Aircraft Design

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Lecture - 11
Design Considerations: Power Plant, Gross Weight

Good morning friends. I am recording this lecture after gap of two weeks; in the last lecture we tried what is the conventional way of getting an idea about what will be the gross weight of the airplane for particular mission requirements. And we were clear that we are talking about fuel maybe ATF; typically combustion dependent engine was in our mind whether it is a jet engine whether it is a turboprop. We are talking about fuel; fuel, a conventional fuel oil or gas whatever we are being addressed to and the question is whatever I was doing last two weeks.

It is interesting that last two weeks we were trying to launch one of the UAVs design here along with a private company we are trying to test it at high altitude, but around 6 kilometer and we were looking for particular rate of climb particular endurance particular range; the difference was we were testing UAV which was supported by electric power propulsion or I say to more specific battery driven propeller engine (Refer Time: 02:03) I am having a motor battery power it gives power to the shaft and shaft has a propeller and rotates and gives the thrust and it propels.

It is important to mention at this point because you will find in the previous lectures we were bothered about what is the fuel fraction required to the I have an idea how much fuel have to carry for a particular mission. Why that is important because, I need to not only know that my airplane will have sufficient fuel available, but also as a designer if I know the amount of fuel I need to locate an area a volume in an aircraft maybe near wing maybe the fuselage where I should be able to accommodate that amount of fuel.

But, if it is a battery driven then the story is different then I need to look for an volume where I can put the battery this is extremely important because there is huge amount of work going on in developing propulsion other than the conventional propulsion mechanism basically the energy part of it. So, in this course I will try to cover whatever limited knowledge I gathered in electric power propulsion especially motor propeller battery combination so that you have initial understanding how to look for better and more precise knowledge on those topics because this is going to be electric part propulsion is going to be the order of the day in coming years we have also got the solar power and we have been flying regularly one of our solar power UAVs last one month. So, some aspects of solar power also will come in this course very limited I repeat very limited. So, that it motivates you to do to read more.

But why today I am mentioning all these thing if the type of experience I got type of experience I got through limited failures you although we had success, but there were 15 to 20 percent failure and for me that failure was more important than the success we had and I want to use these understanding this knowledge. So, that our design people can especially youngsters for experienced people this may be very trivial, but for youngsters they should set themselves right from the beginning as far as possible.

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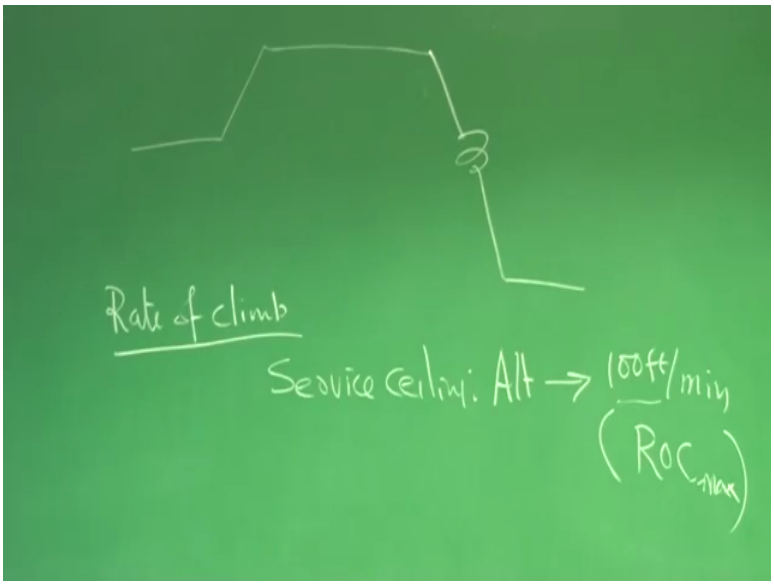

We know last class, we have been talking about particular mission requirement where we have take off flying cruise loiter landing there is another term which is important is the rate of climb whenever you design an aircraft, you have to specify a specified service ceiling which you know when you say service ceiling we say it is that altitude at which the rate of climb maximum is ROC maximum is 100 feet per minute. Therefore, when you are designing an UAV if you have not incorporated this feature in the airplane as per the customer’s choice that design will not be acceptable; for example, if I am designing a let us say a 5 kg UAV fixed wing UAV and I specify its service ceiling should be 6 kilometer from the mean sea level service ceiling is 6 kilometer from which mean sea level; that means, at 6 kilometer the rate of climb maximum should be 100 feet per minute.

This is a mandatory thing although we do not cover all these thing here you see I will be going on adding these features sometime I will be talking about accelerations limit, right. So, I thought I will be sharing with you this has huge importance because you know.

