Introduction to Helicopter Aerodynamics and Dynamics

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Lecture No. # 04

I thought, I will give you a table essentially providing the details of helicopter control for different configurations that mean you can have a single main rotor and one tail rotor, you have co-axial, you have tandem and you have side by side. Now the controls slightly differ depending on what configuration of the helicopter we are addressing ok.

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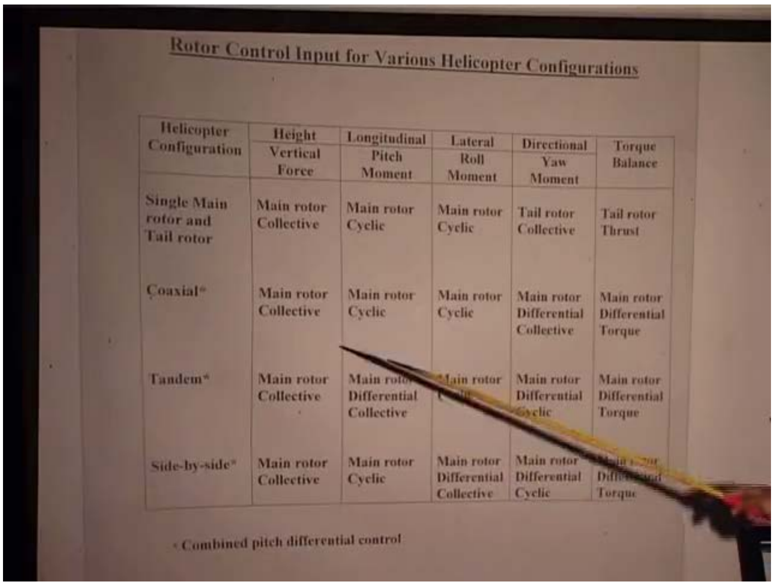

Rotor Control Input for Various Helicopter Configurations

Helicopter Configuration	Height Vertical Force	Longitudinal Pitch Moment	Lateral Roll Moment	Directional Yaw Moment	Torque Balance
Single Main rotor and Tail rotor	Main rotor Collective	Main rotor Cyclic	Main rotor Cyclic	Tail rotor Collective	Tail rotor Thrust
Coaxial*	Main rotor Collective	Main rotor Cyclic	Main rotor Cyclic	Main rotor Differential Collective	Main rotor Differential Torque
Tandem*	Main rotor Collective	Main rotor Differential Collective	Main rotor Cyclic	Main rotor Differential Cyclic	Main rotor Differential Torque
Side-by-side*	Main rotor Collective	Main rotor Cyclic	Main rotor Differential Collective	Main rotor Differential Cyclic	Main rotor Differential Torque

* Combined pitch differential control

Here you see height that is for vertical moving up and down, all are controlled by the main rotor collective everything has main rotor collective. Even if you have two rotors co-axial see all these are two horizontal rotors, but again collective means you saw that the pitch angle changes uniformly over all the blades at every azimuth location. Whereas, when you take a longitudinal that mean pitch, you will find main rotor cyclic co-axial has main rotor cyclic.

But when you have tandem that means, one rotor behind the other I can have a differential collective that mean one side I increase the collective other one I reduce so, there is a pitching moment generated. So, the nature of control can be I increase the collective here means I increase the thrust here, compare to this automatically I will give you a pitch. So, that is called the differential collective, main rotor differential collective if you take side by side then you have main rotor cyclic, because for pitch you have two rotors. So, if you want to go down you have to give a cyclic control ok.

But when you go to lateral for different configuration again this is main rotor cyclic for the single rotor, co-axial again main rotor cyclic, tandem cyclic now because you want to roll whereas, side by side you see differential collective. Because I can increase it I can decrease it. So, I can roll now when you go to the yaw moment for the single main rotor, tail rotor, tail rotor collective that mean he operates the pedal. Co-axial differential collective that means, each rotor get different pitch angle as a result there is a torque generator and if you take tandem yaw differential cyclic that means, this rotor you tilt one side other rotor you tilt then you can rotate and side by side also differential cyclic. Now of course, the torque balance is given here tail rotor thrust gives the torque balance for single main rotor co-axial that is the differential torque of two rotors tandem again main rotor differential torque side by side differential torque.

So, if you look at it the control using the two rotors they are little different for different different configurations, but as far as the pilot is concerned he will have one stake, one collective stake and pedal. Now depending on the configuration you have to make sure that when you move the pedal, he does the appropriate change in the either tail rotor or he has to change differential collective it is not that is given some other control lever ok.

That is why in the helicopter configuration is important and how this various forces and moments generated by essentially using the rotors. And that is why they call I put a star here just to indicate they called combined pitch differential control mechanism which goes to the main rotor, this is is a kind of a different terminology. And now when we analyze in this course we always take this pretty much the configuration is a single main rotor, single tail rotor. And most of the books everything they deal with this, because if you understand the basics of this then rest of the things are fairly easy only thing is you have to know what to do. As far as the rotor behavior is concerned we have thoroughly understood and then whether you put two rotors are one horizontal and one vertical that depend on the type of configuration ok.

And next is, this is a preliminary thing about the power required for helicopters which you will be calculating this is just an introduction I am giving for you to see, because helicopters have to hover and they have to fly forward. Now what happens to the power required, generally the power required are classified into three major factors you can call it one is call the induced power, another one is the profile power and third is parasite power.

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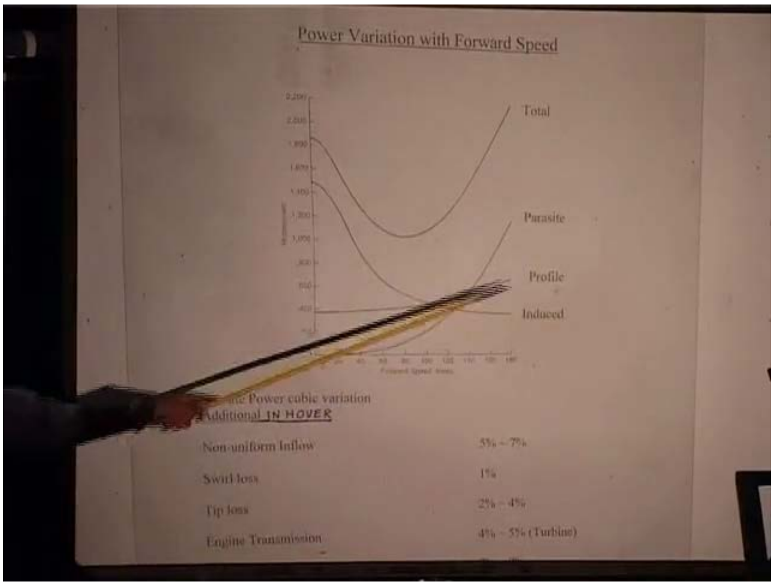

Now what is the meaning of each one of them is induced power essentially represent, you want to lift the helicopter the power required to lift that is called induced power we will be calculating all these things. Because that is that will become part of your assignment also, the profile power is essentially you are dragging the blade in air. So, there is a drag force on the blade and the power required to drag the blade is the profile power.

