Aircraft Design

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Lecture – 24
Thrust Loading

Good morning friends, I wish you all belated happy Independence Day. And let me tell you after the last lecture, I had a discussion with my one of my students, and he had a complaint, he says that lot of things I am are being discuss on T by W thrust weight ratio, but our hanger we are having aircraft which you are having propeller. And we try to characterize benchmark in propeller driven IC engine driven propeller engine through power ragging, we do not talk about thrust.

So, the propeller driven aircraft. For a jet, we definitely talk about thrust. How to handle this? When I ask the same question to myself, I also understand that whenever you talk about motion, we are mapped towards F equal to m a. So, if you want to accelerate, if you want to accelerate to given mass, you need a force. So, thrust is very near to us because it is a force immediately we know what will be the acceleration, but directly from power when an engine is related to power it is not so straightforward. So, I taught I will discuss something on that aspect and try to bring a commonality because after all if somebody has to accelerate, it can be accelerated if it is acted upon by external force. Before I do that let us see what we were we discussing about thrust towards ratio and why we are discussing those things.

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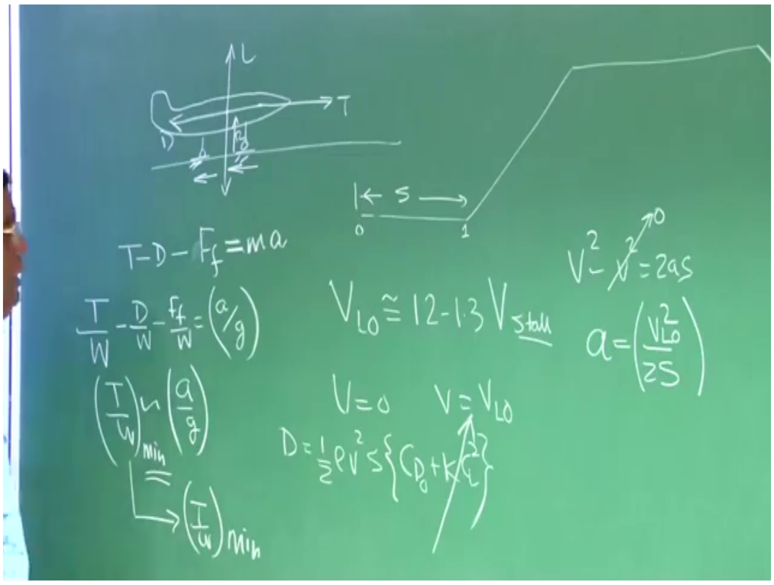

If we recall we have agreed that this the basic flight path or basic maneuvers within airplane we will do it will warm up, takeoff, climb, cruise then descend and landing. If I see here 0 to 1, which is warm up plus takeoff when you say take off you need a takeoff speed at which if you can put the aircraft at a desired angle of attack or desired C L closer to C L max and it should be able to lift off. So, I say V lift off which is typically we can write as 1.2 to 1.3 V stall. Now, the question comes anyway I am starting from U equal to 0, V equal to V lift off within a specified distance. So, as an operator or as a designer, I would like this distance required to ensure the aircraft achieves we lift off within the specified distance it is a challenging task, because you cannot have very large takeoff distance that goes against the operation because you need you need large area large land.

Now, even at class tenth and eleventh knowledge, if I write suppose this airplane is accelerating on ground and there is a thrust and there is a drag, there could be lift, and there is the weight and here there is a reaction R, this is very straightforward for you. So, what we should write thrust which is causing the acceleration, and drag which is causing the deceleration minus mu of or minus let say frictional force because as this gentleman tries to move this wave as a friction force. This is net force the net force acting on this aircraft, which will cause acceleration. I can write this equal to m a because I am assuming that change in mass is negligible and I am also taking a liberty let say a is average acceleration along we do into that as a designer initial stage. We know very well this acceleration is not going to be constant, because this drag will go on changing as speed increases. Because drag is half rho V square S C D means C D naught plus k c l square.

