Introduction To Flight
Professor Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology, Bombay
Lecture 05.4
Low Reynolds Number Aerofoils

We move on now to a special kind of airfoils called as the LRN airfoil, airfoil designed for very low speed aircraft because they will be operating at very low Reynolds number. Now, we know about the Reynolds number. We know that it is a ratio of inertial and viscous effect so, when viscosity is predominant, Reynolds number is higher, when viscosity is less predominant Reynolds number is lower but viscosity is always there, ok. So you may have a flow with a low Reynolds number so, there was a question raised in the Moodle and I am very happy that so many questions are being asked and it is very nice to see that the students are thinking over the questions, coming up with arguments about what they think is the correct answer, quoting literatures, it is amazing, it is very interesting.

And as you saw we also found a mistake in one of our examples to do with the swing bowling, ok. So, I have referred to some sources and based on those sources I have some understanding but my own understanding became better because of a clarification that was given yesterday. So, this is something that I would encourage you to continue doing.

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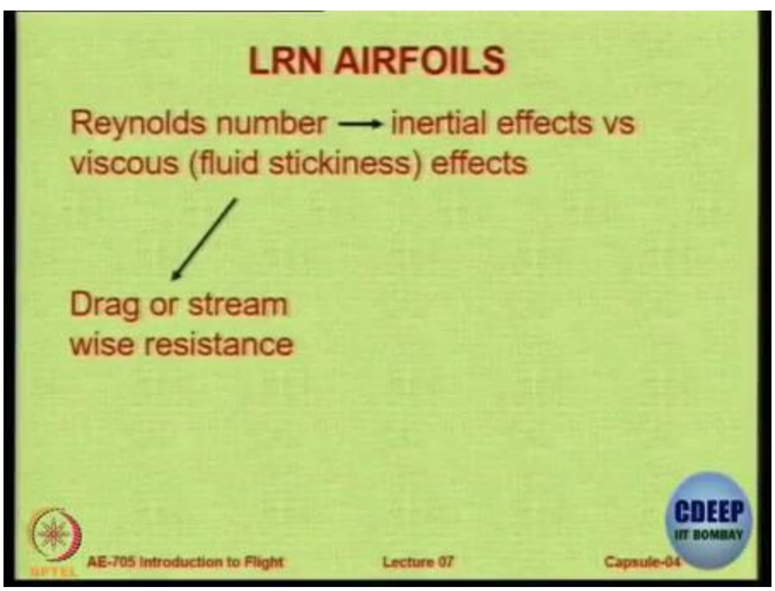

So, similarly here also what you have to see now is that if you have a low Reynolds number, you will have drag or stream wise resistance and the maximum lift is going to be limited and we know that the Reynolds number. Now for Reynolds number we need to have a defining characteristics length or dimension so for the wing it is the chord of the wing, ok.

(Refer Slide Time: 2:01)

So, look at aircraft like Gossamer Albatross, do you know about this aircraft? What is special about this aircraft? This is the human powered aircraft, the pilot is peddling the aircraft. Essentially, there is a propeller behind and you can see there is a pilot who is sitting in the cockpit and the pilot is actually like a bicycle, ok. So can you tell me, what is the typical energy that a human being can produce in cycling? How much energy can be produced by the, let us say a very fit, not like me, a very fit individual an experienced cyclist, ok who does long distance cyclist etc, people who do tour de France etc, how much energy can they produce? Can you guess? Is it 1 horsepower? 747 watts? Do you think we can produce the power of a horse? I do not think so.

We can produce probably half a horsepower, 200 watts to 250 watts is the, maybe 300 watts that is a maximum energy. So with 300 watts of energy capability that means the engine can produce 300 watts, you have to fly an aircraft that can carry the aircraft and the horse and the person who is flying it. So it is a very tall challenge with 200 to 250 watts of power available or a muscular power generate 200watts to fly an aircraft, obviously this will not be a high speed aircraft it is a very low speed aircraft. So the airfoil to be used for the wing of this aircraft is also an airfoil that is suitable for a low Reynolds number flight.

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So, the gossamer albatross airfoil you can see the cross section here, I think it is not very clear but this will be a better idea, these are 10 percent thick eppler 193 airfoil ok. So, such an airfoil is used for low Reynolds number flow. As I mentioned to you in the tutorial, we will look at the shape of the airfoil and the corresponding it to its lift and the drag capability. Right now I am not going to that detail, just wanted to give you some idea.

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This is another aircraft which is design for low speed flight, ok. So where is it use this aircraft? Looking at the aircraft can you tell me something. What kind of plane is this? What do you think? Yes, what is your name?

Student: Sir, my name is Atharv.

Professor: Yes, Atharv.