Now, the other one which is the parasite when you are going forward fly, you have to drag the helicopter. So, helicopter means helicopter and the hub etcetera and that is the parasite power. So, please understand it is not the profile blade also gets dragged in the air and the fuselage is also getting dragged in the air. So, in hover this is x axis is forward speed, this is the power given in horse power do not bother about the numbers, you look at the trend in the curve trend that is the very very critical.

You see induced power initially it is very high in hover, and then with increase in forward speed induced power slowly decreases. Whereas, the profile power which is the blade drag which is the drag C D not naught you may call it which up to some speed it does not vary much after that it shows us slow variation that is purely aero file characteristic. That is the profile power.

But if you look at the parasite it is 0, because you are not dragging the fuselage in hover, you are not moving forward. So, it is fine it is 0, but then as you keep increasing the forward speed this starts going up and it goes in a cubic variation of velocity. Please understand the parasite drag will be proportional to V cube that power drag is proportional to v square power is V cube. So, you see if you sum up all, because these are the major power required, because in any helicopter design they have to calculate all these terms, you see the power curve the total its high in hover it decreases with forward speed and then it starts increasing ok.

So, this is your nature of the power versus velocity curve. So, it decreases and then it will increase. And it will increase you see the slope of this it is very sharp and when you want to fly very high speed you have to have tremendous power and it is going to be velocity cube. So, any increase in speed power required goes by V cube and when you select the helicopter when you select the engine for a particular helicopter, the operation you have to consider. And what is the power available in the engine, how much power is required for a specific flight condition. Now you know that as you go high altitude, there is a variation in density that will affect the engine power that will also affect this, because the density vary you will see when I derive the whole thing after this you will see density is going to influence tremendously.

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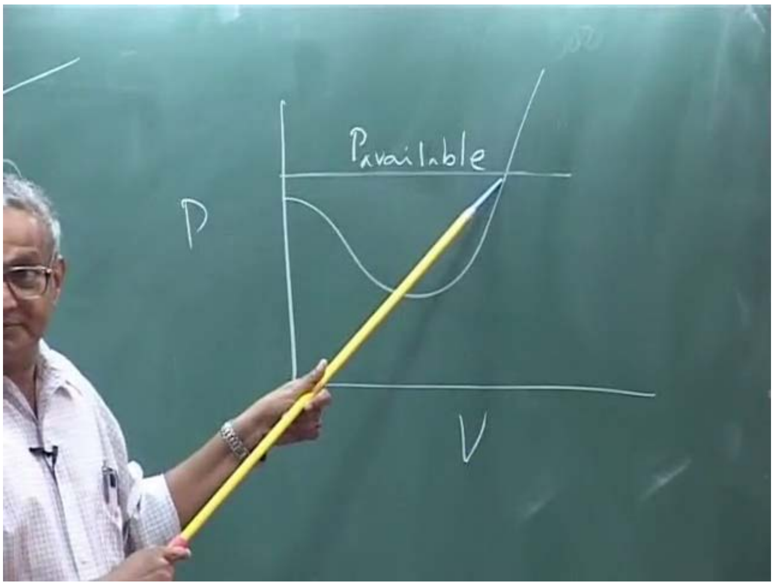

So, that is why the power curve is very very critical, when you are talking about the helicopters and this also tells you are not going to fly just horizontally, you want to climb if you want to climb, you need to have extra power otherwise you cannot climb. Because if you are hovering I have this much power, now if the power available is exactly like this then you cannot climb. So, they will say what the power available is now you see if I draw a curve this is power versus velocity goes like this if power available by taking this this is P power available.

You can only fly up to that speed, you cannot fly beyond that speed and if you are at this speed, you cannot even climb. So, these are all restrictions which come, because of the nature of your power required this all are the major major components of power then you may ask what are the other components there are certain rotor inflow interferes with the fuselage, then tail rotor you need to have some power. Then there are power losses because the engine may rotate at higher R P M you put some gears then there is a power loss into gears and there are tip losses there are swirl affects.

There are several types of that is why I have written for a hover what are the other losses typically it is just for various types of because the inflow can be and the uniform inflow you will understand what uniform inflow means later. Then swirl then tip loss, engine transmission, tail rotor, rotor fuselage these all are not easy to estimate it is very difficult, because you have to do a actual fly internal test and overall today C F D people are trying to do let us still of long way to go. So, you have other losses also these are just estimates. So, your engine has to have sufficient power if you want to fly the helicopter, but one interesting point which I will briefly tell you there is something called a ground effect ok.

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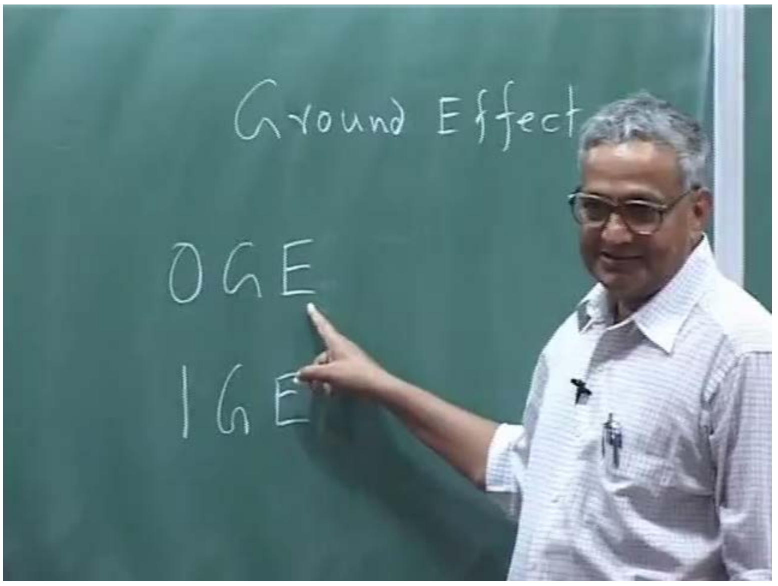

You will learn later there is something called a ground effect, when the rotor is operating very close to the ground very close means how close you may ask you can take it as a one rotor diameter less than one rotor diameter one rotor diameter. When it is operating very close to the ground, the ground provides some kind of a cushioning effect as a result to lift the same weight if you are out of ground they call it O G E or I G E out of ground effect; that means, ground is not there this is in ground effect, if the ground is near basically the power because of the cushioning effect the power to lift the same weight slightly reduces.

As a result that is why you can hover the helicopter near the ground, but you may not be able to hover the helicopter above the ground, sometimes you want to carry a little extra weight what they do is it is a interesting. You see when I increase my forward speed my power required decreases that mean you can give ground run or if there is a wind you try to take off into the wind direction even with a slightly heavier weight. So, these all are the operational things which pilots use it, when they want to take off. And now this particular curve is used what is the best speed for maximum range this we will studied that later that is one question.

