Aircraft Design
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Lecture - 02
Wing Loading and Thrust Loading

Good morning. So, we are discussing about aircraft design. And we have seen in the last lecture 2 components of an aircraft.

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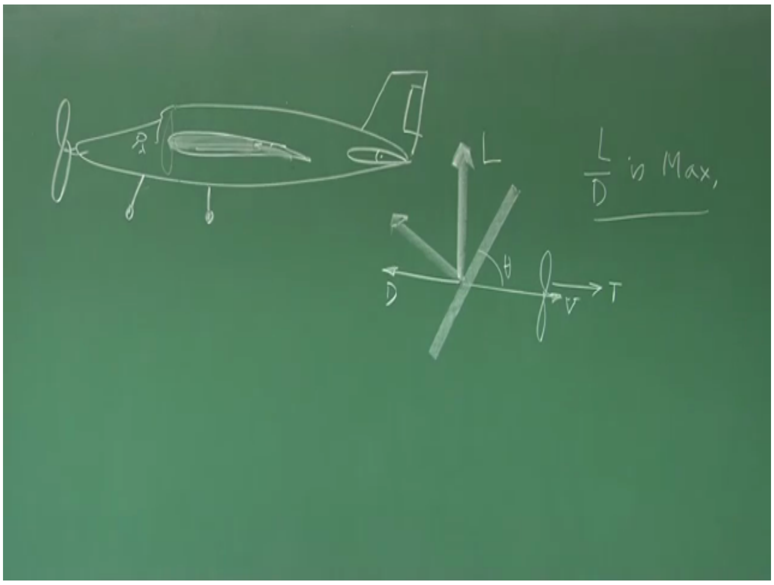

And if I draw an aircraft, why not this is the horizontal tail and this the elevator, there is a vertical tail there is a radder, and importantly there is a wing, and there will be flap, there could be engine, and of course, we will have landing gear these are the primary components we have right. We also know this aircraft is primarily designed to carry passenger or a cargo from one point to another in a civil sense right. So, we have to also bother about what is there inside this fuse large right. And also we know that somebody will be flying it. So, there is a pilot there may be more than one pilot, they look crew members to say.

All those things are to be integrated in the design the requirement is to be integrated in the design. Many times this requirements are conflicting. So, as we develop we will see how to handle these issues. As I have told you earlier this course will focus primarily on the conceptual configuration design with more stress on the aerodynamic aspects right.

Once I say aerodynamic aspects let us go back to our first course where we talked about airplane performance. And we knew that if a flat plate is moved with a velocity v, then it will have a reaction experienced and one of the component of reaction is called lift another component is called drag right. As a designer I need lift because I need to lift the weight as a designer I want drag to be as low as possible, because this drag will try to reduce the speed because after all how I am getting the speed is through an engine which is producing a thrust a force. So, if I want this drag to be handled with at is I will always prefer the drag to be as low as possible, but in totality most of the time we look for a configuration where L by D is maximum.

Most of the time whenever I think of lift and from aircraft we know that the major responsibility of the wings is to take care of the lift right and from here also we know if there is a angle between velocity vector and the plate, that will be responsible for generating the lift at a given speed given altitude etcetera. We know right, and whenever you say the aircraft should produce lift equal to weight.

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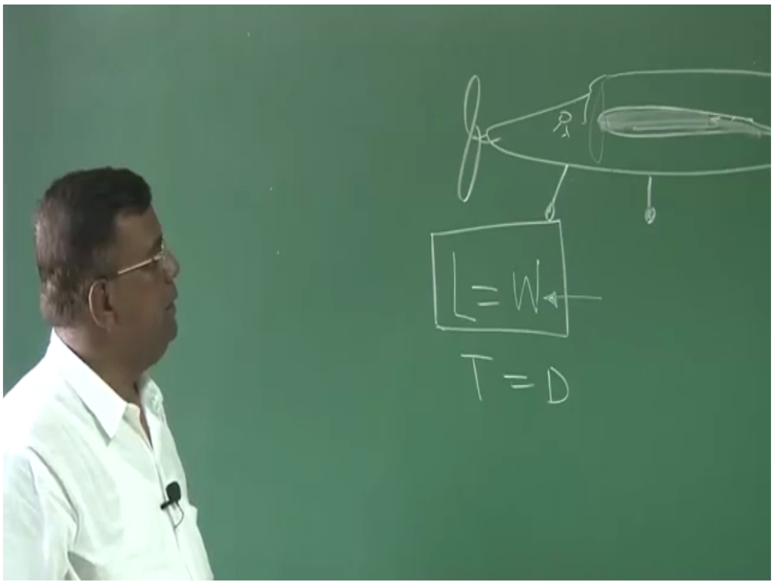

When I am flying at a cruise like this that is if I recall your performance lecture you have list to popular equation lift equal to weight and thrust equal to drag. If I see here first equation lift equal to weight, how a designer will see this condition lift equal to weight.

Why it is important question, I need to have an airplane I need to have an wing because we have agreed that lift is primarily responsible for generating lift. So, I need to have a wing especially designed. So, that it can generate lift at different altitudes a different speed as per our requirements. Here also the designer when I see lift is equal to weight. So, if I can somehow minimize this weight without compromising the volume, because after all we have to carry cargo passenger etcetera. And if somehow I can reduce the weight reduce the weight, means what it is the aircraft empty weight somehow if I reduce this it will help me my conditions will be lesser taxed.