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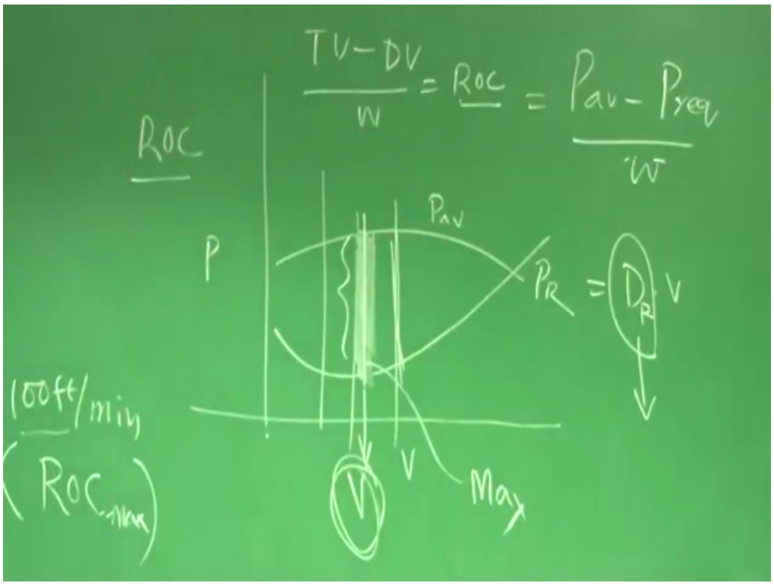

When I talk about rate of climb how do I perceive to go to performance course to say if this is my power required and this is power available then these are the speeds which will give me particular rate of climb because I know T V minus P V; your T V minus D V by w is equal to rate of climb the assumption is I am climbing with the constant speed and also I know that when I am calculating power required. I am taking it is as if it is cruising indirectly I am telling this graph is valid for power required for a small climb angle because the climb fuel will be less.

So, this also I interpreted as p available minus p required by w let us understand if I really want a good rate of climb I should fly somewhere where this is maximum this gap is maximum. So, corresponding to that speed I should fly to achieve rate of climb maximum the same time I should ensure that this speed should be more than the stall speed your stall speed is the minimum speed at which you can make the airplane fly level and stretch unaccelerated.

Now, see who decides the power required should be less this is you know drag required into V who decides drag required should be less I repeat if I want to make this gap more I have 2 option: one is I ensure that power required that every speed is relatively less and power available is relatively more then I have a wider gap. So, I focusing on power required.

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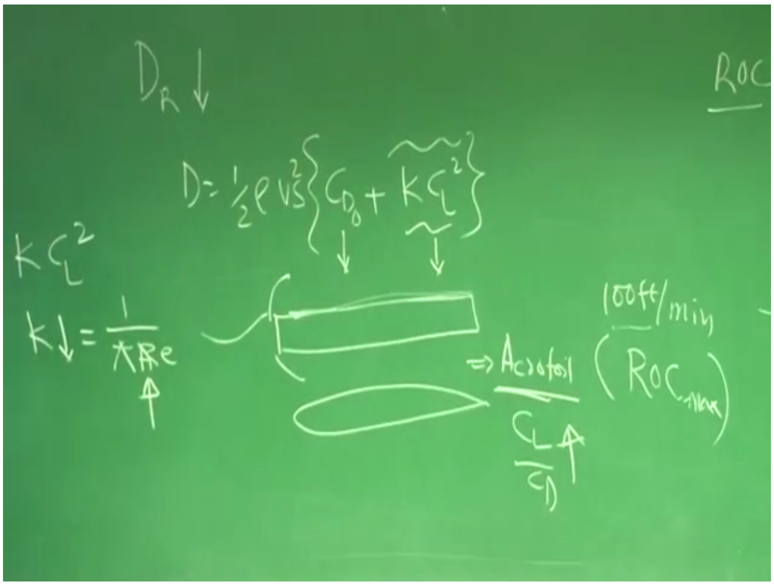

If I want to see the power required is less; that means, a drag required for a given speed should be less and what is the meaning of drag required being less I see drag required if I want to be low then drag is nothing but half rho V square S C D naught plus K C L square.

So, for a given dynamic pressure you could see that if I want to really minimize drag then I have to handle C D naught this gentlemen should go and this contribution should also go down how do I handle C D naught C D naught you know C D naught has a skin friction drag component primarily for a subsonic airplane. So, I try to make it streamlined I try to ensure that surfaces smoothen there are less pressure losses that is flow should not suddenly jump out and all those things suppose rough suppose this cross section is like this and flow is coming like lot of losses will be here.

Similarly, if there lot of roughness is here that will lead to skin friction drag. So, what we do you see in design evolution with this understanding attempt to are made to make a streamlined body. So, in doing that especially for wing you have found out that a lot of aerofoil shapes have emerged. So, this is that much the requirement for aerofoil. So, you will see how aerofoil shapes have evolved; what was the designers looking, but expecting from those shapes.