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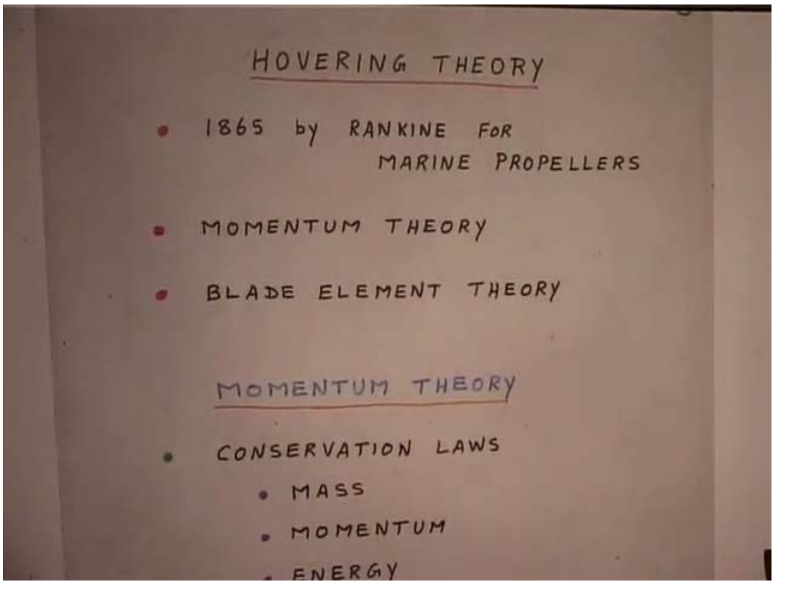

Another one is what is the best speed for maximum climb rate, these are important things you will learn about that from this curve as we progress in the course. Now with this pretty much the introduction to the helicopter is over. Now we start with the first topic which we consider is the hovering theory. What do you mean by hover key is hover means the helicopter is rotor we consider rotor because of fuselage is just have weight.

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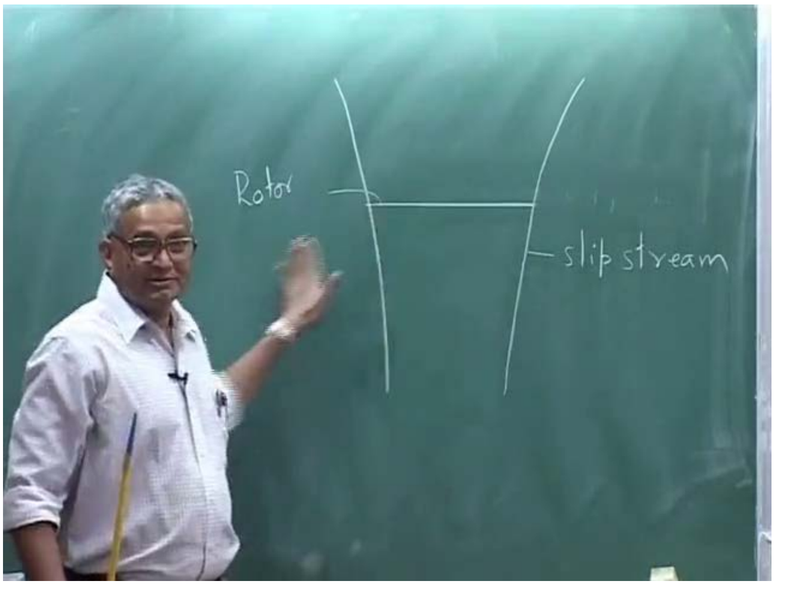

Helicopter is stationary and with respect to the wind outside some slip stream there is something called a. So, you take this is my rotor and you say this is an idealization please understand, you draw some something like this this is called slip stream this; that means, the air inside this region only is affected outside this region vary stationary and the rotor is stationary with respect to this and it is a still lap.

Because you can have the effect of forward flight, even though the helicopter may be hovering with respect to the ground please understand with respect to the ground, you are fine because you do not move, but wind is flowing then that is equivalent to forward flight then the pilot has to keep controlling. Here when we talk about hover theory, the air outside the slip stream is stationary and the rotor is stationary, but within this the flow is affected this is the condition for hover where did this theory start. So, brief history it was by marine propellers it was started.

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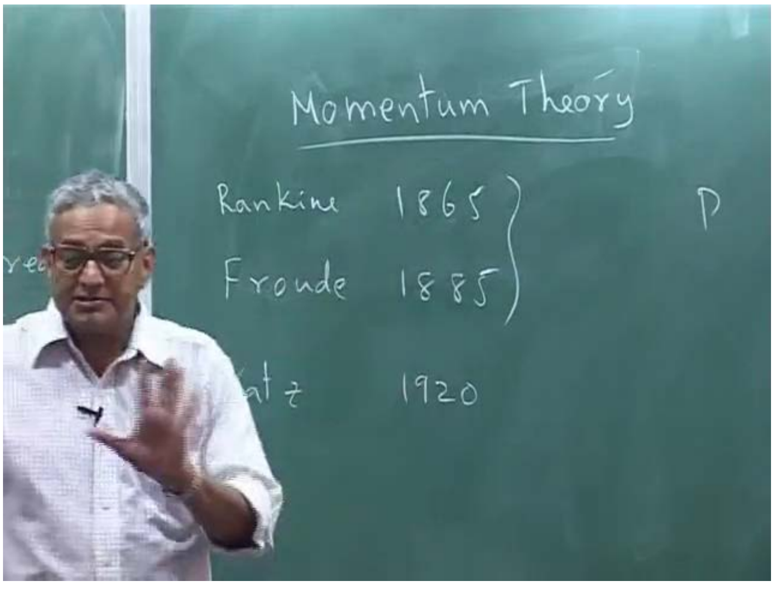

Basically the momentum theory momentum theory I will briefly tell you what that the hover theory was originally by ranking for marine propeller's in 1865 later modifications were made. And 1920 the some rotational effects the swirl effects were considered, but thus is momentum theory please understand 1865 then Froude 1885 and then Katz 1920 and this is Ranking 1864. Basically proposed he added some swirl effects later all these for just marine propellers not for a helicopter.

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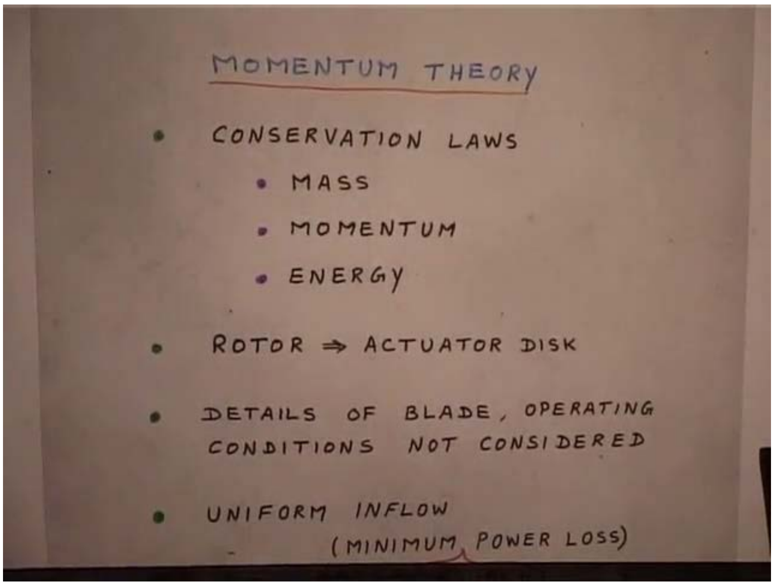

Now what is the basis of this momentum theory is purely the physics which is conservation laws: conservation of mass, conservation of mass, conservation of momentum and conservation of energy incompressible flow, treated incompressible. And these are the basic three because fluid mechanics we have mass conservation, momentum conservation, energy conservation that is all using this they came up with the theory for a is called the momentum theory.

