Introduction To Flight
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Lecture 12.1
Flapping Wing Aerodynamics: Part I

So this presentation is based on a similar presentation, which I gave as part of a course on UAV design, when I was in NTU Singapore for a year. So, we are going to just look at some lessons from the aerodynamics of flapping wings okay. So, first I think it is very important for us to compare where we are as compared to where nature is, so we will do a very quick comparison between the aeronautical technology available to us and the natural evolution, okay.

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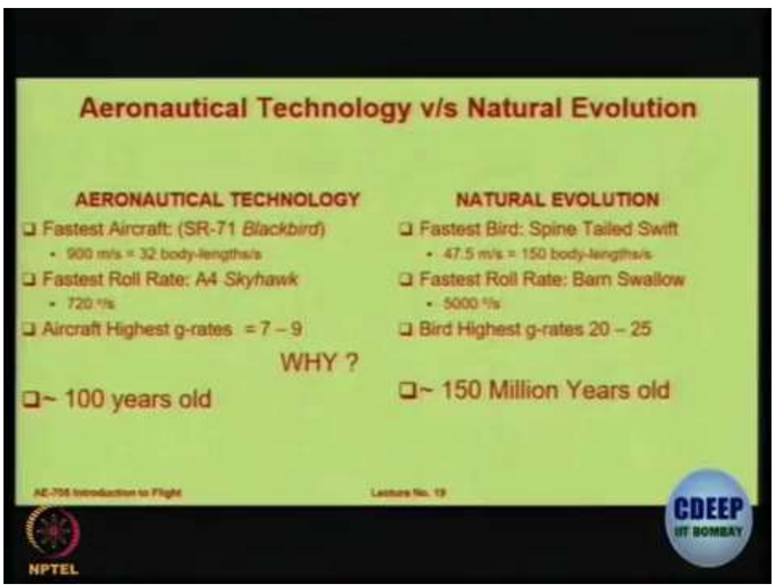

So the fastest aircraft as all of you definitely know is SR-71 Blackbird, which flies at 900 metres per second, but when you put it in perspective with its own dimensions, it travels 32 times its body length is seconds, in comparison the fastest bird is the Spine Tailed Swift, I will show you a small video of this particular bird and it can travel at 49.5 metre per second, which is numerically very small but compared to the body length, it is 150 times the length of its body ok. So, you can see the difference between the fastest aircraft that we have made and the fastest aircraft that the nature has made, alright.

Roll rate is another measurement about how efficient an aircraft is. So, the fastest roll rate recorded is for the A4 Skyhawk aircraft which is 720 degrees per second. So, in one second it can go how many rounds? Okay. The fastest roll rate is in a Bam Swallow, which can go at 5000 degrees per second. So the rate at which a bird can turn is far more than the rate at which an aircraft can turn. The highest g-rates, or the vertical load factor that we encounter during flight is between 7 to 9, and we might design the structure for a g-load of around 12. The fastest birds routinely hit a 'g' of 20 to 25, as measured by accelerometers mounted on their body, okay.

I will show you one such dive in which the bird is going to encounter 20 to 25 g-force, so why is it happening, can someone tell me? With all our great aeronautical knowledge, with all our knowledge of physics, everything, control, engines, why is it so that the birds can do much better than what the human beings can do. So, we have a same policy even in the last lecture of the course, raise your hands, pick up a mic and tell what you feel. What do you think? The answer is because we are only 100 years old in our quest to fly, we are actually trying to copy the birds, is not it? We are trying to imitate them, whereas evolution has taken 150 million years, so after 150 million years may be the aircraft can do the same thing. It all depends on this future generation of aeronautical engineers.

So, to reiterate this point, there is a very beautiful statement by John McMasters, who is considered to be one of the most outstanding aeronautical engineers worked for the Boeing Company, he was felicitated by Ferdio University recently, as an outstanding distinguished aluminus. What does he say; he says that "humans fly commercially, whereas the birds fly professionally." So let us enter the professional world of birds today, have a very very basic glimpse. Normally, there is a one semester course on aerodynamics of birds, there are books written on this, but we will try to capture the whole thing in about 45 minutes.