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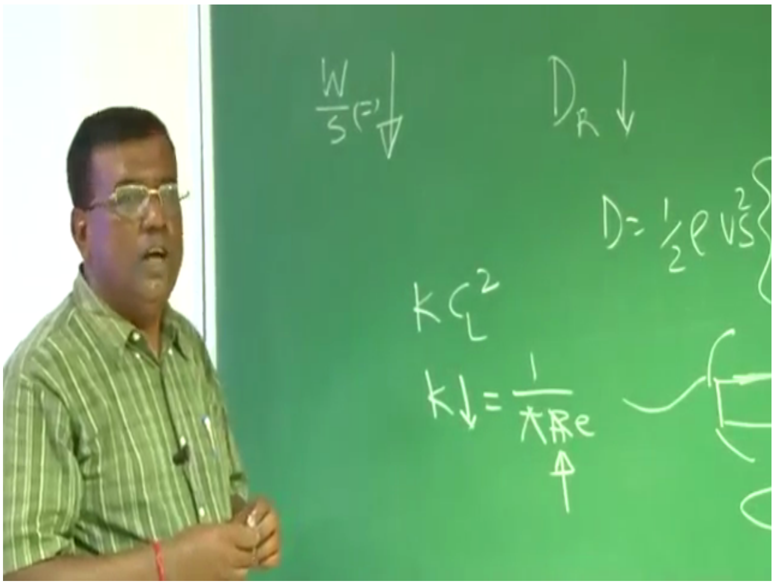

So, come to second part here if I want to reduce K C L square which is the induced drag I need to reduce K how do I reduce k you know for subsonic fairly good model pi aspect ratio e. So, if I increase the aspect ratio then a value of K will reduce. And if I ensure that the wing shape is conforming to an elliptic leave distribution then I can get e value as one and the question is if I want to increase aspect ratio you want to make it more and more for example, typically aspect ratio for this sort of an aircraft defer designing which are flying at 100 meter per second or 80 meter per second that 160 knots roughly.

The aspect ratio will be 8 9 around that, but if you are talking about glider it has to be more because we want to glide right indirectly or a clever designer he will talk in terms of another parameter called wing loading w s if you use designing a glider or designing a UAV or an aircraft which has good gliding ratio he will say gentlemen I want to bring w by s as low as possible right, but then there is a problem if w by s is low it may become too sensitive too wind also so those sort of a trade off will go on.

Since we have already talked about how to estimate w naught takeoff weight we serve as a machine requirement and now we realize that I need to ensure selected proper aerofoil for the purpose that it is lift efficient or lift to drag efficient that is we will be talking about C L by C D to be as high as possible. So, if I now focus on aerofoil what a designer would look for that tribute which will help him depending upon what flight regime is flying if I am talking about low subsonic.

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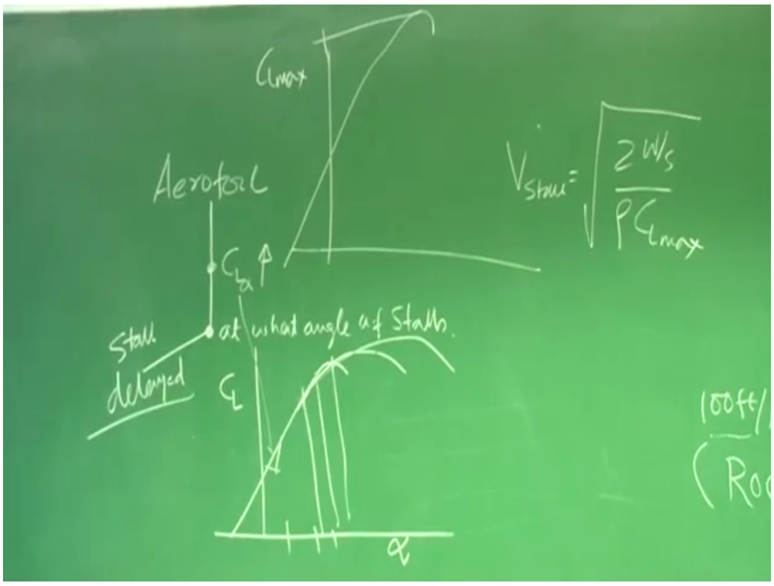

Then if I see an aerofoil I will check for C L alpha to be fairly good although I know the C L alpha is limit set by the fact that it can be maximum to pi per radian then also I look for at what angle aerofoil stalls because you see that I have an aerofoil something like this which is the cambered aerofoil C L versus alpha this slope is the C L alpha, but another point is as I go on increase the angle of attack to C L increases to a limit at which the aerofoil will stall the aerofoil stalls in the wing stalls wing stalls means your aileron which are sitting on the wing are also ineffective. So, not only there is a lot of lift increase meant in the drag, but you lose control as well. So, you have to avoid that. So, a designer will wish oh this point could be somewhere here somebody somewhere here to the extent possible; that means, with the delay stall delayed.

