Introduction to Flight
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Lecture No. 06.4
Introduction to Drag and Types of Drag

Welcome to lecture number 10 which is second lecture of capsule number 5. Today, we are going to look at drag and what efforts are made to reduce drag. In the last class we did look at methods to handle wave drag. So, our task today is to look at drag and its reduction. When we talk about drag, we first have to pay respect to Sir George Caley, who is widely considered to be the father of aeronautics.

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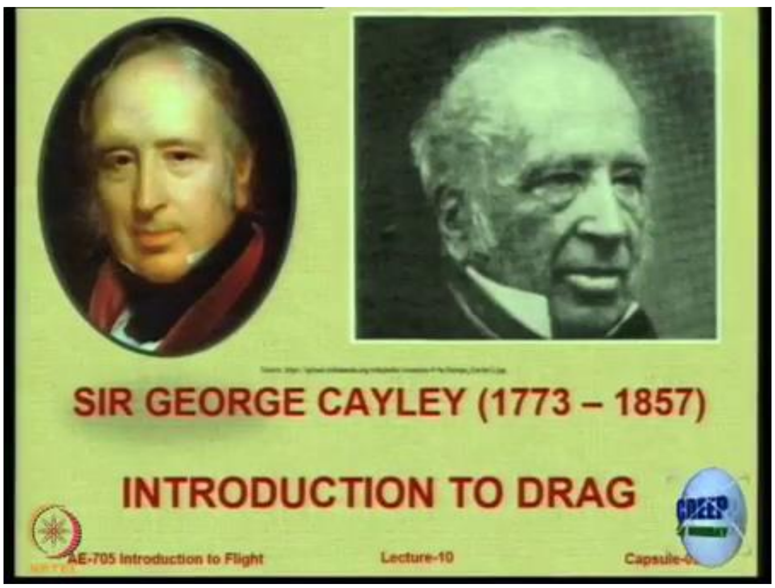

This is a portrait of Sir George Caley and this is the only available photograph, real photograph of Sir George Caley taken when he was approximately 80 years old.

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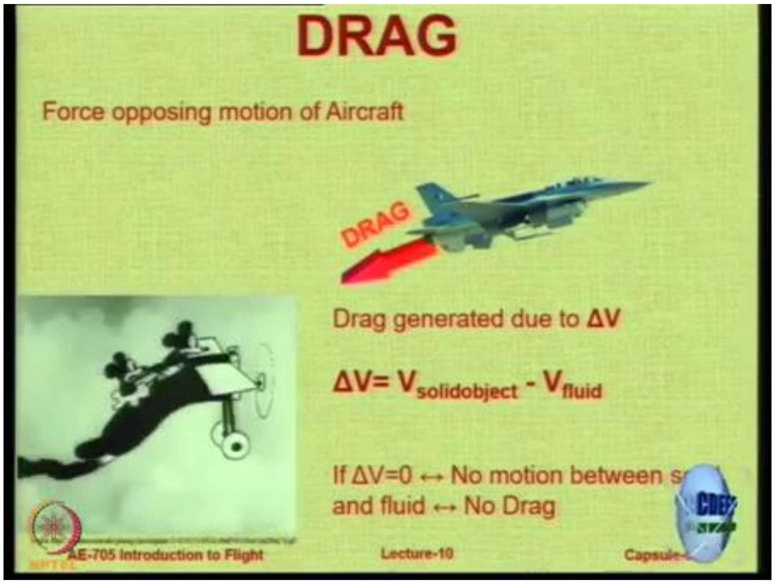

So, drag basically is a force that opposes the motion of the aircraft and it acts only when there is some relative motion between the aircraft and the ambient air. For delta V the relative velocity between the object and the fluid that is needed to create drag, and if there is no relative velocity or if there is no relative motion between the solid and the fluid then there will be no drag.

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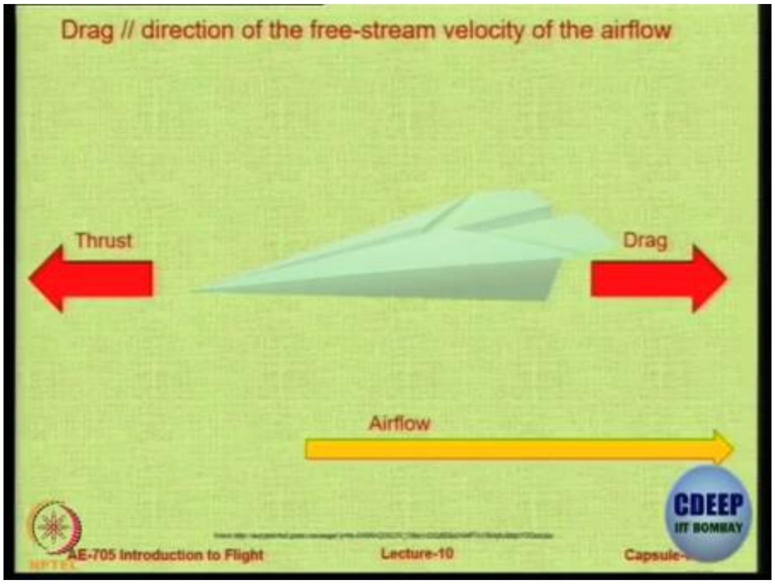

We are all familiar that when you have air flow or relative velocity you get a force and the force is basically the reaction acting on the body, a component of that which is parallel to the free stream direction is called as the drag and that is overcome in flight by providing the thrust force.

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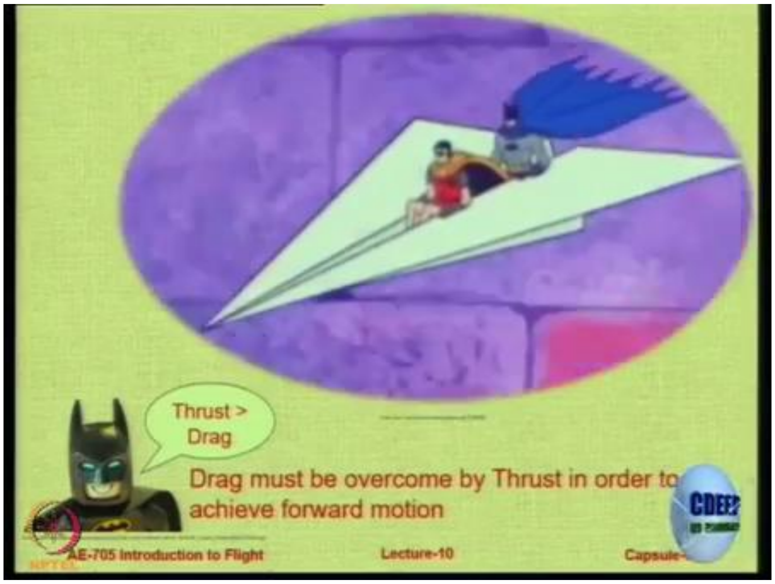

So, essentially we need to have thrust more than drag if you would like to have forward flight and for that we will look at a special presentation on power plant or engines after the mid semester. So, the question that many people want to know is, who was the first person to actually talk about drag or observe drag?

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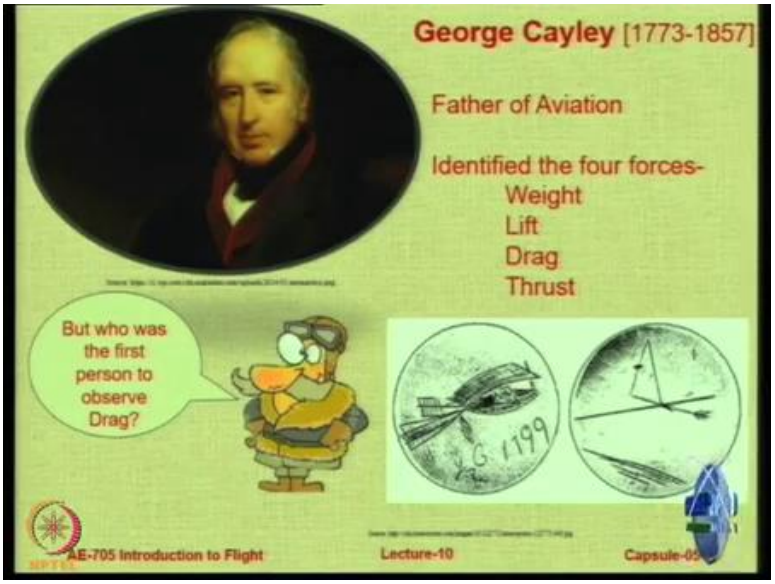

And none another than the father of aeronautics Sir George Caley, in fact, not only drag, he was the first person to talk about the four forces and the proof of this is in a silver coin that was edged in 1799. On one side of the coin was a sketch of Sir George Caley's gliders concept, on the backside was this nice diagram which shows the action of the forces on a flat plate. So, this is a first historical recorded sketch of the four forces acting on any flying body.