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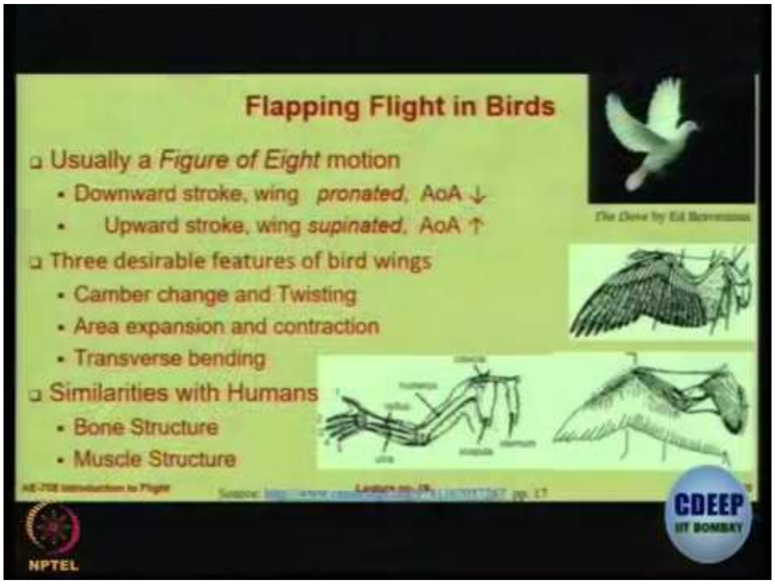

So, when you look at how the birds fly, they do not simply flap their wings up and down, if you observe closely, they go into a figure of eight motion, okay. So what is figure of eight motion?

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Let us have a look how actually the birds flap their wings, so this is just an animation, this is not an actual bird flight, but it is a very close animation of the way in which the birds flap their wings. So notice now, in the down stroke the wings are going forward because the bird wants to go up in the back stroke, the bird is actually taking the air and throwing it backwards, so it is like gathering the air and throwing it back and notice the feathers at the wing tips, they do not remain stationary, they undergo a lot of curvature okay. So there is a downward stroke at which the wing is pronated, in which the angle of attack is reducing and then there is a upward stroke in which the wing is supinated or the angle of attack is increasing.

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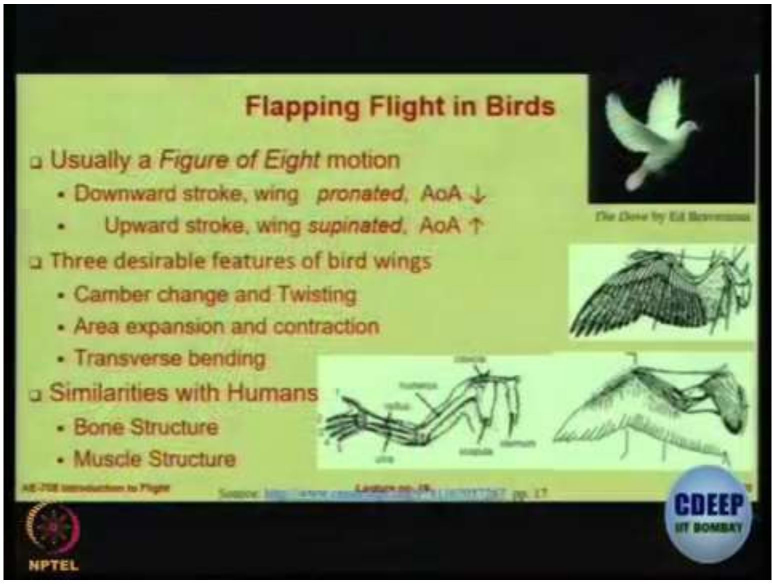

So like a helicopter, when it goes, the rotor blades go around, the angle of attack does not remain same. The purpose there is to ensure that there is no tipping moment. Similarly, the angle of attack of the birds is always changing. There are three desirable or three special features of a bird wing which makes it such an efficient flier. The first one is that it undergoes a constant change in camber and a constant change in twisting. So camber basically means as you know the change in the curvature and twist means the change in the angle from root to the tip. So what is the optimum rate of change or linear change of angle along the bird's wing is a topic of research and I will talk about that in the end, okay.

