Introduction to Helicopter Aerodynamics and Dynamics
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Lecture No. # 16

The equation of one blade is always written in the rotating frame you understand, because that is easy to identify what is the motion. Suppose, if it is in the non-rotating frame it is difficult because after sometime blade may be their (( )) somewhere else. You write the motion or the degree of freedom beta with reference to a rotating coordinate system, but you get the absolute values are you clear about that hub loads are in the fixed frame, because you want to transfer it to the fuse large. Fuse large is not rotating please understand there is one non-rotating frame there is a rotating frame in the rotating frame the blade is moving.

So, you are observing the blade motion that is later when we go you cannot look at the particular blade, but you see a rotor rotating suppose, you are lifting standing on the ground you see some rotor is spinning. You do not know which blade is coming where, but you see a disk, then you are looking at the motion of the disk you will come to that later. Because you are observing a flap motion from a non-rotating frame you understand, but right now the equation, which we have written is observing the motion of one blade as it goes round and round is it clear and it does the same motion please understand.

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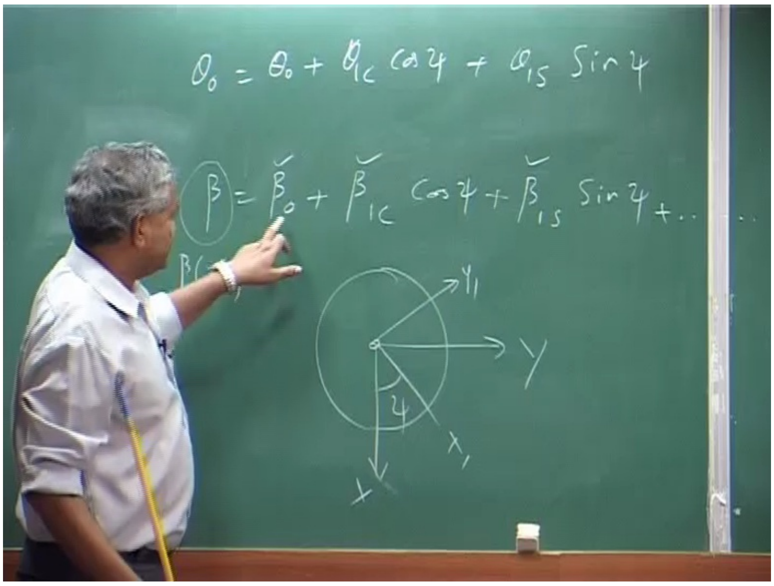

That is why we wrote beta equal beta naught does beta 1 C sign psi. So, we wrote this that this is a and psi you know this is psi and this is actually your capital x and this is my this are a hub fixed this is you have x 1 and you had y 1 and in this x 1 y 1 the blade is moving up and down. So, you were writing the equation of motion in the rotating frame x 1 y 1, because in that frame only you have the blade is flopping up and down. How that is beta that is this quantity you understand, but this particular this itself this is a function of time time means, I can put it non-dimensional time you agree? But how I am representing it is in this passion, this psi is non-dimensional time only you follow.

So, the blade what happens is it has a constant flapping agree that is called the conning plus the value depends on beta depends on where the location list, but we do not know these quantities. You do not know what they are that is what that equation is because that depends on what is the aerodynamic load that acts on the blade that f z and r cross that moment you took it.

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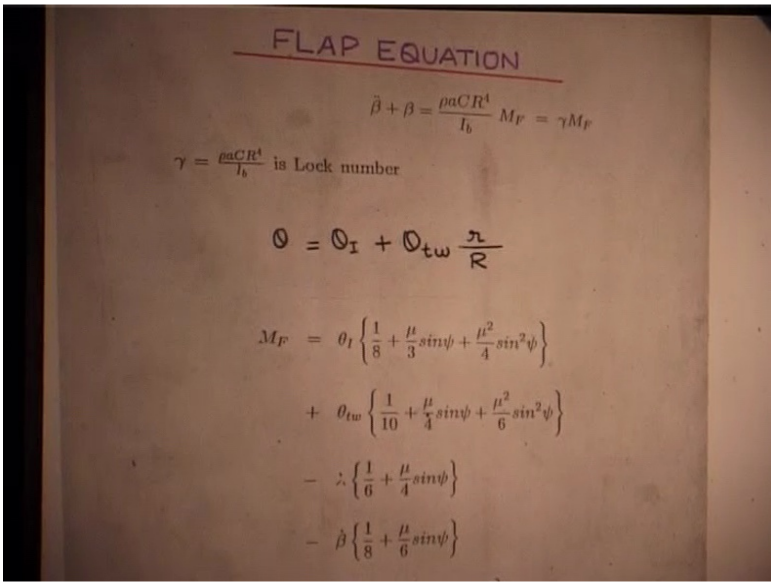

That is how you get the flap equation, flap equation is a simple dynamical system equation which has a like your m x double dot plus e x dot plus k x equals some f of t. Only thing is m c k they are not constants time is constant, but c and k are not constants that is all they are also varying with time. So, please understand the difference and we are looking at steady state response, steady state response is essentially if you have a fixed harmonic input that is this you are giving see this is my equation of motion and M F I have written below, that moment due to flap and of course, lap number is here.

