Introduction to Flight
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Lecture Number 05.5
Lift Generation by Wings: Part I

This is the 8th lecture which happens to be the second of capsule number 4. And today our focus will be on determining how airplanes really fly, by fly I mean essentially how lift is generated. We will look at some theories which have been proposed for generation of lift and then we will try to proceed on to a term called lift coefficient and then other coefficients which are commonly used in aeronautics.

The material for this particular lecture has been prepared by an undergraduate student of our department named Kartik Mahesh who underwent this course AE152 last semester. So I am thankful to him for helping me out during this summer to prepare this material. Our first question tonight is how do wings generate lift and to answer that let us look at some theories which have been proposed.

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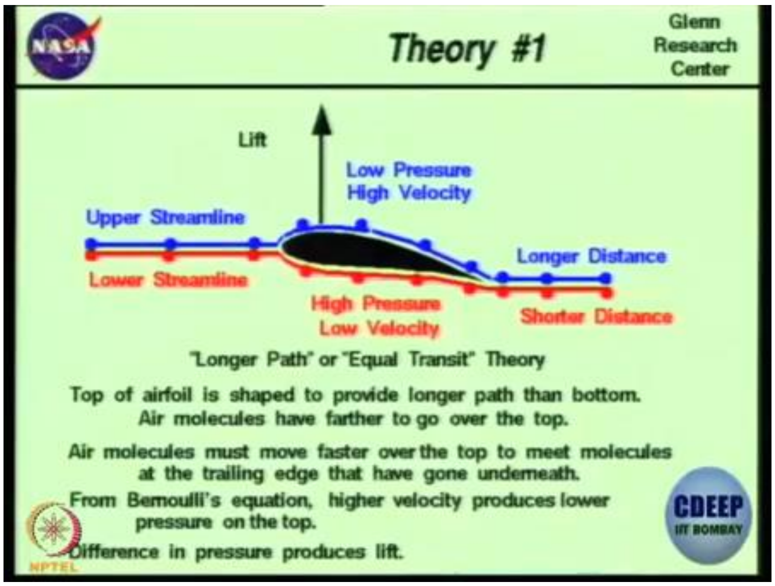

The first theory is theory number one from the Glenn Research Center of NASA. As per this theory lift is generated because of curvature. Curvature of a cross section called as aerofoil about which we studied last time. So this theory states that two particles one along the blue stream line or the upper stream line and the other particle along the red or the lower stream line,

they are coming in with the ambient wind which is supposed to have the same velocity and the shape of the airfoil is such that the top side has more curvature than the bottom side or as in this case the airfoil is placed at a slight angle.

Therefore the path which the particle along the blue stream line has to travel is slightly longer than the path that is taken by the particle below the stream line. As per this theory the two particles which come in the front at any given point of time, they have to meet at the back because there cannot be any mass loss. There cannot be any momentum flux loss also. So the two particles which are ahead of the airfoil they have to meet at the backside. So this is called as the Equal transit or a longer path theory.

The particle on the top side because it travels at a faster rate than the particle on the bottom therefore it should have a higher velocity. And as for Bernoulli's principle it is incompressible flow which can be assumed for this case because we are assuming loss no shock etc are present then the higher velocity produces lower pressure on the top and the difference produces lift. This is one theory.

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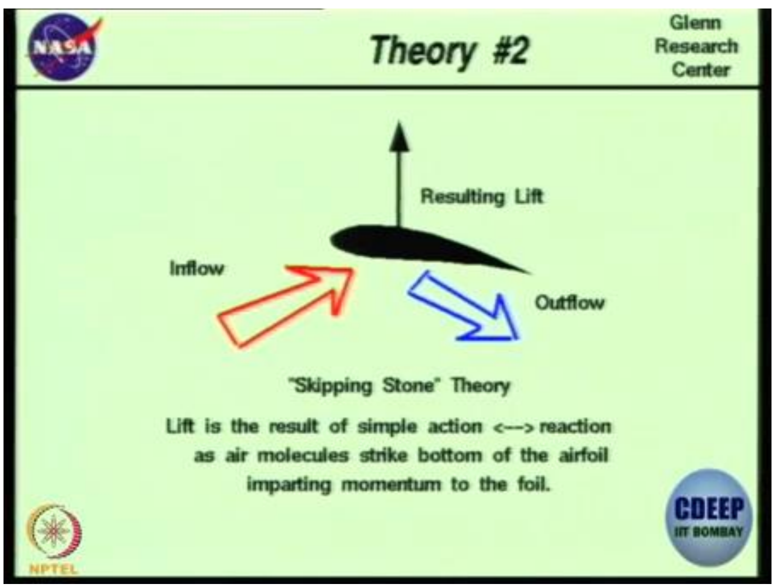

Number two theory is called the skipping stone theory or also called as a bullet firing theory.

