Introduction to Flight
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Lecture 12.2 – Flapping Wing Aerodynamics: Part II

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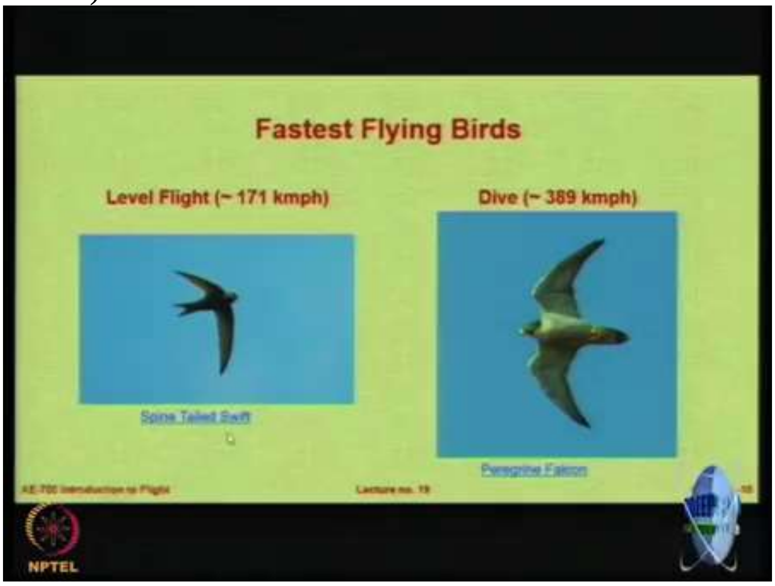

Okay, so let us see some fastest flying birds. So, one on the left is the one that has the record for the fastest flight.

So I found this very interesting video which talks about the spine tailed swift. Okay, so I have just put the video with no editing. Now only you can see it, there you go. Can you see it? Were you able to see it? Let us see it once again now, okay, look carefully and try to spot the bird. Only at 25 percent or 10 percent speed you can actually see that something is moving. So that is the speed of this bird. 10 percent with zoom, okay, so that is the speed. Now, let us look at dive. Okay, so as I mentioned they encounter 25 g-force.

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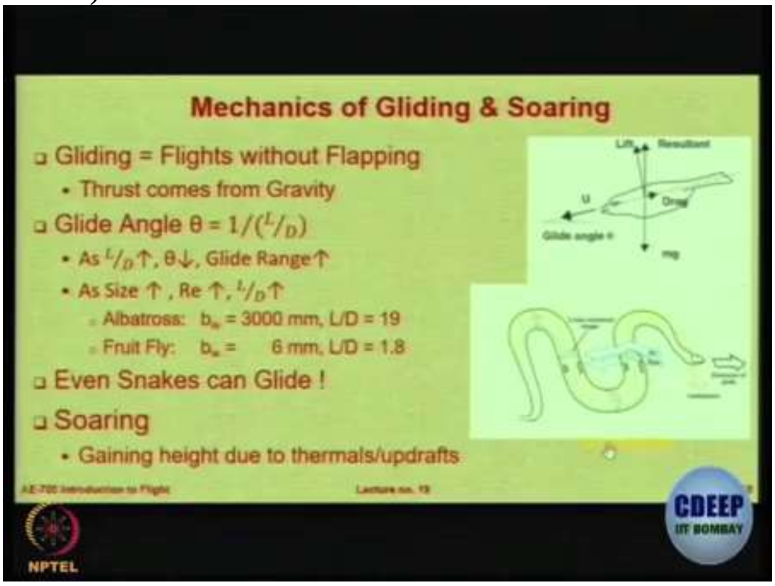

Let us see, let us see how do birds glide. Now we have done a complete lecture on gravity, on gliding, so we do not have to really spend too much time. It is the same thing that you have studied under gliders. They also have to maintain a particular glide angle, they also have to maintain L by D maximum, okay. So as the L by D increases, the glide angle reduces and therefore, the glide range also increases.

So, when you increase in size, you have a high Reynolds number, high Reynolds number normally gives you high L by D. So, very large bird let us say, let us say Albatross which is 3 meters wings span, L by D can be around 19 which is comparable to Boeing-747. The 747 has L by D max of around 17 and a half to 18, okay. And the bird has the L by D of 19. But if we take a very small bird called as the fruit fly which is only 6 millimeters wing span, it is actually an insect not a bird, but if you look at it carefully it is a bird, so 6 millimeter wing span L by D is only 1.8, but still more than 1, nearing to 2, okay. And can you believe that even snakes are able to glide, okay. So this is a very interesting, very interesting video about gliding snakes, those of you who are scared of snakes, you can close your eyes.

