study of aerodynamics. So for details there is a YouTube link which I will put here and you can have a more look at it. The practical application of such aerofoils is fairly limited. Except for certain applications, but basically they are meant for some theoretical optimization so here is one aerofoil which is an Eppler 1211 aerofoil, again you will tell us what these numbers mean and what the categories are. So then there are so many so many other families. We will not spend too much time on other families.