Aircraft Design
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Lecture - 22
Thrust Loading and Power Loading

Good morning friends. We have been discussing at length on wing and different types of thrust which are relevant for our aircraft. And you might have seen by now, one lecture by our chief engineer where he has demonstrated various parts of the airplane. This was done to familiarize you on what are those aero dynamic surfaces you need to be careful as you progressed in designing the first conceptual aircraft.

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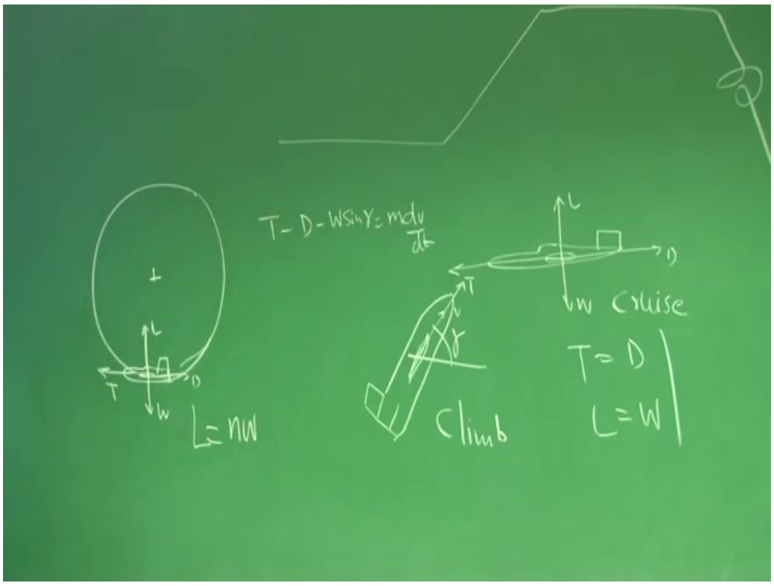

And if we recall we started with a mission requirement: what we say takeoff, climb, cruise, then loiter, and then landing, alright. We also are familiar with these two diagrams: one is this; this is thrust, drag, lift, weight. We are also familiar with diagram like this. This diagram reminds you about cruise and this one climb. And we can also recall we have done something on maneuvering flight where we draw the schematic. And this with thrust, this is drag, this is lift and this is weight, and this is radius of turn.

If we see this 3 diagrams the moment diagram you have to focus here; I write thrust equal to drag lift equal to weight. When I focus here I write T minus D minus W sin gamma equal to m DV by dt. That is net force causing acceleration. And here when I see important thing is if I want a particular radius of turn I need to generate lift which is n times weight. So, this gentleman has to be more than weight so that it can go the vertical loop.

These are the primary maneuvers based on will be actually configuring our airplane.In this diagram you could see the thrust plays an important rule.

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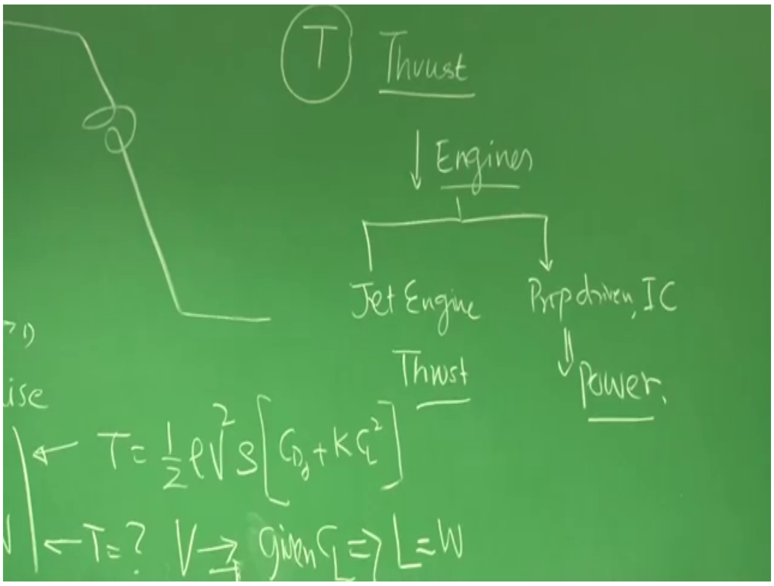

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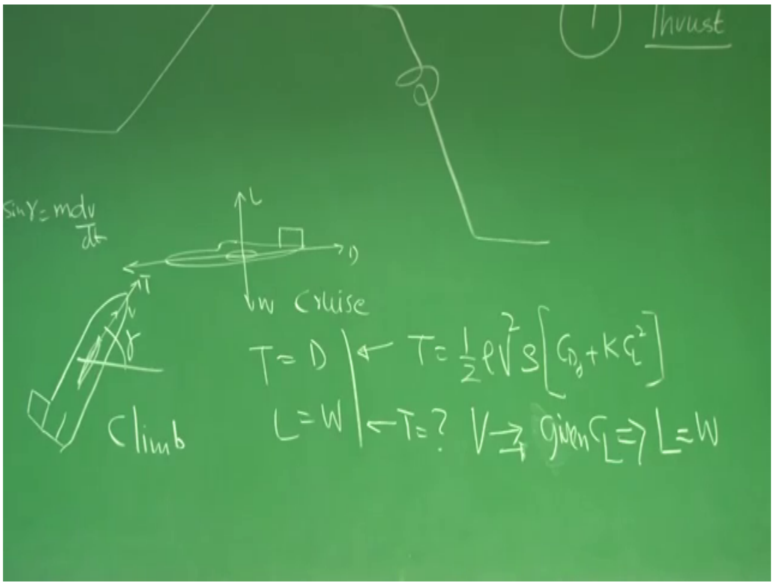

As designer I need to ask question how much thrust do I require for a particular airplane. If I try to answer that from this mission- the cruise mission my answer will be; I should have sufficient thrust which should be able to balance drag and that is half rho V square S into C D naught plus K C L square. When I see here lift equal to weight it tells me I need to have that much of thrust which should give me enough velocity; if I see this equation then it tells me I should have enough thrust which should give me enough speed so that for a given C L I should be able to produce adequate lift to balance the weight.