You see this is a gliding snake. Can you see? This is a gliding snake. Okay, so this is a faculty member from Virginia Tech who has taken up a project. These snakes can go up to 50 meters in a glide, so they go up a tree, they launch themselves, they flatten their body so that they give an aerodynamic shape and then they launch their head and keep moving it, so that the body goes in waves, okay, let us see it once again. Let us see this once again.

[Video Presentation]

So there is also very interesting video when there are five students who work with this professor, so the snakes are launched and then they run after the snake to catch it and bring it back, I would not work on such a project, okay.

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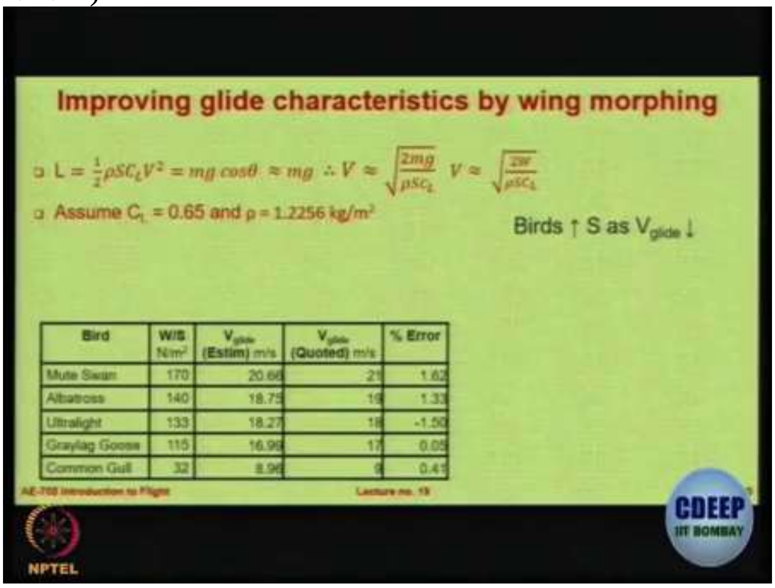

Now, the thing is how do you actually improve your shape? You do it by changing your wing or by wing morphing, okay. So we can see there that if you take a very very shallow glide and ignore theta, then the velocity at which you launch yourself is just proportional to the $\sqrt{\frac{2W}{\rho s C_L}}$, okay. So if you assume some C L value and assume some rho value, you can see that depending on the wing loading values, you would have a glide velocity, okay. So, it is very interesting with a very simple formula, we can estimate the quoted or calculated glide velocity and you can see that the percentage error is well within 2 percent plus minus, through a simple formula.

So you just get the wing loading and you can estimate the velocity in glide, okay. So in birds as their glide velocity reduces or I should say like this as they increase the wing area, the glide velocity reduces and hence the time in the air also increases, okay. Also the distance travelled by them will also be a function, so larger birds which have larger wing area, they glide slowly. At the same time if they want to change their glide velocity just like we saw in the video about this vulture, if you want to change, if you want to change the glide velocity, you can change the area. So the same bird when travelling at 31 kilometers per hour has the wings coming out and it goes for very very closely placed wings, this is just like the variable sweep that we see in the aircraft. So we can always say that the variable sweep concept of the aircraft is inspired by the birds.

Okay, so there are two examples there about the falcon and the pigeon who undergo a shape change. So this shape change is called as morphing, so heavier birds glide at higher speeds. If you look at rotary wing aircraft or helicopters versus natural fliers, you see lot of similarities. First of all, in a helicopter, what do you do is you create a relative flow around the rotors by rotating continuously and here also they are flapping it along the arc. If you actually take the locus of the tips of the bird wing, you will be surprised it goes in a circular path or elliptical path. I will show you some videos of that also.

