Aircraft Design
Prof. A.K Ghosh
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture – 27
Take off: Wing Loading and Thrust Loading

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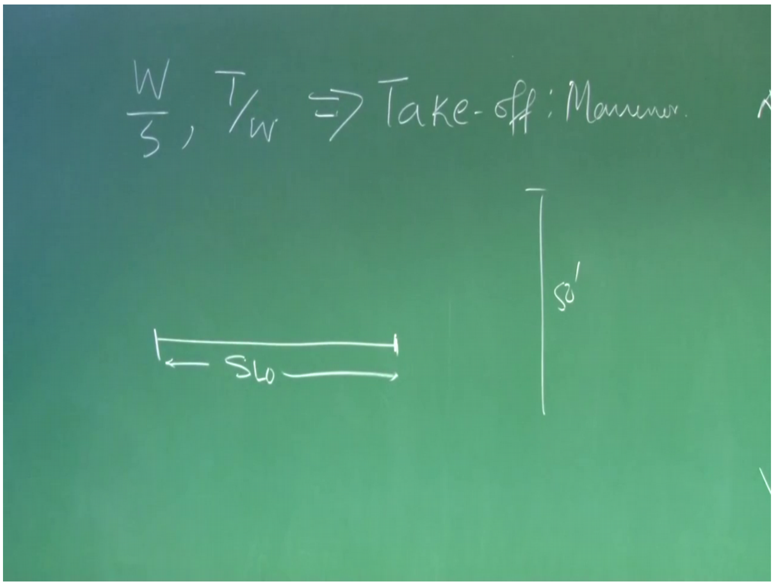

Good morning friends. Today we will be discussing about wing loading and thrust loading together to meet take off conditions, what is our aim to take off maneuver.

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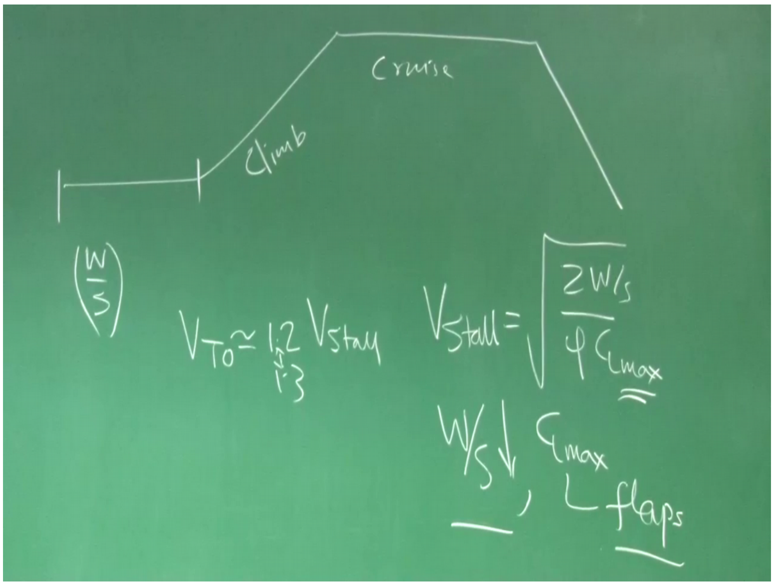

So far you have seen we have talked about say climb, we have talked about cruise, we have talked about loiter range, but today most important thing we will talk about is, what should be the wing loading or how a designer should perceive wing loading to meet take off conditions. This take off landing are two very important operations because you understand most of the accidents you will find may be minor, may be seniors you have been during take off all landing. For example, if you are trying to take off and you have not attend the required speed and you try to take off and you increase the angle of attack and it may go into a stall, it can fall like this we call premature take off.

Sometimes we will be coming for landing and the speed is much higher than desired. So, it hits the ground and it may cause serious damage to the aircraft. You also know that when I talk about V take off, this is some percentage of V stall could be this some percentage, 29 percent or 30 percent more than V stall and to ensure that V take off, it is less. We try to see that V stall is less. V stall is again 2 W by S rho C L max and to reduce V stall, we have two options. One is reduced the wing loading or increase C L max, that is W by S, I reduce or increase C L max. Once I try to increase or decrease W by S, once I try to decrease wing loading that effectively means I want larger wing area.