Whether the stall angle is higher by characteristic of the aerofoil or artificially or externally you use some mechanism. So, that the stall is delayed, but the designer ones right this way or that way if the stall angle is delayed he will be happy because he can generate more lift. So, this is C L alpha stall delayed and what I say C L alpha you could see here designer also look like look for a good value of C L max he wants C L max should be as high as possible why because if C L max is high then V stall which is 2 w by s rho C L max.

You see C L max is high then V stall is low. So, he is happy. So, so when he goes for takeoff landing is fairly comfortable because we can get the smaller value of V stall. So, less power will be required less takeoff run will be required. So, he always wants can I have a higher C L max typically C L max value for conventional aerofoil will be around 1.2, but we have seen you belong to increase it. So, one way is you contour the aerofoil. So, that C L max goes by implicitly by because of shape second thing is people use flaps right.

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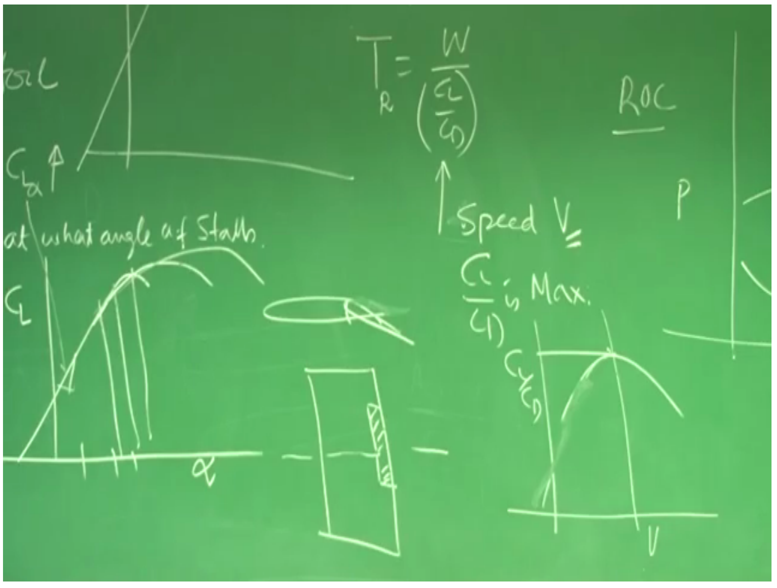

For example if this is normal aerofoil dry part of a wing. So, they put a flap the wing if I see the wing shape some part here this is like flap so that increases C L max and these are used to retake off a landing these are not to be used in cruise because in any case you do not require a lot of C L in cruise because the moment you put the flaps down you will understand drag also increases. So, C L by C D also goes down general. So, you do not like that and for cruise anyway you know that for cruise I can write thrust equal to w by C L by C D if I want for cruise thrust to the minimum for a given weight what I should do is I should fly at a speed at a speed V such that C L by C D is maximum.

So, if you could draw straight your notes if this is your C L by C D C L by C D versus V derive the particular V at which C L by C D is maximum and that is to revise you C L by

C D maximum fortress required minimum; that means, C L equal to C D naught by k right and you also know that if I go on increasing aspect ratio then we get unrealistic value of C L that is C L the aircraft may stop.

So, these are few things you must understand before we go into the aerofoil also what is important for you at this stage to understand this is a typical observation and I thought I must share you at the beginning.

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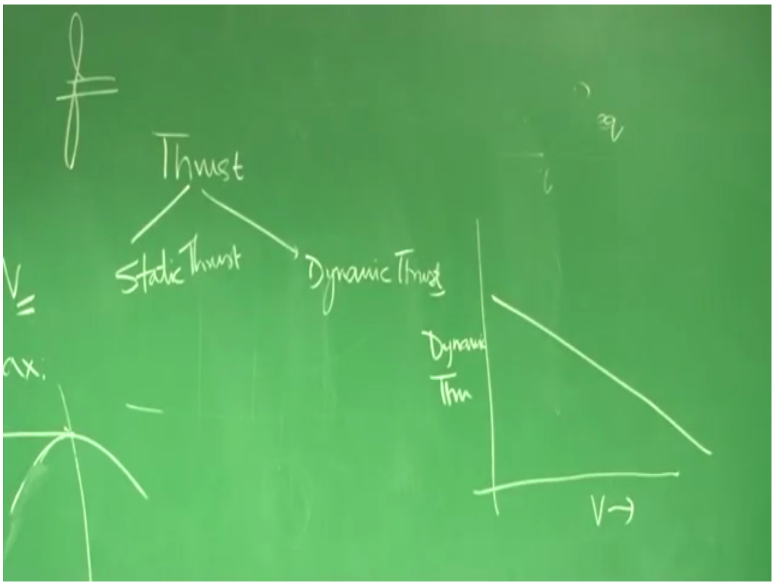

If you are using a propeller driven engine then you know when I talk about thrust may something called static thrust another is called dynamics thrust you can very well understand the very mechanism of thrust developed by the propeller we are not going into any equations or any technical term the propeller develop thrust by pushing the air backward.