Secondly, the area of the wing often does not remain same, it undergoes a continuous change, okay. So in the down stroke, the area is actually reducing, in the upstroke it is increasing and also it can change depending on the motion and then you also have transverse bending. So it is a very complicated mechanical motion, which involves all the motions that we think of. But interestingly there is a lot of similarity with human beings and that is why all the initial attempts to fly by human beings were based on trying to mimic the birds because human beings thought, I also have the arms like the bird have, so this is the human arm and this is the wing of a bird. So what human beings thought is that all you need is, you have an arm like a bird, you just have to attach some kind of wings and then you can use this motion and this motion to create twisting, changing of area and if we flap it with some kind of a frequency, we should be able to take off.

So, many people as you know in history have tried and many of them have killed themselves while trying to imitate the birds. So tell me there are similarities in the humans in the bone structure and the muscle structure, we have very similar muscles like the birds have then why is it so that it is unlikely that a human being can fly by attaching wing like things and flapping, what is the reason? So grab a mic, yes

Student: We need very large wings since our weight is too much.

Professor: So you feel that the area that you need, you feel that the area that you need to create the lift is very large, but that is not true, that is not true, the limitation does not come from the area okay, area can be manageable okay, anybody else? So it is not because we need a much larger wing area. Any other answers, yes what do you think?

Professor: So when you say power in our hands, which kind of power, it is the muscle power, okay, so there were some calculations done by biologists, and they found that if a human being has to fly using the power of the muscles, just like the birds have a pictorial muscle, then the chest has to be more than 1 metre wide ok. Remember 56 inches, you need more you need much more than that, you need much more than that even to be able to lift yourself okay. So even if you lose weight, someone like me there is no chance we can fly with flapping because the lift requirements is far more than what any wing can probably give but there are so many people in this class who are much more able bodied, very swift, very slender, light weight, okay.

Even those people will need such a huge amount of pectoral muscles that it will be impossible to fly. Now this is something which many people did not know and they were just challenging themselves. So do you know who is the person who first discovered this? Who is the, who is the person who first gave us this knowledge that “Look, like birds we should not use the same mechanism for generating lift as well as thrust, we should have a separate system for lift and a separate system for thrust". I think the person who actually figured this out for the first time, we should respect that person as the real originator of aeronautics okay. This was not Wright brothers, everybody gives them credits for everything in flying.

Far before Wright brothers, there was one aeronautical engineer I would say who were able to figure out. Now this is your assignment on Moodle page, okay. Even in the last class I will not leave you, you have to find out who is the first person to tell us "Guys, let us delink thrust and lift producing mechanisms and only after that human beings were able to actually achieve some success in flying".

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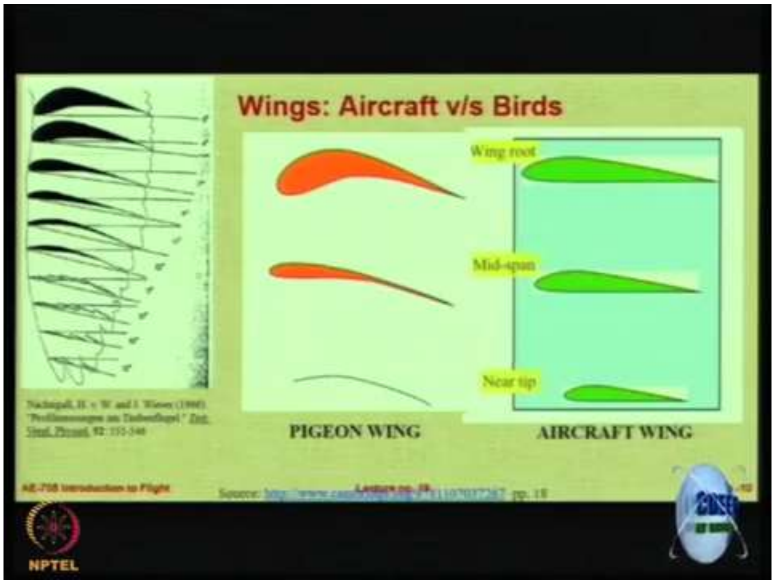

So, let us look at the differences between the structure of the wing of an aircraft and that of the birds. So, here is a typical aircraft wing, you have a thick aerofoil with large chord at the root and you have a relatively thinner aerofoil or may be the same thickness, but a lower chord at the tip and in between it changes, this is what we are familiar with. But if you look at the wing of a bird, you find that not only does it change, now the three wings that you saw, the three cross-sections of the wings have the same camber, but here you can see the camber is changing, the thickness is changing and the shape is changing ok. And if you actually draw the cross-sections around along the length, you will find they are differing.