But it is very very global, because what is that it has you have a rotor, rotor means rotor has a blades, marine propeller also has some blades, aircraft propeller has blades and your helicopter rotor has blades. But what is the assumption that is made in this particular theory, you say this is a new word rotor is treated as a actuator disk, actuator disk means it is a thin circular disc with radius as the rotor radius and it has infinite number of blades that is infinite number of blades, but that means, it is solid. And it is permeable to the flow rotor flow can go through the disk but it supports air pressure difference.

So, this is a assumption actuator disk is simply now it is an area that is why I have drawn this line is a rotor just one line that is all with the diameter of the rotor and it is permeable to the flow; that means, flow can go through this that is a basic first assumption, flow can go through this, but it supports a pressure difference. So, you have a top surface you have a bottom surface there is a pressure differential, but the velocity is or the flow velocity is continuous this is like a looks a little you know you cannot immediately visualize what is really going on that is why this theory is based on the basic laws of physics and it makes lot of assumptions, but please understand it does not consider details of blade operating conditions nothing, it does not require anything it just require what is a rotor diameter that is all.

Thus if you say this is my rotor diameter I can get some basic quantities that is what the momentum theory. So, this theory is important, but this alone is not sufficient, because it does not bother what kind of blade what is your aero file, what is the R P M it is rotating, what is the pitch angle you are operating nothing. Now then you will say what is this theory, where is it used, is it really useful is a basic question that will come up ok.

Yes it is useful in getting some preliminary estimates; now let us see how the momentum theory is formulated. So, this is the that is why I said slip stream this is the boundary, you may assume that it like a it is not exactly like a internal please understand, internal is a closed, here it is not closed this is like a demarcation this line between air outside and air inside. Now the very first assumption I am going to make though I have written here later you will mathematically you can show, this particular thing I assume uniform inflow.

Now I have used a new terminology which is called the inflow, inflow is this is inflow this is a terminology in helicopters, but we are interested in the flow velocity at the rotor disk normal to it, that is important it is a velocity normal and we use a symbol and I put uniform inflow, uniform inflow means the velocity everywhere is same I am assuming it is a uniform inflow.

You may ask how do you know what do you know from you take it there is a starting point, later you start really going deeper into that. So, very first thing is you assume uniform inflow and the flow velocity if it is hovering here it is 0 this is far field and the pressure is P infinity, P infinity or P not or whatever you may call it and then just above that P1 just below this pressure two and far field downstream P infinity, but I say here it is some velocity is coming; that means, it is going out here. So, I will put velocity here this I call it w and here I use the symbol nu, this is the standard symbol which is used in helicopters ok.

So, the symbol which I am using are all what is used in wherever you go inflow they use the symbol nu. Now this is my basic assumption of momentum theory in hover please understand it is in hover only now I have used the something I wrote uniform inflow and within bracket I put minimum induced power. Mathematically you can show this is like calculus of variation, I am telling you using calculus of variation you have a thrust now I used the word thrust, thrust is this rotor is supporting a weight. So, I call that is the thrust T.

The thrust is here I take perpendicular to the rotor disk that is like the rotor is really pushing the air down continuously, as a result Newton's law you push something you get an upward force. So, the rotor gets the thrust upwards and the rotor is pushing the air down. So, this is the momentum theory. So, this thrust, but for it to push the air down you need some power and that power is called the induced power. The power to lift the weight that is all nothing more that is why it is an induced you can say inflow or sometimes you say induced velocity. Induced induced velocity forward flight we use it right now you say inflow is enough.

Now you will find if I have uniform inflow then I will have minimum induced power that is the last means, because you have to supply that much power at least, but that is not sufficient this is the ideal condition, but mathematically you can show. Because that I will give you later, once we get the equation I will say this is the problem now you say using calculus of variation you will say that yes if you have this conditions satisfied you will have minimum induced power for minimum induced power you want uniform inflow that is the key.

Now you may start hovering how way achieve uniform inflow that is the different thing, you follow I assume uniform inflow, if it is uniform inflow in hover everything is hover please understand I get the minimum induced power good now how do I achieve uniform inflow that is the next question. So, you will come to that part later. So, now we will see the momentum theory starting from basics this is the basic stuff. So, here I used a slightly different symbol you can look at the diagram.

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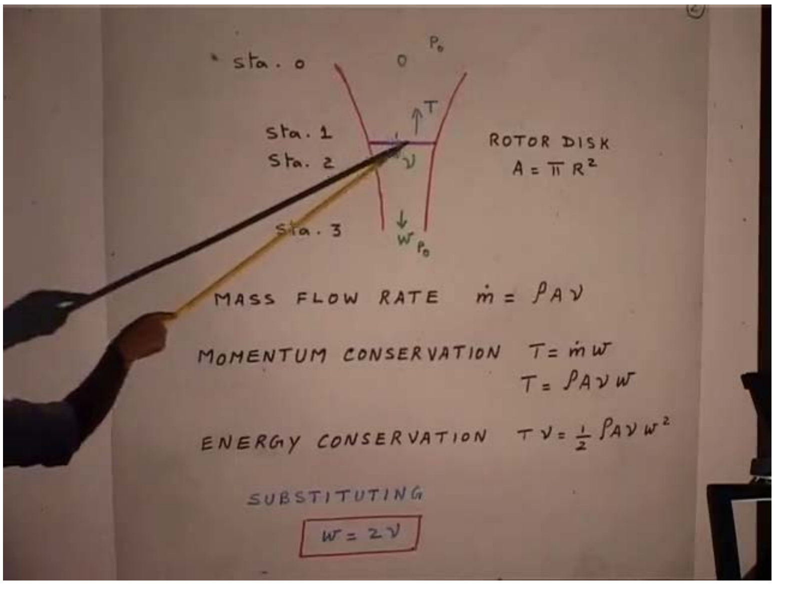

This I call it station 0; that means, far field upstream and the velocity is 0 there. Now as you come near the rotor disk I call it the flow at the rotor disk is nu and it is constant over the disk. And the disk area is pi R square because R is the radius. Now I put station 1 and 2 because 1 is above just above above the rotor disk, 2 is just below the rotor disk and then station three which is far field downstream that is here which I call it W.

And now this is like a tunnel, because the velocity is 0 here as you let us say simple see mass flow rate, when the velocity increases actually the area is reducing that all because same mass has to flow. Now if you look at the mass flow rate that mean the amount of air that is flowing through the slip stream, you have only two quantities one is W another one is nu, but the area you only know one area that is the rotor disc area, because you do not know what is the area here the cross sectional area; that means, mass flow rate that mean density into area into velocity, velocity at that area that all.

So, that is rho A nu M dot now momentum conservation momentum conservation is basically Newton's second law rate of change of momentum is basically the force apply. Now what is the momentum change to the flow per second far field here the velocity is 0, so 0 momentum and here the velocity is W and how much is the change in rate of change of momentum is m dot into w minus 0 that is the rate at which momentum is changed M dot w.