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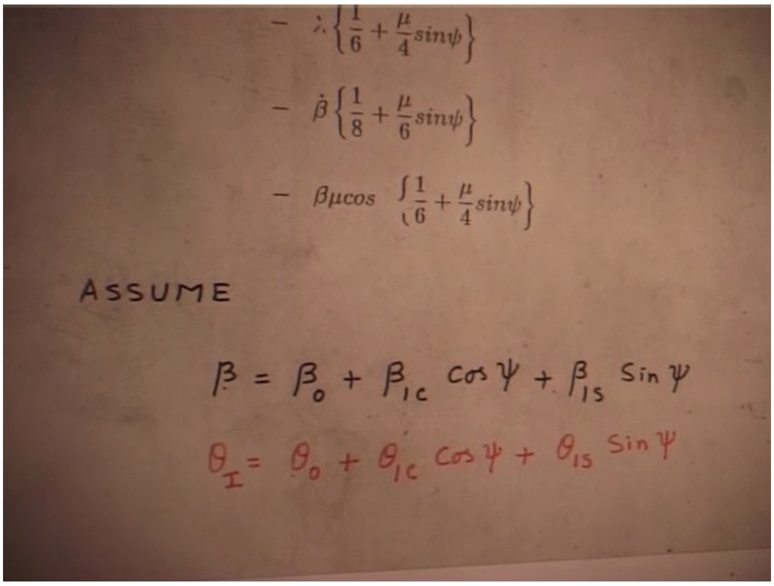

Input is theta I theta I we shown as theta naught theta 1 c plus theta this is a non-dimensional time. So, if my input is varying how my output will vary this is a periodic input, because you must have d1 some at least spring mass damper system. One if you give an initial condition actually, spring mass damper in electronic it is a l c r circuit that is all. If you give a initial condition how the response will look like you have under damp over damp step response you must have study very well we will get back to later another one is if you have a harmonic input.

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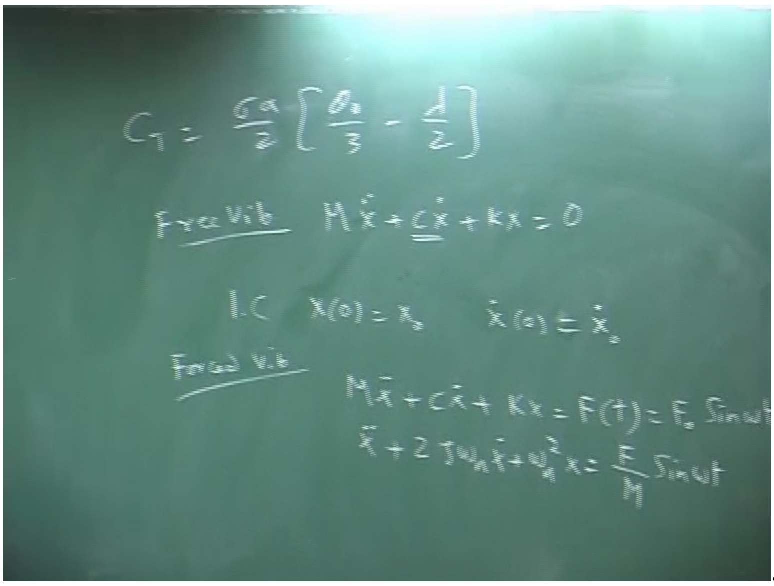

That is if I have this equation 0 I put x of sorry x of 0 some x naught and x dot of 0 as x dot 0 this is the initial condition I C. Again analyze how the system will behave, if this is 0 I give only f dot that is like a pulse impulse you are giving if this is 0 you give you are giving a initial displacement and leaving it how the system will respond. The next part is forced vibration force vibration this is free vibration with damping. In forced vibration you would have studied same equation K X is F of t, but F of t if you study harmonic motion you may write F naught some sinee omega t or cosinee omega t something like that where omega is the excitation frequency, input frequency it is nothing with natural frequency.

You may that equal to that now, what we are looking at here is? You convert this into non-dimensional you may have what x double dot c over mu x dot plus omega n square x here you may F over, which could divide by M from you can do like this and this you may call it some f naught some other. This frequency is natural frequency of the system k root of k over m this is input frequency, if these two are equal that is what you call it resonance. In this problem what we are analyzing is your input is psi, which is 1 per rev because the variation is 1 in a revolution. And you see this is also one, because second derivative this one damping term is on the right side that I can transfer it left side please understand.