So, some people have tried to figure out what should be the change in the camber and in the thickness and in the various parameter of a wing as we go from the root to the tip and they have tried to find the optimum distribution of these parameters to generate the best values. So, a simple observation is that is a wing of a pigeon exhibits far larger changes in camber and thickness along span compared to even a Boeing-747, okay.

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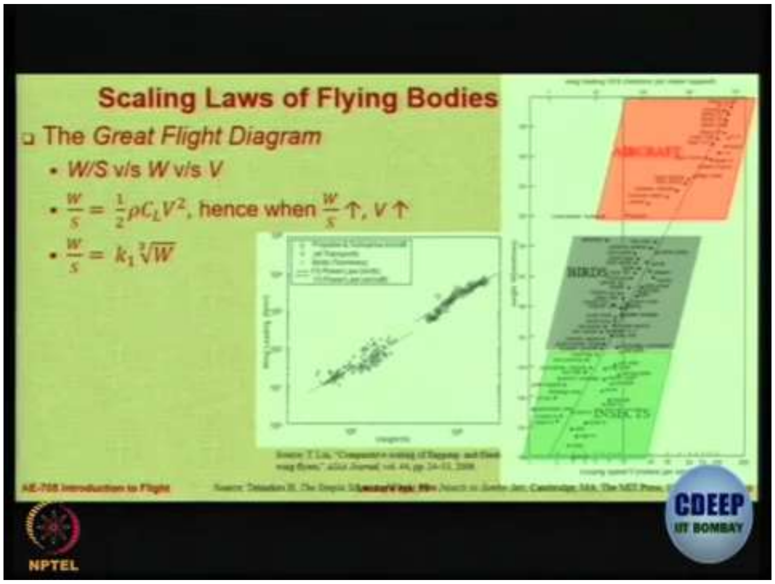

Okay let us go ahead, now some people have done a lot of research on the scaling of birds, this is a very interesting topic, why only birds? There is a gentleman I will show you now, he has given us a great flight diagram that one diagram is applicable to all aircrafts. Natural fliers starting from mosquitoes, insects, to bats, to birds, to fighter aircraft, to transport aircraft, everything comes under one diagram, so that diagram basically is wing loading versus weight versus the velocity, okay. This is that diagram, now you cannot read it, but the top portion consists of aircraft, the middle portion consists of birds and the bottom portion consists of insects. See how beautiful this diagram is, it captures in one page, the parameters related to the flight of all kinds of system, natural as well as manmade.

So, aircraft, birds and insects actually follow the same laws okay. So, wing loading basically is $\frac{1}{2}\rho C_L V^2$. Hence, as W by S increases, everything else remaining same, your density remains same that is same altitude, if CL remains same that is the same inclination or same angle of attack, then W by S increase means V increase. So, if there is a higher wing loading, there is a high velocity, so that is what is shown here. So W by S can be given as some particular value K, a constant K to the third root of W. The reason is that CL also has W correct, and V also has W inside it, so another graph was obtained and where the only difference is the factor K1, which is around 53 for aircraft and around 30 for bird but wing loading can be obtained.