As per this theory the wing shown here has a cross section of the airfoil is basically an obstruction to oncoming flow. So there is some air which is hitting the bottom of this particular airfoil or wing, and because it hits it transfers its momentum and that momentum is transferred back through Newton's third law as a reaction.

So as per this theory lift is a result of a simple action equal and opposite to reaction. Air molecules strike the bottom of the airfoil and imparting momentum to the foil as a result there is a upward force and hence we have the lift.

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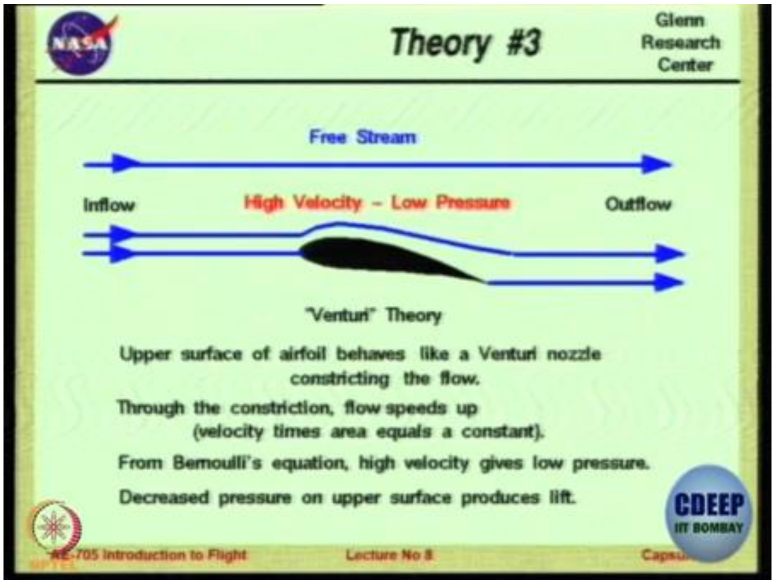

There is also a term theory which is called as a Venturi theory. In the Venturi theory we see that the fluid particles going above the airfoil go undisturbed and because of the presence of the body, the shape of the body is such that the upper surface behaves like a Venturi. Venturi means an continuously changing area with a reduction in area and then increase in area. So since the upper surface of the airfoil behaves like a Venturi, nozzle the flow is constructed. And because the inflow and outflow masses the flow rates have to be the same. If you give a smaller area for the air to go through it is going to accelerate again Bernoulli’s principle is applied. The place where we have higher speed you have lower pressure and therefore you get an upward flow. So these are the three theories which are proposed by NASA Glenn Research Center to explain lift.

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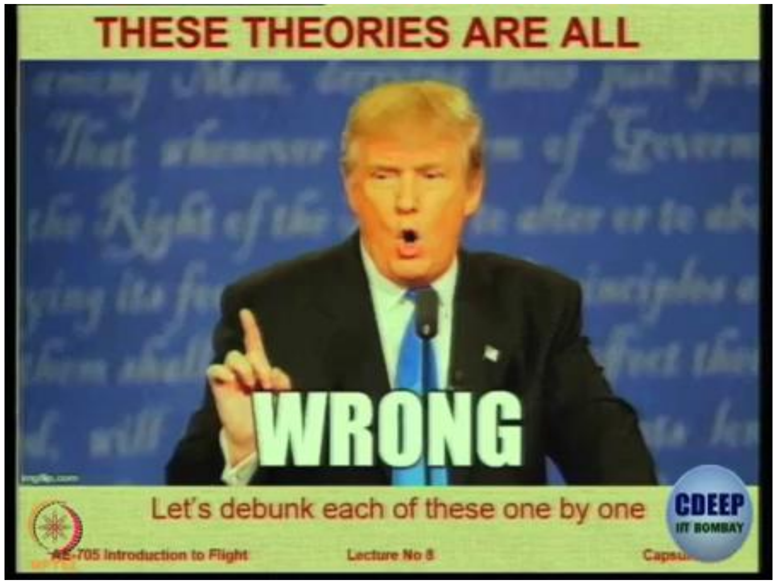

And there is only one issue, the issue is that all these theories are wrong, they are incorrect. Okay so in fact I have done a little bit of mischief here. If you go to the NASA Glen Research page, they are called as incorrect theory one, incorrect theory two and incorrect theory three. I have actually used Microsoft Paint to remove that incorrect thing because many textbooks, even pilot's operating manuals, so many encyclopedia they propose any one or a combination of these theories, but they are all wrong they are not true. What they propose is not wrong. The air above the airfoil does flow faster than the air below that is a fact.