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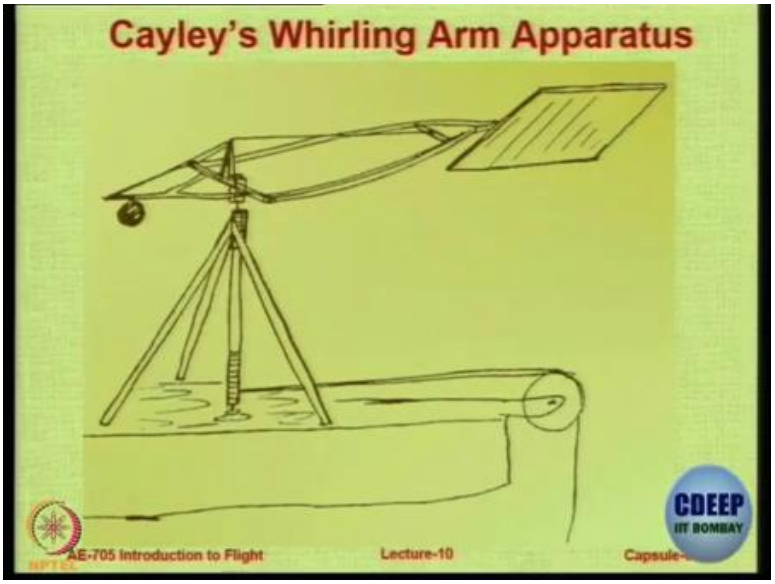

And he was a scientist who also did a lot of experiments. So, many years before Wright Brothers, actually Sir George Caley designed and fabricated this Whirling Arm Apparatus, which was used to calculate or look at the forces acting on the body, here is a small video clip of this apparatus. He is trying, this is a movie which was shot.

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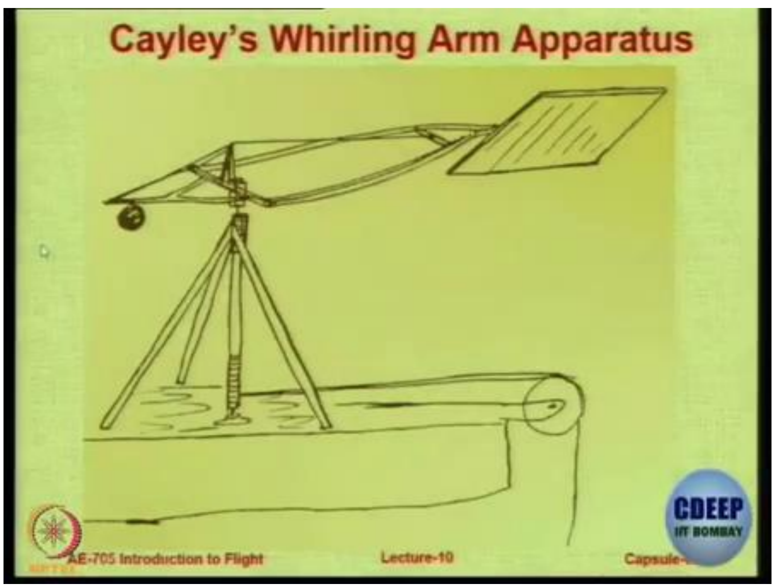

Professor: So, this is a pre curser to the wind tunnels called as the rotary arm or whirling arm apparatus. Such systems were used also to calculate the forces acting on airships and other bodies, ok.

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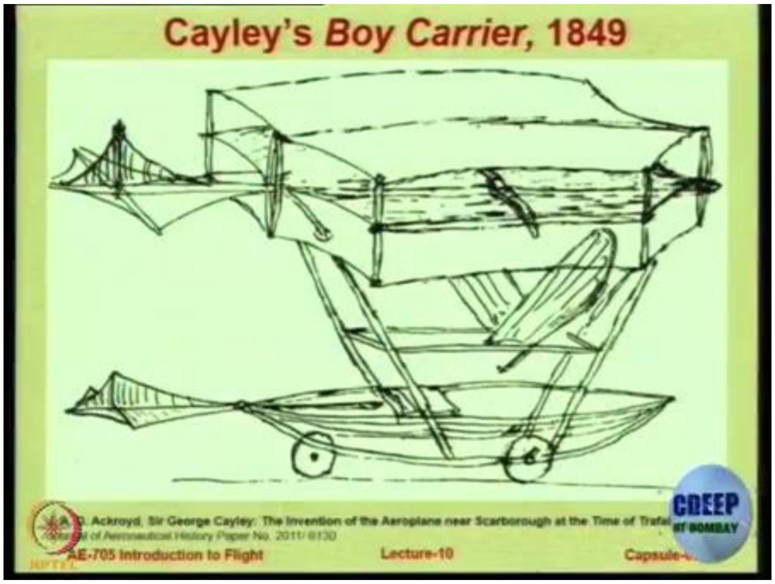

And many many years before Wright Brothers, actually Caley was able to a carry out a manned flight, but for that he designed the special aircraft called as a Boy Carrier. Because, the first ever pilot of manned aircraft was actually a 10 year old boy and this glider was designed to just accommodate a 10 year old person. There is a very interesting 50 page document on history of invention of airplane, and on Sir Caley, I am going to upload that on the MOODLE for self-learning.

That gives a detailed information about what all Sir George Caley has done. This picture has come from that particular document. But, he knew that if I attain flight using children or small boys, people will not take it seriously.

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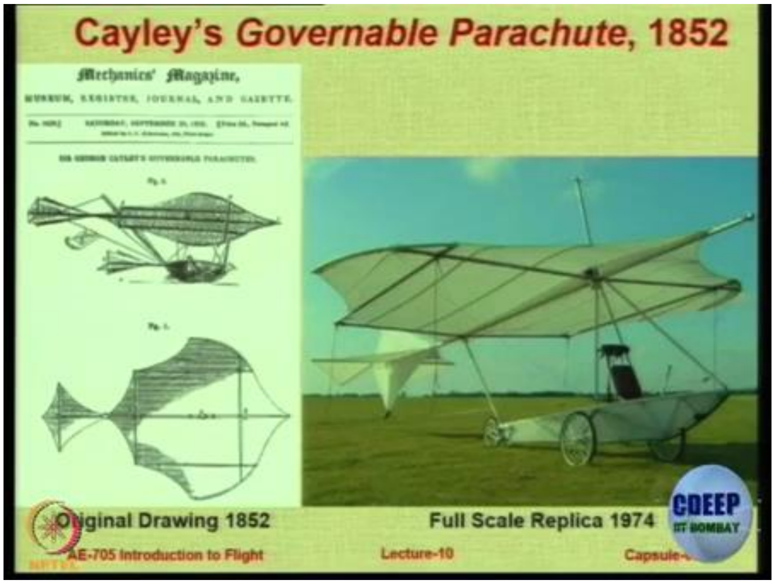

So, then he designed something called as Governable Parachute. That is a name given by him. So, on your left you see a photograph of or the design or the drawing of that, on your left you see the drawing of that particular aircraft in a mechanics magazine and on right you see a full scale replica which was been in approximately 1972, 1974 where the historical flight was re-inacted by a very brave pilot.

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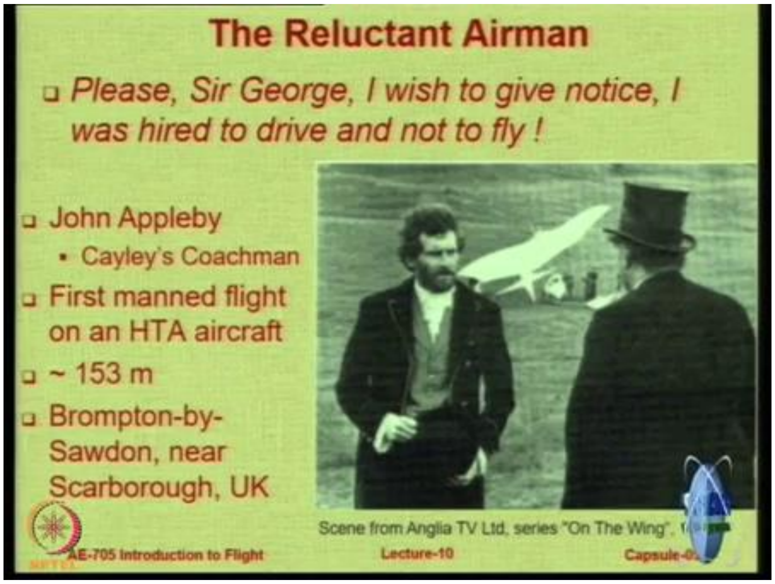

So, there is a very interesting story about who was the first pilot to fly. So, Sir George Caley was 79 years old when he designed this particular aircraft and he had recently hired a driver. So, he told his driver, why do not you fly my glider? So, the driver had to obey his master but he was literally scared. So, there was a successful flight, therefore the first person to fly on a manned aircraft unpowered but manned aircraft which is not a balloon or lighter than air was the coachman and just after the flight he resigned.