That is how thrust get connected here as well, because you understand if I want to give speed it will also cause drag. So, thrust should be good enough to handle this.

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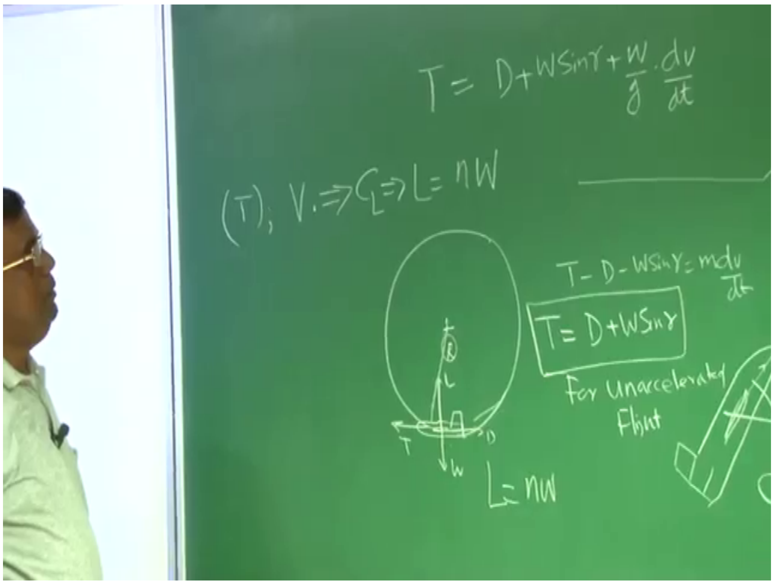

And if I come here, I know that thrust should be enough to give me this right hand side balance for on accelerated flight. If it is an accelerated flight, then thrust should be D plus W sin gamma plus m or W by g into whatever acceleration you want around. If I come here it says I should have enough V such that for a given C L lift should be equal to n times W n could be 2, 3, 1.5, 4. So, here also you could see thrust is implicitly present.

So, that is where you could see thrust is extremely important. And hence for designing an aircraft we should also make a judicious choice of what is that thrust requirement. When I talk about thrust, please understand the aircraft primarily will be covering having two types of engine: one is jet engine another is propeller driven I C. So, whenever you are talking about propeller driven engine, we try to read the engine in terms of power; and jet engine we try to read them in terms of thrust. So, this distinction should be in our mind.

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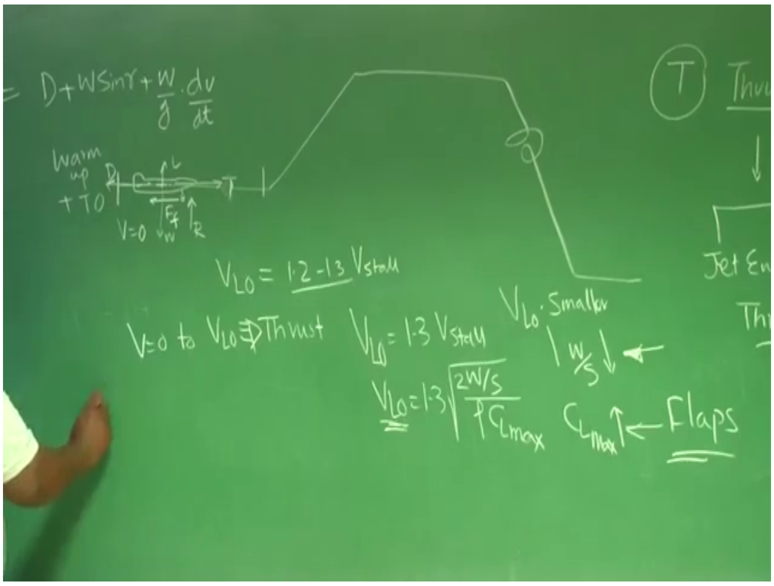

Now come here, this part you know this is warm up plus takeoff. And explicitly what we understand that the airplane starts with V equal to 0 and thrust is applied on the aircraft if you the aircraft here is the thrust, sorry, here is a thrust opposing its drag some lift will be there and then there is the friction force and of course, because of there is a weight and you can draw a reaction which gets coupled with friction force.

Now, what is important here is that the airplane initially is at V equal to 0 right and there is a particular speed V lift off which you know it is 1.2 to 1.3 times; V stall meaning is this if the aircraft attains this V lift of speed then they the airplane; airplane will start taking off right goes like this takes off; that means, or V equal to 0 to V equal to lift of this responsibility comes from thrust primer this thrust job.

So, it has to accelerate the airplane from V equal to 0 to a speed V equal to liftoff. Now if I write V liftoff is equal to 1.3 times V stall you will find between 1.2 and 1.3 times V stall is V lift off based on different aviation regulations. So, it does not matter for understanding what is 1.3 or 1.2 the main point is V lift off is if 1.3 times V stall that we 1.3 times under root W by S to W by h by rho C L max.