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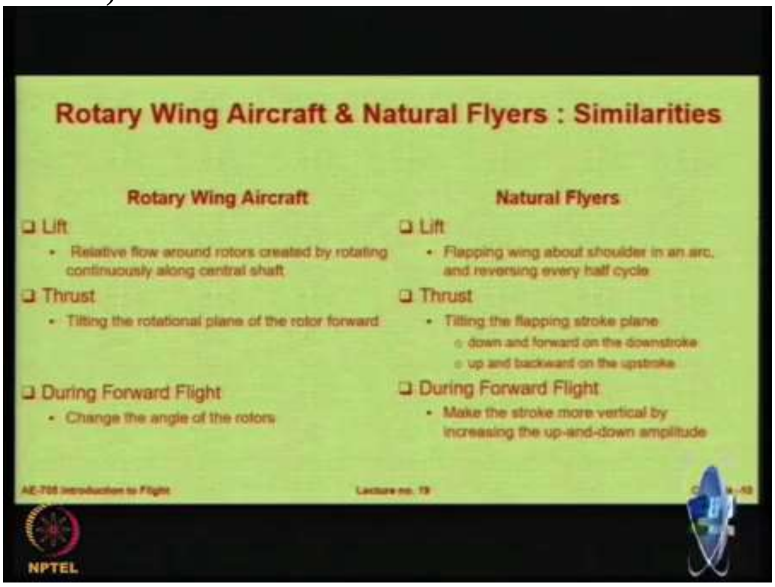

Similarly when you want to tilt, when you want to go forward, you tilt the thrust rotational plane. Same thing is done by the birds and by the insects also, they tilt the flapping stroke plane and that is how they get the forward motion and during forward flight, you change the angle of the rotors. Similarly, you change the angle of flapping. So I would say that the helicopters are actually doing many things just like what the birds are doing.

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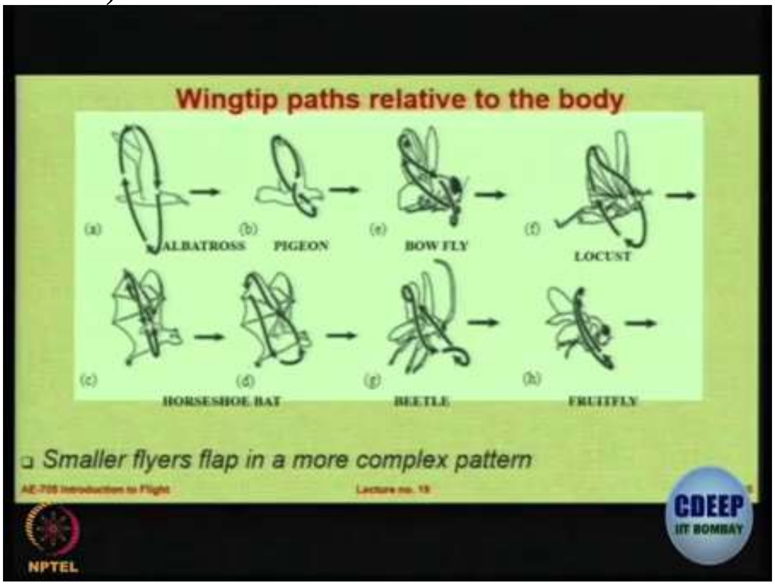

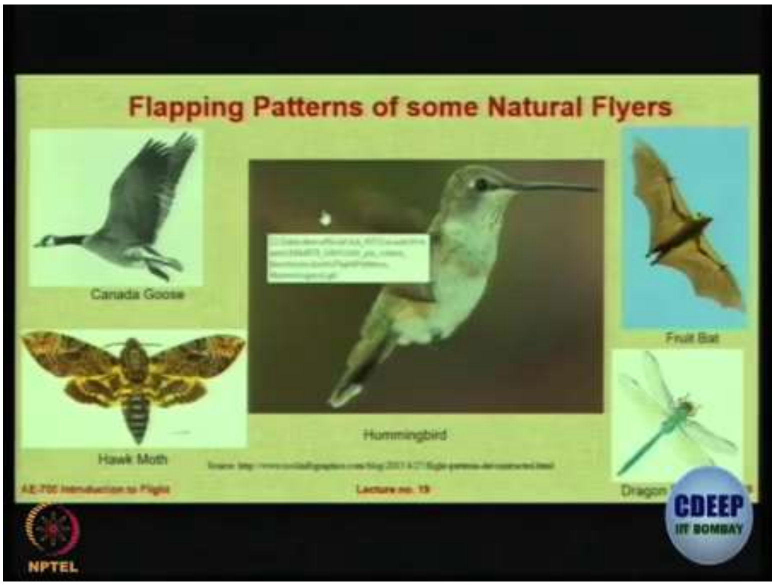

So here is an example of some birds and insects, now these figures are not in the same scale. For example, we have a bird here and we have a fly here, they are not of the same size. Only in movies you can have same size, but if you see the pattern in which the wings are being flapped generally becomes more complex when you have to go into a smaller animal. Larger insects or larger flying objects, they have a very simpler flapping motion. Look at albatross for example, one of the largest birds, it just has a simple helical fashion. But look at the bow fly, look at the locust for example, it goes forward and backwards. So smaller fliers, normally clap in a larger.