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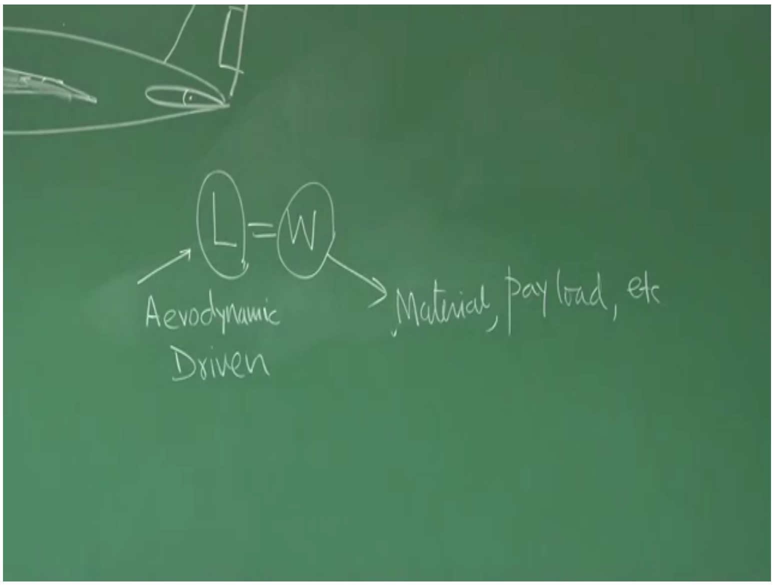

So, if I now try to see little more through this equation what do I see. As a designer when I write lift equal to weight I have weight and lift these 2 aspects. One is primarily aerodynamic driven which is the lift this is aerodynamic driven, and this weight is basically material when payload etcetera driven right. Why weight is important we will find aircrafts are categorized by their weight class right.

So, below 700 kg below 1500 kg like that one characterization will be there. So, weight does play an important role. So, that there is a need to characterize an airplane, one way through weight why weight is important.

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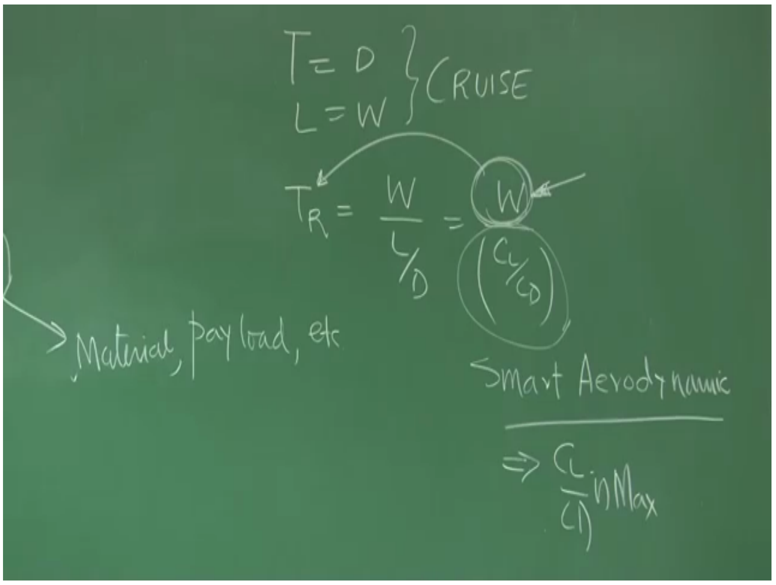

Let us see this if I use thrust equal to drag and lift equal to weight I know that thrust is required it will be W by L by D or W by C L by C D. So, we could easily see that thrust required for a cruise flight this is cruise is directly proportional to the weight we are carrying and inversely proportional to C L by C D. So, here a and smart aerodynamic person or smart aerodynamic approach we will try to ensure the C L by C D is maximum an a person an expert who are on the material side they will try to ensure that the weight is low.

However, the primary objective of carrying capacity are carrying pay loaders etcetera then the strength also comes very important. You need to have particular material a particular composition particular combination of material to ensure that it is enough strengthened to counter the stresses develop when the airplane moves in medium which is air in this case. So, you could see that this is very important. If I want to ask myself how much thrust is required for a particular mission requirement, let us say you want to design an aircraft there will be some mission requirement we will talk explicitly on mission requirement.

But to start with what could be mission requirement that you say my airplane should be able to climb up to altitude of 10 kilometer 11 kilometer, my aircraft will be capable of cruising at that altitude with 150 meter per second hundred meter per second, and if it is high speed is 300 meter per second even then it can go up to 1.5 to depending upon what where you are designing, but if you recall I have mention the initially we will be talking about low speed aircraft. So, I need to know this weight because that will tell me what is the thrust required and I can now think of what sort of the engine. I will be picking up right also remember I have told the engine part will be almost like that taking things on the shelves right standalone engines reliable where I am going to design engine in this course at all.

So, weight is that way extremely important and second part as a designer you need to also look here.

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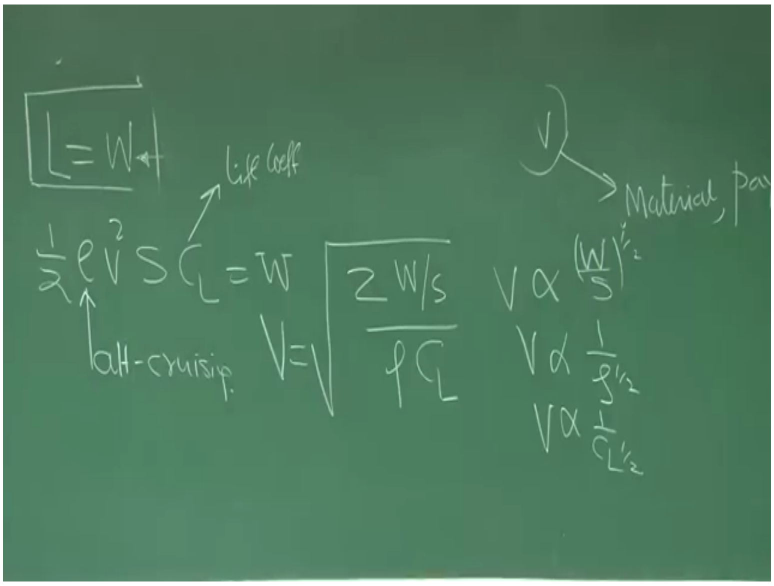