That damping term which is here this can come back here, but in forward flight you also have additional stiffness term that is why we do not write it immediately some frequency, but if it is an hover no external force then you say what is the flap frequency that means, mu is zero and you will have one. So, your input frequency is also one if it is in hover, but in forward flight you will have all the harmonics please understand, because if I put theta I equal theta naught plus theta 1 c theta 1 s sine psi cosinee psi this is getting multiplied by with another sine psi. Getting multiply with sine square; that means, I am having second harmonic third harmonic everything comes as an input. So, my response also will have all the harmonics.

So, we are looking at steady state values and I am not looking at the second that is sine 2 psi or sine 3 psi, because I restrict my response only up to first harmonic. I am not adding the other terms I have actually, neglected this you can have sine cos 2 psi cos 3 psi everything you can keep on writing that, but I am neglecting those. Now, if I say I want to get these coefficient see this is like a solution of the problem how do you solve differential equation with this as the right side and this as the input theta I as the input how you will get the better. One is I will go and do a numerical integration that is the easy way, but you can write closed form solution for this simple problem close form means you can get an expression closed expression and that is what I have done it.

In the sense I assumed my output is in this form there are two ways of doing you I told you 1 is the harmonic balance, harmonic balance means simply substitute everything in that equation. Collect the constant terms, collect the cosinee psi terms collect the sine psi terms you will have equations that is what harmonic balance is each harmonic collects it separately write it as one equation left side equals right side. Another way is called the operator method, which is simply you integrate how you get a coefficient of Fourier series, you integrate a F of t some integral 0 to 2 pie 1 over 2 pie equal to 0 that is for constant.

Then you will multiply by a sinee psi that is for first cosinee to get the second that is an operator same thing you can do for operating method it really does not matter both are balancing only. One is doing integration and get the equation another one is collect all the terms multiply everything then write when you do that this is what you get, because I am not doing all those algebra.

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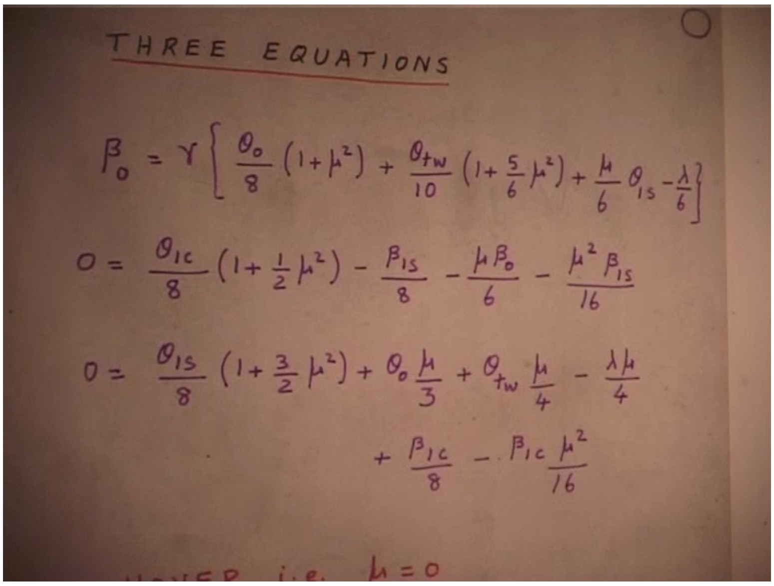

So, I am only saying when you do that part you will get the first if you make the assumption that beta naught beta 1 c cosine psi beta (( )) and I do the harmonic balance. When I do harmonic balance please understand I am only looking at constant term cosinee psi term sign psi, if I have on the right hand side some 2 sinee, sinee 3 psi etc I am just throwing it out I do not consider them I neglect all of them you understand. I will get these three equations and three equations I know theta 0 theta 1 c theta 1 s these are my input theta twist I know and what is the forward speed I know it. Only thing is gamma I know gamma is lock number if you know theta naught theta 1 c theta 1 s and the operating conditions I can get from these three equations.

Because beta naught directly because it is independent of there is no coupling here beta 1 s depends on beta naught. So, I have to solve this substitute here, then I can get beta 1 s and then here is the beta 1 c, beta 1 c you can directly get it, but it requires lambda please understand you need to know lambda inflow. So, if you are given theta naught theta 1 c theta 1 s mu lambda gamma you can get beta naught beta 1 c beta 1 s that means, if you are specified the operating condition of the rotor I can get the flap response. Steady state flap response please understand steady state means, the blade will keep on doing the same thing and that is what you have getting from this equation. You follow, because why I said is if you treat flap equation al1 as an independent equation without bothering about the helicopter then, if I want the response I have to know all these quantities.

Then you may ask who gives me my lambda, lambda should be known before you come to solving these three equations please understand. Before you solve these three equations to get beta naught beta 1 s beta 1 c you must know what is the lambda what is the input pitch angle what is the operating conditions? At least that part you must know. Because I do not know that than I will do that part we will come to the later that is what the trim analysis is the entire trim analysis is related to iterating between flap motion and then fuselage equilibrium.

So, you have to keep going back and forth that is why it is a complicated analysis, even the solution procedure is little complicate this is a very simplest that is what I am showing. Now, I will go to a slightly highly restricted condition that is hover same equation.