And that is the force, but that force is acting on the rotor disk, because that is the one which is creating that. Now you substitute for M dot this value rho A nu W that call T. Now the next part is energy conservation that is the power you supply there is no loss in this, the power you supply is basically goes towards changing the kinetic energy of the flow. Now what is the change in kinetic energy half so, I will write change in kinetic energy is per second everything is per second because here velocity is 0 here velocity is W. So, you will have half M dot W square and M dot is rho A nu half rho A nu W square this is the change in kinetic energy and the power is actually force into velocity and the force is acting on the rotor disk and the velocity at that disk is nu. So, the power is T nu ok.

And thrust is given here from momentum conservation rho A nu W. So, you can write it here substitute you will have rho A nu W into nu is half rho a nu W square. So, you will find you cancel out rho A nu 1 w you cancel. So, you will get W becomes 2 nu this is the basics; that means, the far field velocity in the slip stream is twice the velocity at the rotor disk. So, you had a relation between W and nu now simply go back substitute for what is W is 2 nu.

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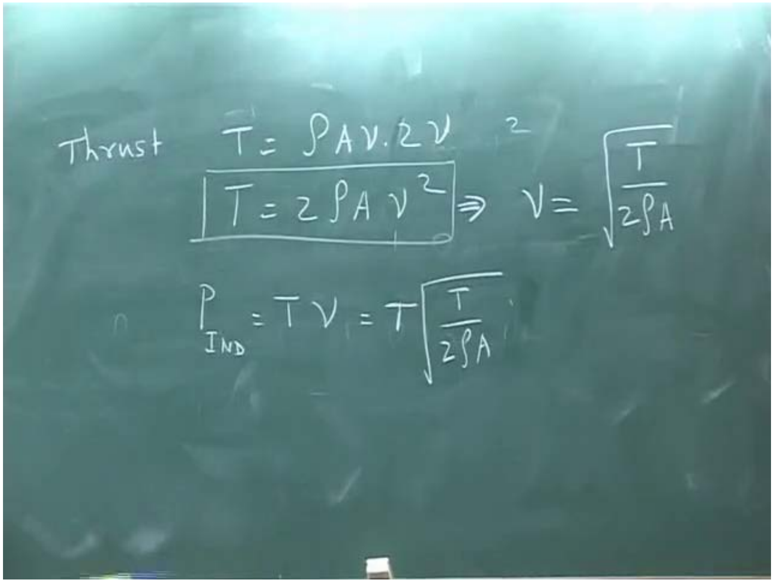

So, your thrust is given by rho A nu 2 nu. So, you have now a nice expression for thrust. So, this is what thrust produced is into 2 nu or you can write it as 2 rho A nu square. And the power is induced power that is why I say this power is only induced, because you are inducing that velocity that is why we call it induced power if you want you can use the symbol I N D this is thrust into nu and you know thrust is here, you can write the full expression or you want in terms of nu, you can write it because here because this leaves you what T by 2 rho A this is the and T by 2 rho A.

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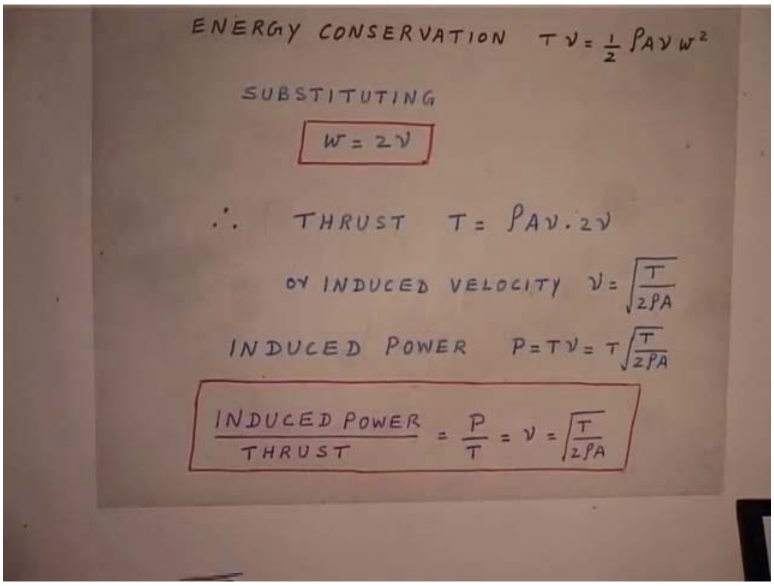

So, that is all nothing more it cannot give you anything. Of course you can draw the velocity profile etcetera that we will sorry the pressure profile now this essentially gives me very simple relationship thrust is basically weight of the helicopter. Because the rotor disk is given by rotor disk area and density of air is known to you. Now you say hey what should be the engine selection of engine minimum, it says what is the weight want to lift in hover, thrust is equal to weight and thrust into square root of thrust divided by 2 rho A all right. Now if your rotor disk area is less this quantity is more; that means your inflow is more and you can get an estimate of what is the power.

Now, if you say if you want to reduce the power you try to equate the rotor area, now you see as the it is directly rotor area dependent, but does it mean that you can you increase keep on increasing now there are other practical consideration it will come later. But the essential part is yes and of course, density now it immediately tells you if I want to fly the helicopter, fly means hover the helicopter at an altitude which is about 19,000 feet.

The density of air drops by half that means, the power required is going to increase. So, you cannot operate the helicopter at any height, because the power required to hover actually increases with altitude, but the engine power actually will decrease with altitude because the density is less.

So, you find it will be an interesting that is this is the power, this is with altitude you will find the induced power will go it will increase this is the p induced, but the engine power may decrease this is engine power that is all that is the altitude you can just barely. Oh. So selection of engine, engine characteristic is very very important it is not that I will go and buy any engine. So, you will find usually see India has to operate helicopters that are much higher altitude there are several helicopters, in the Europe I do not think Europe, US they do not need to operate at that height. So, usually when it comes they want to sell a product it is always the problem because you will find that India will immediately all they you know of course, the services they have requirement of high altitude, they have requirement of desert which is Rajasthan and they have sea water, because the corrosion you have a variety of conditions atmospheric conditions

So, you will find that whatever somebody is oh this will fly you may buy, but you will not be able to operate that. So, these are very very critical when you want to procure and that is why when I say when people are making about I will make a flying car flying, car with four rotors I put it, I will lift it please understand the first thing you calculate is a what is the at least the power I need to lift that particular car whether you put one rotor four rotors any rotor this is the ideal bare minimum. There are other thing because this is that is not take into account all the loses and other things. If you do not have this you will never be able to fly ok.

That is why the primary thing this momentum theory gives some idea of power thrust density rotor area this relationship very very in the most primitive fashion, but these are performance numbers. So, if somebody is there is that I am going to make a helicopter the disk rotor this is the engine suppose somebody gives you a scooter engine you fly.

But you have to check what power is gives what is its weight and then what is the rotor you are putting very very simplistic calculation, very simple calculation that is why momentum theory is gives you the first cut and as you become more and more experience then become an expert in the field.