Larger wing area although we will give you a lesser wing loading, so V stall will be less, but larger wing area means larger drag. So, you need more power. So, you have to do a compromise. So, another way is you increase the wing area to some extent and also, increase the C L max. How do we increase the C L max? We use flaps. The various types of highly devices, using those you can increase C L max from 1.2 to even 5, but you know that nothing is free. As you increase C L max, there will be increment in the drag and also, it will generate more moment about the centre of gravity. So, this is a quick look on V stall, but when I come for take off for a designer, you look for what is that distance I required to ensure that after that it has enough speed and if he rolls up like this, it should be evolved to go for a take off and as per the definition, it should clear 50 feet height. That is as per the regulations, right.

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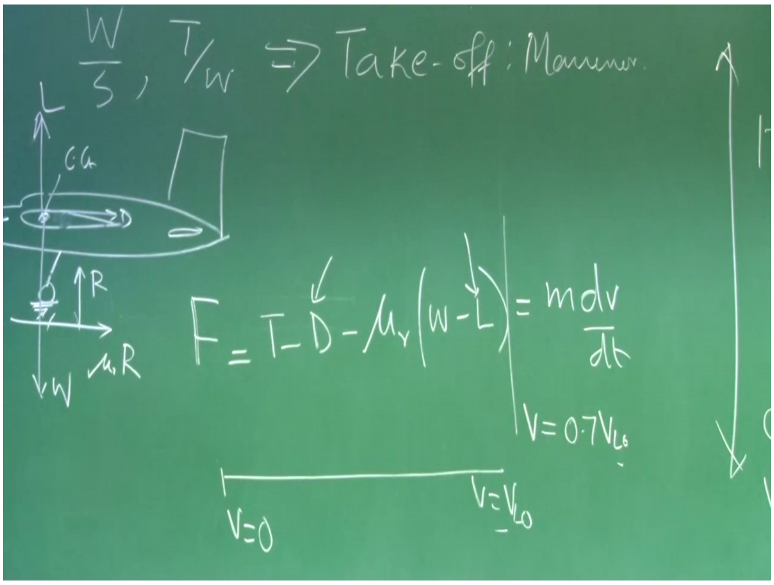

Before we go for all those prescription of T by W and W by S, let us have a systematic look through physical modelling what is happening during take off. See if I draw a simple diagram let say this is thrust and there is one landing here, another landing is somewhere here, the C G somewhere here. C G should be let say somewhere over here. We try to keep C G slightly ahead of the real landing here, otherwise if C G is at the back side, disturbance will make the aircraft end point hitting the ground. So, generally C G will be little ahead of landing, real landing here and if now I draw the diagram, I will have some weight acting from here and then, the reaction are of course lift and drag lift and drag. There will be acting at the aerodynamic centre. In fact, we transfer all the lift and drag forces along with the moment to the aerodynamic centre, but for analysis what we do is, we further transfer those two centre of gravity.

So, when I write lift and drag, assume there is a moment where moment is balance. Let say for our case if I have this sort of a diagram, then I can easily write F minus or F equal to T minus D minus mu R into W minus L and that equal to m d v by DT. What is this? The next force acting that is thrust minus drag and then, there will be frictional force mu R into R and R is nothing, but L minus W. So, minus sin is here, so mu R into W minus l. So, this is straight forward. You have done in performance course. Now, imagine when you are going for take off, you are starting some V called to 0 to V called to V lift off at the speed at which you will actually take off the aircraft increase angle of attack and groove for a claim. The problem is as I am increasing from V called to 0 to V called to V lift off the drag and lift is also going to change because they are function of speed, right.

A designer will not like to do all those meticulous thing. Designer will led to with some average values. We will try to look for some average acceleration which this net force is causing. Once he knows average acceleration and if it is correct where we know V square minus U square equal to 2as. So, S equal to V square by 2a, where the average acceleration using this equation, generally it is seen that if I compute this aerodynamic force at 0.7 V lift off, that is a good approximation to assume. There I can use the concept of average acceleration for most of the aircraft. This is nothing new. I am telling I am just revising whatever you have done in performance. Let us not lose the sight. What we are looking for today is how do I visualize wing loading for a particular take off mission.