When I say lift equal to weight lift I know half rho v square S C L equal to weight right rho is what rho is whatever altitude you are cruising or taking off exist of course, for cruising I am talking about, C L is the lift coefficient and of course, W is the weight. And if you see here the speed required to maintain lift equal to weight will be given as 2 W by S by rho C L. So, from this cruise condition we find that whatever altitude I am flying, I need to have enough engine thrust or power. So, that I can attain this much of v and that v is proportional to W by S. It is inversely proportional to density inversely proportional to C L or C L to the power half or to the power half in particular and if I write it here also to the power half.

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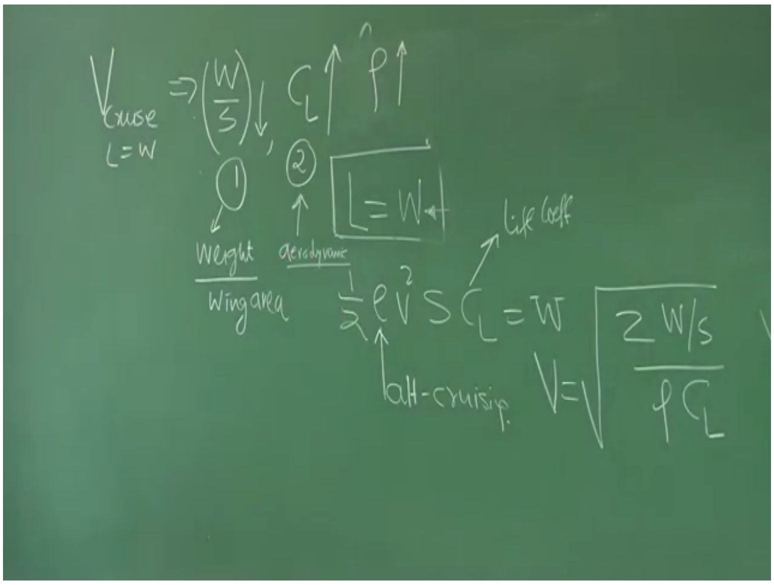

So, if I want to cruise at a speed which is lower. So, that my engine requirements are less what option I have got then, I must if I want to really see that v cruise which ensure lift equal to weight if I want it lower; that means, I have to ensure that W by S is also low, C L is higher and rho is also higher it is directly from here. As for as rho is concerned that is not in our hand you get depending upon which altitude you are flying rho in change right. Now there are 2 things one is W by S another is C L. These are 2 important parameter which we need to understand at the designer and one is W by S which is primarily the weight by wing area and this is primarily aerodynamic.

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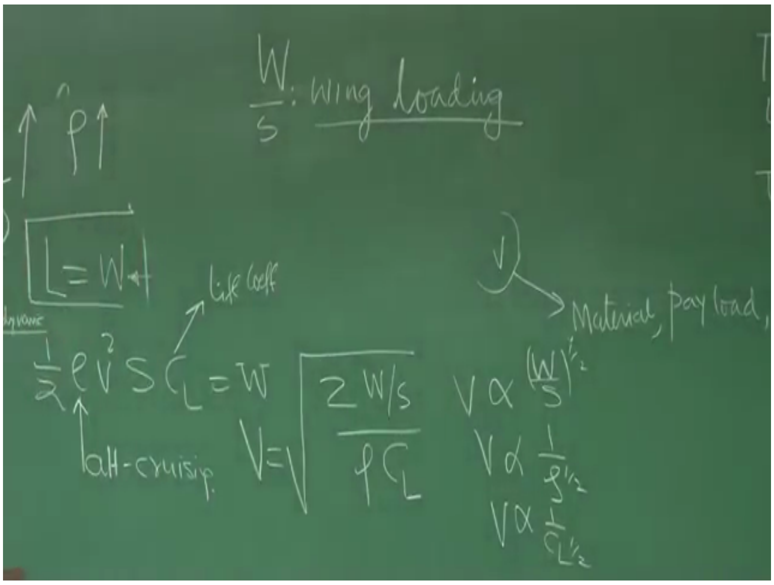

And this W by S is known as wing loading, where that lift equal to weight and half rho v square S C L equal to weight right.

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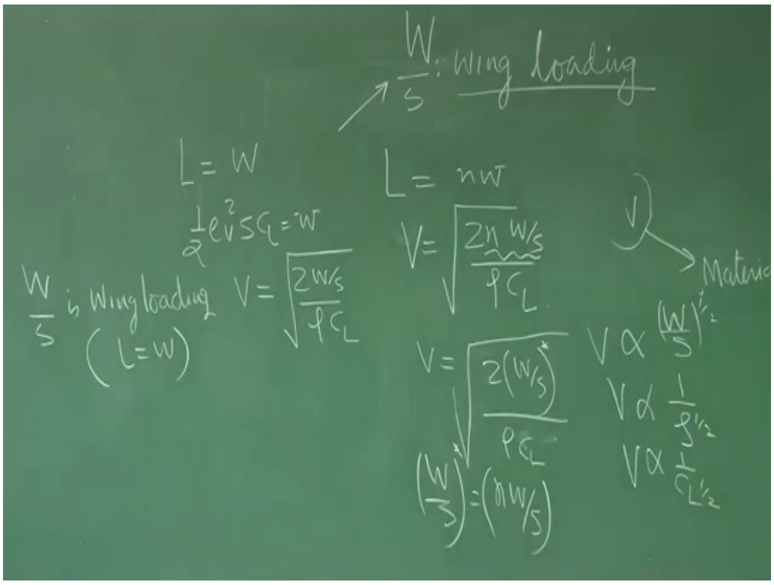

Ah v equal to 2 W by S by rho C L under root this is the speed required to maintain lift equal to weight at an altitude rho which is flying at a given C L.