These are very classical words. He says "Sir, I was hired to drive not to fly." So, he resigned, his name is John Appleby, he was the coachman. He was 21 years old when he did this particular experiment. So, in history if you want to record the first human being other than that 10 year old child who flew on a glider which was heavier than air but unpowered was John Appleby. The first flight was about 153 meters and this is the location where it took place. This flight was re-inacted as I said in 1972 and in 1974 there was a television series which was shot in which this particular this scenes we taken from that particular video series.

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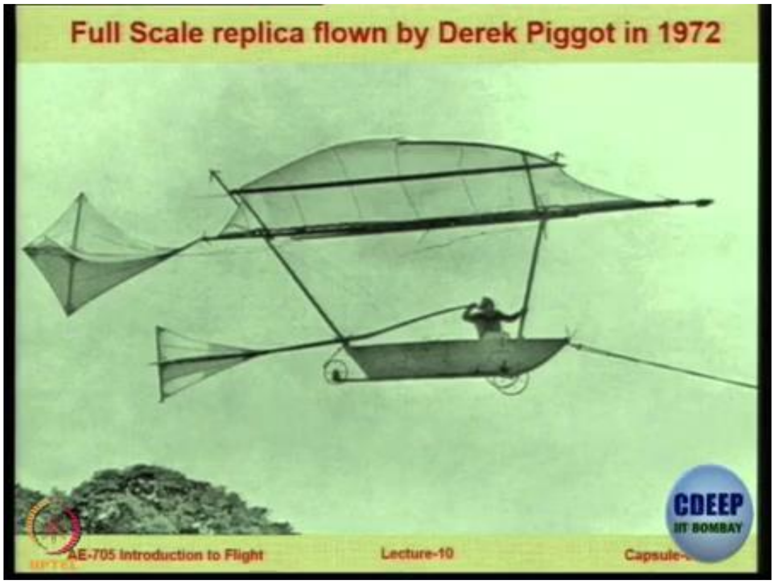

So, here is a picture of the full scale replica of this aircraft, it was flown by Derek Piggot by in 1972 noticed that the radar is hand operated. Now a day, radar is foot operated. But in this particular glider and there is a cable you can see which is attached because it's a glider there is no power plant so you launch it with a cable. So, it was a very successful flight. Ofcourse they did a slight design changes and what changes they did and why they did it is an interesting observation, which you should read that paper which I am going to upload.

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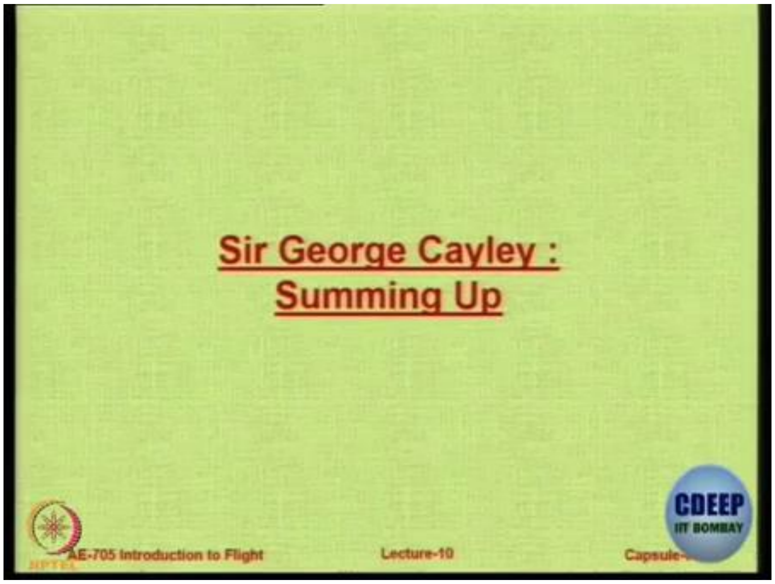

Alright, so this is just a small video clip in gyst, ok. Do not take it seriously but I really liked it. So, this small video clip sums up the contribution.

Video: 08:09

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Video: To get the wing aircraft that man was sir George Cayley. Silly French! I have no time for dirigibles. It is time for the fundamentals of flight I say! What, what, where? My butler flew a glider from here to there. The mechanics of flying, they are a must. Weight, lift, drag, Thrust! I need a lightweight engine but they think I am demented! Sir, it is the 1850's, they have not been invented. Caley's work ushered in the age of steam. From the1870's, lightweight steam engines, were being used for short test flights. And in the1890's, Samuel Langley achieved an unmanned flight of 1km.

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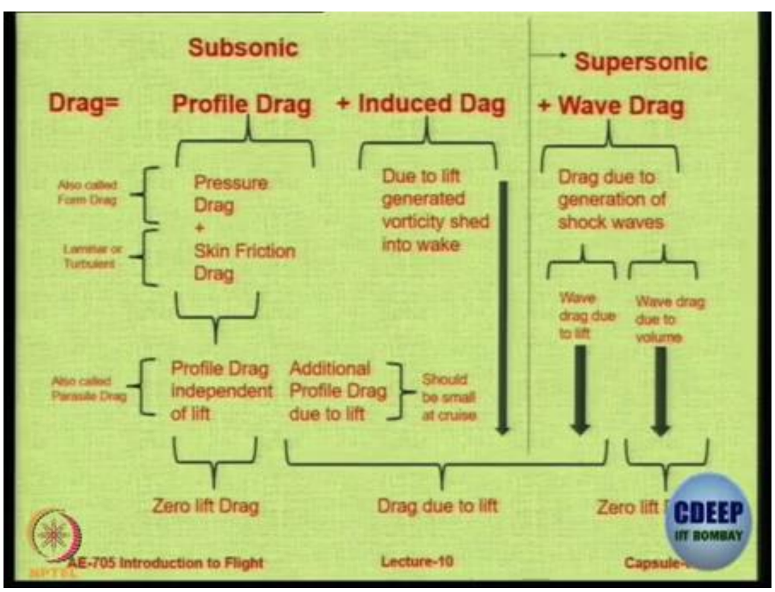

Professor: Ok, this is just for some fun. Ok, let us look at components of drag, break it down into small components. So, this is a very interesting slide and a lot of time was spent in making this slide, you will know why because you will see there are various components. So, let us first look at subsonic flow. Basically drag consists of the many components; the first component is profile drag. This is pressure drag, ok also called as Form Drag.

Because, it depends on or it is driven basically by the shape of the body, mostly the frontal area and the pressure drag name comes because it is caused due to creation of pressure on the upper and lower surfaces, because of the shape of the body. Now, if you you have to add to that something called as skin friction drag which is because of the flow of air on the body. So, one is shape, the other is the surface area, together they are called as Profile Drag.

So, profile is pressure plus skin friction or form plus skin friction and skin friction as you know can be because of laminar or because of turbulent or because of both laminar and turbulent. So, this particular part of drag acts even on bodies which are not generating any lift. So, you can call it as lift independent profile drag. We also have some lift dependent profile drag which we will see later, ok. Is it clear? So, something that does not depend upon lift; it is a function of shape or form, that is why it is form drag or pressure drag and it is also because of the skin friction.

So, the profile drag which does not depend upon the lift is also called as Parasite drag. Then, when you generate lift there will be an additional profile drag because of the lift, ok. And that component should be as small component at cruise. So, the induced drag is only lift dependent; if there is no lift there is no induced drag and it occurs because of the lift that is generated and the lift generated because of the vorticity which is shed in the wake.

This is a story of subsonic drag. In supersonic flow or in transonic flow actually you can also have wave drag; because of the shock waves and here again there are the components. There is a wave drag due to lift and there is a wave drag due to volume. So, all these together you called these components as drag due to lift and on the other hand you have zero lift drag, ok. So, this is the story of drag this is the breakdown of drag.