Now, imagine the airplane is moving. So now, propeller has to push lesser number of the already air is going into going through this propeller or whatever disk we assume. So, in that process what happens the propeller does not generate the same thrust as for a static case right little bit of I add physics to it as the propeller rotates with some r p m and moving forward it induces angle of attack right omega R by V I will be talking about propeller I think it is important, but if that angle is equal to the pitch angle then net angle of attack becomes 0. So, it will not be able to generate any thrust.

So, the issue is when you are designing a prop based airplane you must see that your dynamic thrust will fall and there will be a particular speed at which the dynamic thrust will be 0.

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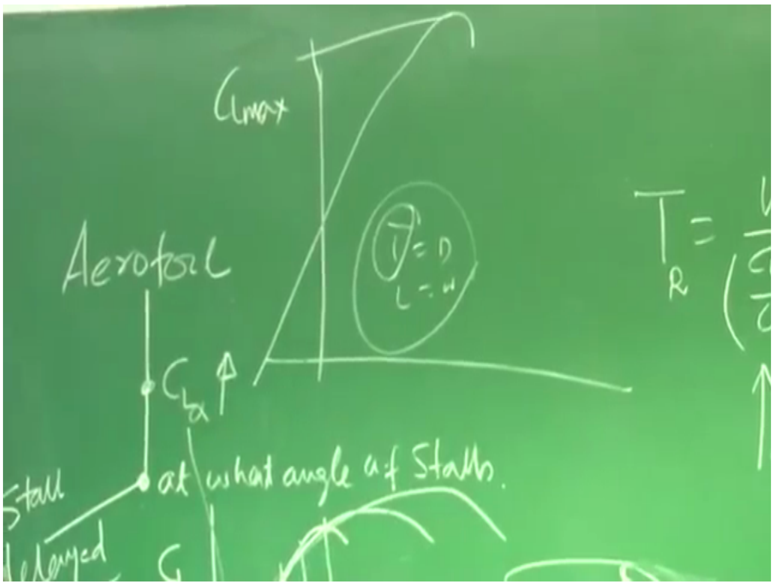

And whenever we I am writing thrust equal to drag or drag or lift equal to weight please understand this we are talking about dynamic thrust and thrust developed at that speed scenario is not similar for a jet driven airplane or a jet driven airplane. Thrust roughly remain constant with speed not that drastically changes like it properly driven airplane this is also an important thing we should keep back of your mind.

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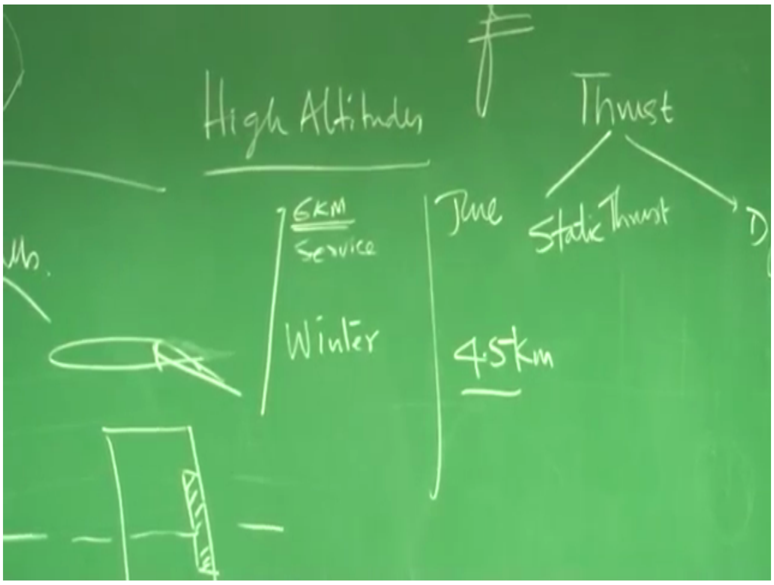

Another thing what we have revalidated learnt in the harder way what I found was in high altitude we carried out test say 6 kilometer and that time we could easily climb up to 6 kilometer and almost 6 kilometer was the service ceiling for the UAV what we are testing and this was conducted in winter then we again repeated this trial in June, we could find repeat only for the everything given you same we can only go up to 4.5 kilometer that is a service ceiling almost 4-5 kilometer you could achieve it is obvious that in winter the density of air was more and sees you are using same propeller density of air was more.