Now, if you want V lift off to be smaller if I want V lift off to be smaller; then options are W by h should go down C L max should go up for a given air density right. So, let us say how much will be V lift off will primer decided by what type of aerofoil we have chosen which is having C L max; whether the flaps or not will come to those things and what sort of a wing loading wing loading low means large wing area if the large wing area relatively then takeoff speed will be less, but same time drag also will increase you become more sensitive to wing. So, all those issues we will be covering in the discussion of W by S and flaps I live devices will cover on C L max.

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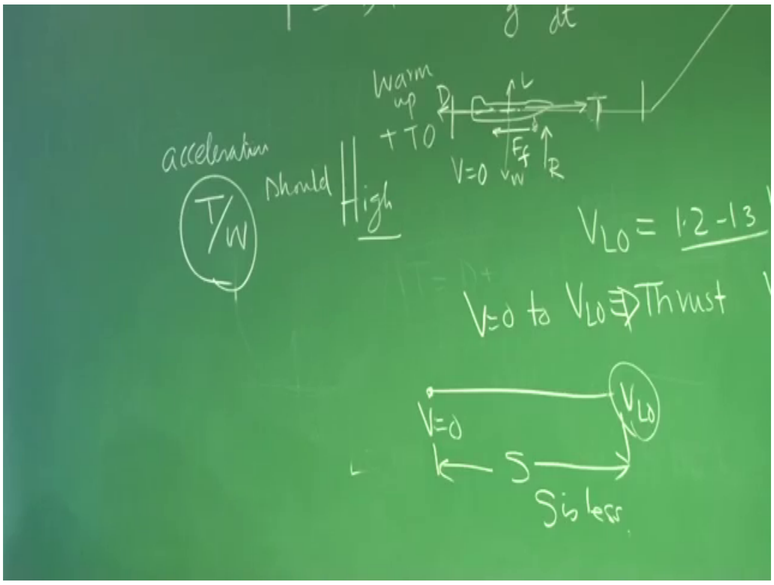

Today what we are trying to understand once we agree from V equal to 0 to V equal to lift off I need to achieve then also implicitly we say that I need to accelerate these airplane from V equal to 0 to V lift off as early as possible. So, that this distance is less; that means, I have shorter takeoff distance, we cannot expect that aircraft will take a large takeoff distance beyond other than which is otherwise not possible general tendency will be you try to design an airplane. So, that is short takeoff distance or takeoff distance is not that large.

So, what is the message? Message is one is you try to see that V liftoff is low that is taken care by this gentleman W by S and C L max, but once V lift off is fixed then I want this distance should be as low as possible as far as possible. So, it needs to have larger acceleration. So, larger acceleration means T by W should be high. This is important if T by W is high or higher then it will have a short shortened distance, but takeoff. So, T by W plays important role in deciding in the affecting the takeoff this is one.

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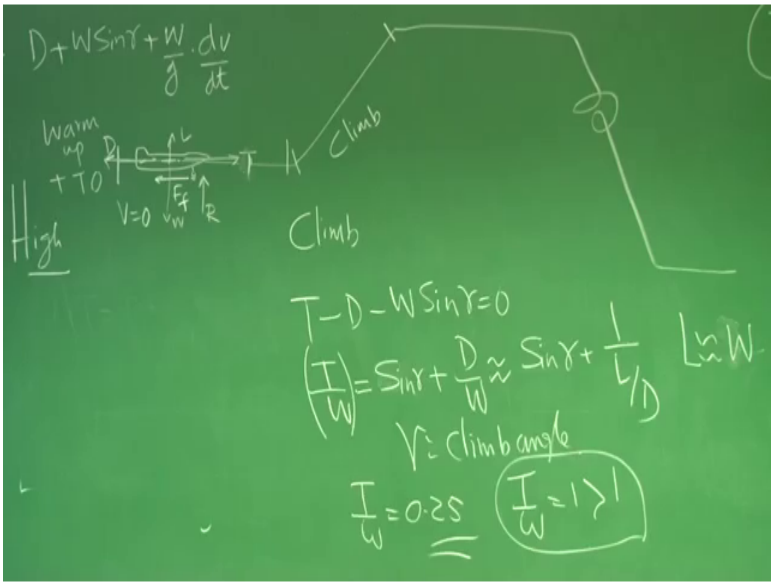

Now, come to climb let us see what is the assumed climb, in climb you know that T minus D minus W sin gamma equal to 0 if it is climbing without any acceleration like a rectangular part is going with constant speed. So, here you see T by W is equal to W gets canceled to the sin gamma n plus D by W which roughly I can write as sin gamma plus 1 by L by D I am assuming lift is equal to weight the gamma is small.

So, what is the message? Message is how much T by W; we require will be decided by what is the climb angle you want right typically transport airplane will find T by W as 0.2 to 0.25, this is the number is, but if you are designing an aerobatic which can go like this can hold the airplane and do a lot of acceleration accelerate maneuver then we find T by W maybe one or greater than one this is fine. So, then I write T by W as a role in climb if we want climb rate to be higher if you want climb angle to be higher.