Student: I think this is a fire extinguisher.

Professor: On what basis do you say that fire extinguisher?

Student: Sir, it has a large fuselage that it can store water.

Professor: No, that is an assumption that it is a large fuselage. So, there are few distinctive shapes in this aircraft which can give you an idea. I agree that the fuselage shape is large but just because something is large does not mean it has water inside to quench the fire. So, this is not a fire extinguisher aircraft, ok.

Student: Sir, is this an amphibian aircraft.

Professor: Yes, it is an amphibian aircraft. Why do you say that?

Student: Because of that thing downside of the wing.

Professor: Below the wing, below the fuselage,

Student: No sir, below the wing.

Professor: The yellow colored.

Student: Yes sir.

Professor: What is it?

Student: Float.

Professor: Basically it is a float, it is a float this yellow color device. Now the team who has done the assignment on aircraft nomenclature ok they have, I saw the assignment that they have submitted, they have looked very interesting, components. Which team is that by the way? Team number the team that did assignment on the? Only you are in the class. Representative of the team there is one more person there that is all, two of you. I saw your assignment and you have given some very interesting things like a small parachute behind a bomb which can be used for retarding the bomb, etc. Those are not part of the aircraft they are special things on special things. This is a part of the aircraft which I would have been happy. I do not know whether you have done it but such thing is what I was looking for. ok.

So, yes this is a float but apart from the float which is here is there anything else in this aircraft that makes you think it should be something that goes on water. Raise your hands please, if you have some idea by the looks of the aircraft. Yes, anybody. Yes.

Student: Sir, my name is Vinay,

Professor: Vinay, yes.

Student: As the engine is mounted on the top.

Professor: Right.

Student: So, if it was somewhere under the wing as in conventional aircraft, then the amphibian, like water landing might not have been possible, right, Professor: So you are right that the engine is mounted high but it is on the wing like any other aircraft but the wing itself is high so that you can keep it away from the water level agreed, ok. But not every high wing aircraft is water aircraft so, something else which is distinctive. Yes, your name first

Student: My name is Rahul and the bottom of the aircraft has a distinct shape.

Professor: Ha ha.

Student: It is like boat kind of.

Professor: Right, that is right, very good observation. The bottom of the aircraft, so you can see from here to here and there is sudden jump here which is not very much visible here, this is the shape of a boat so this is a flying boat or an amphibian aircraft ok. So, now why should they have lower Reynolds number airfoils? Because they will not fly at very high speeds, they are operating from they are operating from sea or from lakes, ok. So therefore, they will not fly at very high speeds so the Reynolds number of these aircraft will tend to be small compared to other aircraft, so therefore they are fitted with special airfoils which are suitable for low Reynolds number. So, this is a Lissaman 7769 airfoil, distinctive shape and the holes in the center are basically holes for lightning it. So, this is another example of an aircraft with a low Reynolds number.

Now surprisingly if you look at L by D or CL by CD maximum versus Reynolds number, you find that rough airfoils are very good at low Reynolds number. And then there is an area of intersection both of them 10 power 5 beyond that smooth airfoils start having higher L by D. So this depends on whether pressure drag is more important or skin friction is more important so from there you come to know, ok. Moving on let us look at airfoils design aircraft that fly very fast faster than the speed of sound. So, what will we have when we fly at a speed more than the speed of sound?

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We will have a shockwave, so you have to provisions in the airfoil to handle the shockwaves. This is an example of shockwave, we have already seen this we have seen videos of this, so nothing great here.

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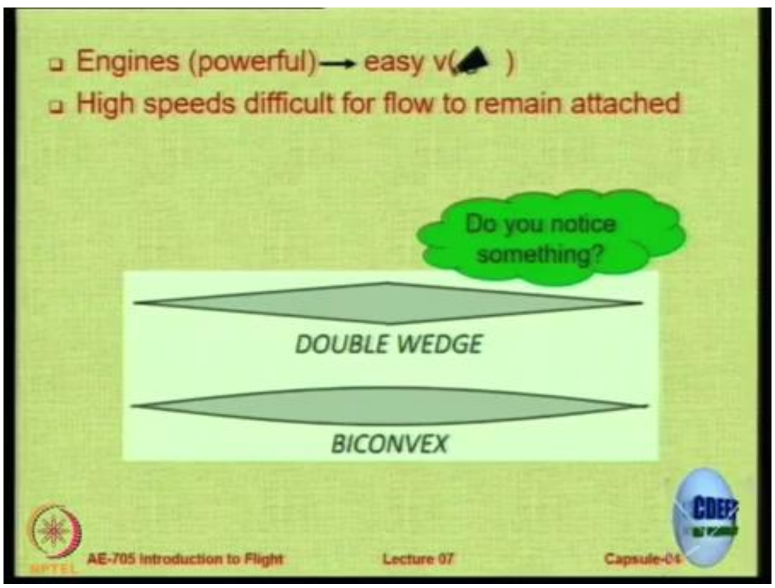