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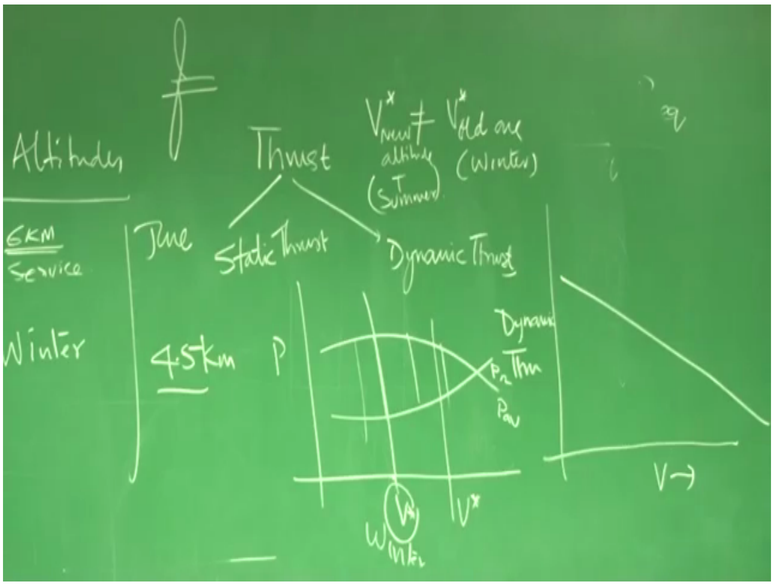

So, the if you see here this power this power available was also going down in the month of June where temperature was higher because density where of air was less, but you may question the power required was also relatively less in terms of in winter because density was less, but what happens if you see the power available goes down very fast. So, your excess power availability becomes questionable right and also you could see if I was getting a particular rate of climb at this V this is very important in winter right say at 6 kilometer as I want to get the similar performance acts of same rate of climb then what will be the V.

Of course, V will be this V for new altitude or temperature will not be equal to V star required in the old one old one means here it is winter, here it is summer because in winter the density is more naturally we required lesser relative a speed to generate lift, but for a summer density is less. So, need to generate those same amount of (Refer Time: 25:44) same. So, to fly the machine with a higher speed right and which goes with the ratio of densities you know that. So, whatever was V star here you have to fly perhaps somewhere here.

But now imagine let us say because of your design and constraints.

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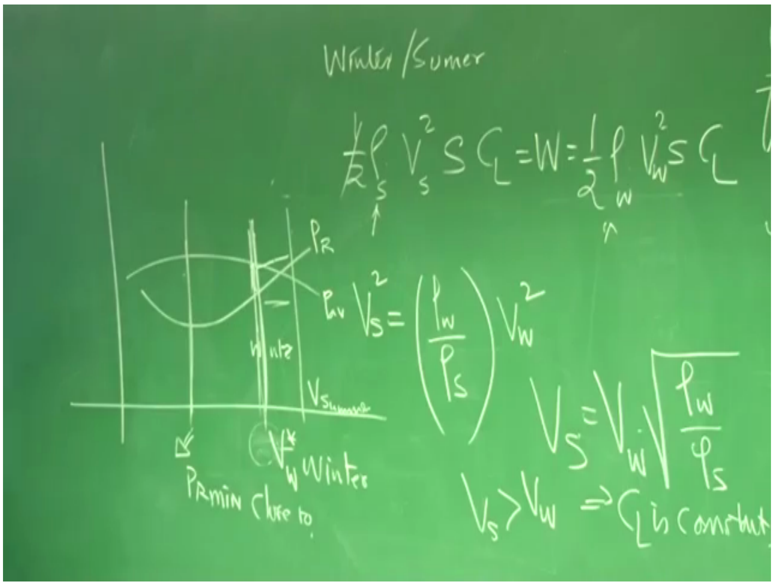

When I am talking about winter and summer I am talking about the speeds being different to maintain the level flight or maintain any operation which gives similar output if I see a simple case of cruise to half rho summer into V summer square into s into C L I am flying at sense C L let us say this should be equal to w where same half rho winter V winters per S C L at the I am flying at the same C L I am; I mean same area same weight everything same the key point is rho summer and rho winter are different.

So, what will happen V summer required will be half of goes off it will be rho winter by rho summer into V w square or V S or V summer will be V w into rho winter by rho summer I am assuming C L is constant why C L constant what is the meaning of that suppose I want to fly a drag minimum for that C L is C D naught by k under root. So, that C L is fixed, but he says if you want to fly same configuration same C L then the; because density of air in summer less than density of air in winter. So, to get the same output the speed and summer should be more than speed at wind by how much by the squared of this ratio, this is important.

Now, suppose because of some constraints already you are flying here in V start in winter right and now we want to duplicate this in summer the summer means now this V star which was V wind in summer it will be V S which will be more than V wind and it. So, happens it may happen that V summer may come summer here if it comes here what is happening this is power required this is power available what is happening the moment that V is here its crossing this point now power required is more than the power available. So, machine will start decelerating and it will start trying to come here it may exceed by inertia. So, there will be oscillation in the (Refer Time: 29:11) like this, right.