But when I talk about wing loading please understand this this wing loading has a clear cut the wing loading need to be clearly understood because there is a generally confusion I have seen among the student. When I say W by S is the wing loading, I am assuming lift equal to weight right, but you can see that airplane can also flies at the lift equal to n W having a load factor of n in that case wing loading or v required to fly will be 2 n W by S rho C L. And you could see that if I write this as 2 W by S star by rho C L, what I am seeing W by star is nothing, but n W weight that is the wing loading has the actually increased right one is way for a load factor n.

So, whatever wing loading we talk about, we are clear back of our mind that we are talking about lift equal to weight; that means, if you want to if designing an airplane for a mission and you have chosen W by S some number you should not expect that number is good enough to do a (Refer Time: 15: 30) flight where the wing loading required is W by S star which is nothing, but n W by s. So, as if the weight has increased by n times right.

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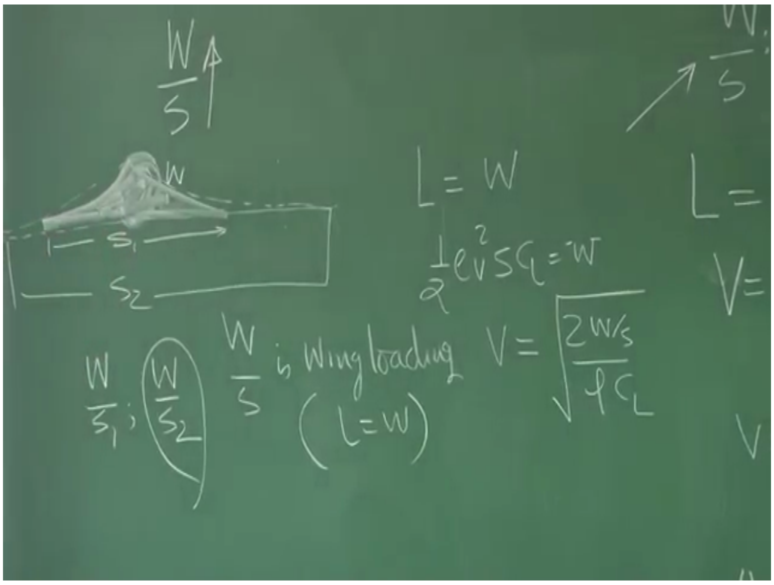

You could easily understand, if I go on increasing the wing loading meaning thereby what does it mean if I go on increasing, the wing loading; that means, I am relatively I am reducing the wing area.

For example, if I have a mass or weight W, I flatten it and let us say W remain same and area is S 1 second case same thing, but I flatten it further and that time the area is S 2, the first case it is W by S 1, second case it is W by S 2 the wing loading W by S 2 is less than wing loading W by S 1 the moment wing loading is less, for the second case you could see that speed required to maintain level flight is also less the wing loading place or the important role in deciding the speed for a given C L right. We further see what this wing loading.

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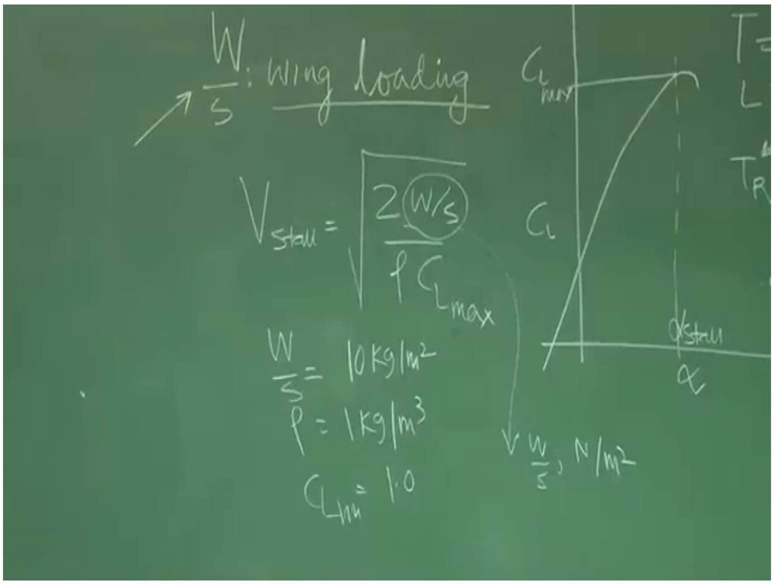

Actually wings an in designer you are aware of v stall, we have talked about V stall as the root 2 W by S rho C L max. You also know C L max of other 2 cruises this is C L versus alpha this is plot it like this, some where there is a alpha stall and this gentleman is C L max. Typically the C L max value for the average side if I say or a conventional wing without any flaps and all, it is not a bad idea to take that value as 1.2. Now see here, what is V stall v stall is the minimum speed required to maintain lift equal to weight right.