So basically, at high speeds it is very difficult for the flow to remain attached because there is a shockwave and there is a shockwave boundary layer interaction. So typically, airfoil which are used for aircraft that fly supersonic are double wedge or biconvex. What do we observe here? Anything special which is not in the other airfoils? The leading edge is sharp, trailing edge is sharp in both of them, but leading edge also is sharp in these airfoils, ok but now the problem is that an aircraft that fly supersonic will also fly subsonic, will be very bad in that condition ok but they will still produce some lift just by the angle.

So, however they will be inefficient, they will be more efficient when you go for so if you do not make it sharp, if you make it rounded and fly at high speeds, what you have is you have a detached bow shock that is a very-very strong shock, it creates lots of loss behind; temperature rises and pressure falls so it is not a desirable thing ok, total pressure remains the same of course, ok. Now let us go to the supercritical airfoil this is for one very specific condition. And this is an attempt to, now the question is a do you really have to fly supersonic in order to encounter sonic conditions, ok. Do you mean to say that you can see shockwaves only when you fly more than Mach number 1? Yes or no?

Student: No.

Professor: No, you can see shockwaves and Mach number 1 even in subsonic flight, ok. So I will show you a small video, which shows a transport aircraft Boeing 737 recently, ok.

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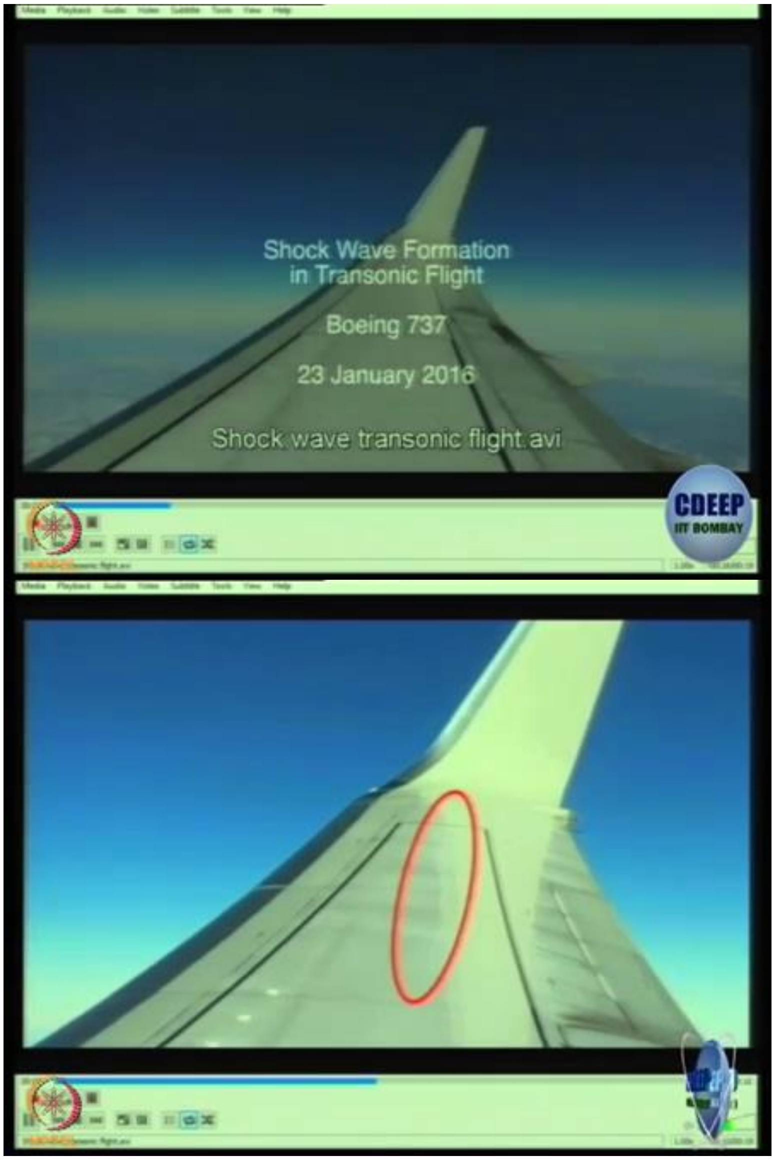

Somebody is putting the camera on the window you can see there is a line and that line is the transition line. That line is the line at which the sonic conditions are achieved, ok. So even though just because of the acceleration from the top of the surface. So, you have shockwaves you can see these shock waves on the top surface. This is the line on the wing that shows you, where the shockwave is sitting. So this is a, so under special conditions of weather the water condenses you can see such phenomena ok.