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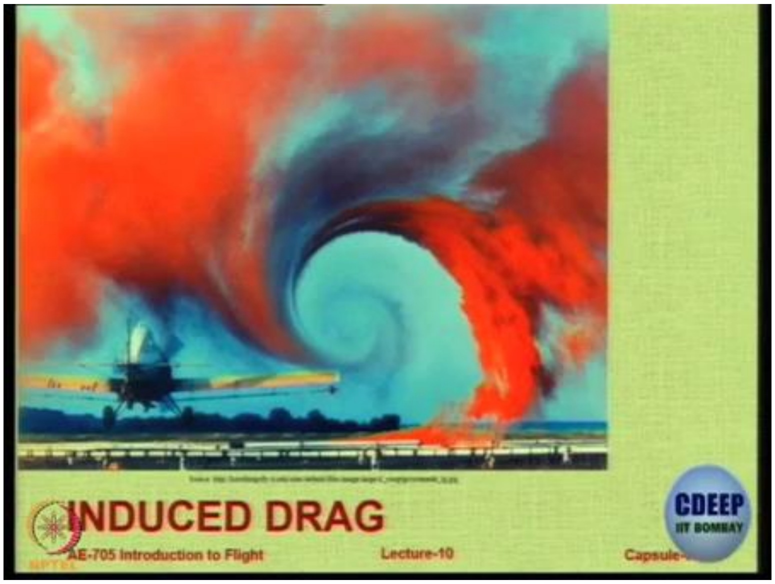

Let first attack induced drag which is created because of lift and the reason why we have induced drag is because of the creation of these vortices.

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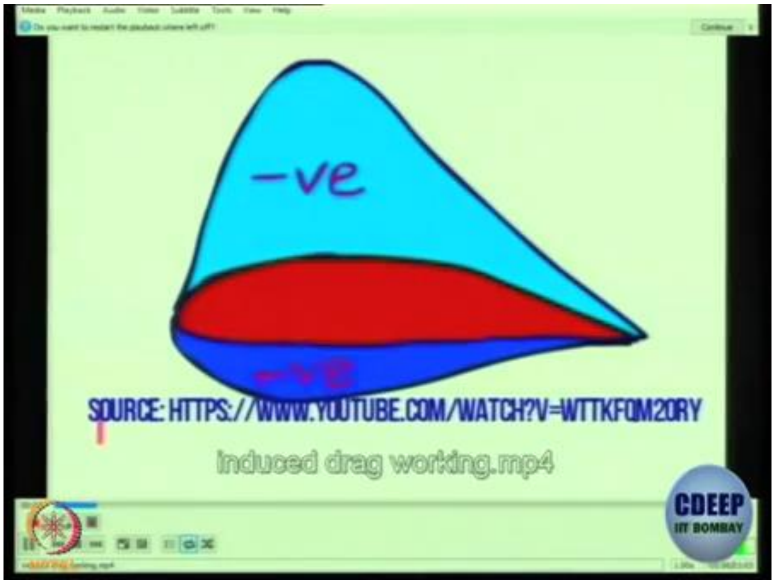
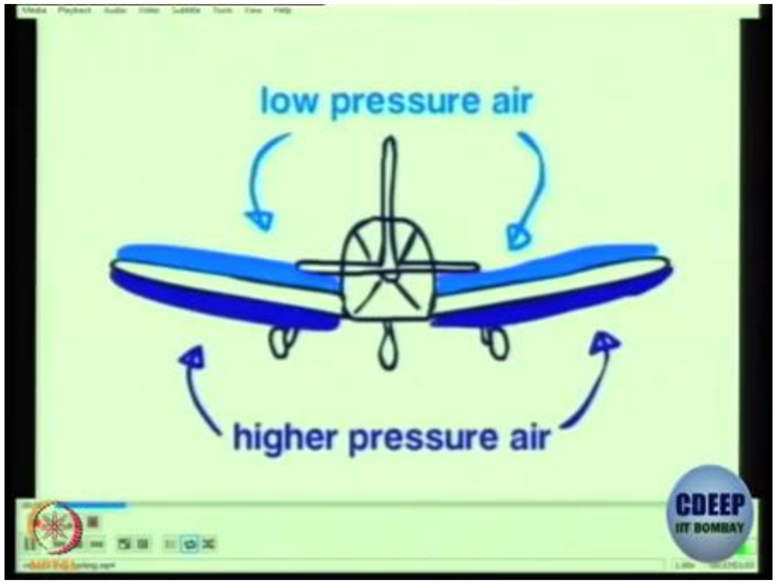
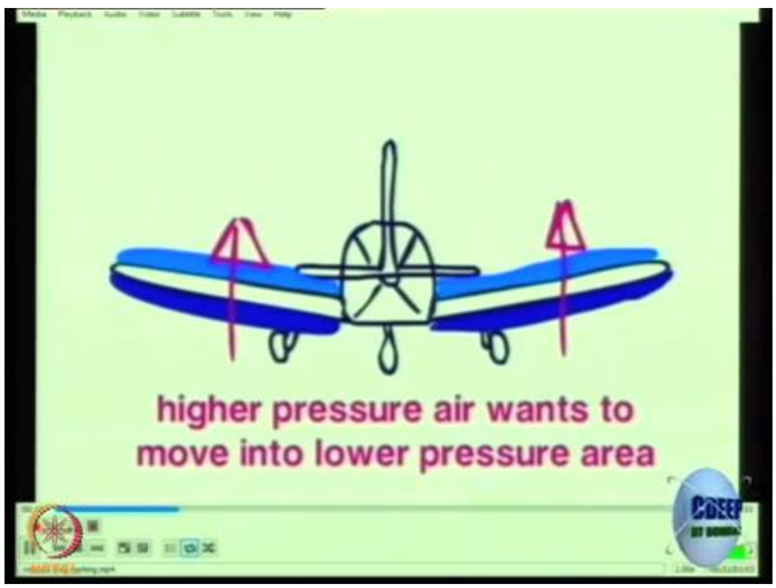
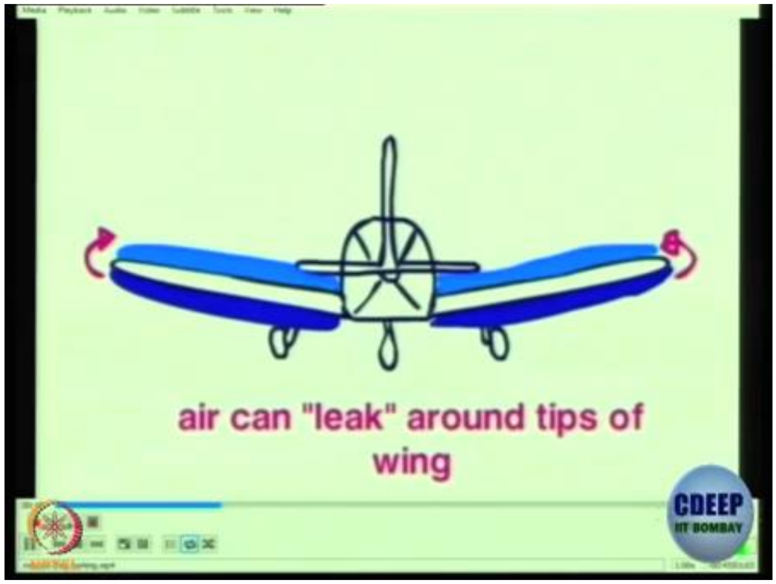
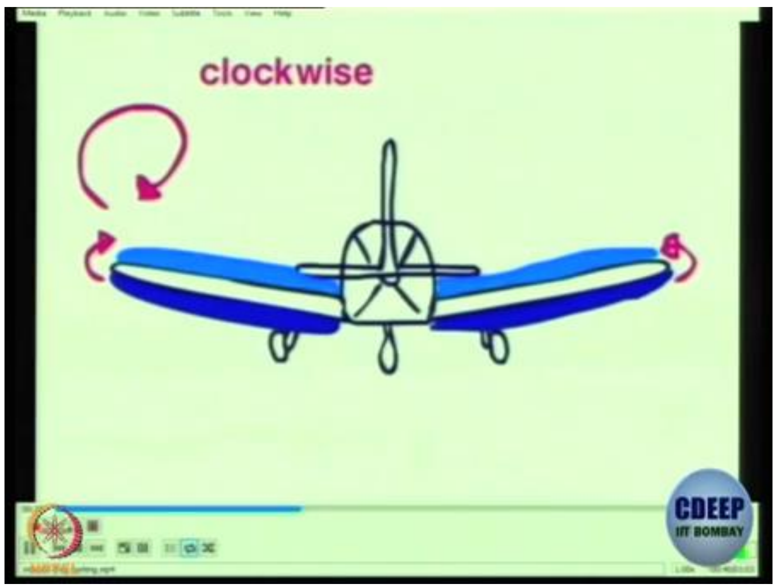
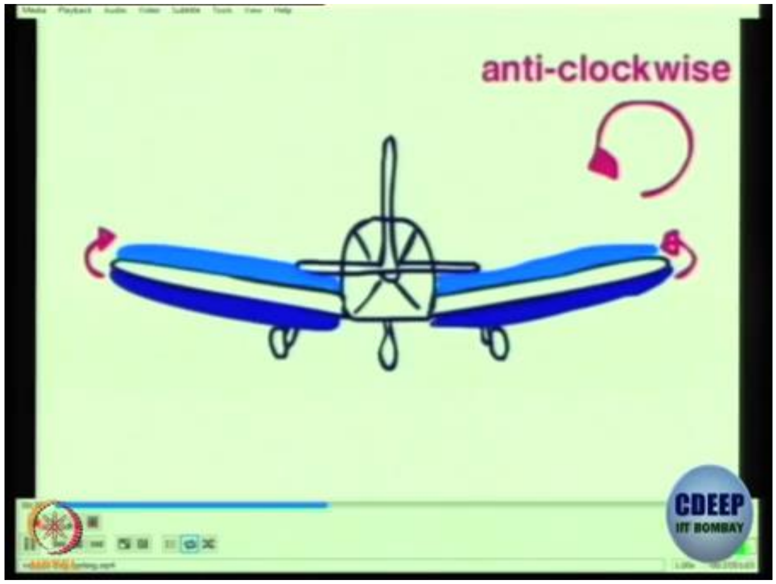