You will immediately have all these numbers quickly you calculate you will say this is meaningless, that is why all these things are very very critical. Now so, you you now see induced power divided by thrust that is P over T see induced power P induced by thrust this is nothing but nu. Now it immediately tells you if your power required is less, you want to have less power increase sorry decrease induced velocity how do you decrease induced velocity go and increase the disk area ok.

So, they will say let us have a increase the rotor size reduce, but of course, it is from the hovering point of view because the helicopter the key is you should be able to hover if you cannot hover it will no longer a helicopter that is the special flight feature of the helicopter ok. So, hover is always considered because moment you start flying forward the power required is less than hover, but of course, if you try to increase high speed then you will find that power will again come and then hit the hover power ok

So, this gives you an expression for induced velocity to thrust is nu and actually there are two terminologies which I will say, power loading and disk loading. Power loading and power loading is actually T over P a one over inflow this is the thrust over power power loading and the another terminology is disk loading this is T over A ok. These are two terminology disk loading. Now, because the T over A is assuming density is constant you take the c level or anything.

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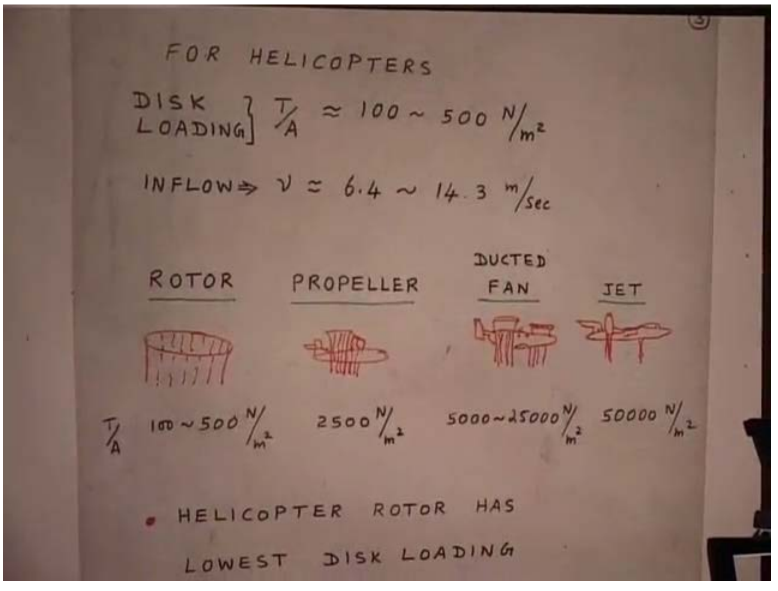

Now why helicopter is a better vehicle for in terms of hover performs vary so, special because you can also that is why now the disk loading for helicopters is usually please understand is usually in the range of 100 to 500 Newton per meter square. And the corresponding inflow basically I took the same value I took this C level density you will find the inflow velocity is in the range of 6.4 to 6 to 14 meter per second ok, this you can calculate because this is the square root of T over 2 rho A.

Now I am just giving her a comparison of various vehicles which have the hovering capability this is a helicopter rotor T over A, I am giving propeller can till the propeller, but in the propeller T over A is of the order of 2500 this is 100 to 500 if you go to ducted fan because there are several types of models there is of the order of 5000 to 25000. Now, you know that jet that is the C there is an aircraft which is a jet will come and then hit their ground and it will it can hover the jet is actually coming out and there the in C over A is of the order of 15000 Newton per meter square ok that also has a hover capability helicopter rotors is also having a rotor capability.

Now if you go to that high value the power requires is phenomenon whereas, helicopters require less power that is the advantage. So, the helicopters require less power to hover usually the C harrier what sometime you may see in the video that is shown only for video while at that is not hover, it is only to demonstrate that it has a hovering capability where I talk some file, they said that if we hover all over fuel is done before we take off. Because we it is just for yes that particular aircraft has this capability because it is operational on a ship it can come and, but it will is it the fuel will just go off we do not try to operate on that. So, that is where the key is helicopter rotor that is why helicopters are still popular with all the problems with various other reasons, because it has less power for hovering.

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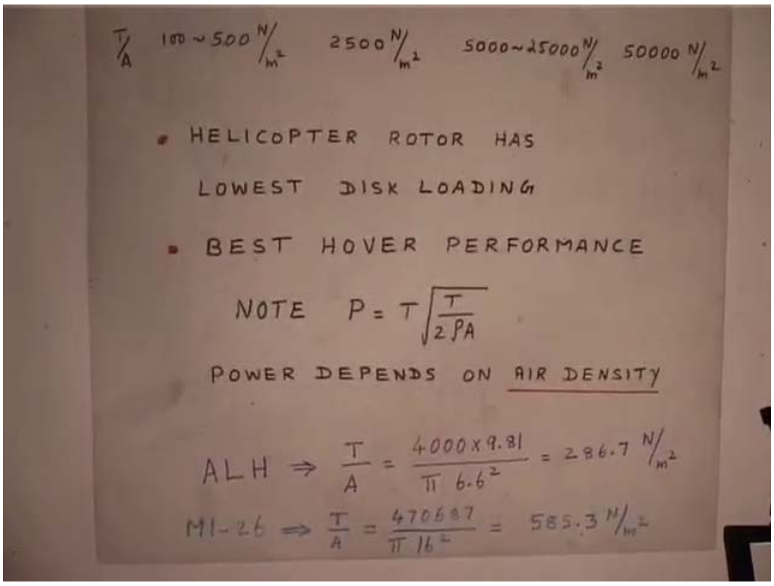

Now we will use certain just some numbers because this is for helicopter rotor has lowest disk loading. So, best hover performance that is a reason helicopters are still and of course, it can land take off from any terrain all those things are there and then the power of course, it depends on density of air. So, that is important and there this is I have given some helicopters which India has produce that is the ALH which is the advanced light helicopter.

I am giving what is the disk loading for that helicopter, because this is just to because there I have written generally it is in the range of 100 to 500 etcetera. Now if you look at various helicopters you will slowly understand that it is in the range this is about 4000 and the T into 9.81 and the radius is 6.6 meter. Now you get an idea of what is the rotor radius please understand helicopter rotors are of the radius of about 20, 22 of that feet 25 feet, but one helicopter that is why I have written here MI-26 this is you see radius is 16 meters that more than 50 feet ok.

It is a huge it looks like a real big elephant, it has a eight blades I think and the that so, this is just for comparison I am saying even though this is also single main rotor tail rotor, this is also a single main rotor tail rotor, but the weight comparison if you look at it this you divide by this is about 4500 kg 45000. This is 4000 this is about 10 times more, but even then when you look at the non-dimensional numbers they are all in the helicopter range, that is why some time all these numbers thrust if you simply say it may not give you a clear picture.

But T over A which is the disk loading that if you compare for different helicopters then you will say they are of the within the zone whereas, thrust you may have a helicopter with 1500 or 1800 kg 3000 kg 5000 kg 10000, 45000 various actually this is the heaviest very heavy helicopter similarly rotor this is the Russian MI-26 ok. Now, you can see approximately all of them will have the disk loading is in the range of 100 to 500 the 12 to 1 time. Now let us define some non-dimensional quantities, because these are going to be very useful we will be dealing with non-dimensional quantities.