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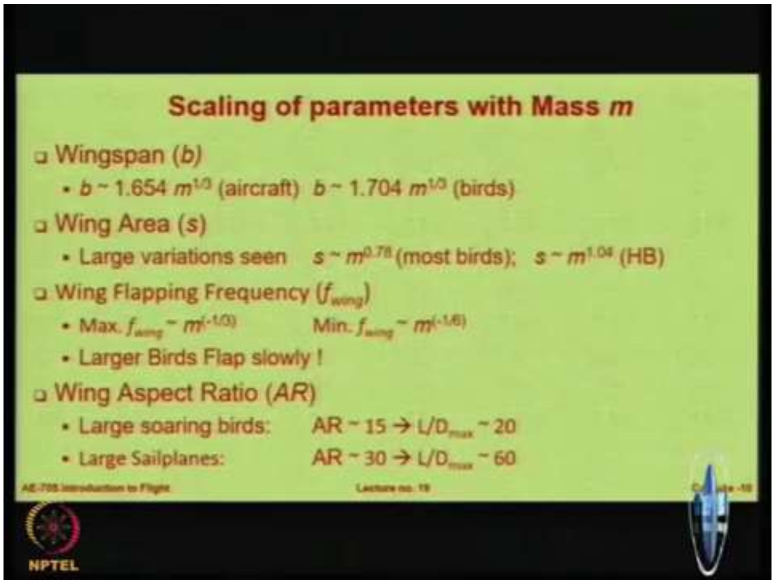

So, you take a bird, find its wing loading, you can get rough idea about how much it weighs, okay. So, wing span that is how much is from tip to tip, that is just a function of the cube root of the mass of the aircraft and also the cube root of the mass of the birds, actually 1 by cube root. So, if you want to scale an aircraft you make a small model and you want to make a bigger aircraft, you know the weight of the model, using the same structural and fabrication techniques; remember this is very important, you can predict what would be the weight of the scalar aircraft. Similarly in birds wing area, in wing area we see large variations, okay. Wing area is not a constant; wing area varies as mass to the power 0.78 and mass to the power 1.04 for some birds. But most birds are of the order M power 0.78, wing flapping frequency also is a function of the mass, cube root mass, so maximum and minimum is one third power and one sixth power.

So, what we observe is that large birds which are heavier, the mass is larger, so because it is mass power minus 1 by 3, so larger birds are going to flap the wings slowly and that is why you see slower birds flap the wings more fast, larger birds flap the wings slowly that comes from this correlation. Then you look at the aspect ratio of the birds, we find that for soaring birds aspect ratio is around 15 and that gives you L by D max of around 20, whereas for large sailplanes, aspect ratios are higher and L by D max is of the order of 60. But these soaring birds are able to do much better than soaring planes, even with a lower aspect ratio because nature has given them the ability to locate where the vertical drafts are there, where the air currents are there and hence they can actually fly more optimally.

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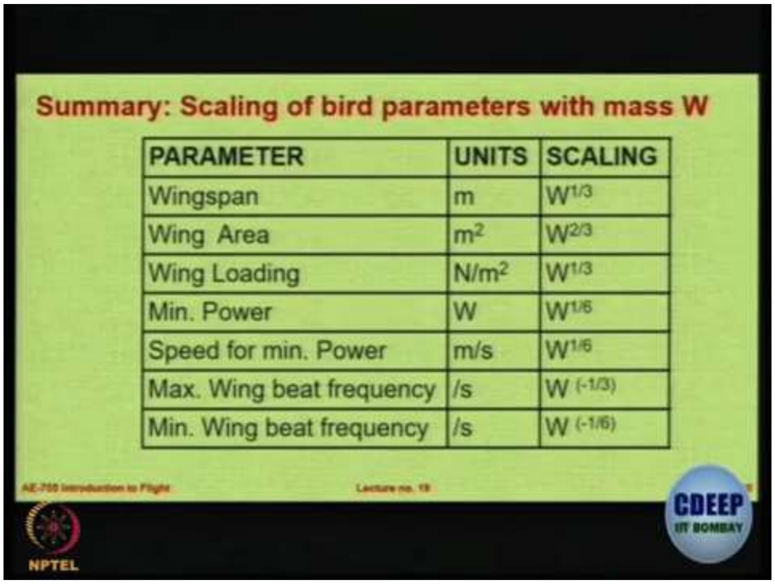

So in a sense summary, this is the correlation between the various parameters and the scaling law. So this just tells you that if you look at 50 birds and if you want to find out what kind of parameters each one will have, you can get your answer just in terms of the weight. So in other words, all birds are equal, they may look different, they may have different characteristics, but mass is the only parameter with which you can actually scale between the birds.