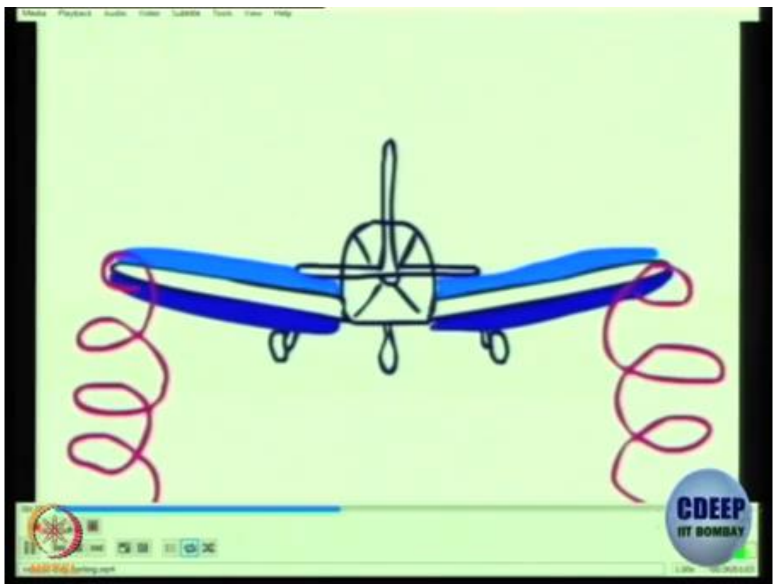

low pressure air
higher pressure air

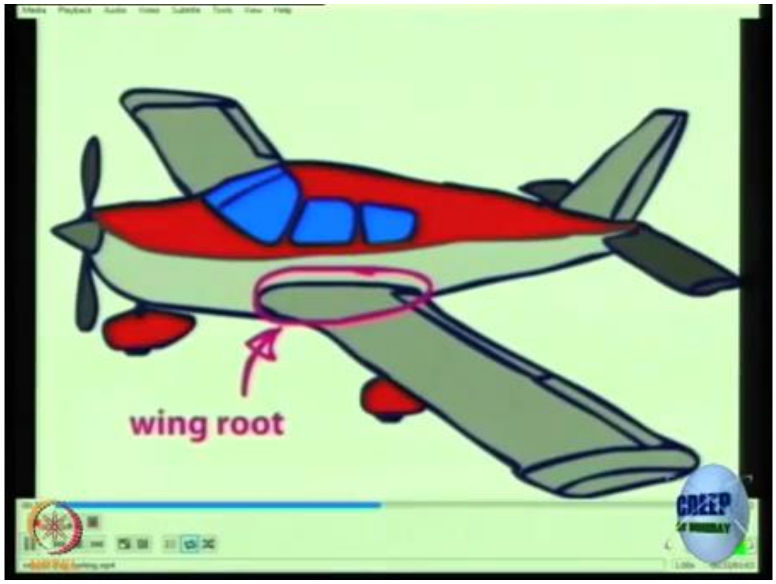

higher pressure air wants to
move into lower pressure area

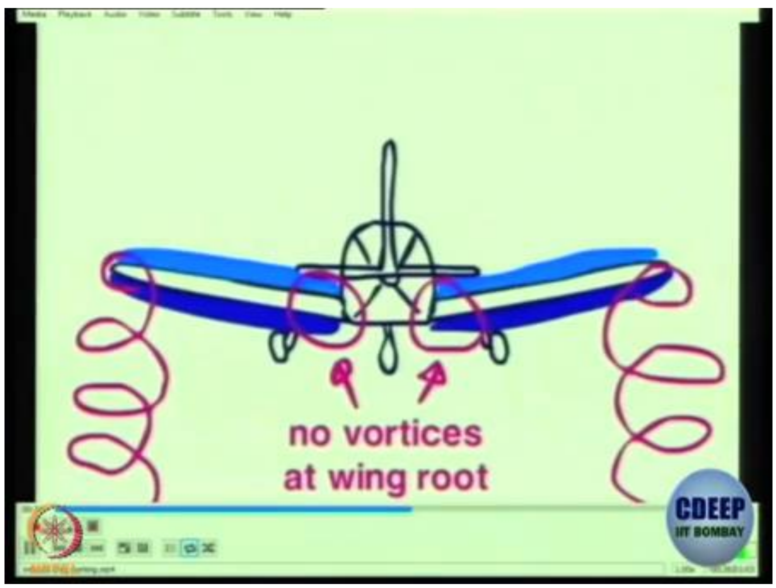

air can "leak" around tips of wing
CDEEP
IIT BOMBAY

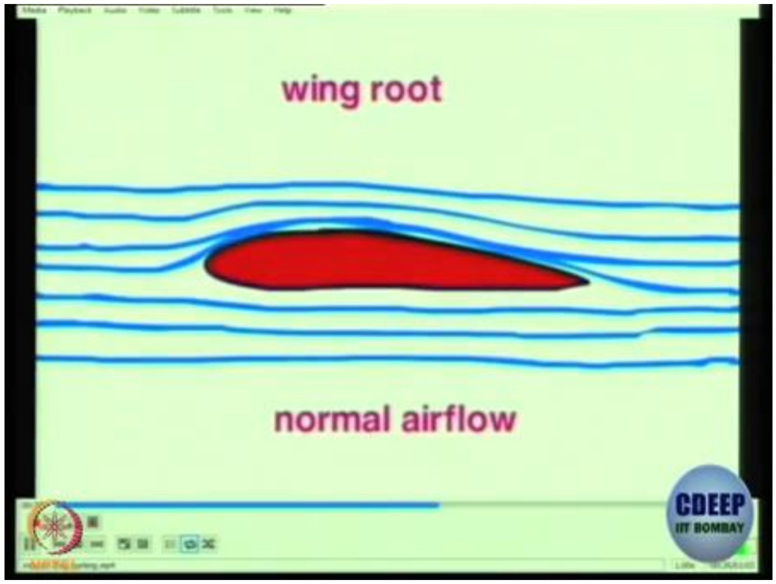

clockwise
CDEEP
IIT BOMBAY

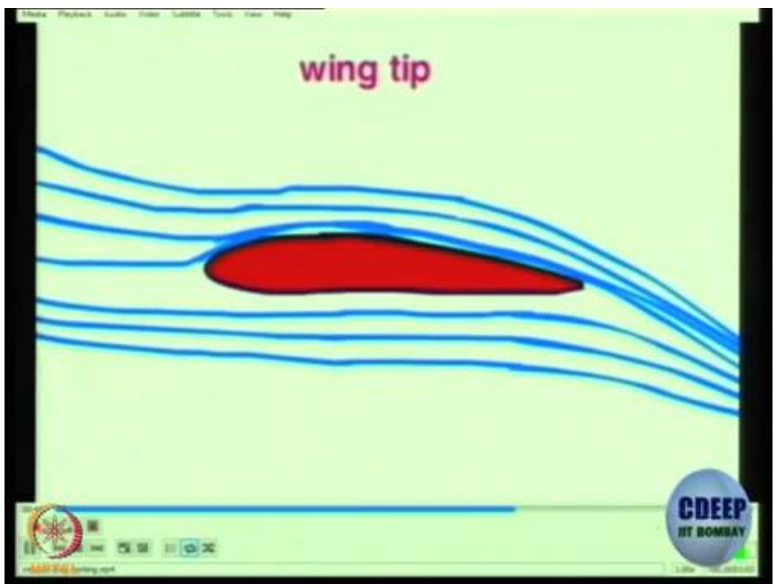

anti-clockwise
CDEEP
IIT BOMBAY

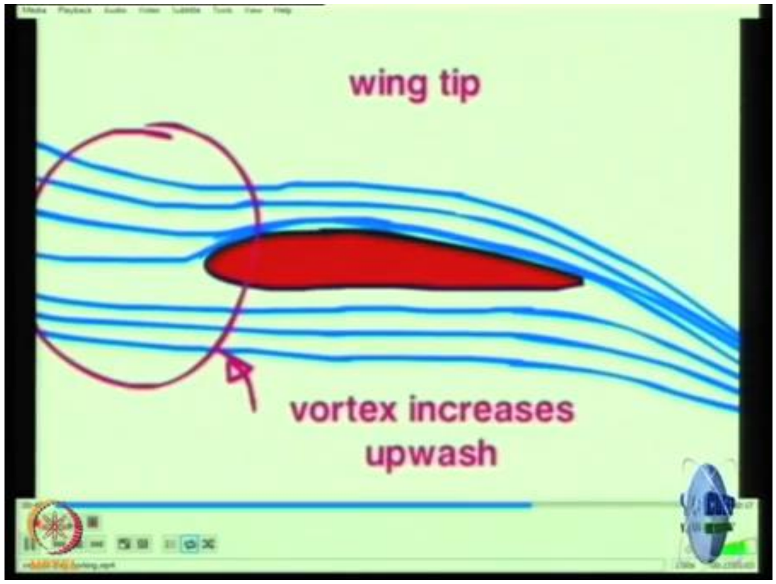

CDEEP
IIT BOMBAY

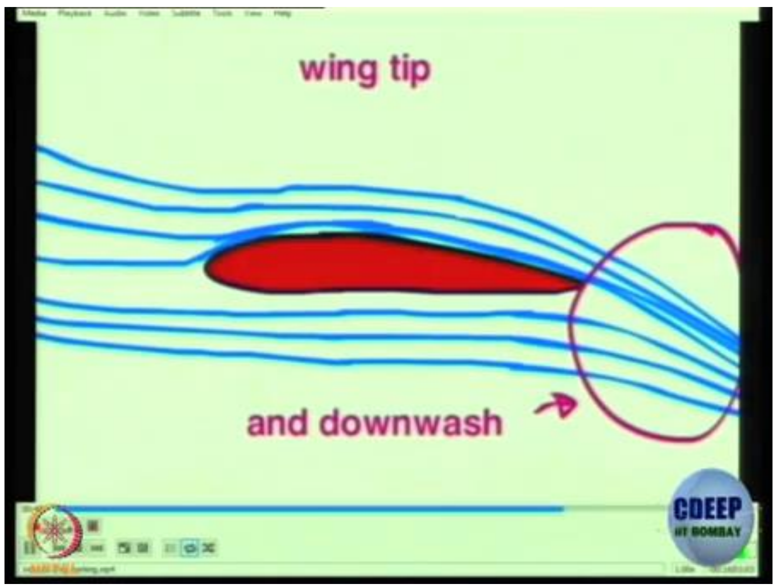

wing root

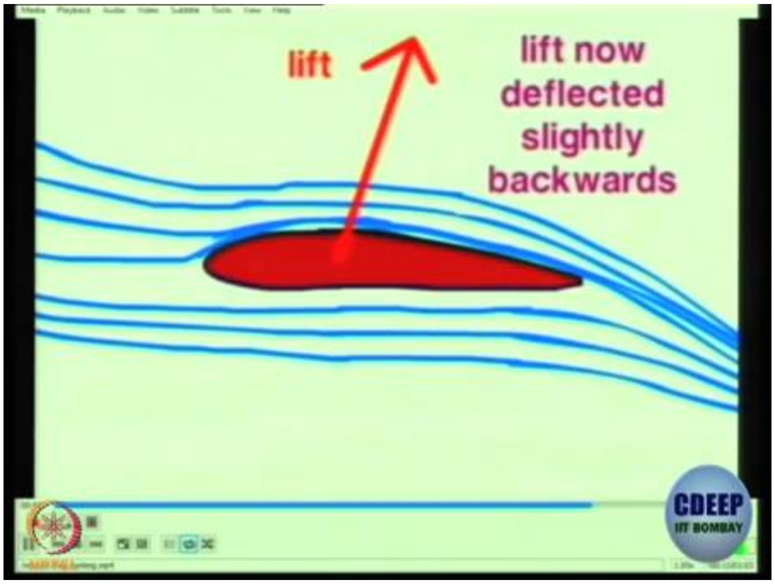

no vortices
at wing root

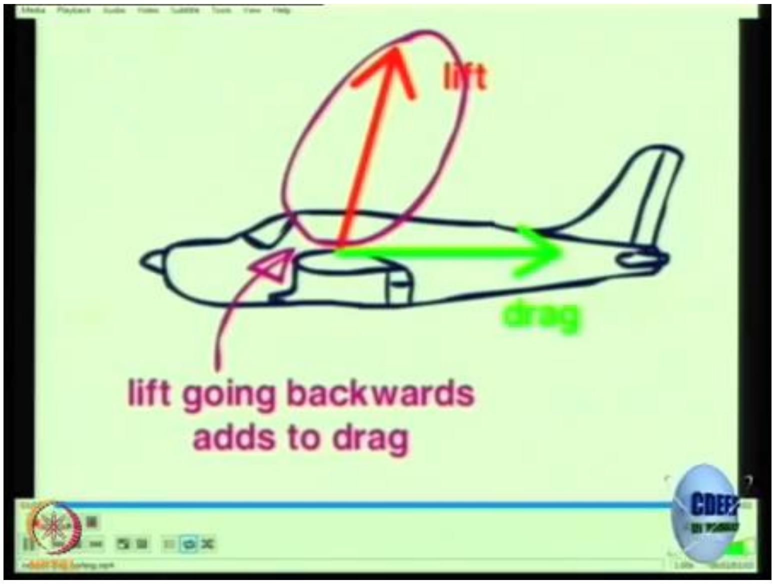

wing root
normal airflow
CDEEP
IIT BOMBAY


wing tip
CDEEP
IIT BOMBAY


wing tip
vortex increases
upwash


wing tip
and downwash
CDEEP
IIT BOMBAY





Video: Induced drag is caused by wingtip vortices. These are caused by the difference in the air pressure below and above the wing as you the creation of lift video. Tips of the wing the higher pressured air below the wing can go around the tip to satisfy its insatiable urge to get with a lower pressure air on top of it. This creates a circular motion of air the tips of the wings. Clockwise on left, anticlockwise on right. The vortices that this action creates effects the air around it. At the root of the wing the vortex action has not fall too much. Air flow is like this.

However at the wing tips where there is a main of the whole vortex action thing going on, air flow is often to become like this. As you can see the air is forced upwards in front of the wing and then forced downwards behind it. This alteration of the air then means that the lift generated by the wing is slightly deflected backwards. This lift force going backwards now adds to the drag force, end is the induced drag of the air craft.

Professor: Ok. So, essentially induce drag. There are many ways of explaining it one way of explaining it, yes because of the presence of the tip or away from the root you are going to get some up wash before the aircraft and down wash behind the aircraft. So, in a way the air has been made to tilt so there will be a reaction. So, the lift Vector will be tented backwards.

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So, there is another explanation where the same thing is explained. Let us see how they explain it.