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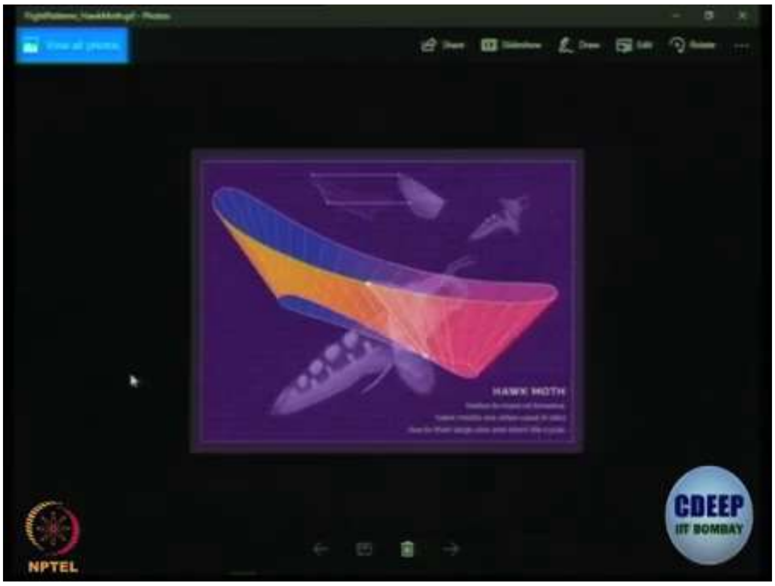

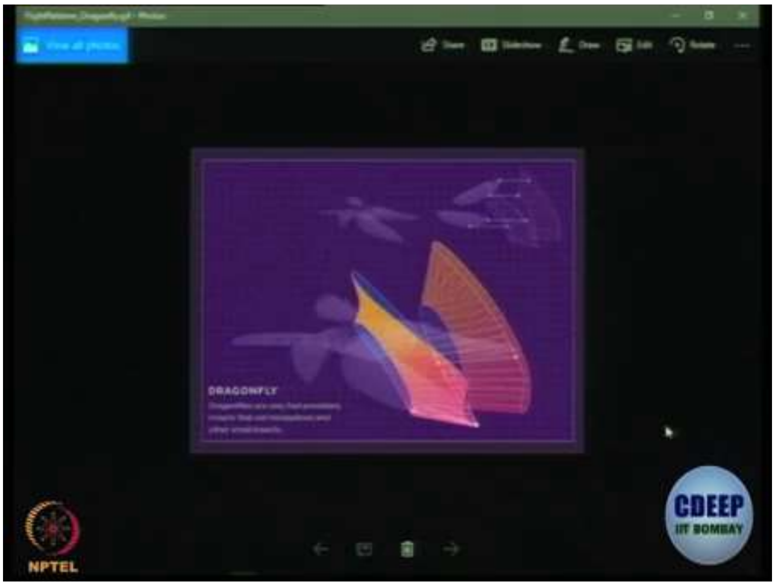

So we will have a look at some animation. So this is the flapping motion of the bird called Canada goose. So the locus of the inboard tip and the outboard tip shows you the flapping plane. On the other hand, if I look at a moth, you can see now it is more complicated. So now not only is there are two distinct top and bottom, there are two distincts, the bottom is actually figure of it, the top is not figure of it and also notice that the body also keeps flipping along with the one, that is meant for center of gravity control. If they do not do that, then they will also start moving and they will not be able to hover at a particular place.

If we look at dragonfly, now there are two sets of wings. Dragonfly has two wings and as we can see here, they are not moving in the same manner, there is a lag between them, okay. So you can say that these are two independent set of wings which are flapping in a conical, in a in a frustum of a cone manner, but that is inclined and one behind the other with a lag in between, okay.