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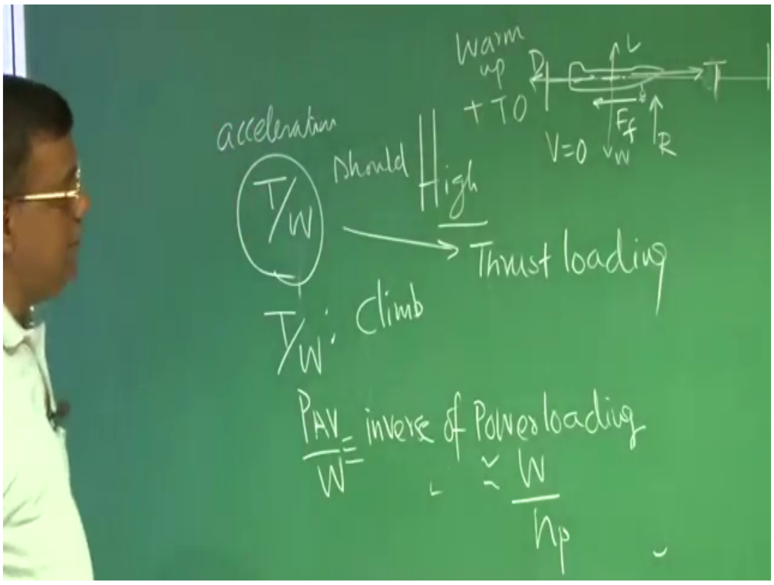

This T by W with a design parameter you need to have, but somebody may ask the question when I am adding T by W; let me am I only talking about jet engine what about propeller driven I C backup engine or prop engines.

So, there is answer is simple nothing new we require and we are familiar with this we multiply both sides by V.

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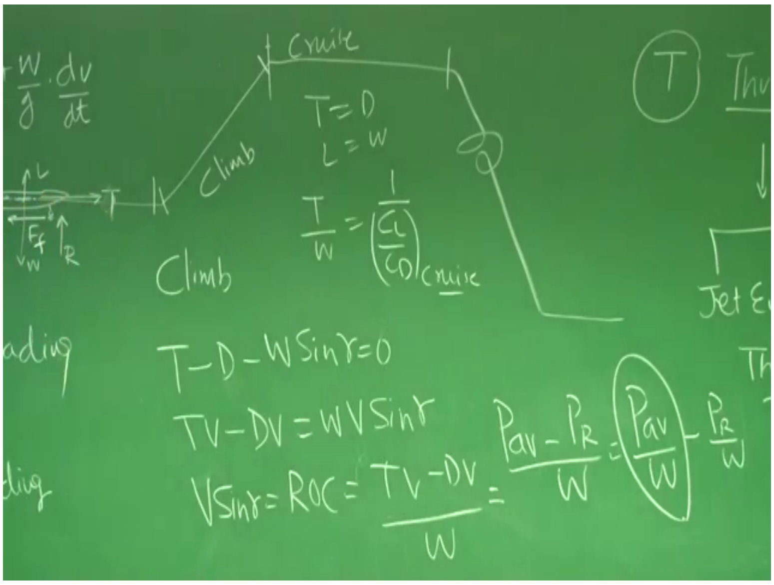

So, we get T minus DV is equal to W V sin gamma and here you find that sin gamma V sin gamma which is nothing, but rate of climb is given as TV minus DV by W and TV is nothing, but what power available, so, power available minus power required by W which I can write power available from the engine by W minus power required by W. So, T his man power available by W is somehow closed related to power loading.

So,P a v available by W is actually by definition is inverse of power available by W is basically inverse of power loading which is given by W by horsepower that is the power available. So, T by W for thrust loading and W by horsepower available is power. It is a macro of definition. So, when you talk about propeller driven engine we try to talk in terms of power loading talk when we are talking about jet engine we talk about thrust loading at the same time you will see that this power loading can be interpreted through thrust loading as well we will discuss that right this part I am stopping here.

Now, we are coming here called cruise; cruise you know thrust equal to drag lift equal to weight. So, thrust by W is 1 by C L by C D. So, for T by W cruise will be decided by what is the C L by C D cruise and this is important you must understand as a designer; what is the meaning of this if I write T by W equal to 1 by C L by C D.

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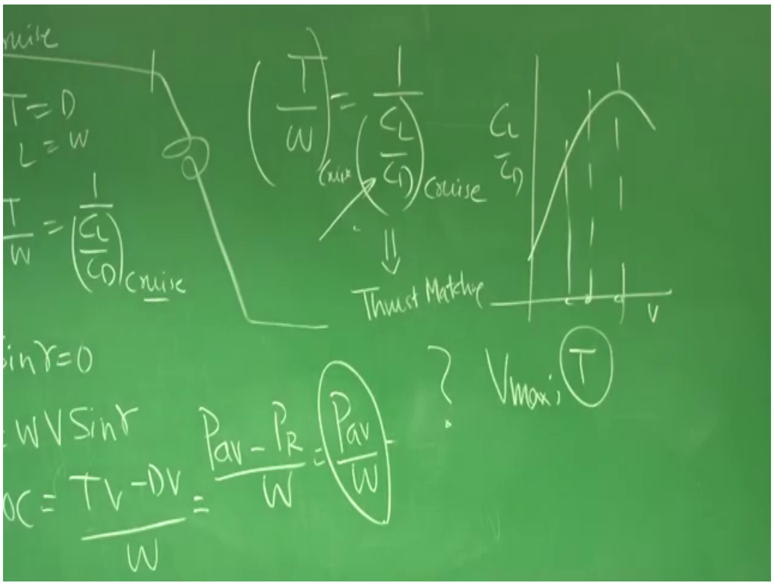

And let us say this C L by C D cruise and if we want to fly at optimal condition then C L by C D may be maximum, but not always possible to fly at the C L by C D maximum, but important point is if you plot C L by C D versus V we will find you need to have a definite value of V to have C L by C D desired right; that means, your thrust loading should be enough to balance that that is why we call it thrust matching that is why if you see in textbook when they are trying to find like this they give a title called thrust matching what is the meaning of that if I want to fly at C L by C D cruise then T by W is one by C L by C D at ensure that T by W for cruise is exactly given by this when I will able to maintain.