But the reason given and hence application of Bernoulli's principal is wrong. So we will look at what is wrong with them one by one. Okay so let us debunk each of these theories one by one. To start with let us look at the Equal Time Theory. So can someone tell me what do you think is wrong with the equal time theory. Should I show you again the theory? Okay let me just show you the theory once again.

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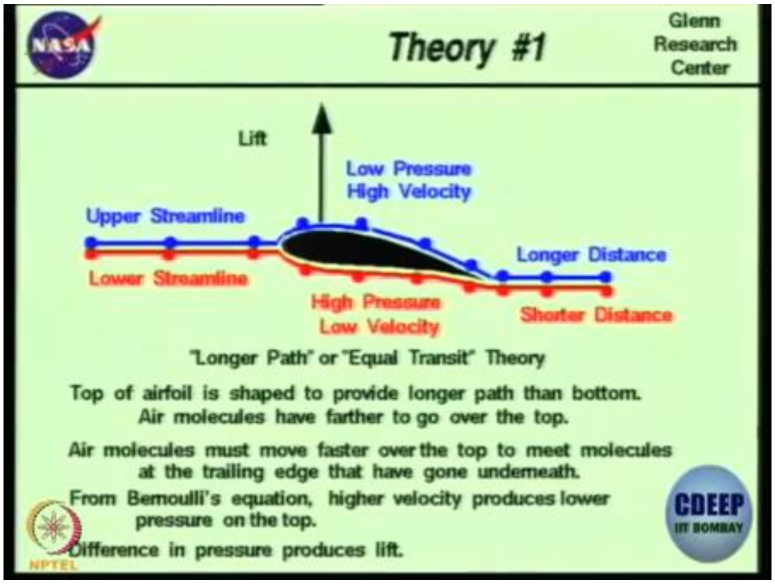

So tell me what is wrong with this theory. Now you know it is wrong, so in the multiple choice question you cannot say all answer are right, all three are wrong. But now you need to explain what is wrong. Okay So let us look one by one. Yes.

Student: My name is Vinay.

Professor: Yes.

Student: And it has been shown through observation that the same streamline passing over the top and the bottom never reach the trailing edge at the same time.

Professor: Okay let me interrupt you. You cannot say same streamline top and bottom, you cannot flow across streamlines. That is a first fundamental part about the streamline. I know what you are saying, you are saying that observations and experiments have shown that particles along the blue and red streamlines in this figure do not meet at the end right that is true.

So if they do not meet at the end does that debunk the theory? The theory only says that there is a lower pressure on the top and higher on the bottom because in the same time the particles which meet at the front of the airfoil have to reach at the back end. And you have said that based on some experiments and observations I will show you some experiments also. I agree that is a good observation, but how does that debunk the theory. Yes.

Student: My name is Aaishwarya and here it is written that from Bernoulli's equation because we know that the flow above airfoil has some velocity gradient and hence have some rotation. So we cannot apply Bernoulli's theorem in rotational flow and viscous flow.

Professor: Okay. We cannot apply Bernoulli's theorem in rotational flow and viscous flow and also we cannot apply Bernoulli's principle across two stream lines.

Student: Yes sir.

Okay let us say so that I agree. Okay so therefore this particular theory which is very popular is wrong. What is wrong is not the phenomena of higher speed at upper surface, lower pressure at upper surface but what is wrong is the explanation.