So, let us have an idea if W S is increased what will happen, V stall will go on increasing. Similarly, if rho goes on decreasing that is I am taking off in Kanpur then taking off in lay Ladakh, V stall also will increase in lay Ladakh for same W by S or C L max. That is for same W by S and for same C L max, if we want to fly with a minimum speed lift equal to weight that will be higher compared to in Delhi or Kanpur because rho is will less in lay Ladakh area.

Let us see, let us have a num field for number let us see W by S is 10 kg per meter square. Please understand this W by S you need to be consistent should be newton per meter square right.

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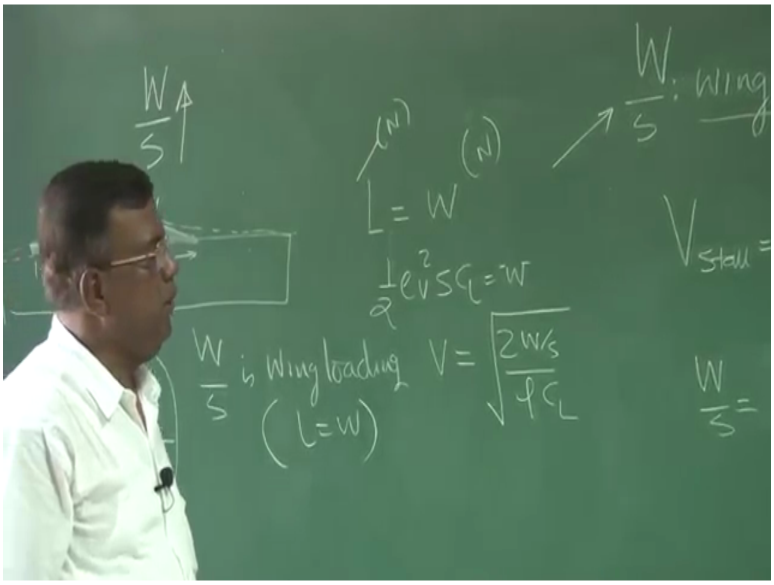

Because lift equal to weight. So, this gentleman is newton. So, W also has to be newton right, but I am writing W by S as 10 kg per meter square. And if rho if I take it is 1 kg per meter square meter q, and let us a C L max I am taking here again 1.0 just to make like simpler what will be the V stall, V stall will be 2 into W by S that is 10 this is kg per meter squares we have to multiply by 9.8.

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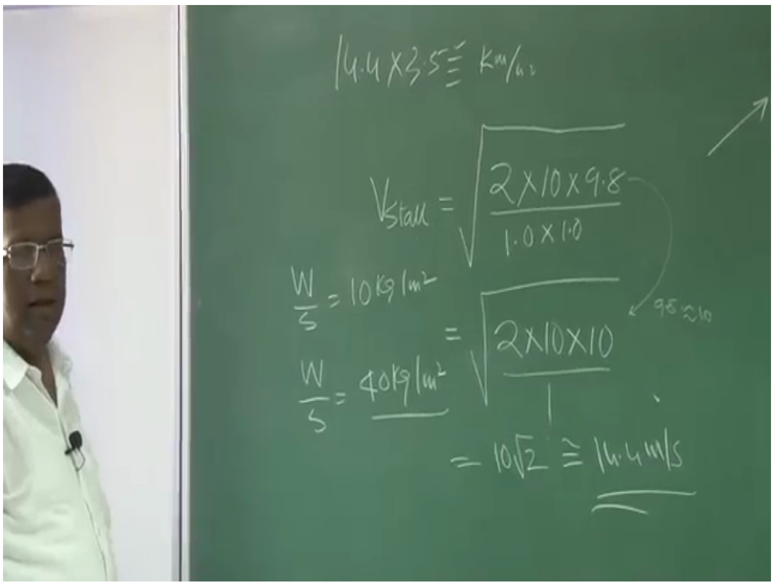

So, for the newton and rho is 1 and C L also I have taken 1. So, this will be around the let us say roughly I take this as 10, 2 into 10 into 10. So, I am approximately 9.8 equal to 10 just for calculation purpose divided it by 1. So, this will be 10 root 2, this is 10 root 2 and root 2 is 1.414. So, this is roughly 14.4 roughly let say meter per second. And what is this 14 meter per second as the designer how do you visualize what is 14 meter per second because mostly like what the filling in terms of kilometer per hour. 14.4 means roughly 14.4 into 3.5. So, multiply this will give you kilometer per hour roughly right.

So, around 50 kilometer per hour right that is the speed now see if I increase wing loading in this case wing loading first 2 as 10 kg per meter square. Now suppose I raise this wing loading to 40 kg per meter square. This 40 kg per meter square is the wing loading typically for motor glider right. We have shown you the first lecture the sinus 912. This is typically the wing loading, if I assume other things that other things are good enough in approximation then I will get V stall as under root let me write it here.