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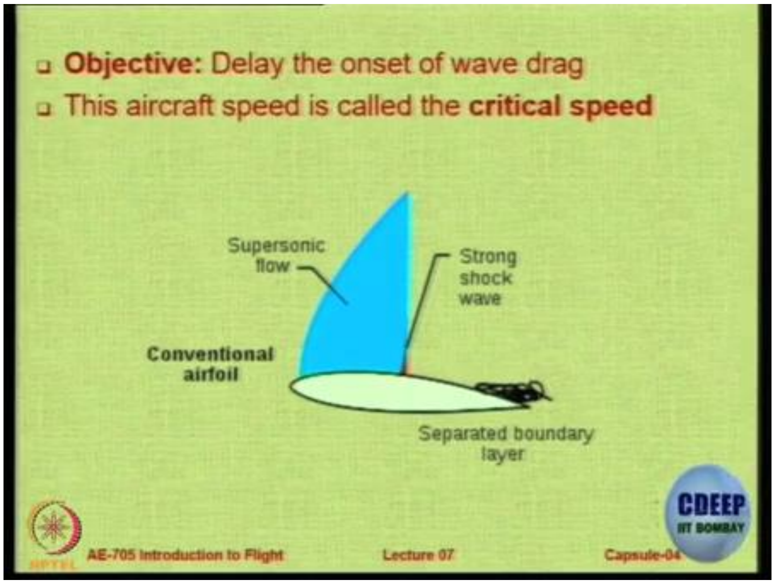

So the purpose of a supercritical airfoil is to delay the onset of the wave drag because there will be a very strong shock at that so we want to delay it. This particular speed at which you start getting these High drags.

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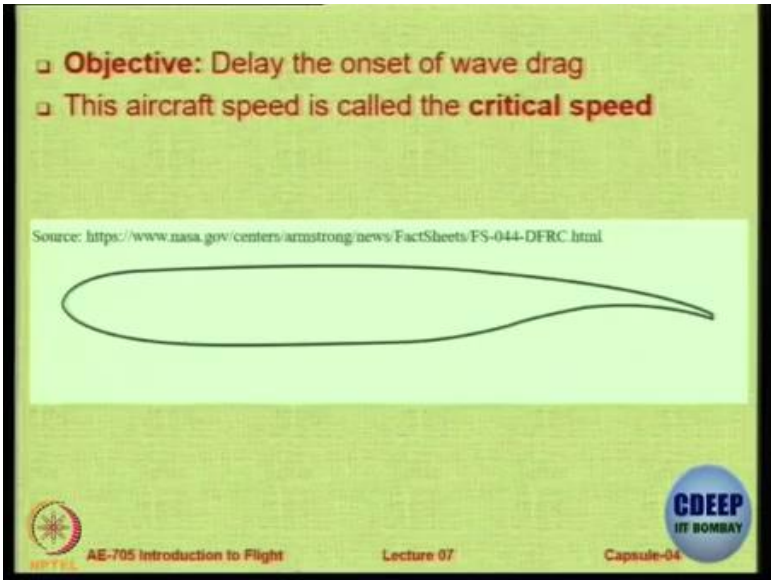

So there are two speeds that there is a critical mach number and then there is a drag-divergence Mach number. The critical Mach number is the free stream Mach number at which the sonic conditions are first seen onto the wing anywhere. And just behind that or just slightly more than that is the drag-divergence Mach number because, the drag will suddenly increase because of the presence of the shockwave. So to delay this, so I want to fly faster and faster without encountering sonic conditions. So for that, the airfoils are called as the supercritical airfoils and you can see the feature of these airfoils ok, they have a flat upper surface, they have a rounded leading edge and they have a reflex on the back, ok.

There is a large leading edge radius, there is a high cambered aft section and there is a flat upper section. These are the three features of supercritical airfoils. And so again in the tutorial I will show you how this curvature leads to pushing of the sonic conditions, so it is the flat upper surface that does the magic basically