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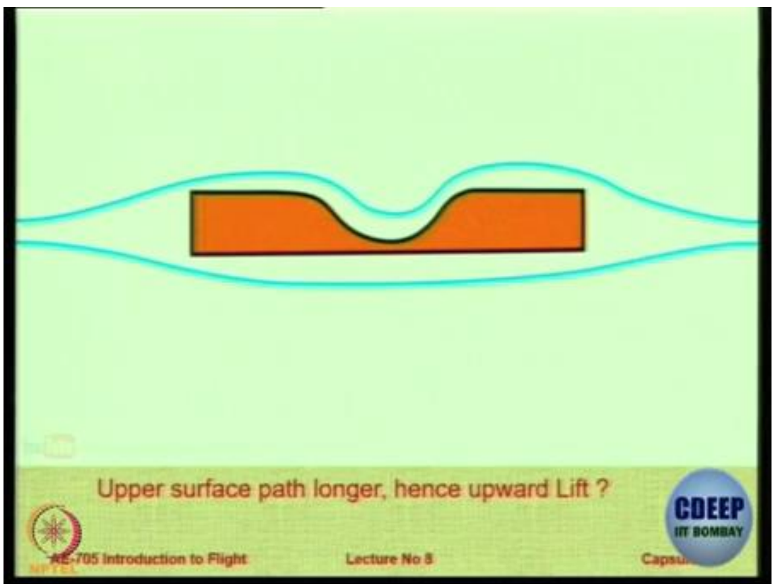

Now if the equal time theory was correct then what would happen to a body like this. It will generate some lift in which direction downward our upward? But do you think if I put a particle like this in flow I will get lift so let us have a look.

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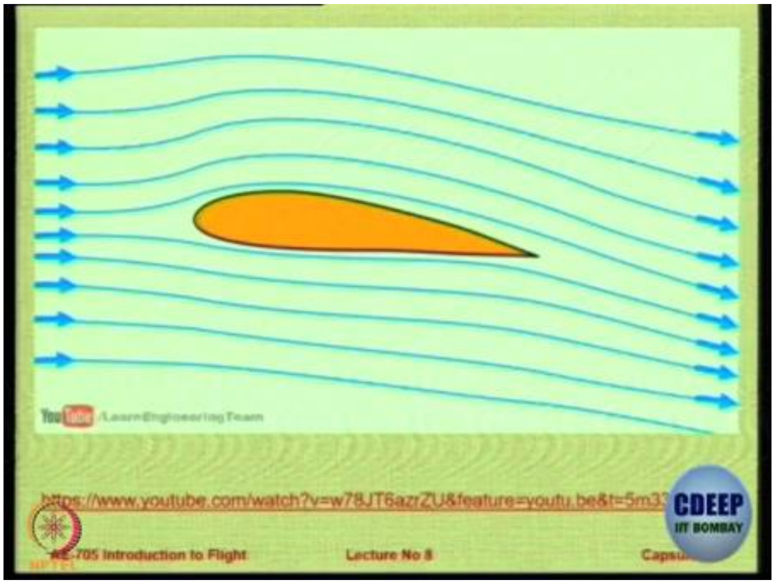

Video: If you find that others still support the equal time argument ask them to generate lift from this surface. If they are too lazy to do so we will do it for them.

Professor: Some experiment.

So they are keeping this particular shape particle in a string so this particular string is basically representing the flow direction. Okay there is a fan which is blowing air because of that

For this such geometry equal time argument and Newton's Third Law analysis predicts direction of the lift in different ways.

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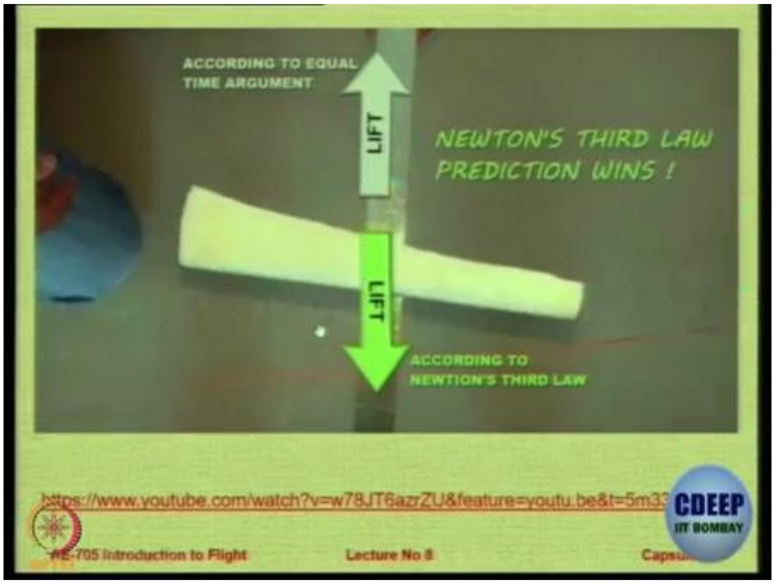

Here you can see the string is bending.