So, if I use this concept that I can take this acceleration evaluated at 0.7 V lift off and use the concept to average acceleration. So, dv by d t will be this force divided by M and SV square minus U square equal to 2as.

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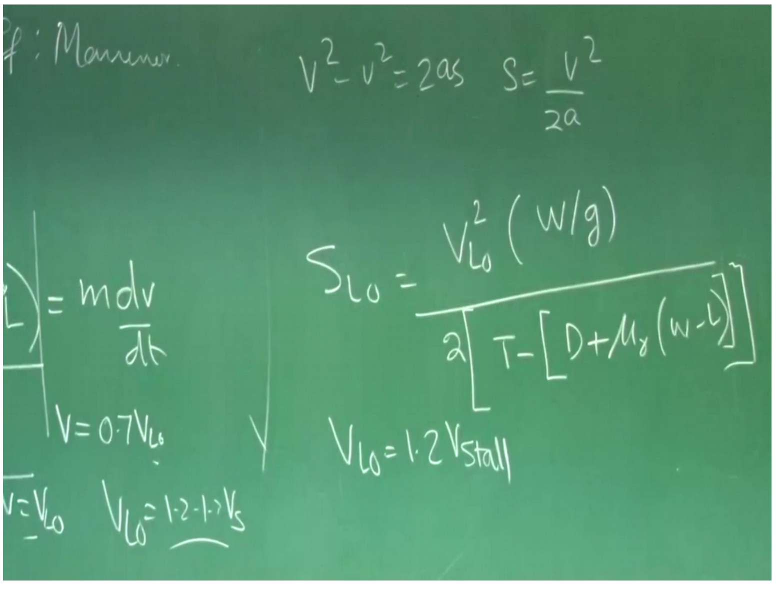

So, S equal to V square by 2a, where a is basically this force divided by mass evaluated at 0.7 V lift off and we know V lift off we can take 1.2 to 1.3 V stall. Generally you will find the regulatory body give those numbers. It is more towards 1.2. Exact FA regulation

I will be discussing when I will be solving a case. This is just to tell you how do you proceed.

So, if I follow this, then I will get S lift off as V lift off square into w by g divided by 2 T minus Dd plus mu r W minus L. This is average and if I take V lift off equal to 1.2 times V stall.

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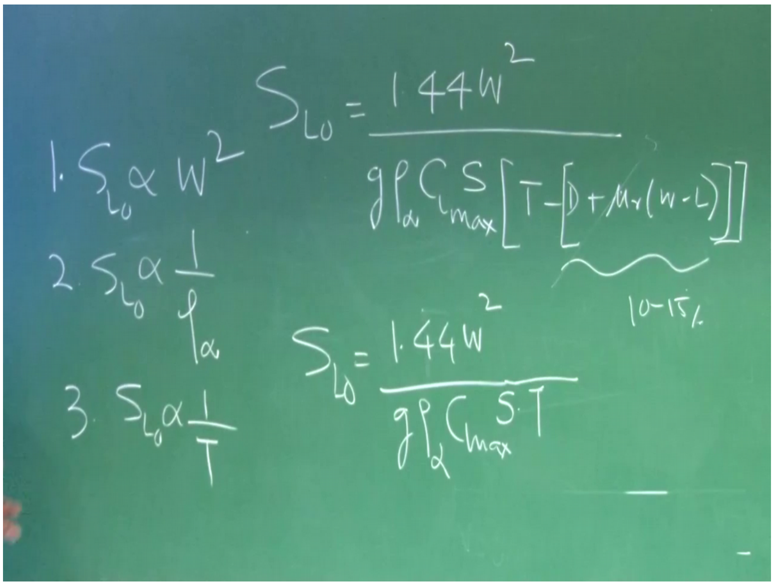

Then, I further get S lift off expression as S lift off equal to 1.44 W square by g rho infinity C L max into T minus D plus mu r into W minus L. If I am not wrong which is correct g rho, yes.