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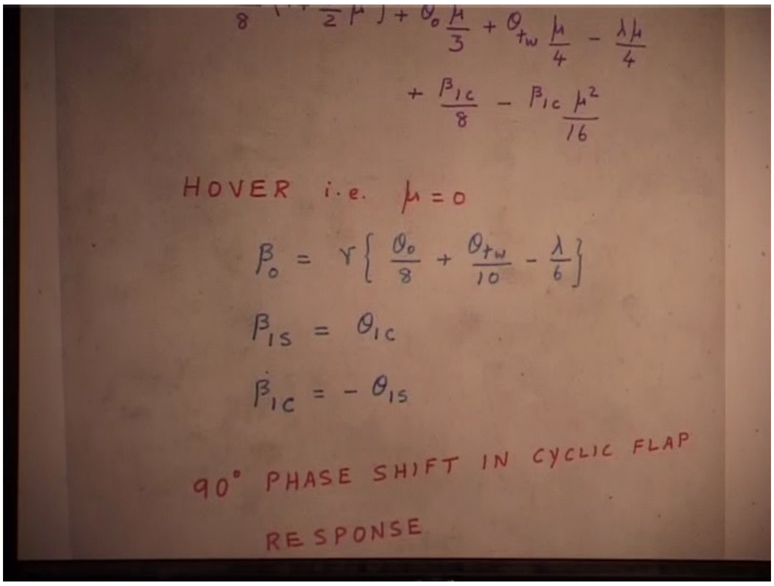

This is just a blade flap dynamics in the study state response, if I said mu 0 just for because I am powering. If I said mu equal 0 this is what I will have from the from these three equation I can get what is the beta naught beta naught is given by gamma theta naught over 8 some twist lambda by 6. That means, to an extend if you see this is the lock number which is aerodynamic force by inertia force i b row a c r power 4 over i b, i b is the mass movement of inertia of the blade about the flap. And then of course, collective pitch this term looks somewhat like c t somewhat it is not exactly, because c t is sigma a by 2 because you know that c t is sigma a over 2 theta naught by 3 minus lambda by 2 in hover.

So, it is some crude way of theta by 3, but here theta naught by 8 there is it is not that same expression and lambda by 6, but some close thing it looks similar theta minus lambda. So, you know that flap coning beta naught is related to what is the rotor loading, if the rotor is loaded more your coning will be more if it is less it will be less. And then when you come to the cyclic response that is 1 s and 1 c this is you see this is somewhat directly related to this angle theta naught coning is related to theta naught theta naught is related to your loading.

So, you say my beta naught is somewhat related to how much my helicopter is loaded my rotor is supporting, if you put more weight it will go up a little bit same operating condition please understand it is not that my r p m is changing fixed r p m. But when you look at this 1 c, 1 c is related to and as from this equation beta 1 s is related to theta 1 c.

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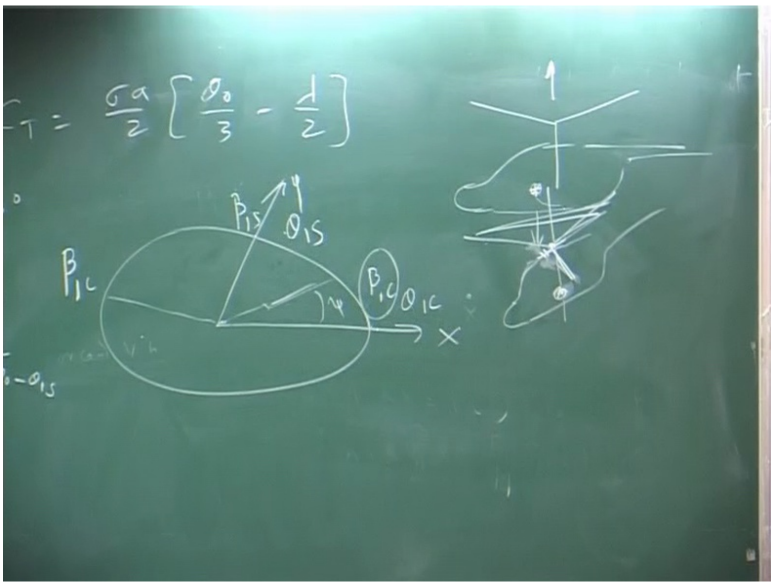

That means, when I change my pitch angle if I take this as my rotor this is my x this is my y and my psi, if I change here pitch angle gets changed here, but I get a because theta 1 c is pitch if I increase my pitch angle when psi is 0. That means, when the blade is here if I increase my pitch angle the blade will flap up here, it will go up their not that immediately go up please understand. Similarly, beta 1 c is related to theta 1 s theta 1 s is given here and the blade will have beta 1 c here or you can call it beta 1 c you follow that means, when I give an input here if I increase my pitch angle beta 1 c will become minus, minus means what it will go up.