We have been talking about T by W for cruise for takeoff or climb, but also understand the moment we talk about thrust or power for that matter we also ask a question will this airplane be able to achieve the speed maximum assuming that at that speed at that dynamic pressure the structure will be good enough to withstand the load that is the assumption because you cannot go on increasing the speed or the dynamic pressure. Why I am saying dynamic pressure at sea level; you may be able to fly the machine at 300 meter per second. But that at as you go higher and higher if you want to fly a 300 meter per second the structural load will reduce the density is reducing, but the reverse if you are flying at 300 meter per second at 10 kilometer and if you want to fly at 300 meters second at sea level, even if your engine gives you power, you have to ensure that. Now the dynamic pressure has increased; what does the structure will be able to withstand that load or not.

So, what I am saying assuming that structure is good enough to withstand a design V max the question is for V max.

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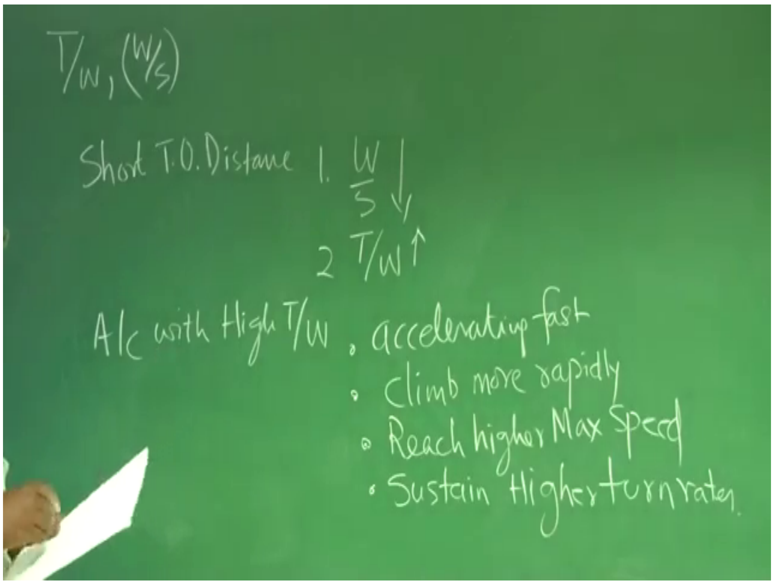

Whether my thrust is sufficient or not or the power is sufficient or not right; with this background I can write T by W and W by S they play their important individual role and also they decide the final design together and you will see why I am saying that if I am talking about for short takeoff distance I need W by S to be low. Next T by W should be high then if we want T by W to be high that means thrust generated is higher. So, so what happens for a given technology it is expected that the engine size will increase the weight also will increase. So, it may affect you takeoff wing.

So, all this conflict will come W by slow means S is very large it may add up to the weight. So, it is finally, you will see that we have to do lot of compromise, but stand alone you should know these things also we have understood aircraft with high T by W will help in accelerating fast number 2 climb more rapidly number 3 reach higher maximum speed and sustain higher tolerates.

So; obviously, if you want to turn you have to bank and what you are banking and turning the moment you bank it will lose the height. So, we have to increase the speed because you may not be able to increase the angle of attack it attack the stall, but increase the speed. So, you should have enough thrust available right.

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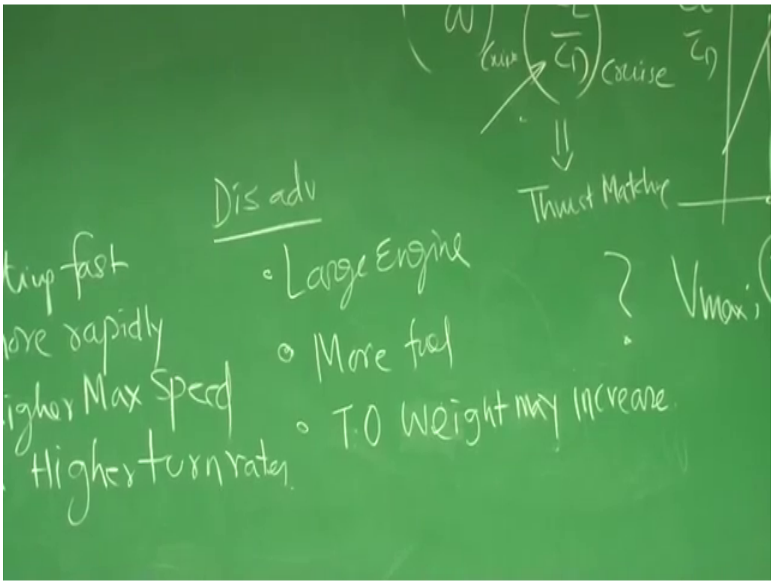

So, this is the advantage the lose disadvantages are large engine if you want W by T by W higher more fuel generally and takeoff weight may increase why I am discussing this that if you understand finally, we have to do lots of compromise balancing act. So, that advantage disadvantages they may be conflicting not only T by W it may come from wind loading.

So, the designers chief designer has to look every parameter and see what it is goal and we try to find out that path which gives him what is desired there is another point which is very very important you people should realize before you go to anything in detail when I am talking about T by W right.