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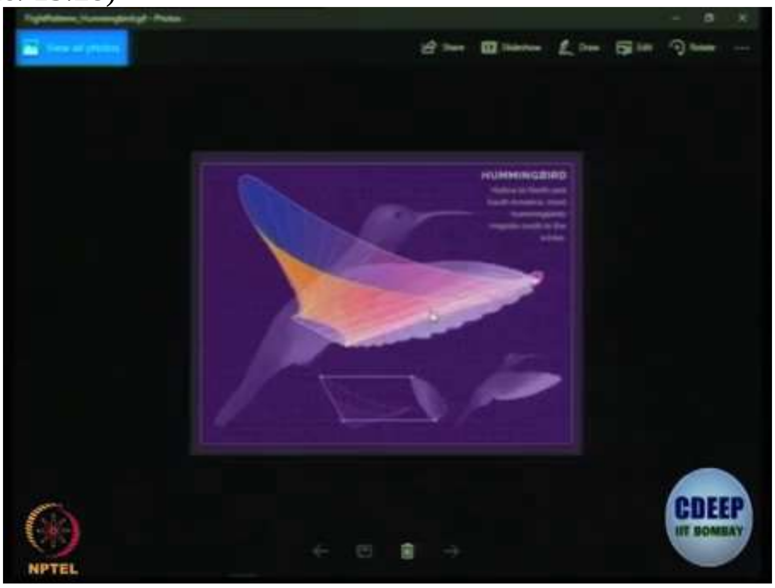

Let us look at the hummingbird. A hummingbird is one of the most amazing birds, the amount of control it demonstrates in keeping its position, flying backwards, flying upwards, flying sideways. So looking at the flapping pattern you can realize more you are near the frustum of a cone, more you are able to maintain hover. Hovering condition depends on the motion. So for the hummingbird, I have actually many many more amazing images.

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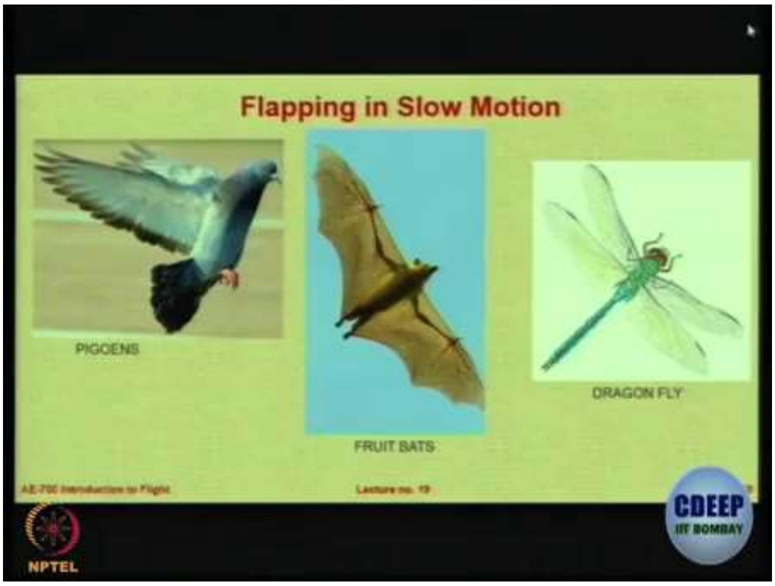

So, let us look at flapping in slow motion, we have already seen a video which was animation, okay.

So, look at that in ultraslow motion, it will give you an idea about how the wings flap. So the pigeon is now perched at a particular location. So now it starts taking the wings out, so the first requirement is to leave the ground, so you can see the downs and also the tail is morphing out, but the tail has also given an angle because they want to turn, so they would like the air to give you a turning flight. Now it wants to go forward, after it has launched and turned, it wants to go forward. So when it is going forward, notice the tail also deflects, there is angle change in the tail, there is area change in the tail, there is a camber change in the tail and that is happening naturally with the wings. Now it is going to turn, okay.

So, there you go, one more look, so wants to launch so therefore it bends down and the wings are going up basically to flap down. So you throw yourself up and now you flap the air down, so basically down and forward so, it is down and forward, I cannot do, I am not so efficient like a pigeon. Look at the landing gear being retracted inside. Everything that you see in aircraft has actually been inspired by birds. It is amazing how much aerodynamics you can look by just looking at these animals.