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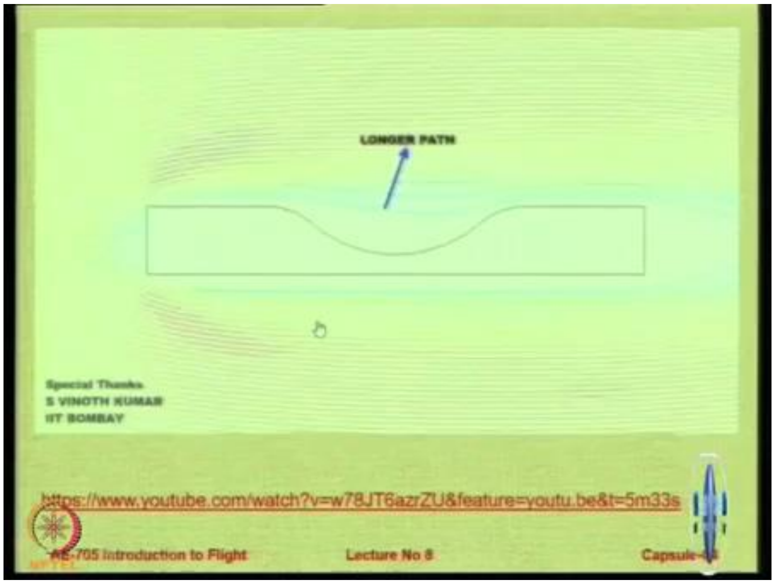

We have even conducted a high quality CFD analysis to prove the same thing.

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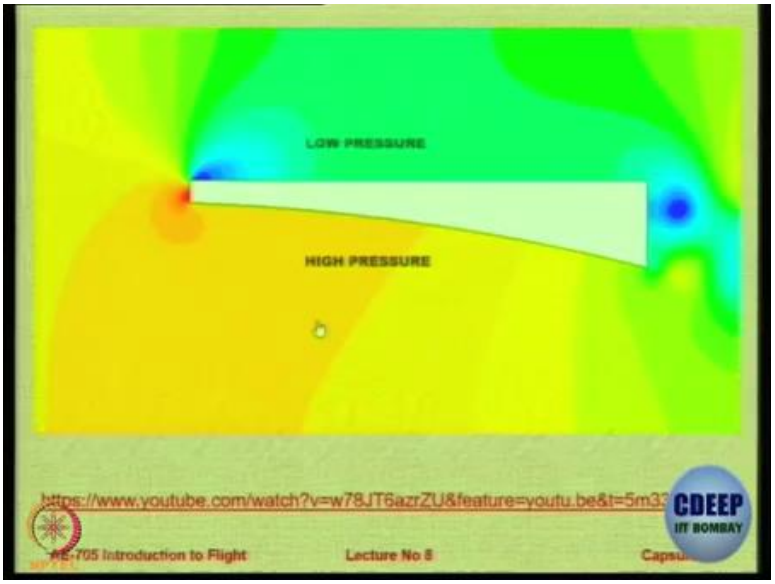

If you understand what we have discussed so far, use one…

Professor: Okay so basically equal time theory is can be debunked because it is not going to work okay. One more example of equal time theory is this.

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So if an aircraft is flying upside down inverted then how can you get lift by equal time theory, the lift in this case will be downwards. And the lift is downward how can it maintain level flight. It will keep on going down. Okay so interestingly even though it is flying inverted the lift is still upwards and it is overcoming the weight and that cannot be explained by equal time theory because if the plane can fly level inverted it cannot fly level in normal condition and vice versa so therefore that is not true. One more example is shown in this video.

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Video: It is often said the lift in the wing is generated because the flow moving over the top surface has a longer distance to travel and therefore needs to go faster. This common explanation is actually wrong. This video shows that the air on the top doesn't go faster but it doesn't reach the end of the wing at the same time as the air on the bottom. Here we use smoke to visualize the streamlines random and therefore we can compress the smoke by briefly interrupting the supply.

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This gives us lines that travel through the flow as we can see here. And if you now slow the video down you can follow those lines. And that gives you an idea of how fast the flow is in different parts of the airflow.