Even if I say lift is not that much and the first approximation, but I know drag is directly proportional to the square of speed. So, naturally acceleration also will go on changing, but I am as a designer initial design stage, I am say ok, I will take the average acceleration. And then if I say T by W minus D by W minus F f by W equal to a by g. So, what is the minimum T by W required if I want to get an assessment, but that I can easily find out T by W minimum.

What is that designers trick here? It is ok, drag is not large as compared to thrust; friction force ok I am neglecting it, so that will be proportional to that will be cause proportional acceleration which is a by g. And you know that within this distance S, a will be if I assume a to be an average acceleration, a I can find out V square minus U square equal to 2 a s. So, a U is 0 starting from 0 will be V square by 2S. So, if I want to design that airplane must takeoff within a specified distance S, then I know let what is the V lift off required from the aerodynamic condition that is given by this. So, I can easily find out what will be the T by W minimum requirement. Is this part clear? Suppose, V lift off is coming typical for say it is not I have airplane it could be 30 meter per second.

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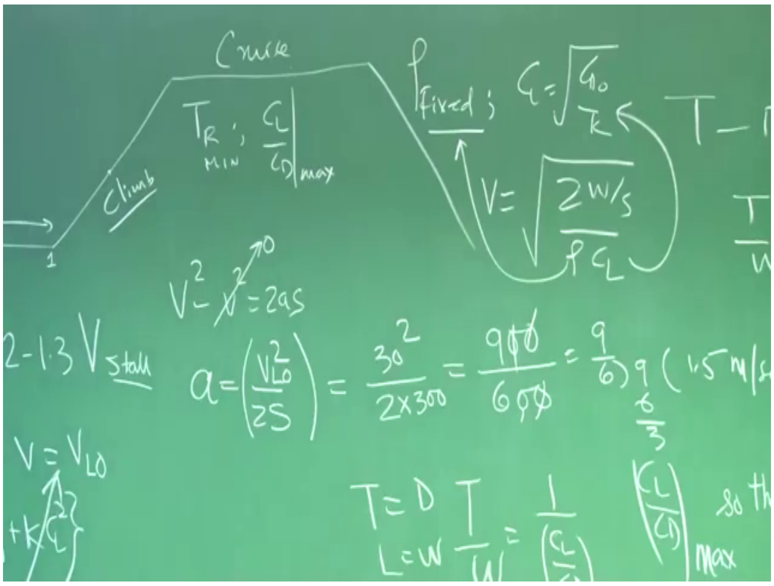

So, 30 square by 2S let say it is 300 meter. Suppose, I want such a thing then the acceleration required would be or acceleration that will happen 900 by 600 and this cancels 9 by 6 and that is 1.5 meter per second square. So, you know that T by W will be now roughly it will be 1.5 by 10 or 9.8. So, you know from here; what is the T by W required for achieving this mission of S. Of course, because drag and this will be not 0, so you can final it right you can go on adding those values and see you got an ideal what is required. So, that was the essence of T by W.

For climb, how as the designer we got the idea these are all I am discussing please understand for a designer if you are thought process is correct which is based on the law of physics then you come in too many mistakes. Any way designer will commit mistakes designer will phase conflict all those liabilities un certainties are there, but you as a designer if you are strong in your fundamental, then you find you have an enough (Refer Time: 09:23) to handle those conflicts and all those mistakes that is why I give more weightage to this before we come to how do I design.