Because beta 1 c positive means 0 is up 180 is down whereas, I want if beta are you may say if my theta 1 s is negative, negative means I am reducing my pitch angle at 90 degree then what beta 1 c is positive that means, the blade will go up at the back at the 180 it will come down. So, there is a phase shift of 90 degree between input to the output. But please note this 90 degree is only for this simple case of hover plus centrally hinged blade it will vary the moment I have a different flap model, if I put a spring it will not be 90 degree it will change. If I put something else hinge offset and a spring it will change then how it changes depends on that is what we will derive.

The phase shift between input and output now, you know if the helicopter has to rotor disc is to tilt forward down you must change the pitch angle when the blade is here not on the zero this is the key important there is a phase shift of 90 90 phase shift comes because it is a resonance. Because if you have studied little bit more carefully your vibration part of a m x w dot problem how the phase varies with frequency all (( )) no matter what damping you have. All the phase curves will cross omega over omega and 1 they will cross us 90 that means, when the input frequency is equal to the natural frequency. The phase difference between input and output is 90 degree that means, if you give an input now effect will be shown after 90 degree then you convert it to time.

Here we know then 90 degree is basically if I in this disk if I change the pitch angle here the response will be here. That I can show it in the lab with a when we rotate the blade, because this you can see clearly only the stabilizer bar you will not be able to see the rotor blade rotor blade is basically attached so, but you can get those from experimentally. So, this is the one of the important results of input to output. Now, if I change my model please understand 90 will not be there 90 will change 90 will shift and in forward flight this is in hover condition only please understand.

Now, in forward flight will it be 90 no it will not be 90 it will be different, but then because pilot please understand now you were slowly pilot is having a stick in his hand he will move the stick forward. But what he is doing? He is only giving a pitch input he is not giving flap response he gives a pitch input, because of the pitch cyclic variation the blade flaps and net result is the rotor disk tilts forward he gets a thrust in that direction. Now, this is also a you can take this two terms on the left side and then you can combine and then try to give a geometrical interpretation. It is a little interesting geometrical interpretation I taught I will just show you that is all this for only centrally hinged, because when you say centrally hinged immediately you must know flap frequency is 1 per rev that means, flap frequency flap natural frequency is rotor r p m itself nothing else.

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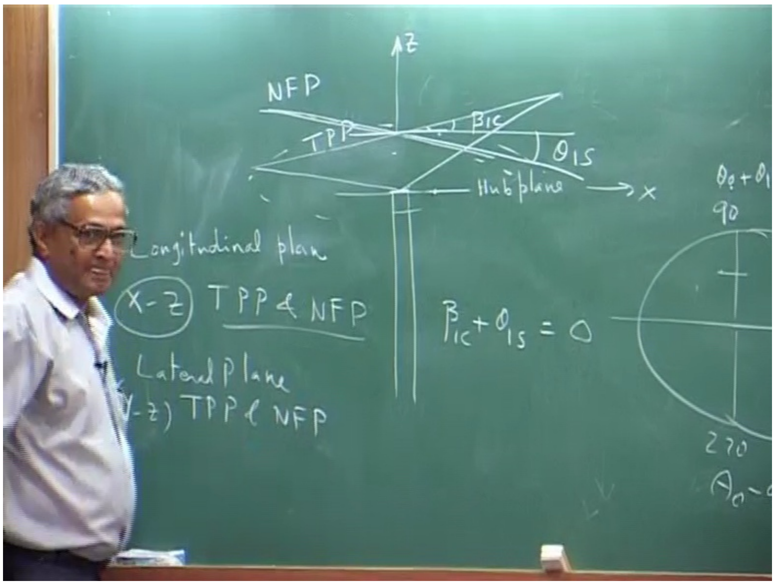

Now, let us look at because we define earlier some different planes suppose, you put that this is the shaft and this is the tip path plane this is my hub plane. Now, what is this angle? If this is my x direction this is beta 1 c, because this is x and y is down and this is E direction tip path plane is this, but we also define the no feathering plane no feathering plane it is a plane in which there is no change in the pitch angle. If that is theta 1 s now look at it because plane is like this no feathering plane means, I am giving a theta 1 s because in this I am looking at it this way in this y direction.

The pitch angle I gave when the blade is at 90 degree I give a theta 1 s which is positive you assume that you are giving a positive pitch angle and then when it comes to 270 you give minus, because sinee 270 is negative. So, your hub plane to no feathering plane it will be because you are giving f which angle like this that is a theta naught we have increased one side you have decreased other side. That means, in this this is 90 degree you have increased theta naught plus theta 1 s 270 degrees you made it theta naught minus theta 1 s that mean the plane should tilt a little this way. Because then you are actually decreasing the theta naught is same theta 1 is g1 up that means, you are trying to reduce it is angle so, you were no feathering plane will be I mean draw like this no feathering plane with this angle that is theta 1 s.