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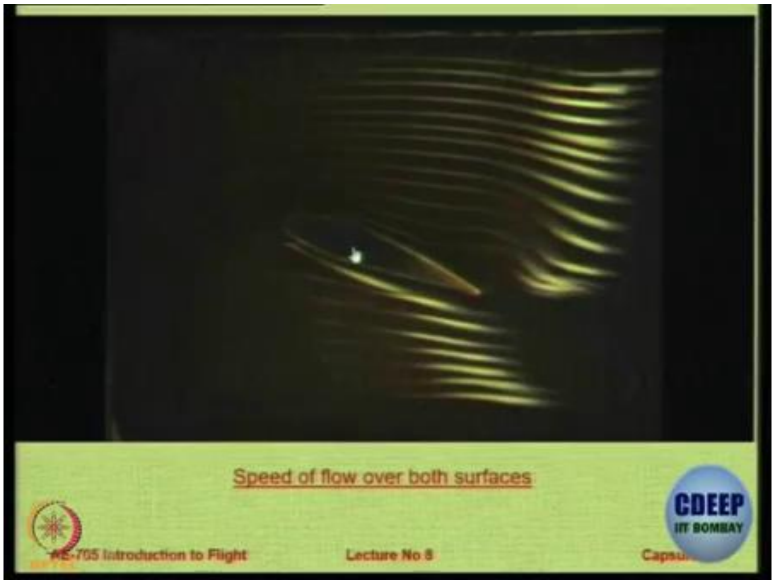

Here you can see, it speeds up as it approaches the air foil and it moves fast over the top compared to the bottom. You can see that it reaches the end on the upper surface much earlier than it does in the lower surface. In fact, by the time it reaches the end and the lower surface the flow is already gone a long way past in the upper surface. This shows very clearly that the flow does not take the same amount of time to reach the end of the wing.

Professor: So this is basically a proof of what our friend mentioned. That experiments have shown that the flow in the upper surface definitely moves faster than that on the bottom surface. On that there is no argument. But the argument is on the justification for that particular theory. Okay.

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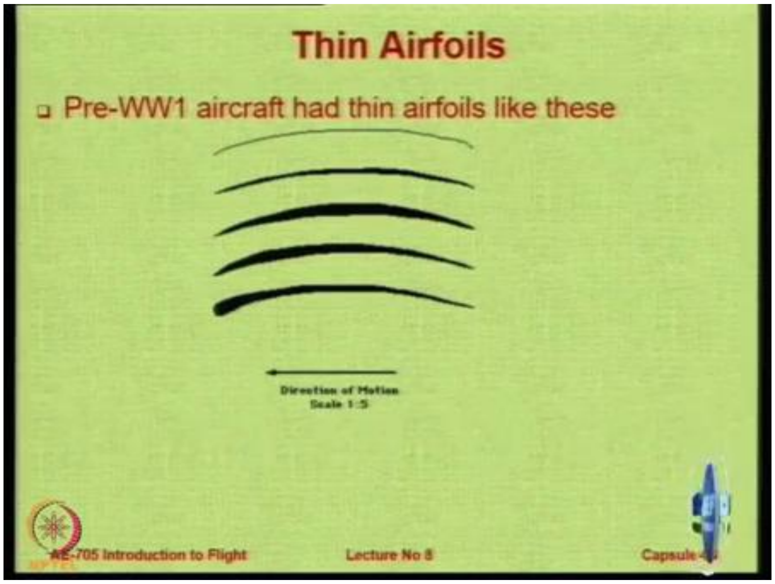

Another example which will completely debunk the equal transit theories thin airfoils like these which were used. Now if the equal time theory is correct then such airfoils can never produce lift because there is nothing like now more curvature on top and less on the bottom. The curvature is same on both top and bottom but they do produce lift. In fact Wright brothers flew the aircraft for the first time using an airfoil like this so they cannot be wrong, they did produce lift. So in other words this is not a correct theory. Okay let us proceed to another example.