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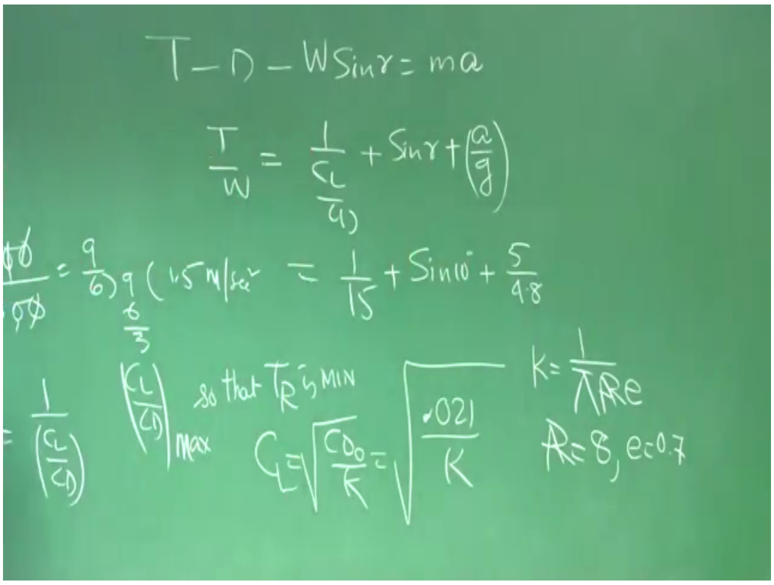

But a climb we know T minus D minus W sin gamma equal to m into a. For a study climb, we assume that a is zero, but if you want to climb at an accelerated motion, you know T by W will be equal to roughly 1 by C L by C D plus sin gamma plus a by g, because m will be W by g, m is if I that is right. As a designer C l by C D of it is 15 or

13. So, I will put 15, I want to climb at an angle of 10 degree let us say. So, I put it here sin 10 and what sort of acceleration you want you put that number divided by 9.8.

So, if you want 5 meter per second square let say there will be 5 by 9.8. So, you will get typical value of T by W required during climb understood. But we also understand this at this point that as I am climbing higher and higher, my thrust will go on changing because of altitude effect and because of dynamic thrust for a propeller driven that also will change. All those actions you have to incorporate. Also you know W will change and F l is changing, but when I am talking about first climb it will be may be up to 1500 feet around that or for bigger aeroplane may be 1500 meters. So, those are matter of details right, but this gives you an idea what is this T by W we are talking about why we are spending so much of time right.

Then for cruise for here we know that T equal thrust equal to drag lift equal to weight. So, T by W is equal to 1 by C L by C D. So, if I am cruising at a best C L by C D that is C L by C D maximum ,so that thrust required is minimum, then your C L is fixed C L is under root C D naught by K. But the issue is your aircraft is not ready, you do not know what is the value of aspect ratio wing has not been finalize. So, number feel for number.

Typically for aircraft, you will find C D naught will be 0.021 better aircraft will be 0.018, 0.017. And for k since subsonic I can write pi aspect ratio into e is not a bad choice if you take aspect ratio 8, and e equal to 0.7 not the bad choice. So, that gives you a idea what is the C L you are you need to fly. So, that you find what is the C L by C D max and you know what is thrust required minimum. But there is an issue you see now how the conflict comes. If I want to fly here for thrust required minimum then I have to fly such that C L by C D is maximum at a given altitude.

The altitude for a jet driven airplane long distance will be decided by the SSC of an engine thrust specific fuel consumption. Generally I had tropopause, 10 to 11 kilometers where temperature variance is almost negligible there this is very efficient. So, any jet driven aircraft will always fight to fly cruise at that altitude that is indirectly what I am telling rho gets fixed. Rho means density of altitude a density of air at that altitude 10 to 11 kilometer when you are flying in any such airbus or Boeing aircraft from Delhi to Bombay then to Chennai you will find that the paramedic command will announce we are flying at 33,000 feet right, so that is the altitude that we talking about.

If rho is fixed the problem is and rho fixed same time C L is under root C D naught by K this is fixed. So, your V becomes fixed 2 W by S by rho C L. C L is this and rho is fixed here and that speed will come much lower than the speed during cruise you will expect. You want to go faster right that is why even at that altitude there will be compromise and it may happen that more weightage is given to that fuel consumption, because any way you have to move faster, the passenger will not lie from here to Delhi if you are taking more than one hour, people are annoyed. So, it is not possible that all the time you flying with this conditions that is where I was telling you the conflict comes.