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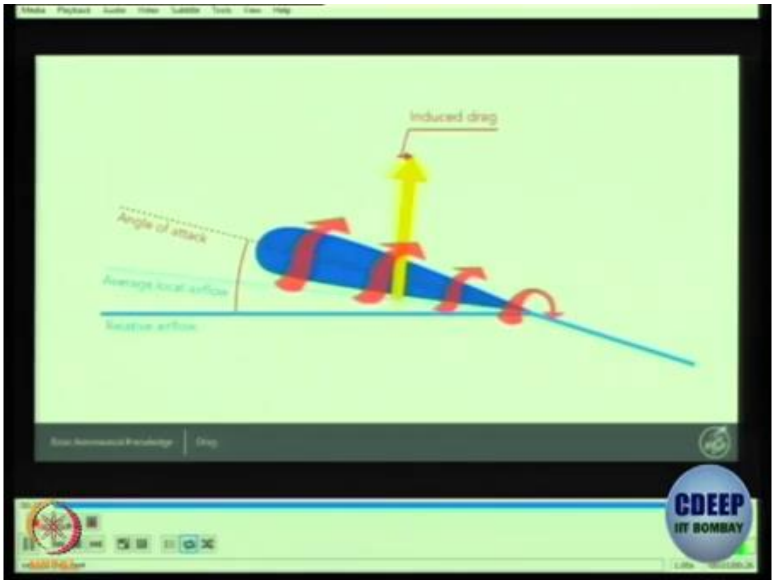

Video: At high angles of attack, the high pressure air below the wings likes to swirl around the wing tip towards the low pressure air above the wing. A twist in vortex of the air falls behind the wing, deflecting the air flow to the angles. In incline the local air flow is collated which is the average of relative air flying in the deflected air flow resulting in a lift effect tilting backwards and contributing to the drag.

Professor: Same thing, just the tilting back. Now, this tilting back is occurring because of the effect of the presence of the body locally, this does not occur at the wing root where there is a junction; this occurs only at near or at the wing tips where there is no Junction.

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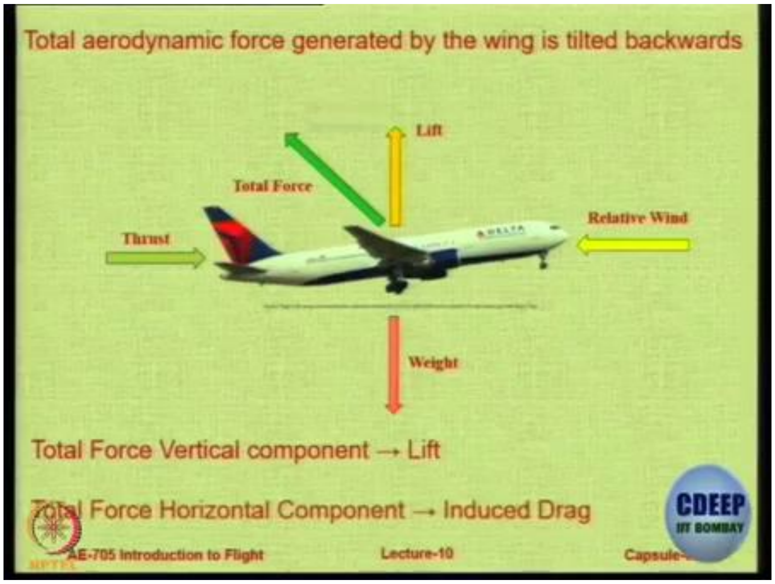

So, you have relative wind on an aircraft you have thrust there is a net reaction but then there is a backward components and that backward component is the induced drag.

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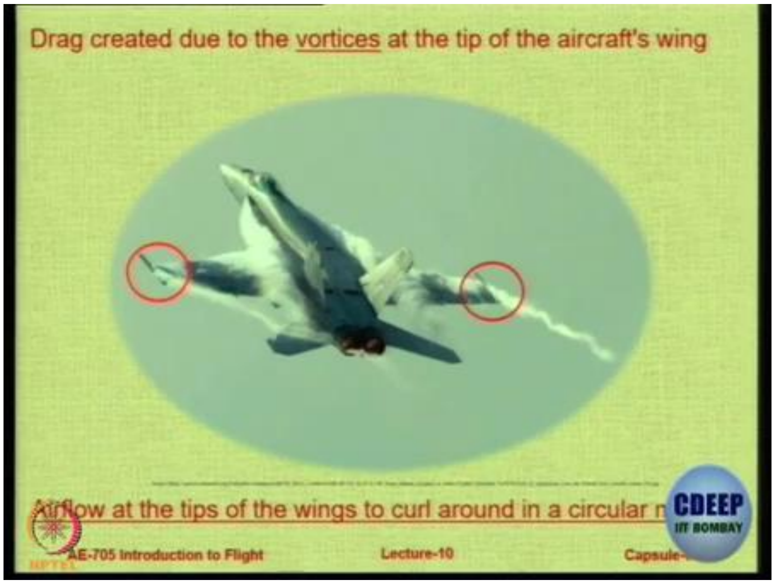

So, the reason why we have induced drag is because of the vortices at the wing tip. Now in this case the vortices are near visible. But sometimes nature also tells us or shows us the vortices.

Video: 15:11

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You can also do it in the wind tunnel. You see the curling up and invert turning of the vortex at the wing tips.

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And if you want to have visual information, this is a very beautiful video which shows what happens. You have already seen one such video here is another one. This is natural flow visualization. But my question to you will be why did the aircraft not land? It is coming to land and then it is rejecting the take off. So, what happened? Why is the aircraft not landing? Do you think the pilot got the aircraft down just to show you the vortices?

No, I think the pilot wanted to land. That is why the flaps are down. This is something I would like you to answer notice. It is only on one wing. You can visualize the vortex only on one end of the wing only on the port wing of the left wing as a pilot seat. So, this is a question which remains unanswered in the class. And therefore, I expect the answer on MOODLE. Somehow, people are become little bit lazy and MOODLE now.

I asked question in the last class nobody was answered it. I hope you will get answer to this question, ok. Alright let us drive the expression for the induced drag. So, induced drag is basically a function of the same forces or the same parameters. But here I am used $V_{equivqlent}$ and ρ_0, you can replace it with ρ_∞ and V_{true} also. So, the induced drag coefficient $C_{D,i}$is basically a function of square of the lift coefficient and the aspect ratio of the wing.

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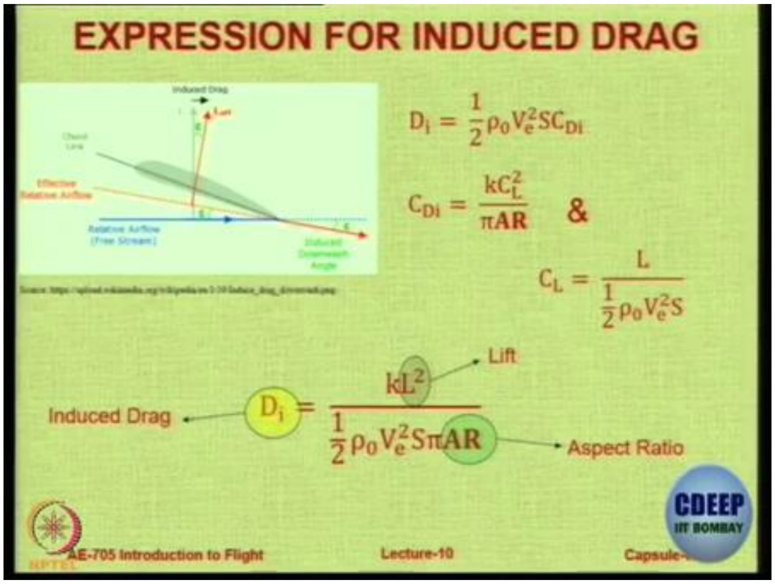

And for level flight or when you when you generate lift

$$C_L = \frac{L}{\frac{1}{2}\rho V_e^2 S}$$

So, therefore induced drag will be obtained as a function of L Square and K. So, what are the parameters are the affects induced drag, first is the lift. So, an aircraft like Airbus A380 which will have more lift than a Cessna 172 will have more induced drag at the same speed.

Remember because lift is far-far more an aircraft which has at a very high aspect ratio will have a lower induced drag as compared to an aircraft with low aspect ratio. In other words for the same aircraft is to change the aspect ratio; if you increase the aspect ratio, you will reduce the induced drag of the same aircraft. So, how do you do this? How do you change the aspect ratio of the aircraft during flight?

What can be done for example? Any suggestions? During flight I want to have a higher aspect ratio created. What would you do? No suggestions, we have one suggestion, take a mic please, we have a mic here. So, mention your name, there is a mic for you, mention your name and then give your suggestion.

Student: Sir, my name is Deepak.

Professor: Yes, Deepak.

Student: Sir, can we use this sweep back wings to move forward so that D can increase and so that the aspect ratio can increase.