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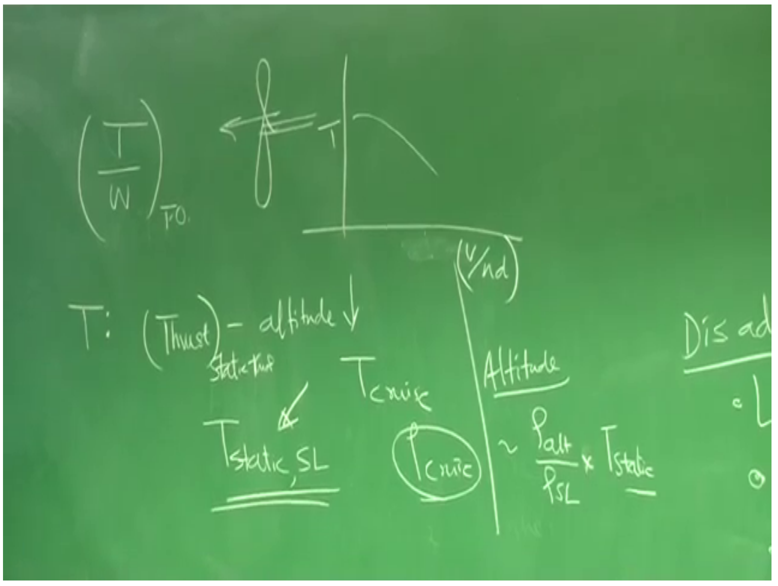

And if I write (Refer Time: 24:24) what here I must take if I talk about thrust. So, realize that thrust what you are talking about static thrust their availability with altitude will drop. So, without jet engine on a propeller driven engine I C driven we find as altitudes increases the density where they are air reduces.

So, your thrust available goes down when you are talking about static thrust which is generally rated at sea level conditions and if we are talking about thrust at cruise we must ensure that what is the altitude at cruise. So, rho cruise; so, I must correct this to the altitude of operation that is extremely important this is altitude effect similarly thing is true for power from a propeller driven as well directly proportional to the density as density reduces thrust available for available also reduces. And mostly it is not a bad approximation; rho at altitude by rho sea levels if I multiply with this factor. So, thrust static or power static you will get the value of that AST that altitude this is general guideline.

Now, think of a propeller driven engine its thrust also reduces with V speed. In fact, this is I this is V by nd if you see the propeller driven engine that once ratio. So, what is rpm what is the diameters of propeller what is the speed in generally you can see the thrust available from propeller driven engine a dynamic thrust drops which always less than the static thrust.

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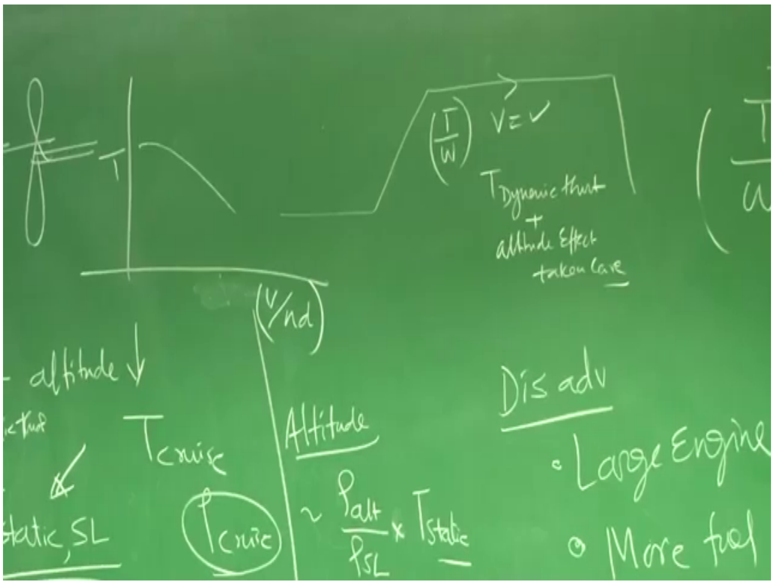

So, I need to know what is the dynamic thrust available during the operation that is if I am talking about cruise I will moving with some speed if I talk about T by W here the T should be the dynamic thrust dynamic thrust plus the altitude effect taken here right; this is extremely important.

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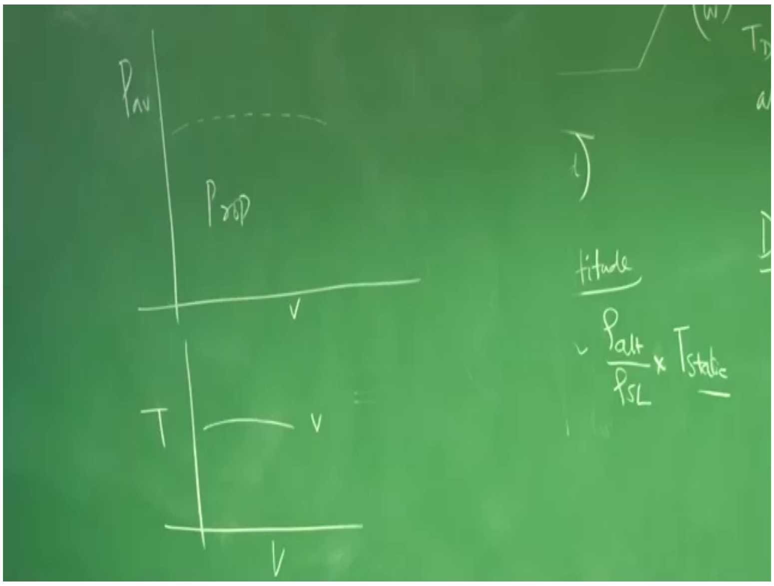

Typically power available the propeller driven engine they remain almost constant with speed of course, for a propeller you have to ensure that the T speed condition is met for the jet engine this is propeller for a jet engine it is roughly you can say thrust given constant with V. So, dynamic thrust corrections if you are doing for jet engine you can assume that not going to changing with a speed and power is almost remain with constant with speed. This is the initial design assumption you must know is not very bad it is fairly obvious, but do not forget the altitude the effects are predominant it goes with the ratio of density at altitude by the density at sea level. So, these 2 things you should keep back of your mind.