But T by W you can always find out how much is required once you know C L by C D, it is not necessary you will be flying always at C D, C L by C D maximum right. So, this is the story of T by W. And we have given you some numbers for different airplane. But what as a designer you should do if you want to learn this subject based on this based on some mission requirement you try to find out how much should be T by W for a given type of aircraft takes that the 206. Take (Refer Time: 16:18) take a airbus A320. And apply this and try to see what sort of C L by C D should fly what sort of T by W the designer must have kept and see actual numbers how they are close that is the part of learning to be an designer to be a designer.

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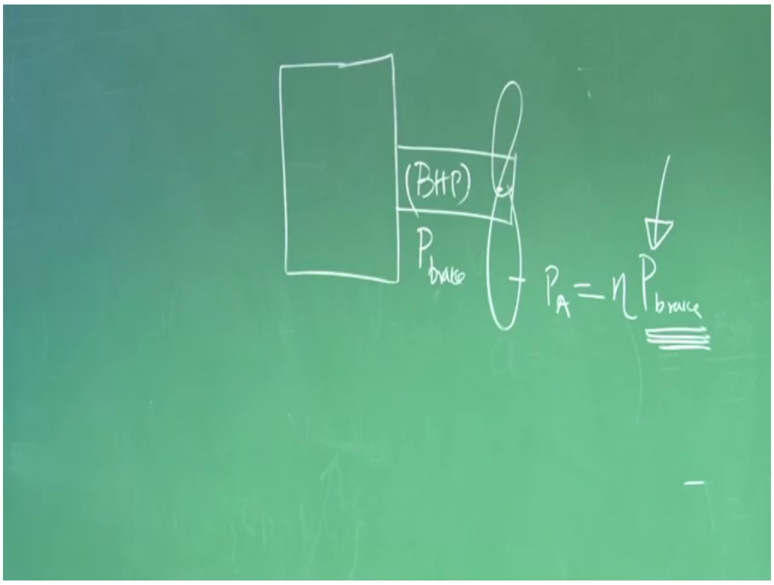

Now, coming back to that question for a propeller driven aircraft like we have propeller driven aircraft with IC engine back up they are rated as power horsepower right. What is that horse power means, this is your camber where combustion goes on, this is your brake over that you put the propeller. So, there is a horsepower power valuable at the brake. Now, you effectively use that using a propeller. So, this becomes power brake and this is power available which is not equal to power at brake, there will losses that is n into power at brake. Your fuel consumption is decided by this gentleman power.

How much useful power you are able to get out of this said by neta the propeller efficiency. So, now, for a jet driven nomenclature where we talk about thrust loading natural question comes is there something called power loading. Before come into that let us understand how do I define, how do I prepare myself to get a understanding how to translate from power to thrust. And what is this power, this power is required to overcome the drag experienced by the propeller primarily apart from accelerations of the propeller to get a particular rpm.

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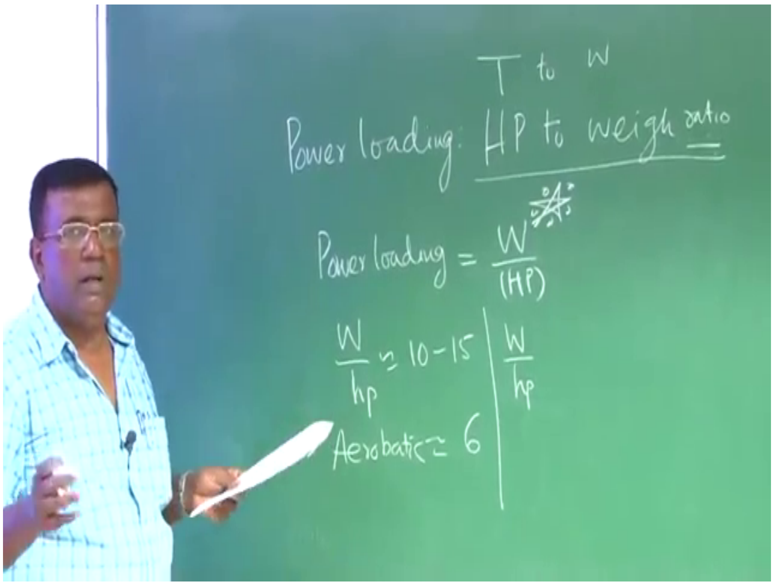