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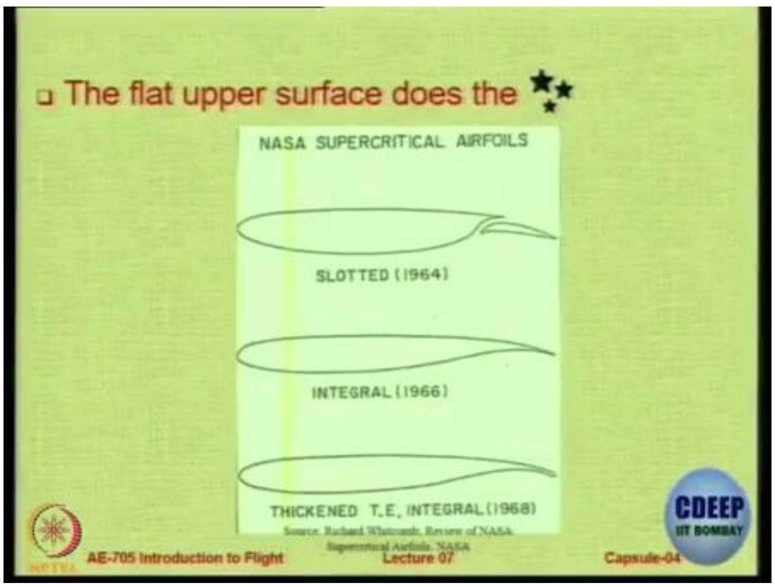

So many of these airfoils have been designed by NASA, so you can see slotted, integral, thickened trailing edge all kinds of airfoils are available for this application. And the main person behind this particular airfoil is a scientist called as Richard Whitcomb. So Richard Whitcomb is the person who actually came about the supercritical airfoil and essentially how they work.

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Now let us look at some airfoils which are even for lower speed lower than low Reynolds number. So now the question is, what are the applications? Where will you have airfoils on aircraft for very low speed, even lower than what we have seen so far. One would be UAVs Unmanned Aerial Vehicles, we have seen that line airfoils for that purpose, ok. So these are called as (VLS) airfoils very low speed airfoils.

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So, you want to provide lift but the speeds are very low, so these are very common in the modern aircraft which are solar powered aircraft because we would like to have ability to fly with least possible ambient power because it depends on solar power.

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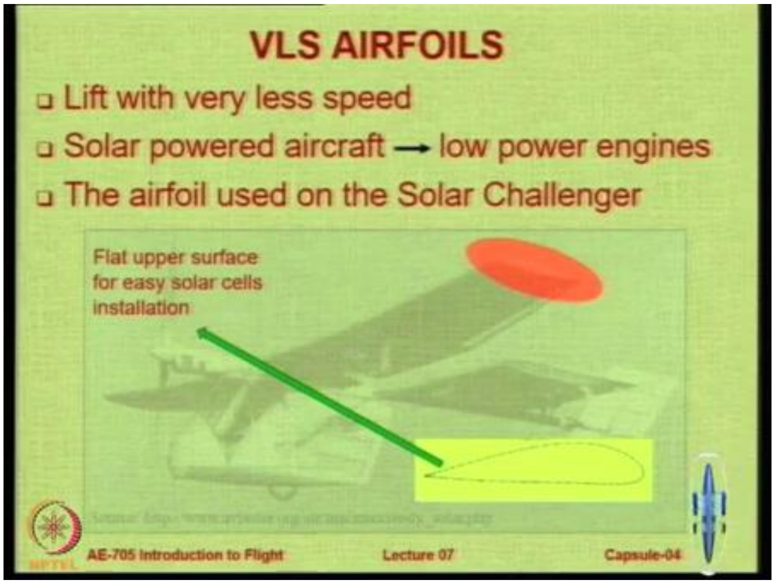

So one example is a solar challenger a recent aircraft and the airfoils used in a solar challenger, they have a flat surface on the top so that you can mount the solar cells nicely and the solar cells work very well when they are flat because of the incipient radiation. So they have a flattish bottom surface, a flattish top surface and some curvature in the front.

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So first they started using this laminar flow airfoils, but the recent example is this aircraft called solar impulse. How many of you know about this aircraft solar impulse? So I have a very interesting video, a short video with which we will probably very soon we are going to stop this class. It is an amazing video which shows the working of solar impulse, an aircraft with a wingspan larger than Boeing 747 but 25 pounds of weight.

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Video : 72 meters long covered in solar cells, solar impulse to fly day and night. This is the Solar wing, an extraordinary flight calls for an extraordinary wings to be built, wider than a Boeing 747 Solar Impulse too has a wingspan of 72 meters, an additional 9 meters from the prototype aircraft.

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In total over 17000 solar cells across the wing, stabilizer and fuselage providing the power for Solar Impulse to fly day and night with no fuel where it has aerodynamic skin across the extensively such a large wing require intelligent design to make it as large and strong as possible. Swiss company’s decision is not used to build hypothermia performance with carbon fiber says America's Cup with blades to the Sonoran swimming. Developed in carbon fiber weighs just 90 grams per square meter.