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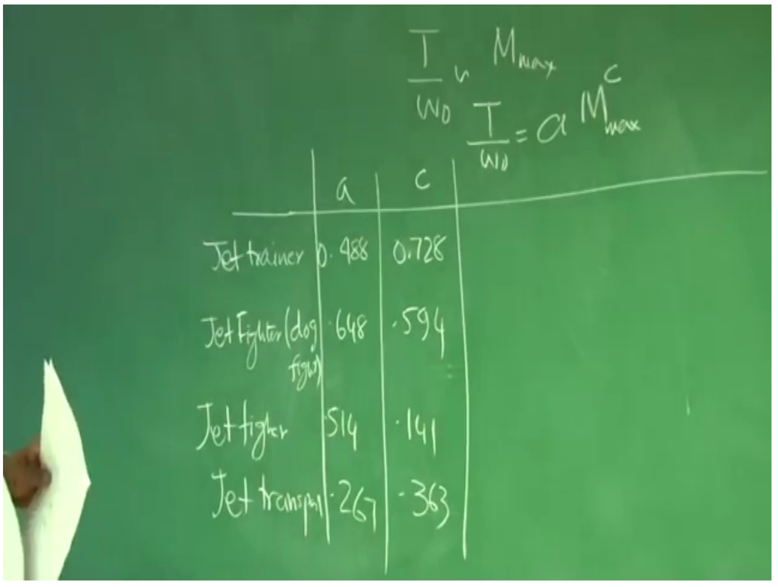

So, whatever T by W the reoperation we are talking about we should talk about dynamic thrust corrected for altitude effect dynamic power corrected for altitude effect right that should be back you of your some statistical data may be useful and every time I am telling you please refer some book on the aircraft design whether it is Raymer whether it is terrific whether it is Google uncle whatever it is this sort of data gets updated and you must use those.

T by W naught W naught is takeoff it verses max M max where is MAC number this table is useful jet trainer jet fighter this is like dog fight and jet fighter otherwise then jet transport T by W is calibrated as a M max to the power C and you will get the values of a and C from this table for jet trainer it is 0.488 and C is 0.728, this is for dogfight this 0.648 and this is 0.594, this is 0.514; 0.14; 1.267 and 0.363, this are typical guideline numbers and I again and again request you please use latest data sheet.

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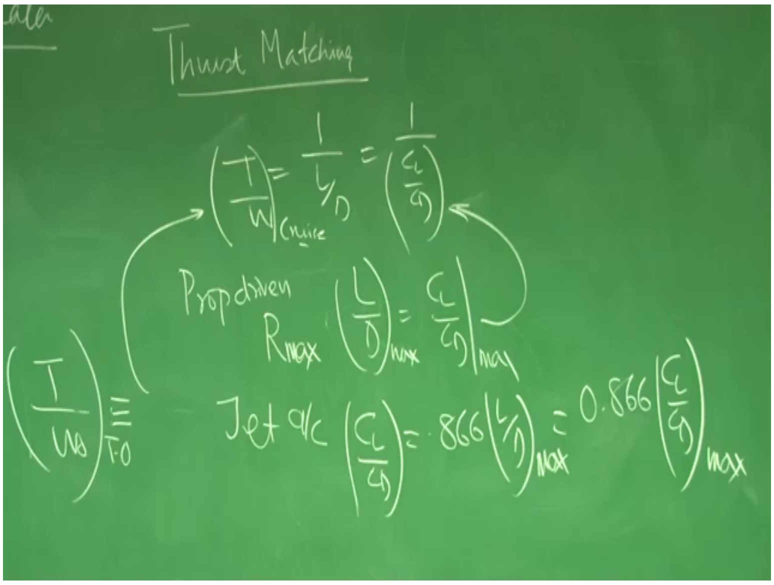

So, that lot of new engineers calibrations are given to make the designers handy we are talking about thrust matching, but this T equal to T by W 1 by L by D equal to 1 by C L by C D and you know if it is a propeller driven engine if we want to go for R max then the condition was it has to fly such that L by D is maximum. So, that is C L by C D should be maximum. So, you put that number here for if your mission is getting a maximum range propeller driven engine that this will give you what is the T by W cruise requirement and you have to ensure that really this T by W cruise available at that altitude because you know whatever static thrust at ground available that is going to reduce of that altitude you also know the weight of the airplane and the takeoff is going to reduce at that altitudes.

So, you have to give appropriate corrections and ensure that T by W naught takeoff is such that your; at cruise you get this value this is important you will design your airplane such a way that T by W at takeoff is such that when it goes for a cruise to an altitude T by W cruise is given by 1 by C L by C D. C L by C D given by since the maximum range maximum for a proper propeller driven airplanes and similar for a jet aircraft; you know that C L by C D it has to fly for range maximum is 0.866 L by D max or 0.866 C L by C D maximum depending upon what type of airplane you are flying or designing the requirements for T by W cruise should be evaluated like this.