So, let us see power loading how it is conventionally we define, horsepower to weight ratio that is in our mind right, we have thrust to weight ratio. So, naturally we when you translate thrust horse mind you say- what is horsepower to weight ratio that is a natural question. Keep this in mind and see how in reality how things are defined that is you must note that, otherwise you may commit mistakes. So, in actual practice, power loading is defined in a reverse manner W by horsepower. What is this? This is important, what mind says T by W, so horsepower to weight, but actually it is defined as W by horsepower inverse of what comes to online now you just extend the concept of thrust to weight ratio right, this is important we should understand.

Typically for airplane, this ratio could be a order of 10 to 15; for the aerobatic, it is 6. What is this 6, this is W by horsepower. A typical number, you can get this number forty five and weight glass of airplane because this you understand this will have something to do with the weight as well right very, very important thing that is why W by hp. To answer that question from horsepower to thrust how do I draw a mapping because I am condition, if there is a acceleration I only thing in terms of force. But we are now trying to rate through power rating.

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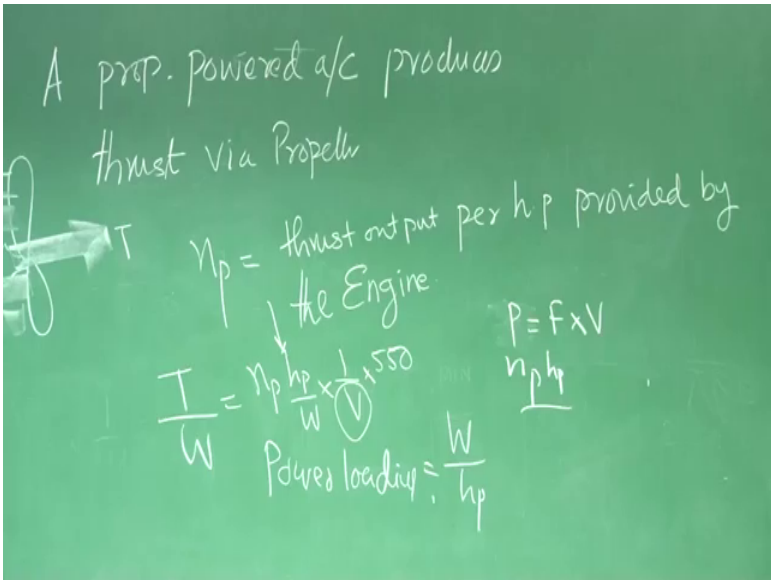

So, let us see this is again from (Refer Time: 20:39) a propeller powered aircraft produces thrust very important statements I am almost permuting writing this via propeller this is no problem as we have discussed. What is thrust this is the brake which will have a power brake horsepower I attach a propeller. So, in the propeller rotates, it pushes air this direction, and it produces a thrust is the basic understanding. And you can know that when a propeller rotates almost like wing at an angle of a triangle, it goes like this. So, there is a lift here you can think like this lift and there is a drag here. And this drag has to be overcome by the power of the motor or whatever mechanism I have got.

If that is the way I want to perceive then n p I define as thrust output per horsepower provided by the engine. This is so T by W is defined as n p into h p by W 1 by V and of course, 550 you know that f p s we need 550 comes because of horsepower has to be converted into watt in f p s. Why this V has come we could see that after all it if it is cruising power is nothing but force into speed that concept has been used here. And n p into h p is what is the power that has been extracted of out from the brake from this brake how much power has been extracted divided by V because moving in constant speed that gives me a thrust and then I divide it by W. So, I get T by W this is way I perceive.