Now, let us see how a designer will look into this expression, so that you can find out the wing loading required for S lift off. There must be some S missing here, right. If I am a designer, I will ask myself what will be the contribution of this compared to the thrust to have initial number, right because at this point my aircraft is completely ready. I need not know what is exactly the wing area, what is the city. So, what do I do which experience I know this gentleman maybe 10 to 15 percent of the thrust. So, I say as a designer I said let me neglect this term compared to thrust. So, I will get S lift off equal to 1.44 W square by g rho infinity C L max S into T.

This is a compact expression I would like to see whereas, wing loading hiding here and whereas, T by W thrust loading hiding here because we have agreed when I go for a take off, if I have more thrust loading, I will be able to accelerate faster, right. So, S lift has to be a function of T by W. If w by s is small, so wing area is large. So, it will generate lift much earlier than if the area was less. So, W by it also plays a role we have seen that whereas, these W by S and T by W hiding in this expression and how a designer will draw its attention.

So, designer first we will simply see that S lift off goes directly proportional to W square wet square. That means, sensitive to total weight and that is why the aircraft or classified in terms of weight also. So, below 700 kg, below 1500 kg, below 2500 kg like their classifications of their because the weight directly affects how much land role distance you required to take off and that is a very important constrains for an aircraft operator. Also, it tells you that S lift off goes inversely with air density from where you are going to take off. So, imagine if you are design in airplane which is just adequate to take off in Delhi, right and now you want to take off same aircraft from lay area which is the high altitude lower temperature, then what will happen in lay this density of air will be much less compared to Delhi.

So, the lift of distance will increase. So, it is possible that you will not be able to a take off which same load what we will have been able to do in Delhi. So, how we will handle that? Suppose I am going to full capacity passenger and I am able to take off in Delhi, right and now same aircraft I want to take off from lay. So, how the designer will tell or advice you what you do? Designers is that it is proportional to W square. So, it will same aircraft I can take off from lay provided we have reduced the weight. How can we reduce the weight? Either you take less passenger or take a half full load. You reduce it will take off from there, go to a nearby station where there is a enough land load distances and that is how its operations are optimized.

Another thing you please remember when you are taking off from Delhi with full load and you have to land in lay, you know the weight has reduced because full consumption is happened. So, that helps you reducing LS lift off or S touchdown lift off and touchdown you can see that they are almost equal. All are very close, right. For normal generalization aircraft also, I understand from here that S lift off goes universally with thrust. More thrust means lift of distance we will be less which is correct. More thrust means more acceleration. So, it will quickly get that top speed. So, it will recall a lesser distance. So, nothing unusual, this is conceptually correct, but unfortunately a designer primarily thing in terms of wing loading and thrust loading that is W by S and T by W.

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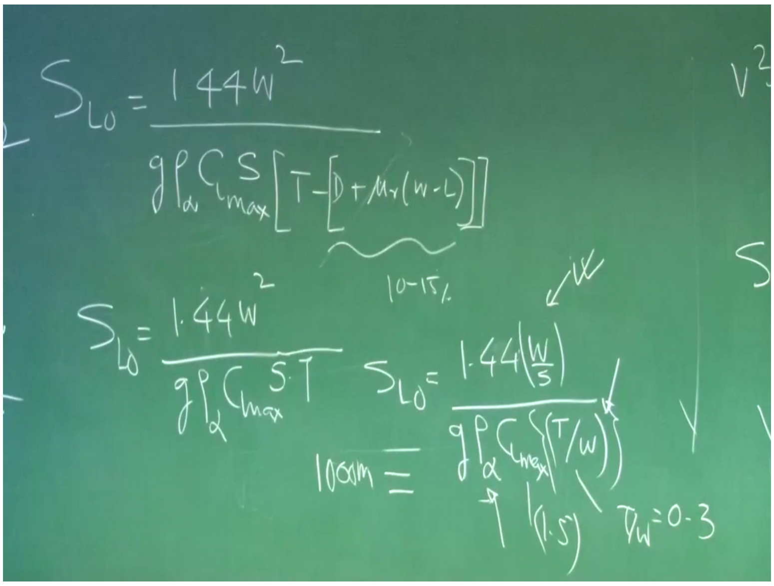

So, now, how a designer will look or extract juice out of this expression through wing loading and thrust loading. I can write S lift off equal to 1.44 W by S divided by g rho infinity C L max T by W. This is equal to expression, right. So, now, designer is more comfortable with this sort of an expression. These are all through analysis. You know somebody will give you expression. This is a simplest example. You will get lot of complicatory expression derived by mathematician aerodynamics whereas, as I told you designer is not a huge highly analytical personal, highly mathematical person.