With respect to the hub plane please understand, all are referred in the hub when you look at a blade pitch angle will be what here theta naught when you go to 90 degree theta naught plus theta 1 s 270 theta naught minus theta 1 s. So, you want to make both of them equal because that means, you tilt the plane a little up as a result when you are look at that the angle through which you tilt is theta 1 s. That means, you are actually subtracted from here you have added here, then my pitch angle is theta naught in the no feathering plane the pitch angle is only theta naught is it clear not clear. See what happens is? You see this side this angle is theta naught plus theta 1 s that is at 90 at 270 this is theta naught minus theta 1 s this is less I want this angle to increase means, the plane must come down here it should be so, this to line you join that plane is this display.

So, in the no feathering plane the pitch angle is constant in the tip path plane there is no flapping motion all tip is going. Now, if you look at the angle between T P P and no feathering plane that is what beta 1 c plus theta 1 s, this is the angle between tip path plane and no feathering plane. Because that is the angle beta this is the hub plane please understand this is hub plane these two are parallel both side theta nine minus theta 1 s y axis x axis is here, x is this this is x. See here aerofoil comes here I am looking at it then what will happen if you look at it will be like this is it clear.

Now, you see the angle between tip path plane and no feathering plane is this in hover you look at it beta 1 c plus theta 1 s is 0 that means, these two planes must be parallel that is this angle should be zero this angle should be zero means, what both plane must be parallel. So, what and if you look at the other this is tip path plane and no feathering plane in longitudinal direction, because you are looking at x and z, if you look at the tip path plane no feathering plane in the y z. You will get the opposite in the y z this is x z plane that is longitudinal plane and in the lateral plane you will have that is y z plane T P P and N F P.

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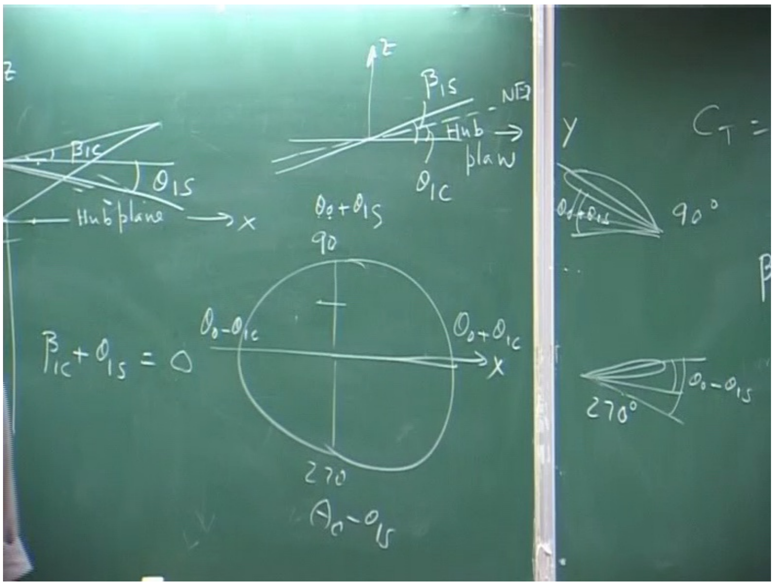

This will be, because you are giving what beta 1 s if you look at the y z plane this is my hub plane and this is the z axis and this my y direction this will be beta 1 s this is beta 1 s. And theta 1 c will be because you are looking this way here you would have added theta naught plus theta 1 c here it is theta naught minus theta 1 c. So, you will tilt the plane like this because it is more pitch angle. So, you will tilt it like this which means this will be your N F P with this angle theta 1 c. So, the angle between tip path plane and no feathering plane in this lateral is minus theta 1 c now, this is also 0 for hover, but please understand in forward flight they will not be 0.

Forward flight you will have some value sitting there and that is a function of forward speed how much is the rotor disk loading, because please understand this is I am again putting it hover. The moment I go to forward flight these two planes are different, because forward flight I have to solve if you want I can show the I have it no it is not here I have to write it. If the c z is not on the shaft what will happen is if the suppose, you have the helicopter this is the shaft c z is somewhere here if you have then what will happen? So, you have to give cyclic such that what will happen is ultimately the resultant this will come below so, that the helicopter attitude also will change slightly.

Shifting in the sense because this should be right below this that is all so, you orient this suppose orient it means how do I, because I want this point to be below suppose, if I rotate it like this what will happen? I am (( )) the diagram so, the c z has come here. Now, the shaft is like this I may be I should put it like this I it is a little to too much the shaft is here I go like this, this is on the (( )) may be (( )) c z is here tip path plane is horizontal shaft is tilted here. That means, hub plane is like this which means I have to give a cyclic input depending on the c z location that is what happens usually, became depending on the c z location he has to give a cyclic that will.

If it is right on shaft no problem thrust is you take it a hub plane in the sense it is you will get a horizontal comp1nt that is why in hover, if the c z is right on shaft if you give a cyclic helicopter will start moving you cannot be in hover. And at the same time I do not want the helicopter to move, but I will give a cyclic no, but if you do clamp it that means, you do not allow. The helicopter to move clamp what we are doing as an experiment you give a cyclic then you will see the tip path plane tilting it doing like this depending on what input you give, if you give a longitudinal then it may go, but then that is only for centrally hinged we can demonstrate that in the experiment.