So, you could see that T by W is proportional to h p by W, and there is a V sitting here. So, when I am trying to visualize power loading, power loading is not h p by W, power loading is W by h p. So, reverse of h p by w. So, this is the way it has been handled in the literature or any manual if you see, this is the way you can perceive. If this much is my power loading which is inverse of this, this is the efficiency what speed I am moving then the equivalently I can see that T by W is that with I am converse into T by W. So, T by W at that speed is this much. When the machine was delivering horsepower of h p with a propeller efficiency of n p that is the understanding fine.

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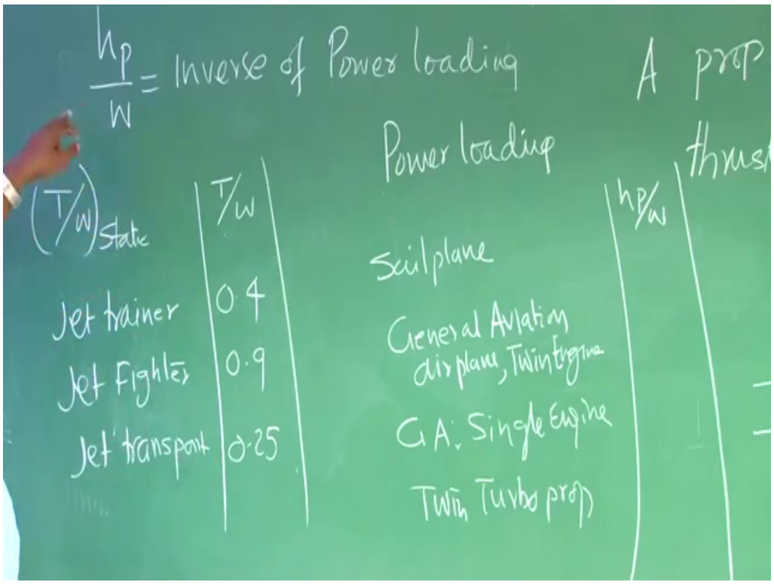

So h p by W is inverse of power loading, and typical values if I give you T by W, when I write T by W, I have now mandated that I should write static at sea level. And also I write for different airplane jet trainer which I have given you earlier jet trainer, jet fighter and let say jet transport, this value would be T by W would be typically 0.4. Here it is jet fighter has to be more 0.9, and jet transport 0.25, which is obvious jet fighter as T by W higher because it as to accelerate fast is not it? Jet transport is cool it as nothing in a hurry to accelerate. And jet trainer of course, has to be little more because you have to do so many of maneuvers it has to be taught.

So, we can apply whatever we have discussed and see take a jet trainer aircraft dimensions and see how much T by W you would accept and see how much being utilized right. Since we are talking about power loading, so I will say for power loading category of airplane also will be different because power loading we are talking about propeller driven aircraft. So, you have sail plane, you have general aviation airplane, let say twin engine. So, natural question would be general aviation single engine, I think I have given you earlier also single engine and then comes turbo prop twin turbo prop. Typical value of h p by W, please note that we are talking about h p by W in the manual you will find h p by W will be prescribed, but h p by W is inverse of power loading; power loading conventionally is defined as W by h p. So, this sort of a mix up is that, so you should be careful.

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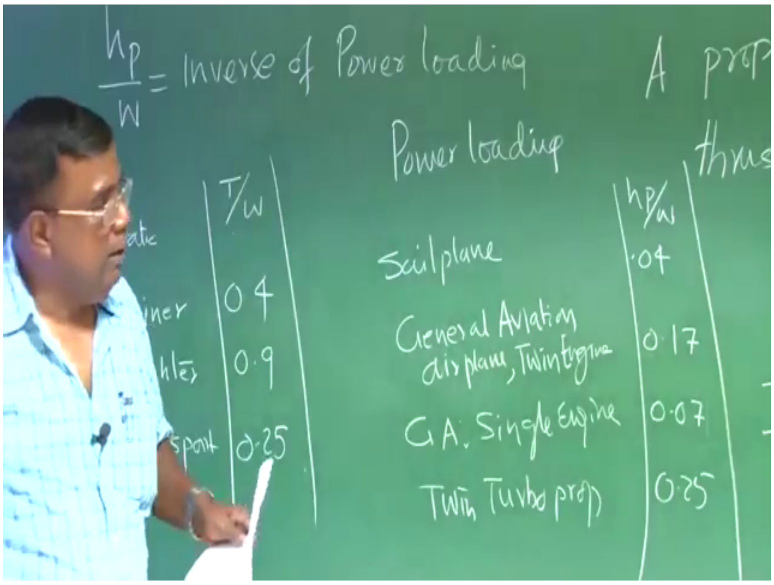