Most of the UAVs you will find it is difficult to fly here where power required is minimum this condition is close to power required minimum very close to right.

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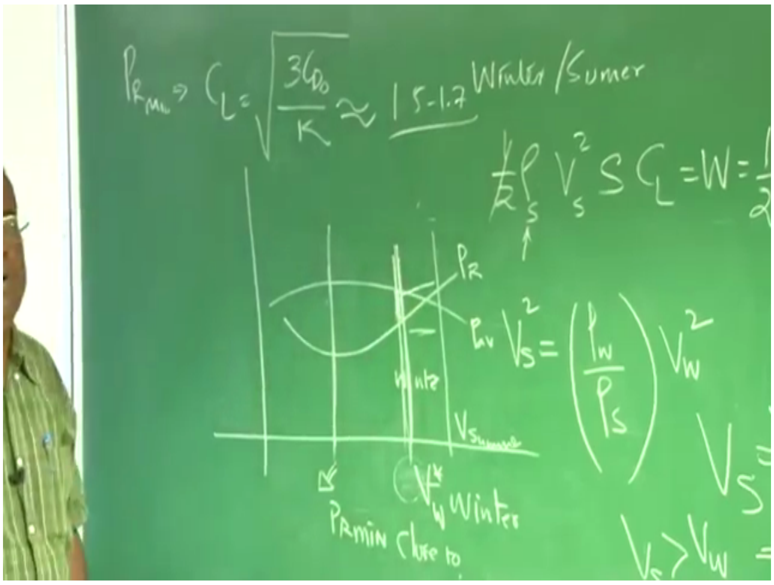

And power required minimum means P R minimum means C L equal to under root of 3 C D naught by k and this value for high aspect ratio machine this may goes between 1.5 to 1.7 and most of the UAVs normal configuration this is beyond the stall angle. So, we do not really find conventionally fly here and automatically if try to fly somewhere close to this or what we do you select a power. So, that this gap is huge the moment you put powerful power the weight increases again speed changes. So, these are the challenges which we face and will be facing in a normal aircraft also I thought of sharing this experience.

So, that we know now what will be the roadmap for our next reserve lectures if I summarize you could see that first part what we will be talking about is very simply the aerofoil.

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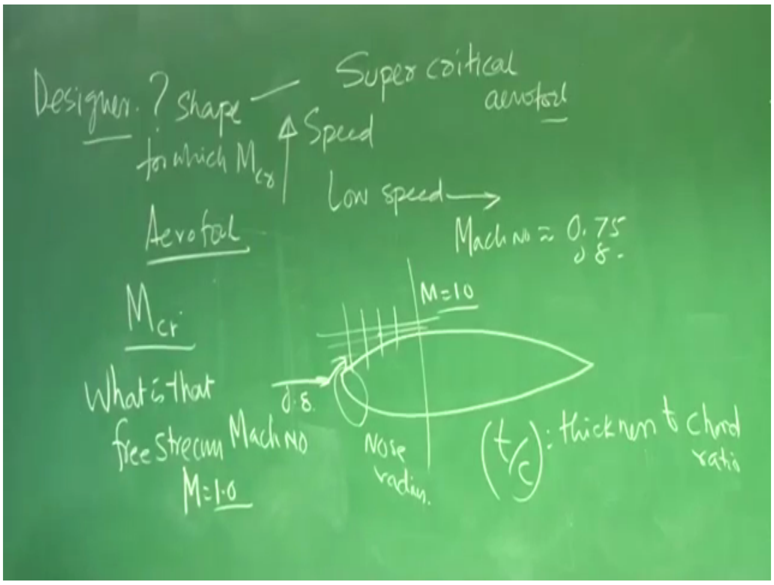

We must look for do I understand what sort of aerofoil I require this is also important please understand why I am talking about aerofoil because whatever flying machine we make these are primarily designed with an understanding that if I give a nearly horizontal motion to an aircraft on to the body it will be able to produce a vertical lift force right unlike an helicopter you rotate like this it gives a vertical force here you move horizontally and you generate a vertical force that is where the aerofoil plays important role.

Also we know when I talk about speed if I am low; low speed and he tried to increase the speed. So, that Mach number Christine Christie; Mach number goes to 0.75 0.8 something like that what is the danger; danger is if this is my aerofoil some shape like this you could see here the flow which comes it turns here and how much it should turn. So, that lot of energy is not wasted that will be decided by nose radius.