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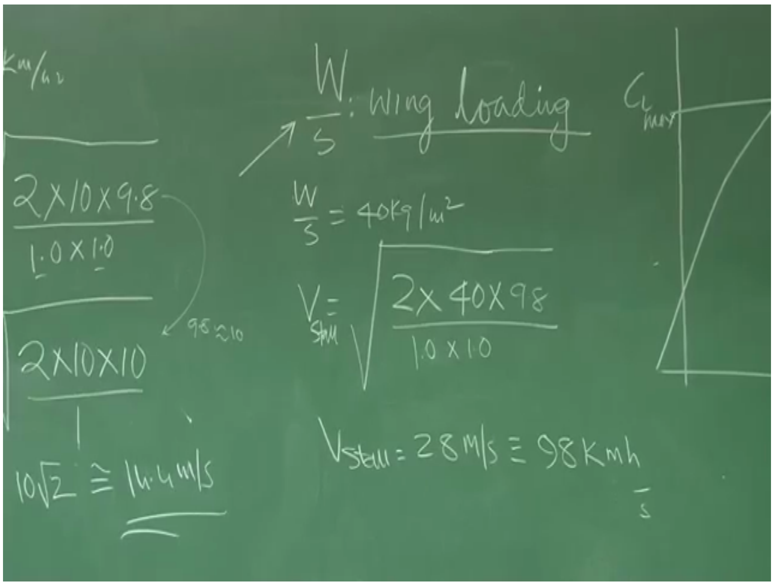

So, what do I am saying is W by S is 40 kg per meter square. So, we will be V stall will be 2 W by S is 40 again into 9.8 to convert a newton rho I have taken one and C L I have taken one please understand C L typically is 1.2 maximum you get for V stall all I need to take C L max, but we are taking it 1. And this also now comes out to how much.

Student: 28.

How much?

Student: 28.

28 meter per second which is equal to this multiplied by 3.5, 98 km per hour. So, 98 kilo meter per hour you understand if you drive a motorcycle is almost hundred kilo meters per hours a huge number right. We will see what happens is W by S become hundred which is typically passenger small business aircraft order will be around hundred small 2 seater, 3 seater.

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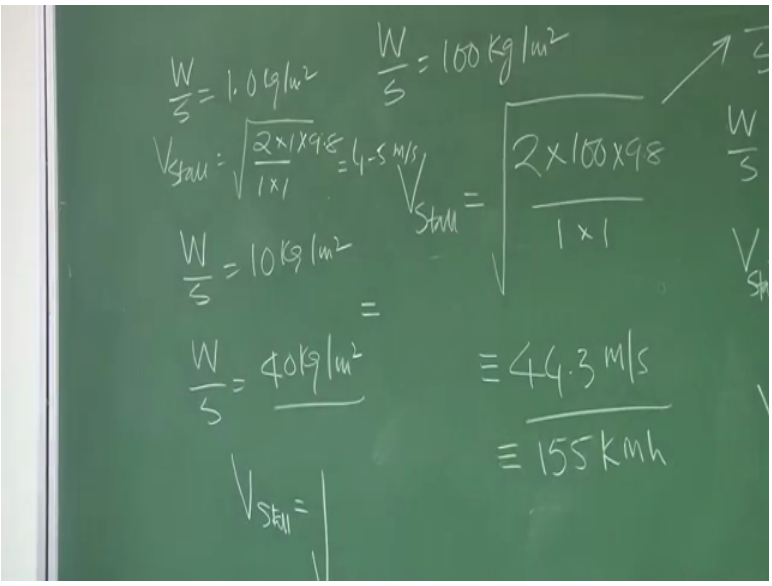

If W by S equal to hundred kg per meter square, if what happens to V stall again keeping density and C L whatever we are using earlier. This will be 2 into hundred into 9.8 by 1 into one this will be how much you know just check.

Student: 44.3 per second.   .

44.3 meter per second. That will be how much 155 kilometer per hour. So, you could easily see that as I am increasing wing loading from 10 to 100 the stall speed is changing from around 14 to 44 or 45 meters per second. Most of our airplane Cessna Saratoga all this thing there will be V stall will be around this right. This number has a meaning we will understand if I now go to typical aero model for aero model W by S is other of 1 kg per meter squares smaller one I am taking about. If it is 1 kg per meter square typical aero model which you know it just takes off, what will be V stall, V stall will be under root 2 into 1 by in to 9.8 by 1 into one this is how much.

Student: 4 to 5.

4 to 5 meter per second as where you say easy to fly such machine, when I am saying V stall from 4 to let us say hundred and for a bigger airplane this W by S will become 300 400 500. So, if you see the V stall will go on increasing, and the increase in V stall means what V stall means minimum speed required to maintain lift equal to weight and who will ensure this V stall. Who will ensure that yes the airplane is moving we cannot if capable of flying with this much of speed this.

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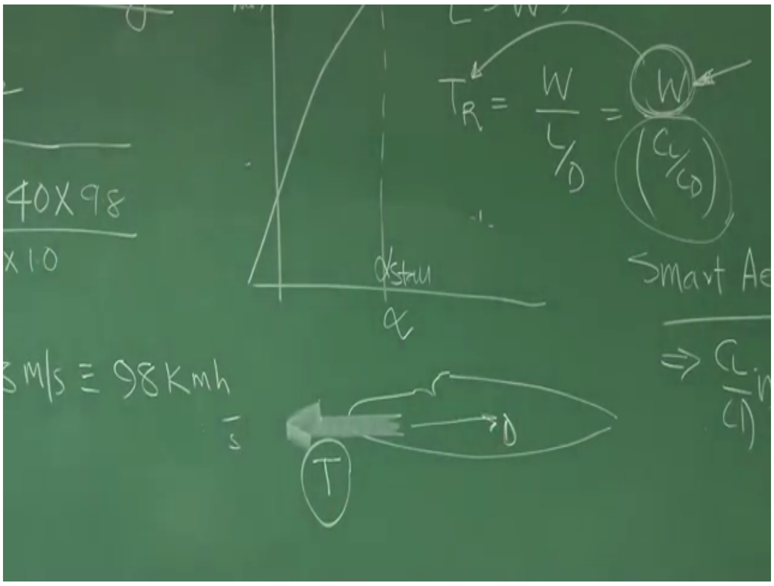

This or that what you require you require this is the airplane we require the thrust of the power should be capable enough to overcome the drag experience by it, as to maintain the speed which we are demanding.