For sail plane, it will be 0.04; general aviation, twin engine 0.17, single engine 0.07, and twin turbo prop 0.25. So, if you see equivalently what is the value for power loading you have to just sure that you take inverse of it, so that will become W by h p.

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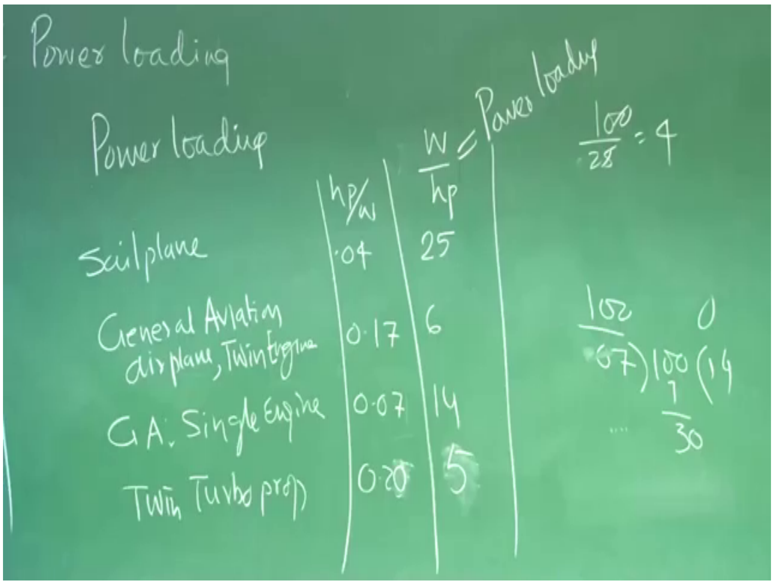

Which is power loading that will be typically 25, this will be roughly 6. This may be 14, this may be 5. 1 by 0.25 is how much, 1 by 0.25 is 100 by it is 4. Twin turbo prop is this value h p W is typically 0.20. So, W by h p which is inverse of this is 5, and this is for this airplane single engine general aviation 0.07. So, 1 by 0.07 will be 100 by 7, so that will be 14, around 14 which is there just take the inverse. So, as a designer, you will find sometime numbers where having this magnitude less than one. So, immediately you know that typically this is inverse of power loading, power loading values are generally like this sort of a field you must have.

Yu have been noticing that we have completed fast exposure to thrust loading and power loading. And we also know that very important another parameter design parameter is wing loading. So, if you want to design an airplane, you select what is the wing loading you required, so that all the missions are performed optimally. And what is the thrust loading required, and what is that combination thrust loading and wing loading that gives you the best result, because you have seen that thrust loading and wing loading place important role together for many, many performance activities.

So, next on time onwards, next lecture onward, I will be devoting time on wing loading. And before we do wing loading, we will have some discussion on flaps, because flap flaps when they are deflected it changes the C L max value. And as the C L max changes, V stall will change and most of the parameters are characterized via V stall.

So, next class we find I will talk about V stall, I will talk about flaps and talk about what is the wing loading required for particular V stall for a given flap configuration; do not forget when you deflect a flap you do get higher C l max, but you also get more drag. So, what is that suitable for you; and if you put more complex flaps the maintenance becomes an issue. How do I handle for what the aircraft I select these types of flaps, all those things will be discussing giving some historical data.

Thank you, thank you very much.