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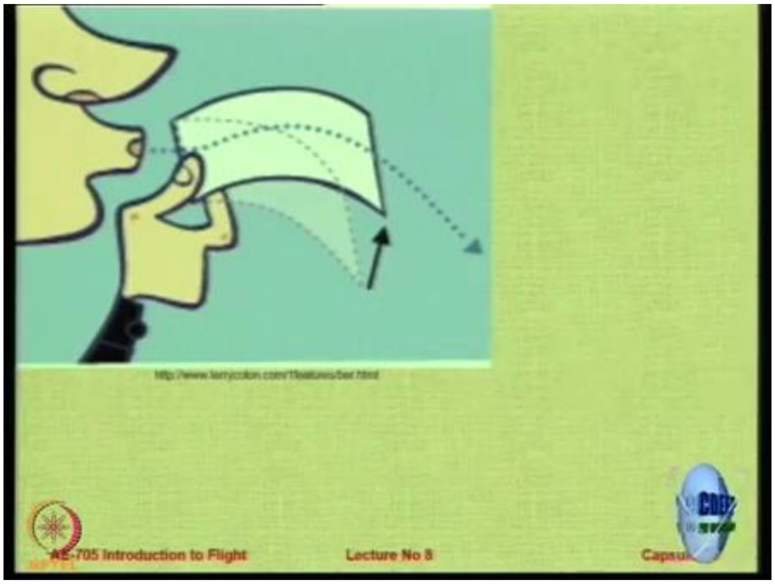

So for this I am going to use this piece of paper as an example okay. So here is a piece of paper, I keep it horizontally in front of me and I blow air on it okay. Look at what happens to this piece of paper. Actually I'm putting pressure on the paper it should go down but it is going up. Can you see?

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So even though the flow of air is on the paper and normally the momentum from my breathe should push it down like this. But when I blow it, it is actually floating up okay so why is it happening? This is happening because the fast moving air across the paper actually it creates a lower pressure on the upper surface.

Is it because Bernoulli's principle? No it is not. This is not Bernoulli's principle, this is Coanda effect. So a large number of sources in literature, on YouTube and even at many other places explain working of the aircraft wing generating lift using this example and then they say Bernoulli's principle as I blow air on top of it, the speed is large so pressure is low and hence it lifts up, that is not the reason.

The explanation for this particular phenomena is coming from the Coanda effect. So Bernoulli's versus Coanda conundrum is very common. Similarly if I place a spoon with a curved surface in a stream of water at a reasonably slow speed so that I do not create too much turbulence flow you will notice that the water follows the curvature. And more important there is a force acting on the spoon in the direction opposite to curvature. So when the fluid, in this case water flows along the curved surface such as the fluid flows.

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Notice I was always keeping it like this so that it remains a little bit curved. If I make it stiff. Okay and if I do not allow curvature it may not lift up. Let me try difficult but it will not. It will not lift up. It will lift up only if I allow it to have curvature. Okay so when I have curvature and when I make the air flow along the curvature, a force will act opposite or perpendicular to the direction of curvature. And that force we make the spoon move towards this side and this is very important.

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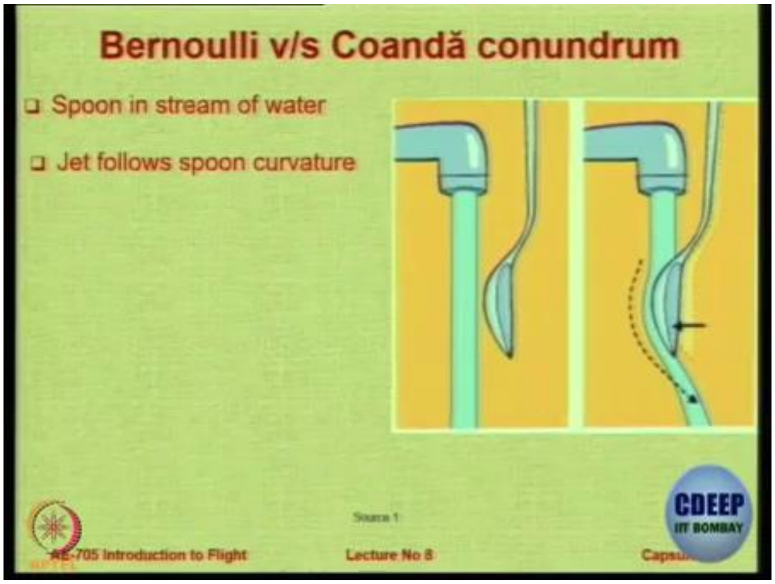

So the jet of the water follows the spoon curvature and the spoon feels a force opposite to the deflection. Okay that is more important.