If this number is more it means you need to high power engine. That also means the weight of the engine will increase, the weight increases me again you see your wing loading will change everything goes into a iterative mode right, but as a good designer you should understand what are the implication of wing loading.

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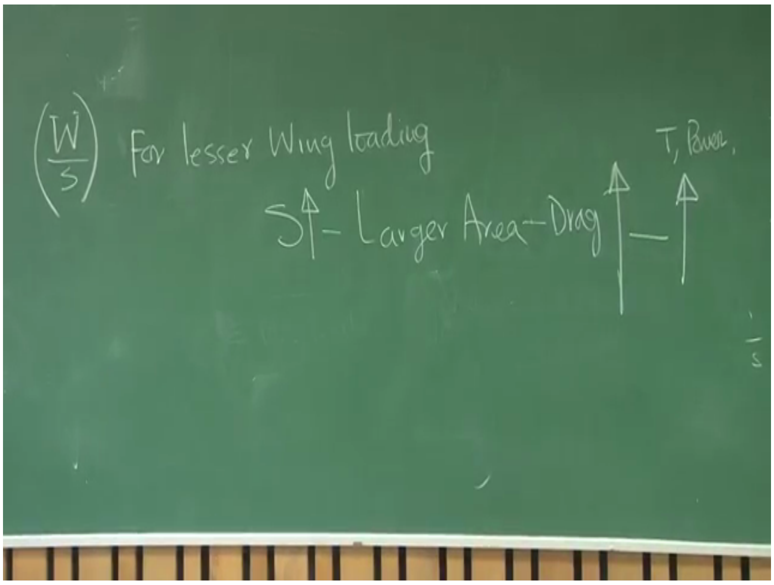

Is there another observation which designer need to have prairie on wing loading, is if I increase wing loading; that means, relatively the area of the wing I am reducing right. If I want lesser wing loading, so that V stall is less for lesser wing loading S is related relatively it should be higher for a given weight right. What is the implication of S being higher? S being higher be larger area; that means, larger area that is good as for as lift is concerned, but what is the problem as there is a larger area that means.

The drag also will increase skin friction drag primarily so; that means, if drag increases that tells you need more thrust or power right. So, you could see that there are conflicts a designer has to satisfy everybody and depending upon the mission requirement will satisfy one aspects more than the other. For example, if it is a fighter airplane where I need larger maneuver I will not fly at a smaller wing loading. I will fly, that wing loading is low. So, if wing loading is low I can accelerate fast because the drag part will be less and also if wing loading is low means relatively the wing is smaller means the aero plane is compact.

So, I can roll very fast if the wing is very large rolling will become difficult. So, all those conflict will come, but we need to know the we need you should be able to smell a wing loading, if a number comes to a figure on your table this wing loading is this immediately should know that oh this has the this has that. This will have this problem this will have this advantageous that is why I am revising few concepts like wing loading etcetera. After a wing loading is a another concept we will be talking about we will be going in detail about wing loading, and all in each lecture and before I go for those lecture I just thought.

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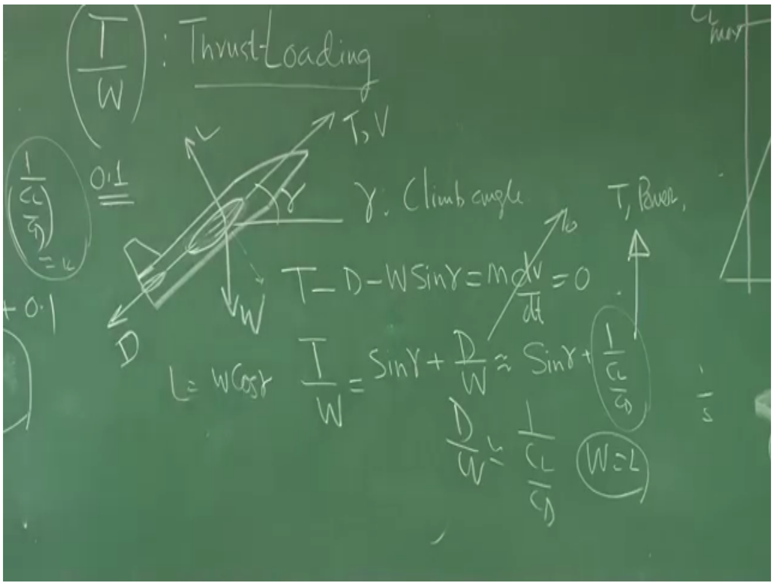

I revise few things there is something T by W if W by S is wing loading what is T by W T by W is also some loading, but this is thrust loading what is the implication of thrust loading for example, wing loading we have seen wing loading has direct relationship with the V stall minimum speed to fly level lift equal to weight. Thrust loading if I want to see again you have to go to your performance lecture, where for a steady climb with all the diagram, which all this diagram that we are flying we are flying such that it is climbing at a climbed angle gamma, gamma is the climb angle and we have explained about steady climb for a steady climb I can easily write T minus D minus W sin gamma equal to m and D v by D T since this is a steady climb. So, I equated this equal to 0 and is climbing at a constant speed length.

Now, if I see this equation, I can write T by W equal to sin gamma plus D by W, which I can approximately write because the sin gamma plus 1 by C L by C D. This part is approximate I am assuming lift equal to weight, but here you could see lift is not equal to weight the component, if you see like this lift will be W cos gamma, but I am assuming gamma small.