Professor: This is one way; one way of doing it is to sweep the wind to lower sweeps from higher sweeps. So, if you are flying at high sweep back and if you want to reduce induced drag you will you can sweep the wing ahead. That is ok, that Deepak you are right. Somewhere there is another hand raised, take a mic.

Student: Sir, my name is Amitesh, we can deploy the flaps so that the surface area will increase the aspect ratio will increase in that case.

Professor: So, if you increase surface area aspect ratio is span square by area, area increase means it will reduce, aspect ratio will come down. So, actually induced drag will increase, increase, it will not decrease. Anything else?

Student: Sir, I am Vinay…

Professor: No, if you increase the area of the wing by deflecting the flaps; I am assuming it is fowler flaps. So, you are bringing it back aspect ratio will will not increase it will decrease because it is in the denominator. That is fine; I understand what you are saying usually the definition of S is the wing reference area which may not include that. But my question to you is what is your suggestion to increase aspect ratio during flight.

Student: Sir Manikandan,

Professor: Haan Manikandan, yes.

Student: Sir, instead of span area, if we increase the angle of attack, projected area will reduce.

Professor: So, once again we come back to this point of view. There is something called as wing reference area, which will not change too much. So, just by increasing angle of attack, you will not be able to change aspect ratio. So, why are you only looking at S? See, how did how did Deepak solved the problem by increasing b. Can you do something else to increase the span?

So, we are working on a project, in which we are talking of span extension. So, you have a wing which has a wing and a small wing inside and when you want high aspect ratio, you take out that wing. So with that you get a larger wing span. Obviously, is not very straight forward; when you when you take out the wing what are the problems one is you are eating away the volume available for the fuel in the wings.

Secondly you have to put actuators to create so many loads. So, there is a Plus and a minus. So, we have a PhD student working on the pluses and the minuses and using detailed design calculation we are trying to figure out what is a limit to which increasing in span is beneficial compared to the drawbacks. So, it is possible to do it by using Innovative techniques. You can have a folded wing like this in flight and opens up like this.

So, you can do things increase the span, ok. But it is very, it is not vary easy. There are many pluses and minuses. The other point is the area and the equivalent airspeed and the air density, ok.

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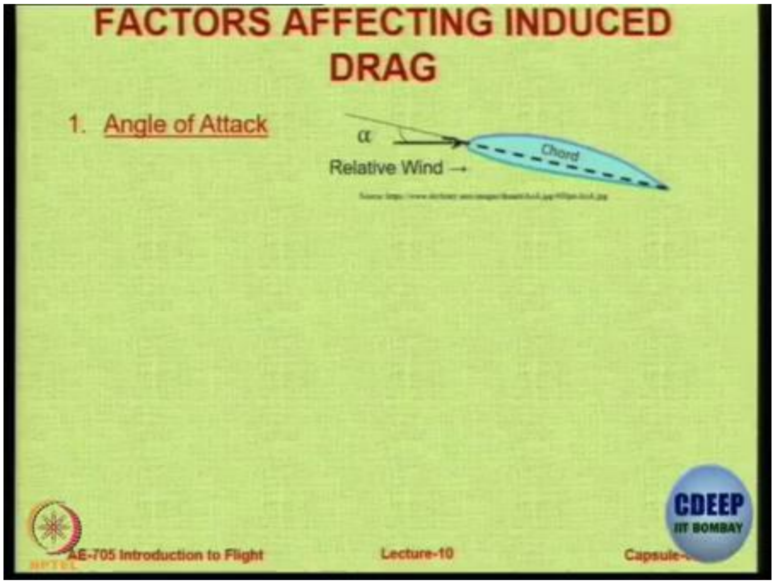

So, let look at the factors which affect the induced drag. So, let see this is not a aspect ratio but induced drag. Induced drag is more when aspect ratio.

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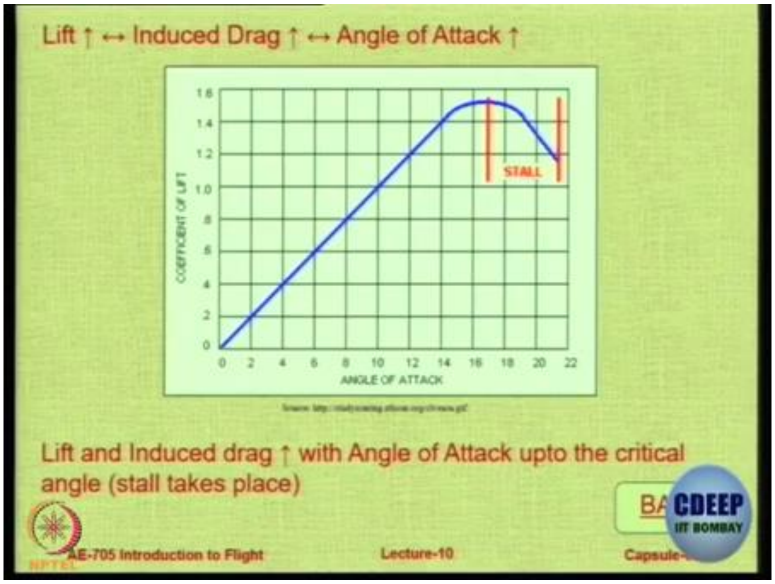

So, if you change the angle of attack then the lift is going to increase correct. So, this is one way the angle of attack change is actually going to affect induced drag.

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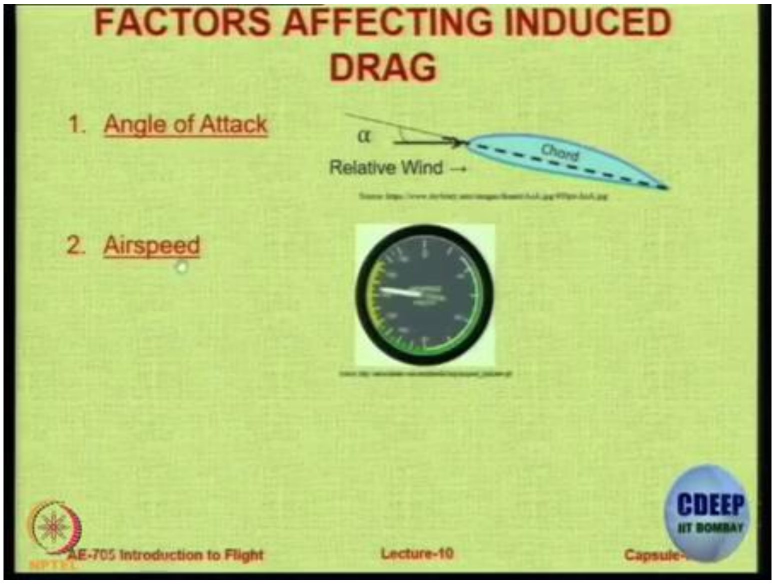

The next parameter is air speed.

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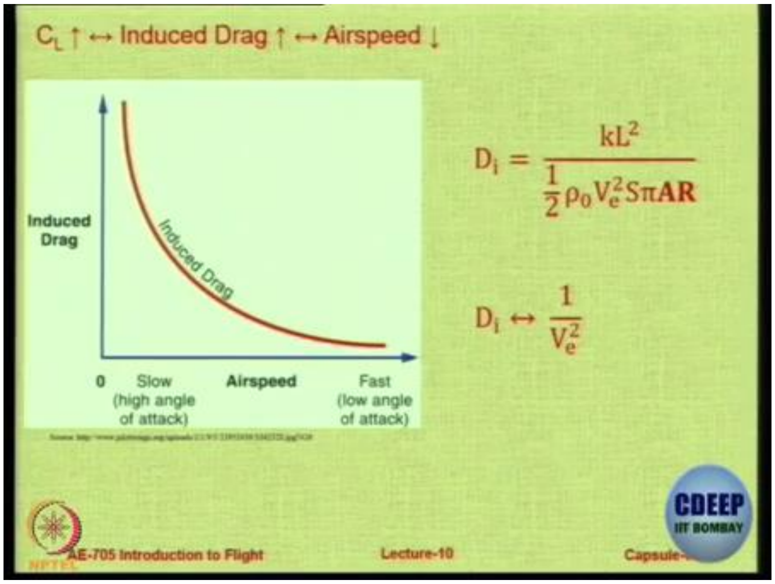

So, if you change the air speed the CL will change, because you need to maintain lift equal to weight still so as the air speed increases the CL will reduce; and if CL reduces, $\frac{C_L^2}{\pi Ae}$ will come down. So, that is one way of reducing the induced drag, fly faster, ok that is one solution.