Now, is this clear because the face shift 90 degree essentially, what the pilot does is? Pilot does swash plate plane which is actually if there is no other coupling etcetera that is the control plane, which is also no feathering plane if you do not have any other some flap pitch coupling etcetera. So, he is tilting only this plane no feathering plane he tilts that is all and because of the blade dynamics the tip path plane tilts he does not tilt the tip path plane he tilts only the no feathering plane that is the swash plane. He just tilts lateral at any orientation and as a result, because you know in hover they were highly simplified case they are parallel so, wherever it tilt that also goes there.

Now, the question is you can ask what is the time lag between is input to that tilt you can do that if there is a time lag then you will find pilot will give what is an may slowly that will come that part we will study. Because the flap is very quick it does within almost 1 quarter of a revolution substantial thing we will do the time constant and other thing then you will know that that is why pilot will not feel that I give an input the helicopter rotor takes lot of time to tilt. But that part if you really want to see we have a small experiment may be next class we can bring it, but with the aerofoil and without the aerofoil that I can demonstrate here by showing you just a simple model we have.

I will just tilt it you will see with aerodynamics it will respond very quickly without that it will come very slowly. So, that seeing is believing so, next class we will show a video, video means you have to take the video, but we will demonstrate that motion then you will see this is what really happens.

Now, the major part of the flight the relation between input flap is clear for a very simplified case. Now, if you complicate the problem because all this is that is why usually industry will say what is the input face shift 90 degree, but 90 degree is valid only for centrally hinged with flap frequency 1 per rev that is 1 omega. Suppose, if it is not that which is true actual helicopter do not have 1 then the face will change and is it same in forward flight will the face shift remain constant in forward plane no it will not it will change slightly.

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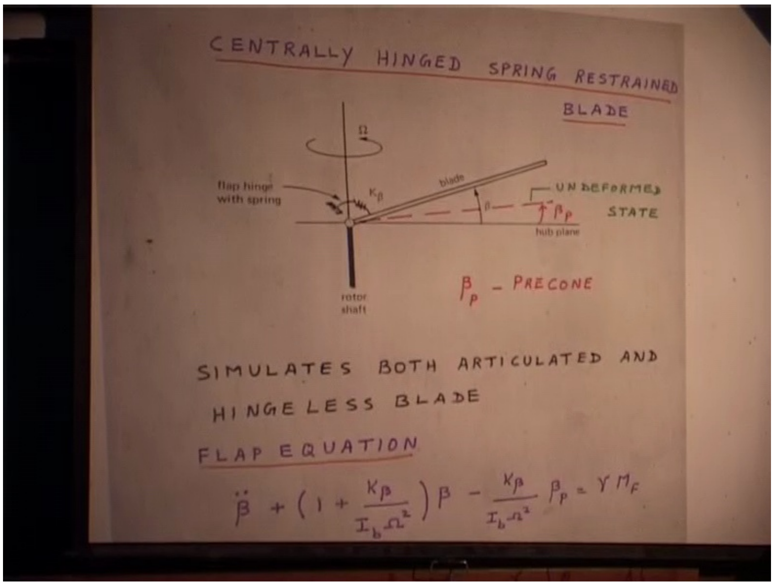

So, now, we will go for a slightly more I would call it an improved model here what I have d1 is I put 1 more spring, because this 1s we understand this part then we can there are lot more things even here. I put a instead of a hinge I put a root spring which is k beta this is the flap spring that will also give a moment when I move it, it will give that means, in my equation of motion I must include this effect the effect of the root spring. And one more thing I have added in this diagram that I put a red line and I put beta sub p which I call it precone that means, my rotor blade in the undeformed position is not horizontal it is slightly kept it angel when you attach it itself in the manufacturing in the assembly of the blade you are giving a coning angle precone it is a set geometric angle.

If you put these two what the what really happens, we will just study that part I will not again derive the entire equation, please understand that is why I said once you get one equation position vector you take again rotate it get the acceleration get the aerodynamic load only load what I have added is a spring. Now, the spring will give a spring moment which is essentially depends on how much is the deformation that is I call it beta is the flap angle please, understand beta is measured from horizontal plane hub plane. But the blade is already kept that means, how much elastic deformation I give into the spring is beta minus beta precone and that much of the moment it will act on the blade.