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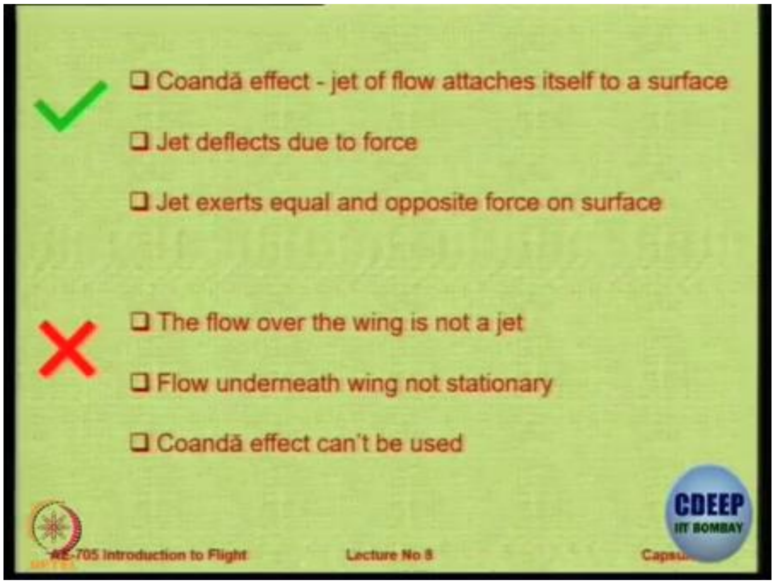

So certain things about this particular theory are right. Number one; Coanda effect which says that a jet of flow attaches itself to a surface which is curved and also the jet deflects due to a force. And also because the jet deflects towards one side there will be an equal and opposite force on the other side. So these three points are correct about this explanation, but there are also three wrong explanations. One is the flow past of wing is not a jet because there is flow above it there is flow below it and it need not be only at a very high speed. It can be at a reasonable speed or low speed also but it is not a jet. It is not that only on one side you have a flow.

It is a uniform jet so the flow along a airfoil actually like this. It is above and below both. Second point is, the flow underneath the wing does not remain stationary it also moves. And thirdly you cannot use Coanda effect here because it is not always having curvature. Even a flat plate at some angle can give you a lift. So let us see. Yeah.

Professor: The Equal transition time theory was proposed by some people for attempting to give a simple explanation to school kids and two other people general public about how lift is generated. It is very convenient to say there is something called Bernoulli's principle in which when there is a velocity increase there is a pressure decrease.

And you know so it was not proposed by any scientific argument. It was proposed simply to go for these are called hand waving arguments. So you try to just convince somebody by giving a general argument which are wrong. So the repercussions of the argument or the justification that there is low pressure that the upper surface fluids speed is faster is correct but the reasoning is wrong that is why we are debunking the theory.

Student: Sir my name is Samir, my doubt is that we are saying that we cannot apply Bernoulli's principle for two different streamlines. But the value of, $P + \frac{1}{2}\rho V^2 + \rho gh$, is almost equal for both of them.

Professor: No no

$$P_1 + \rho_1 V_1^2 + Z_1 = C_1$$

and

$$P_2 + \rho_2 V_2^2 + Z_2 = C_2$$

so along the stream line the constant C one remains the same, across streamlines you have two constants they are constants but not equal.

Student: Sir almost equal.

Professor: Almost is not a not acceptable in science.

Student: Sir means pressure is almost same in both of them. And the velocity of both of them are almost equal.

Professor: They are not equal just now I showed you.

Student: No, when they were attached before hitting the foil.

Professor: So when they approached the body, the velocities were almost the same. But when they went towards the end the velocities were different. So when the velocities were different the pressures cannot be the same. However, you cannot apply Bernoulli's across two streamlines because the two constants are different.

Scientifically you cannot apply Bernoulli's principle across two streamlines. If that is a case I can apply Bernoulli's principle at a streamline which is 1 kilometer above the airfoil 1 kilometer below the airfoil and I can say the two pressures are equal, I cannot. So you cannot say they are so near we can assume it to be constant no, along the streamline yes but across streamlines you cannot. You just cannot apply. So that is what I am saying. Do not apply a principle or a scientific tool wrongly to explain something simply that is why we are trying to debunk these theories. They are not scientifically correct. Okay Now Yes.

Student: My name is Aman. But in case of Bernoulli's theorem we can still write two different equations and manipulate them right above and below the airfoil.

Professor: You can. But then you will have not have the same constants.

Student: Yeah but initially the constant are same right so.

Professor: No, when you apply them at one particular point okay. Can you apply the principles exactly? Just think about it. As it is we have been told flow is not irrotational so you cannot apply Bernoulli's. As it is been told the flow is viscous so we cannot apply it. On top of that we cannot apply Bernoulli's across two streamlines so that is why let us not try to explain some phenomena by application of a principle in the wrong manner. There are simpler methods available which we will see just now.