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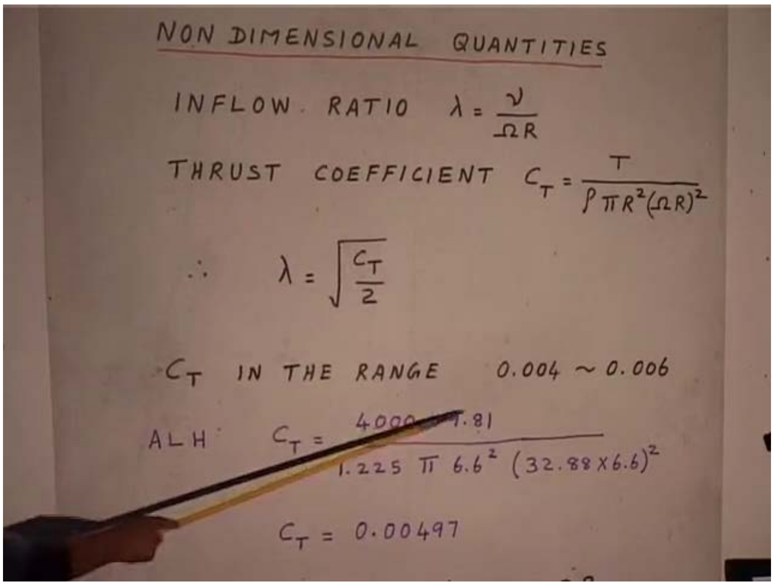

The first quantity is inflow ratio please understand this is very important and the symbol used is lambda inflow ratio lambda is nu over omega R. Please understand omega R is tip speed, omega I may give in RPM, but please understand radian per second you have to take it and then calculate the tip speed this is the inflow sometimes people do not use the word inflow ratio they will simply say inflow ok

So, please understand inflow even if I mention I do not have to give you in meter per second, it can be a non-dimensional number. So, you have to know that these are quantities which are very very important and they will be used throughout the semester and then now you see thrust coefficient. So, in the aircraft terminology thrust is something which is taking you forward whereas, in the helicopter terminology thrust is actually that which supports the weight. So, there is a big difference between aircraft and helicopter terminology.

So, trust coefficient and the symbol used is CT, C sub T which is thrust divided by density rotor area which is pi R square and then omega R whole square this is the thrust coefficient. And now the relation between lambda and C T you can get it directly from here, I erase this here because you divided by T over rho pi R square omega R whole square. This is again 2 rho A is basically pi R square that is the rotor area and then nu square over rho pi R square omega R whole square this you see this is nothing but C T this is 2 lambda square or in other words lambda is square root of C T by 2 simple. So, inflow is and C T if you look at it C T for helicopter is usually in the range of this.

So, 0.004 to 0.006 if you give a slightly suppose you say my C T is point 0.01 or 0.02 that means, it is not a helicopter. So, that is how people immediately is a good design us good people over very good understanding they will say that density it has to be in this range if you would say that mine is a helicopter otherwise just by giving a thrust or area or anything it is difficult.

So, either disk loading you specify or C T you specify and you will find in the industry in the publications C T is very commonly used very commonly used thrust coefficient, because thrust coefficient 0.05 is usually for a helicopter 0.05 normally that is why I put 0.004 to 0.006 and you take now I have say I again took the reference are there advance light helicopter that is the Indian thing, you see C T this is the weight and density 1.225 Please understand again density is important in defining C T. You may say what is that this is always like this means if I go to high altitude what happens yes of course, C T will go up. Now you automatically see if the thrust coefficient goes up inflow goes up if inflow goes up power goes up for the same rotor ok. That is how everything is related C T for A LH, the rotor radius is 6.6 and the tip speed this is around 32.8 radian per second it is actually around 300 plus RPM 317 or something like that I do not know what is that 300 something R P M.

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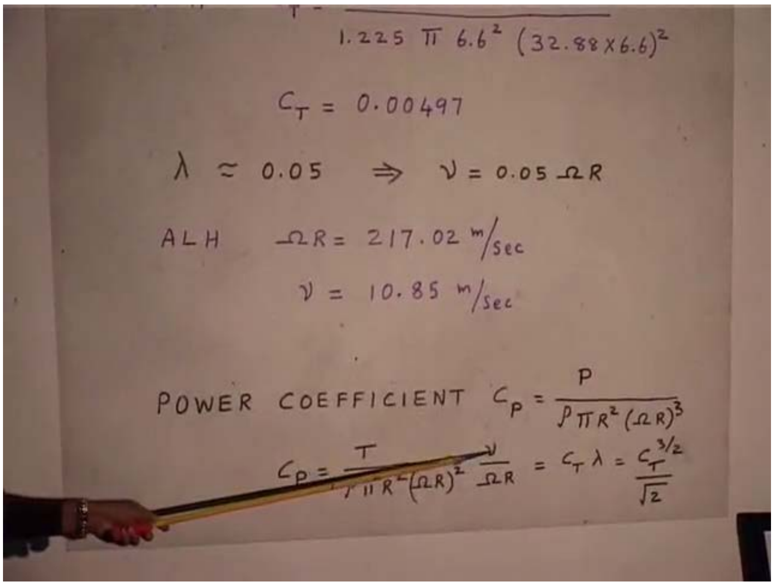

Now, if you multiply these two you see for the ALHCT for 4000 class this is around 0.0497, but you take some other helicopter it will be around that range even if you increase some weight it will become slightly you see a tip speed this is omega R 217 meter per second. Now, you may gone to earlier I showed you another rotor with the 16 meter radius what is RPM of that because I did not specify the RPM there it is much lower it is around one point some hertz its very slowly turning.

Then what is that really very very important in the helicopter rotor, one is the radius another one is the omega angular velocity. These are the two parameters radius you know that if I increase my radius I require my C T will actually come down, my inflow will come down, the my power will come down, everything will come down beautiful. But then if I increase my omega actually what will happen again that will also reduce my C T, but then if I keep on increasing my omega my tip speed will keep increasing and then you may start getting into adverse effects of the flow.

Because you start having lot of compressibility, divergent drag divergent there is something called a drag divergence speed beyond with the drag force will start increasing because your mark number is increasing. So, they try to keep the tip speed around 200 meter per second it may be 180 also. So, you will find most of the helicopters I have you say you take any helicopter the tip speed omega R is in that range, it is not that because you see this is about in the C level it is about 0.6 mark because 330 you take it around 0.6. So, 0.6 mark is a tip speed they keep it.

Do not try to go very high value of course, you have to fly forward also that comes later I am taking about all these numbers I introduced in the beginning to indicate the range of numbers which are used. Now even if I give you any data anything to you you will find that it is it should be within that zone ok. Now, 217 meter per second now power coefficient is C P is power divided by rho pi R square omega R whole cube this is power coefficient, thrust coefficient inflow these are your non-dimensional basically numbers ok.

Now, where you can relate again C P to C T because you know power is related to thrust you non-dimensionalize it that is what I have written here you will get power is what T into nu and I am dividing rho pi R square omega R square that is C T and nu by omega r that is lambda lambda is root of C T by 2. So, C P is C T power 3 by 2 over root 2 power power coefficient. So, today you have learned this basic basic quantities, because this is very very important and this is all from hover theory. Now, there is one more point which is important which is always referred.