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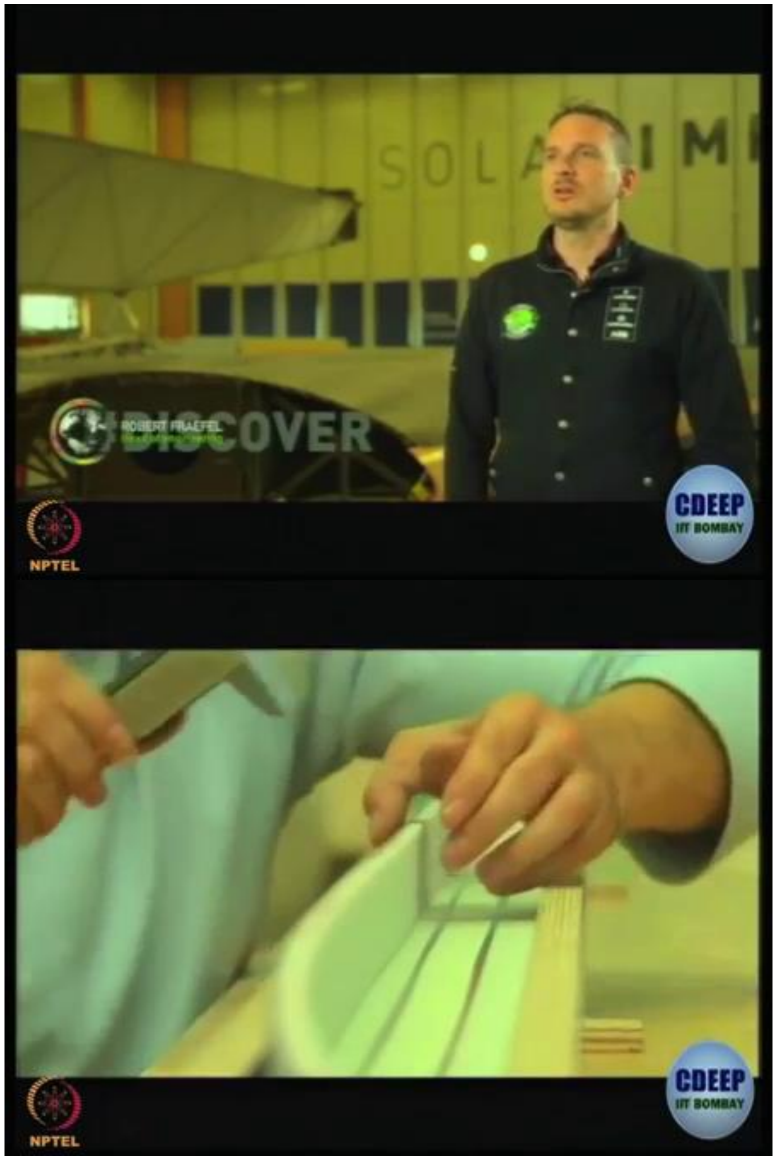

So, the most challenging time we had in the wing construction was the same flow we have the first ferryboat in question. It was a bit technical challenge but also a challenge for the team because we had put quite a lot of efforts to build the airplane.

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We have a construction of main spar in the menalist on both sides of it. So I left sails so I have never seen a similar construction like that and it has to be very light and it is very light and very satisfying.

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The wingspan is the carbon structure that runs from the center of the entire wing. A honeycomb structure developed is sandwiched between carbon fiber layers providing the strength required to handle.

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Attached to the wingspan carbon fiber ribs spaced at 50 centimeter intervals this gives the wing its shape without having excess mounts. The underside of the wing is covered in a flexible fabric that is land on each wing using crunch mounts blue. A thin solar skin made of the solar cells that powers solar covers the top of the wing. To ensure good adhesion a huge possible oven heated to 70 degrees Celsius is used to change the entire wing.

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The wing is amazingly large but amazingly light as well, so as a single part of plane is actually moving the wind so we should put two people on every side of the wing to hold it. You can hang roughly two people on each hanging mast under the wing that is a backward and forward about only 25 kg of weight which is very light.

Professor: So can you imagine a wing which is 72 meters in span. and the total weight is 25 kilograms. Total weight of the wing is 25 kilograms. Really an amazing structure.

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 the aircraft but fight incredibly. Incredibly the wing is designed to be embolted from the fuselage and split into three sections for transport.   The process in which it is loaded onto the hold of a cargo launch pad Boeing 747-8, the largest of these sections is 24 meters long it weighs only 350 kilograms. Of the lower is the horizontal stabilizer a much shorter way. It is also covered in the solar skin.