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This is a fruit bat which is again captured in slow motion. Now look at this particular pattern carefully because I will very soon show you a study about the aerodynamics of this particular animal, done by one of your student, one of your seniors, okay. So notice now, how the outboard tips, so it is like a human hand only, it is like a human hand if you see. But the motion is very complex, okay.

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This one is far more exciting, the speed is one by four hundreds of recording. Landing gears comes out, retracted forward. So notice the tips of these are dark black spots, so you can put some dyes or markers and take a video recording and get the motion that is how the previous videos were recorded, okay.

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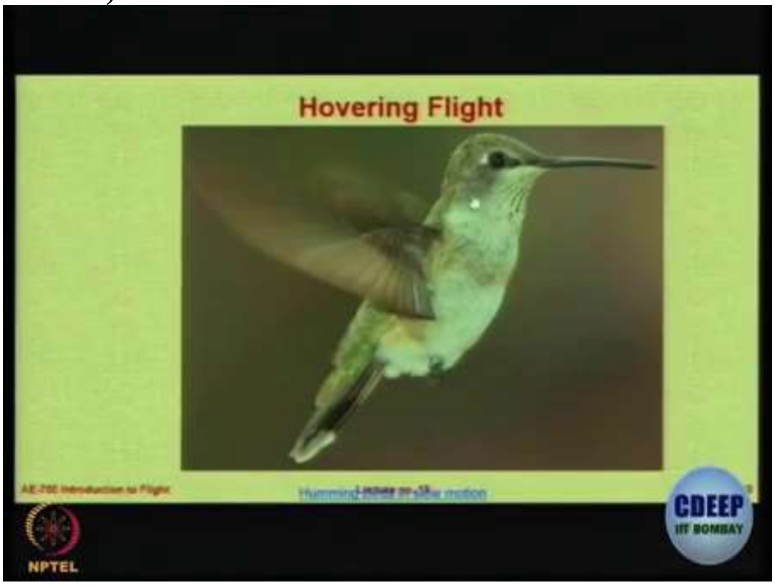

Now, let us look at hovering flight. So you see how she is able to maintain position at just one place and the tail is also twisting slightly, the rear is also going up, and now a slight change in the inclination and you can go turning. This is in slow motion, I have some very beautiful pictures of these birds in full speed, I will show them also to you towards the end when I have some time.

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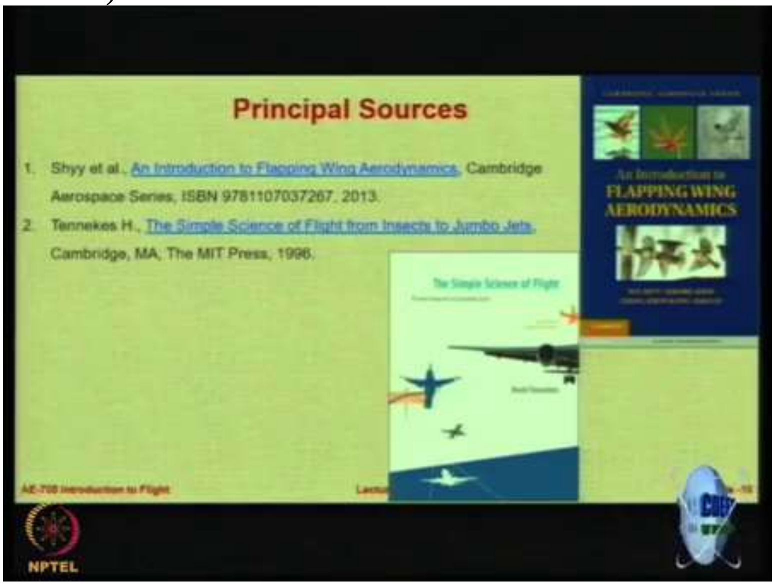

So the material for this presentation has been taken from these two very interesting textbooks which are available freely online, okay. The one is called as Simple Science of Flight from Insects to Jumbo Jets by Tennekes, okay and this is available with me also if you are interested. And there is also a very nice AIEE textbook by Shyy et al, An Introduction to the Flapping Wing Aerodynamics, this one is more formal, it contains lot of mathematical expressions, derivations for the flight.

I will show you some videos. See, this is in fast motion, this is in full scale I mean full speed, this is slow motion. So they consume so much energy that they need water in ten minutes of flying. See no interference; you will never see them hitting each other in flight. See full scale. The useful skill, see how they clean their wings, okay.