Suppose I am flying a supersonic machine. So, I want a supersonic wing. So, I will prefer this portion to be a pointed because you know it will generate their oblique shock right not a normal shock your blunt nose will read a normal shock, but we restrict to our self to a subsonic. So, so when I talk about aerofoil I need to know what should we know radius also you see if this is 0.8 Mach number and across this it is you know by continuity the speed will go on increasing right as it goes on increasing it is possible at some point it is may go to one Mach number may become one and the moment Mach is one or near one there will be shockwave lot of loss of energy. So, you do not like that.

So, aerofoil's are characterized by another term called critical Mach number if you design a aerofoil and if we are operating around 0.75; 0.8 you need to know what is the critical Mach number of the aerofoil meaning thereby what is what is that free stream Mach number for which for the first time some portion of the airplane it achieves Mach equal to one first time.

Now, the question is you want to fly at a higher speed. So, what the designer will do designer will post this question differently said what should be the aerofoil shape. So, that I have got high value of critical Mach number. So, the designers question will be designer what is that shape aerofoil shape for which m critical is higher and when you answer this question you find the new generation of aerofoil supercritical aerofoil came into existence came into existence.

We will be talking about these aerofoil's in detail and this is just to prepare yourself we will be going core into aerodynamics, but in a designers perspective do not starts reading books now you whatever knowledge you have got just glanced through and we we are trying to synthesize as a designer also you will see when I am talking about aerofoil one question I am asking for a high speed what is the critical Mach number I am asking what is the nose radius because if the lift is because of differential pressure with the top and the bottom surface then nose radius should play an important role also I will be looking for what is this t by c that is thickness to chord ratio.

Whether it is a thin whether it is a moderate or whether it is a fat aerofoil we see that they behave little differently aerodynamically they have relative advantages in terms of storing fuel all those things will get summarized. So, we will also look for t by c another important thing will look from or expect from an aerofoil is at what angle is going to stop; that means, which you know very well as flow accelerates here the pressure drops and somewhere there is in generation adverse pressure because adverse pressure gradient the flow separates.

We would like to know; what is that point at which the pressure coefficient which is nothing, but the non dimensional signature of differential pressure right what is that point at which the pressure function becomes 0. So, I know I have come to a critical point beyond that things will be different. So, I would like that location to be far aft if that location is instead of here if it is here I am very happy.

That means, I know the moment there is a pressure drop to C P drops to 0 beyond that the flow will start separating around that and that is not I am looking for I would like that flow should not separate all. So, as a designer I would like this point where the c p the pressure proficient is 0 to be as backward as possible right and with this as. So, that my stall angle also increases critical Mach number increases all those advantages will get.

So, we will be talking about that also and when you talk about that when I will say flow should not separate I am after talking about laminar flow so that drag is low.

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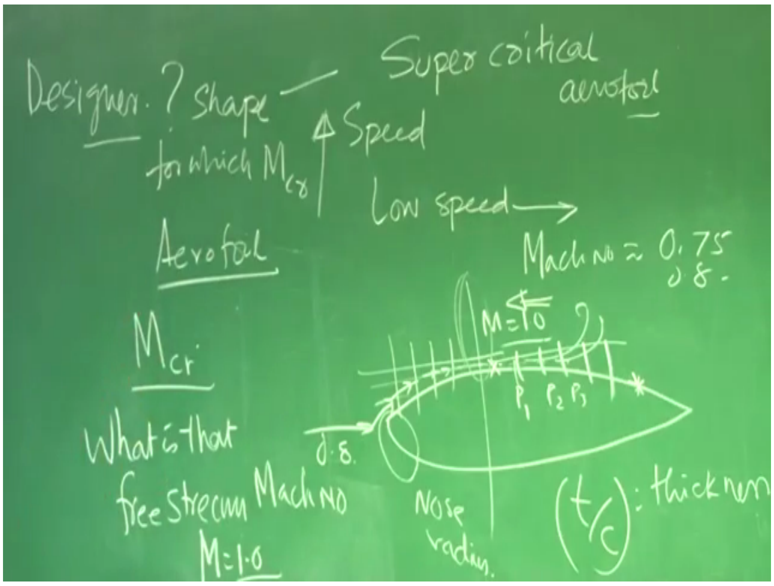

Conventionally if you see here there is a adverse pressure gradient now you could see as you draw line like this the area goes on increasing. So, the speed goes on decreasing to the pressure P 1, P 2, P 3. So, P 3 is more than P 2, P 2 is more than P 1. So, there is a adverse pressure gradient that is primary responsible for flow separately.

If I want to laminar flow for a longer chord length I like to ensure that for a longer length if the adverse pressure gradient should be handled properly the pressure should not be adverse so that it does not make the flow separate, how to ensure that it does not have that detrimental adverse pressure gradient for a particular chord length, will also decide what type of aerofoil you want and since I have just talked about those numbers.

Next class, I will talking only about aerofoil what is the normal nature of aerofoil, how do you read an aerofoil one of the normalization is given, what are the information you will get so that you can easily synthesize these into your aircraft design.

Thank you very much.