And you should design that aircraft T by W naught take off such that as it goes to that altitude you know very well thrust is going to reduce you correct the thrust for altitudes and for dynamic thrust correct the weight because fuel is going to change and ensure that this after doing that T by W cruise given by 1 by C L C D is available that is a that is a designers job.

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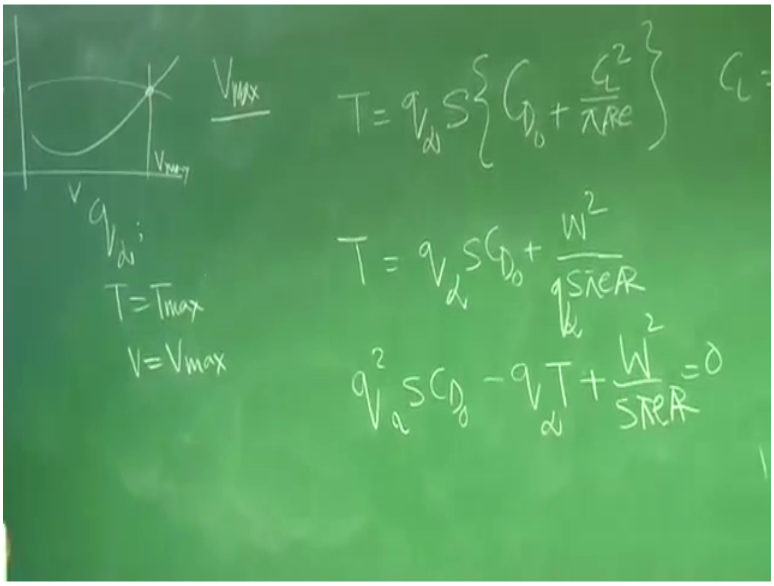

We are talking about V max it is important to see. Now if I thinking of V max that maximum speed what are the design parameters they are going to play a role right before I go for power loading you know for a cruise you see thrust equal to drag. So, I can write this half rho V square this dynamic pressure S into C D naught plus K C L square and K is 1 by pi aspect ratio e and C L square here and also I know C L is W by q infinity S. So, I can write thrust equal to q infinity S C D naught mechanical plus W square by q infinity S pi e aspect ratio what I have done is C L replaced by W square by T infinity square S square and this q infinity one gets cancelled S S get cancelled. So, this is a remaining.

So, I can write q infinity square S C D naught if I do like this minus q infinity T plus W square by S pi e aspect ratio is equal to 0 if I, so, solve this for a given q infinity T equal to T max thrust available is maximum plus corresponds to V equal to V max that you know very well is performance score you can plot thrust verses V which is thrust required which is equal to drag for a cruise and thrust available with V almost remain constants. So, this is the point which is V max I am talking, but that is how it has been developed.

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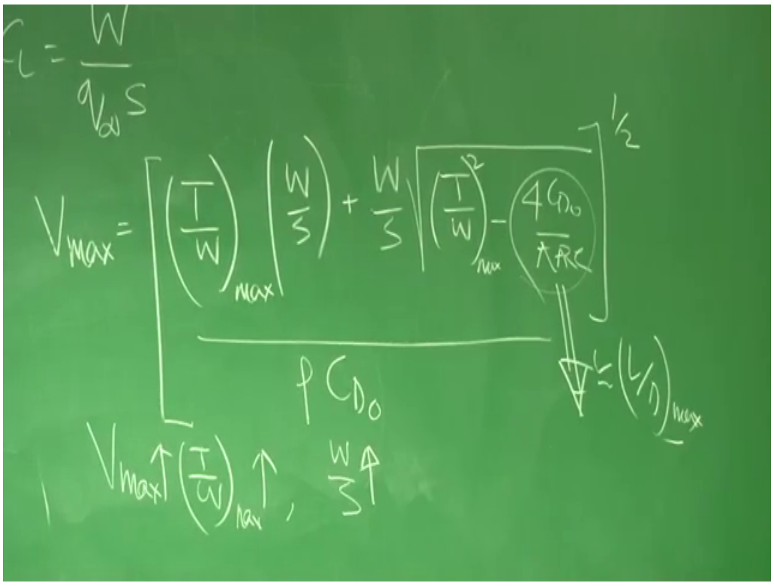

If I do this then I get an expression this is important V max is equal to T by W max into W by S plus W by S T by W square max minus four C D naught by pi aspect ratio e because refer this expression from Anderson; Anderson who find interaction to fly. So, what is this expression is telling that V max will increase if T by W max increases V max will increase. This is W by S increases this is interesting point V max will increase T by W increases naturally it will be more acceleration, but V max will increase if W by S increases; that means, S is smaller. So, drag is less. So, it will accelerate fast.

Remember for V stall I want W by S to be smaller if W by S reduces wing area increases. So, V stall reduces, but if you want to V max then you want W by S to be higher. So, that area is less drag is less is accelerates. So, you could see that V max increases if you want to increase V max you need to increase to by W maximum W by S and also reduce that parasite drag coefficient the next class we will see this term you yourself can do it this is linked to L by D maximum check yourself.

So, you will understand if I want to synthesize a design I need not only talking in terms of T by W I have look for W by S look for L by D I have to look for C D naught I have to

I have to understand what altitude I am going to take off or cruise all these things they merge to have a good optimized design right.

Thank you very much.