So, he has his own vocabulary to extract information and he will immediately translate this. I look like this and I will see this expression as wing loading here. I know this is thrust loading here, right. So, now, what he will do if there is a restriction by regulation that lift of distance should be 1000 meter. We will put 1000 meter here, then what is the wing loading or what is the thrust loading he can afford during take off, you will give more to a thrust loading, right. So, he will pick a thrust loading value T by W. Let say he has 0.3 and he know that C L max I can increase by using flaps highly devices. So, depending upon type of aircraft see for example, if you are using 206, you will not put very complicated flaps. You will put a plane flap.

If it is 22, then you put lot of complicated flaps, right. So, depending upon the type of aircraft you are designing, type of passengers you are carrying or type of air carrying transform, the aerobatic was it is a aircraft, you have an idea what type of highly devices you going to use. So, you have an idea about C L max. So, you put C L max, I will keep around 1.5. movement. It has C L max 1.5 here actually taken decision what type of highly device you going to use. 1.5 means you will be using most likely you have plane flap, right.

If you put 2 or 2.5, you know there will be going to use of fouler flap or some slot something you will do. So, heat also knows what is the density of fair we have from mostly got to operate. So, he picks this, put this number and get what is W by S required is it think clear from this complicated expression and the designer is expected to do this sort of a preliminary analysis that is where we call the other feel for numbers and make the thing simpler and then, translate it into the vocabulary which he will be using in configuring and aircraft, right.

So, this approach we will be using when we do an exercise of designing an aircraft with a test case, right. Before I end this part, please note that which take off distance is described as S lift off plus.

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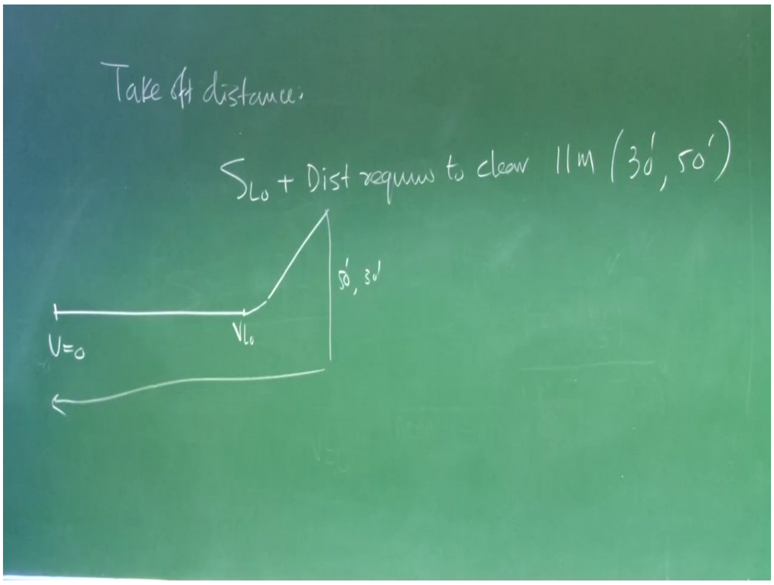

The distance require to clear 11 meter means it is 30 feet or 50 feet. So, with 30 feet or 50 feet depending upon military or similarly as specification that is I start from here, we lift off distance, then I rotate it, then I claim all and this distance height is 50 feet or 30 feet.

So, this is typically roughly is the take off distance for a single engineer craft. We will also talk about balance feed length may be in the next lecture, that is primarily important for multi engineer craft. If one engine fails, then how do I take a decision, but they apply break to hault or I continue for take off and do a circuit fly and come down. So, that will be my next lecture, ok.

Thank you very much.