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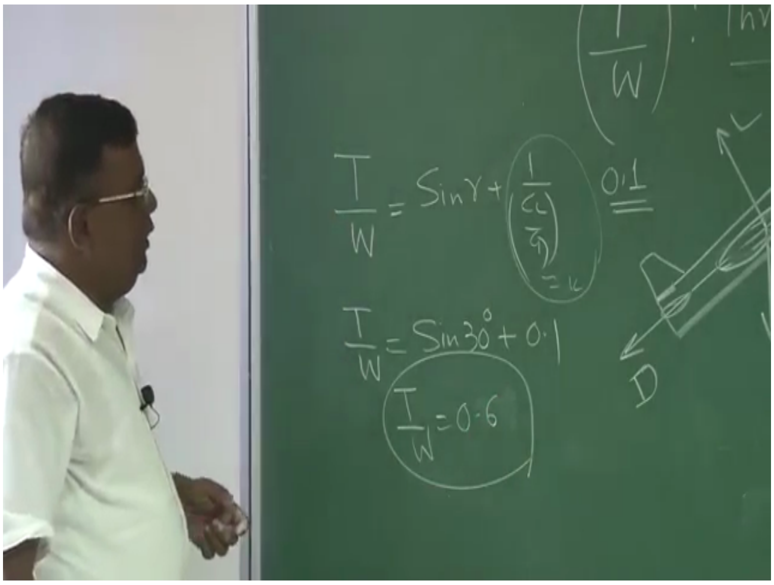

So, I am taking their liberty just for a designer he does lot many approximation to get field for some number this equation is very handy for a designer, once he wants to know what should be the thrust loading typically C L by C D maybe around 10 around 15 depending about what type of aircraft you are designing.

So, even if it is ten. So, this contribution will be at the at most 0.1, if C L by C D will be more than 10 actually we will find 15 20. So, this component will be at the most 0.1 and this is straight forward. So, how much T by W you require sin of if I want to climb by 30 degree. So, this is 0.5 plus point 1.56 right no 0.6 this is 0.6 because sin that is 0.5, if I am climbing at smaller angle accordingly I know what is the T by W required. Because thrust is primarily required for climbing for cruise the thrust regard will be much less.

Because in the cruise thrust will try to only balance the drag of the machine, but while climb it will not only try to overcome the drag, but also take the weight upward. Please understand that when I have written here D by W and D by W I have approximated as one by C L by C d, but they have assumed W equal to lift which is an approximation where clearly you know that L equal to W cos of gamma right. We have just the designer we know that gamma around 15 degree then cos gamma is almost 1. So, some from the approximation we are done for analytical solution of course, you should find out exactly by putting these values. So, that is that should be kept in mind, but from designers perspective please understand that this value C L by C D we will flying at a C L by C D much higher than 10 15 20. So, the designer maximum point one this one. What is our aim we are trying to find out what is the T by W rough value I want, who dominates it we could see that it is dominated more by the climb angle?

So, directly from here you find the climb 15 degree sin 15 plus this value add roughly you will get the value of T by W for the mission. Because you know that T by W is important for climb phase, because thrust required during climb is much more than thrust required during cruise, but this is another clash point you understand when I talking about T by W and W by S that is also a design I need to keep back of his mind.

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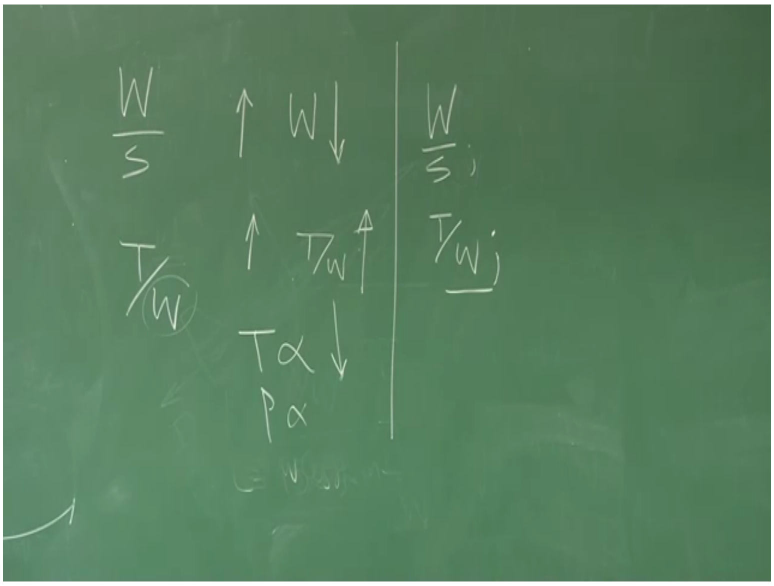

So, you are loosely talking about very loosely you are talking about, wing loading and thrust loading just to give you understanding introductions because you have to go in detail about those things in the design, but one thing you understand that as I am going higher and higher, the W will go on reducing do not forget that.

Similarly, as I am going higher and higher even if I maintain same thrust if it is, but W will go on increase. So, T by W requirement will go higher right. Then there is another thing as I am going higher and higher, the thrust will also drop dynamic thrust will drop with the propeller driven airplane. You could see that density of air outside will be reduced right. So, the thrust available from thrust or power when you talk about propeller engine you know that we talk in terms of power and thrust will get engine, T by W as I am going higher and higher the thrust part also will vary with the altitude.

So, as a designer I need to know how much it will change and keep that has a margin right. So, it is always better to have excess margin on this. So, all those points also we will be discussing. So, for today just for introduction we have just glass cruise W by S and T by W. And I will request you to go through my earlier lectures and performance and come prepared for next lecture.