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At 14.4 meters the stabilizer still larger than many heavy aircraft meaning the length of it is that gives the plane pitch control. The main way has a surface area of 271 square meters, length of the tennis court. Its massive area gives it the ability from ground to the sky ascending at a minimum of 23 meters per minute, with a gliding ratio of 1 to 32.

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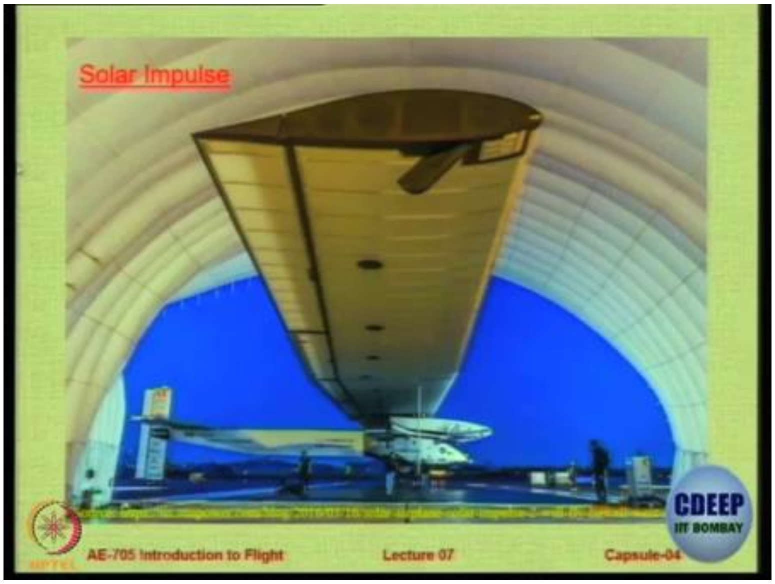

Professor: So the L by D max is 32 and the L by D Max off a Boeing 747 is only 19, ok. So for such very special applications you do need special airfoils so therefore used here was very-very special, ok.

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Very quickly let us move on to Para foils or airfoil which gets inflated with air. This is for a ram air parachute so they have a cut in the front and they have a proper shape on the back and typically they are around 18 percent thick. And as you bring it in the Indian wind, the pockets get filled up and it acquire a particular shape or a parafolic shape.

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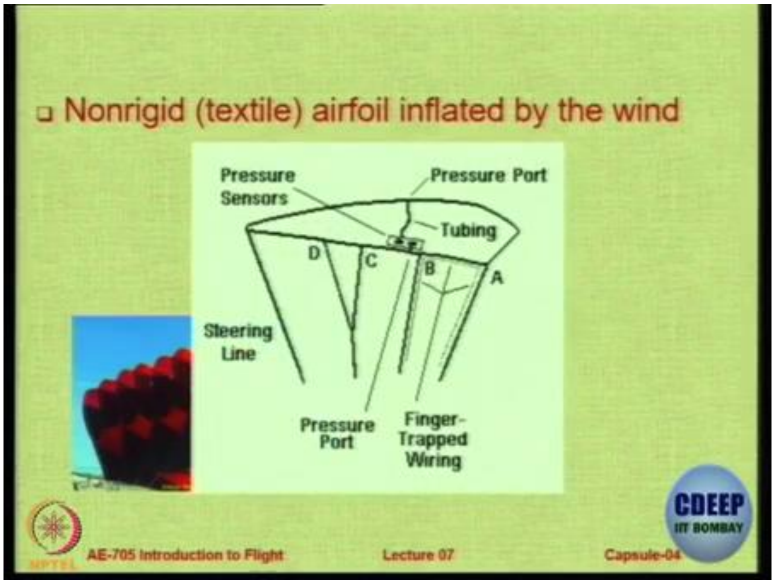

So this is a non-rigid textile profile which is wind inflated right.

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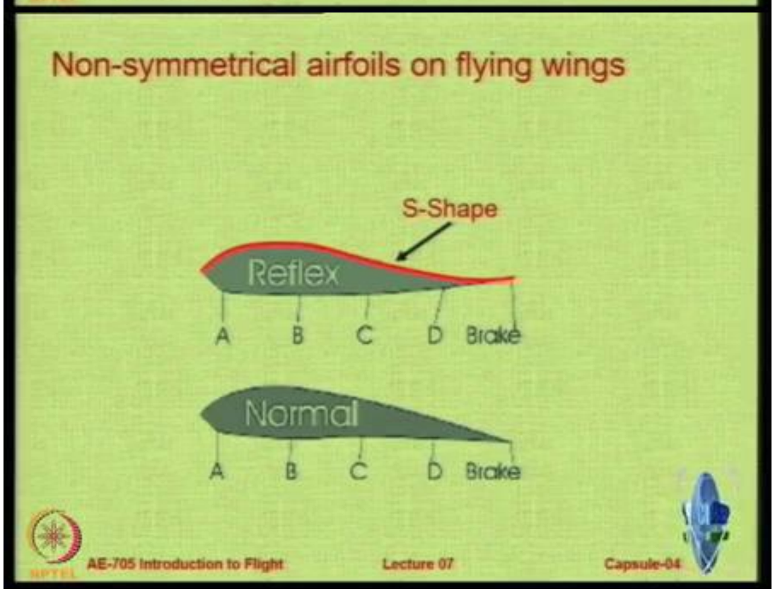