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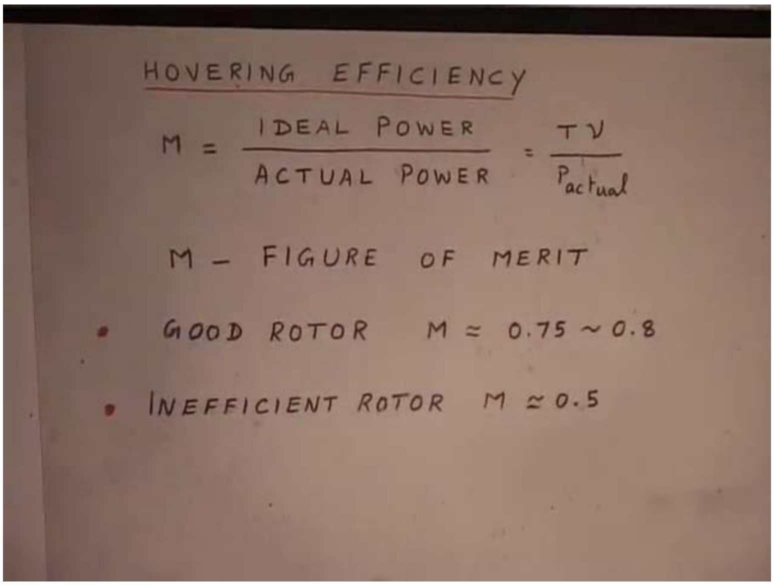

How do you define efficiency you know it is a little bit difficult depending on the situation you may define, but in the helicopters there is something called the figure of merit, it is denoted by the symbol M and please understand figure of merit is only for brace comparison of few helicopters, you should not think that this is the very very important number which should be critical etcetera.

Because you will find it may vary quite a bit, but how it is defined is ideal power; that means, ideal power is the power required to lift the weight that is the minimum that is no lost nothing that is your induced power, induce power is T nu ok. But actual power required where you will have loses that is only when you flight a helicopter you will know or theoretically when you calculate, you can calculate in hover what are the various loses and that is the actual power we will learn how to calculate in a simplistic way the actual power.

So, the part of this course that is P actual so, this is always less than one. So, the figure of merit is always less than one, but later you will find just by looking at the figure of merit it may you may have a you can come to your wrong conclusion that we will see later. So, a good rotor good means good efficiency rotor only from please understand this is only for hover not for forward figure of merit is if you want to compare two rotors good, because you may have a different aerofoil whose drag characteristics can be different. So, from that point of view as figure of merit is good.

So, if it is in the range of 0.75 to 0.8 it is a good good rotor, but if it is below 0.5 it is not that good, but you may find some helicopters may be 0.6, 0.55, but it does not with that those helicopters are flying; that means, it is not that completely inefficient helicopter from a hover point of view if you compare singular rotor helicopter that is where the comparison goes ok you cannot take every helicopter and put them in figure of merit you will find that may you cannot throw that because sometimes you design your helicopter for hover capability is there, but you also want little high speed capability ok.

High speed when you want to go if the rotor diameter is very big you have drag is also more. So, you want to reduce the rotor diameter, but when you reduce the rotor diameter hover efficiency basically suffers. So, you will find depending on the utility of the helicopter the decisions are made about the sizing, but typical rotor diameter and R P M please understand these two go in combination tip speed is the critical number ok.

So, you cannot say that it will never happen that I will have any rotor radius you can if I have put any engine I will rotate at a higher R P M no it is not like that, and I think this much is there basic level of momentum I will just briefly make a statement then I will close today. In the momentum theory we had only rotor radius rotor radius omega we just introduce only for non-dimensional session whereas, the momentum theory did not consider any detail it about the blade how many blades are there in the rotor system there is a three blades, two blades, four blades, eight blades nothing.

But then the theory is not sufficient because you you do not know what is T he R P M it is rotating nothing is known now you realize this theory is not of much use to me. If I want to really do any calculation, any design anything momentum theory is not useful. It give some numbers, but that is not useful for that means, I need to have some other theory, that some other theory is blade element theory BET, because this is a very very important in all rotor analysis.

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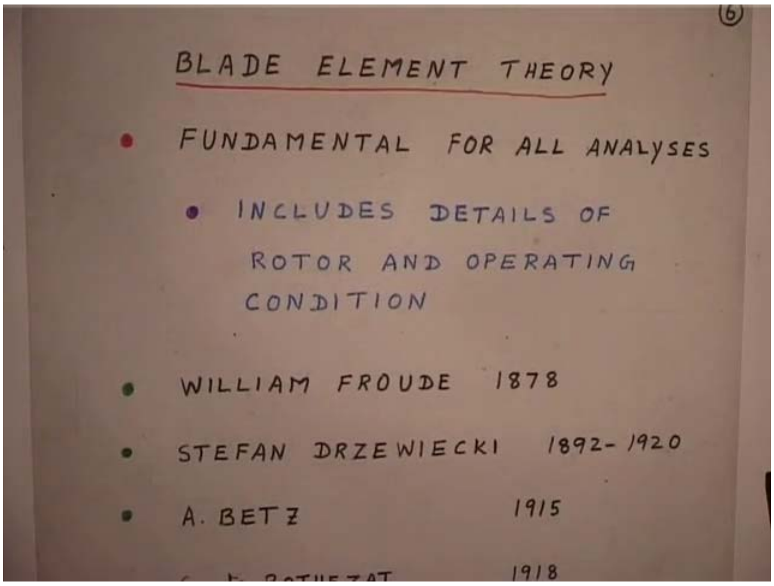

Please understand blade element theory is used every where whether research or anything we have to use this then you will say what is blade element theory that we will learned, but here please understand this is the fundamental for all analysis there is a little history to that that I will describe to you blade element theory may be in the next class. This includes details of rotor operating condition rotor what is a aerofoil, what is the angle up attack, what is the velocity of the rotor in the sense the operating and the inflow everything is required and this includes what is the flexibility of my blade.

Please understand because my blade is not rigid; that means, the structural dynamics. So, you see if I want to use their initially in this course we will have simplistic analysis I will just introduce oh you see the complexity how it starts if you starts including these effects various effects how the same expression in getting a angle of attack.

Now, I use the word angle of attack earlier we said pitch angle pitch angle is what pilot gives, but what each typical section of the rotor blade acts, because from aerodynamics you learned I have an aerofoil it is kept in the oncoming flow at particular angle of attack then I get the lift drag moment. And that is the finer details and what type of aerofoil I am having because that is changes your nature of the lift drag momentum and what mock number I am operating. So, you find all those details are included in the blade element theory. But blade element theory by itself is not good, because you need some information about since like a fan is rotating flow is coming normal to the rotor disk that is the induced flow right.

Now, who is going to give me induced flow because if I do not know the induced flow I will not know the angle of attack properly. Now you see I need an inflow to properly define my angle of attack of a typical section of the aerofoil blade element theory requires all the details, but then I need one quantity which blade element theory will not give, but it requires ok. This is where now I will we will start in the next class how this was the gap was bridged? Now you see how this complexity of the rotor analysis starts.