And then you have reflex airfoils. These are the airfoils used on flying wings so there is no tail here to give the stability so the airfoil itself has to have a reflex on the back to provide the moment so that so the top will be S shaped and they will be a lifted off.

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Finally we go back to the most basic airfoil which is the symmetric airfoil that means the chord line and the camber line are matching. There are some aircraft incidentally which fly with these kinds of airfoils.

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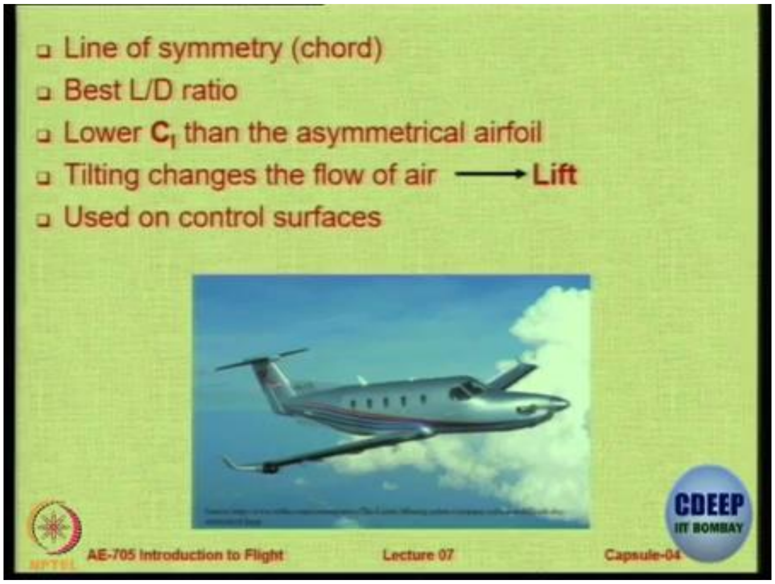

For example, you can see NACA 0012 it is a symmetric airfoil and they are used on aircraft but mostly they are used for they are mostly used for actually control surfaces because there you need to have equal force on both sides.

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But there are also some airfoils that are inverted. What is this inverted airfoil?

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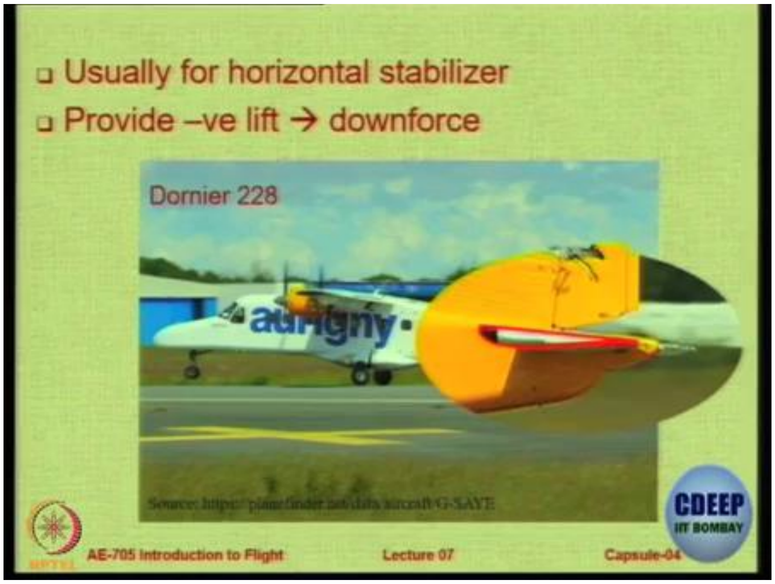

So basically if you look at a stabilizer, you normally want to have down force, so what do you do is you mount the airfoil upside down. So the top surface is flat and the bottom has a curvature so that you have an airfoil mounted upside down therefore under all conditions it will give a down force except when you give it an angle ok so that is all. In the next class we are going to look at part two of this particular capsule in which we will look at the mechanism used for the generation of lift and also to calculate the CP and the CL values, ok. So, the next class is about lift generation and many of the myths will be broken in that about how lift is generated.