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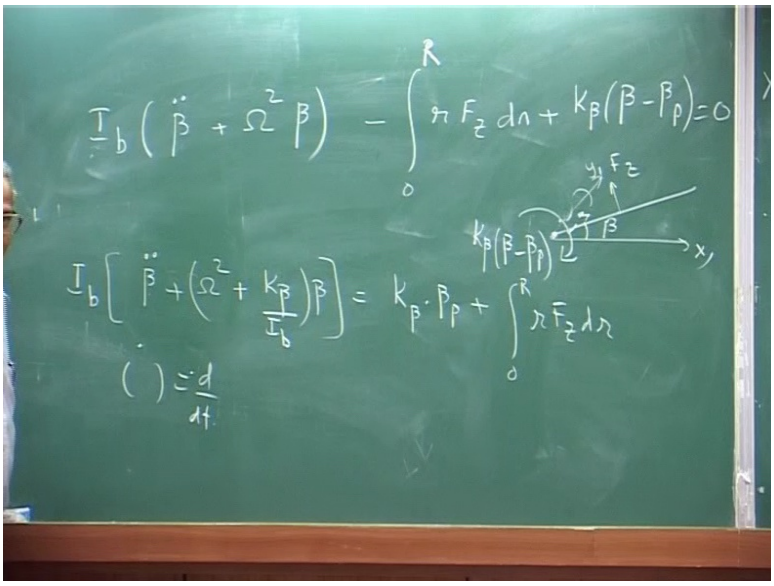

So, my equation I will just write that equation, because the flap equation we wrote inertia is I b into beta double dot this is the derivative with respect to time plus omega square we make that approximation sine beta is beta cosine beta this is the inertia. And aerodynamic was 0 to R r F z d r this was the aerodynamic moment we said inertia plus external now, you have to put the hub moment this moment is clockwise whereas, the spring because the aerodynamic lift is this way. So, if you have that because the lift is this way f z and this is my y axis y 1 this is x 1 and this is flap this is r. So, this moment from y axis is a clockwise that is minus, but when the spring deform this will give a spring moment K beta into beta minus beta p, that will be counter clockwise which is a positive so, I add K beta into this is 0 that is all.

So, this is my may be I have I should put it a little clear you will have a spring moment this is my flap equation that is all. Now, what happens? I have to add all of them and then non-dimensionalize. So, if I do I b I take it out I bring this term here that will be beta double dot plus omega square plus K beta into beta equals you have K beta into beta p plus integral 0 to R r F z d r this is my equation sorry I have to put the I b. Because K beta over I b alright now this is like spring by k by m. So, I am adding additional stiffness to the blade.

So, I non-dimensionalize now the entire equation and write a because this part is straight forward only thing is you have to substitute for I am not writing the entire substitute where F z which we know earlier that is a lift force lift per unit span put that value and expand all the terms multiply. And then divide by this dot converted into non-dimensional time derivative so; you will get a omega square. So, this I can convert it non-dimensional because this dot is d by d t so, I put a omega denominator another omega so, I will get a omega square. So, when I take out the omega square I b omega square beta double dot.

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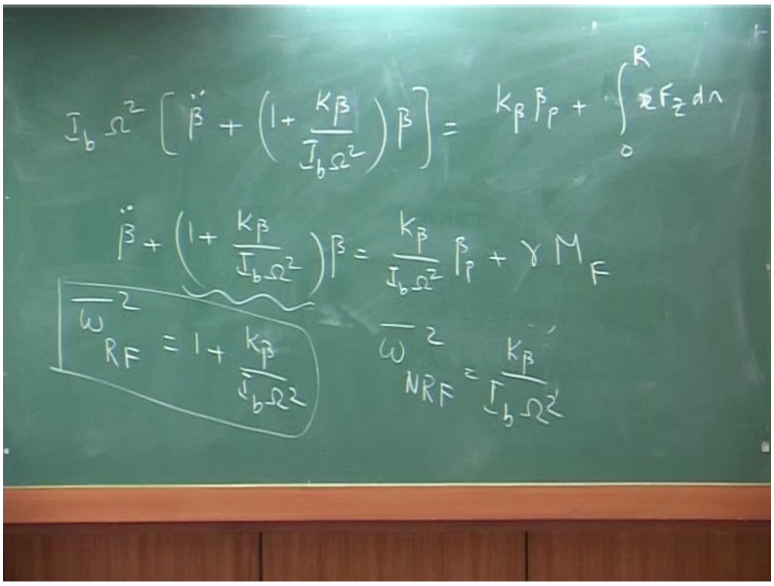

So, I will have I b omega square into beta double dot plus 1 plus I b omega square into beta here you will have again K beta beta p plus your integral F z d r. Now, I make it completely non-dimensional then this will become beta double dot plus 1 plus K beta I b omega square beta plus gamma M F this will not change M F is what we wrote earlier. By adding a spring and a precone I am getting a constant momentum on the right side this is the aerodynamic, because gamma is a lap number M F is all those theta I etcetera, this is my now new natural frequency in flap which is actually more than one. Now, I will write it omega bar R F square rotating flap frequency is 1 plus K beta by I b omega square please understand I have to non-dimensionalize with respect to a r p m this is the omega square.

So, this is my and my non-rotating frequency N R F non-rotating N R is non-rotating, because you have a spring you have I b if you non-dimensionalize that will be k beta by I b and of course, non-dimensionalize with respect to some reference omega that is why I put a bar you do not put zero value there you put whatever. Now, you see my simple equation tells me rotating flap non-rotating flap is 1 plus.

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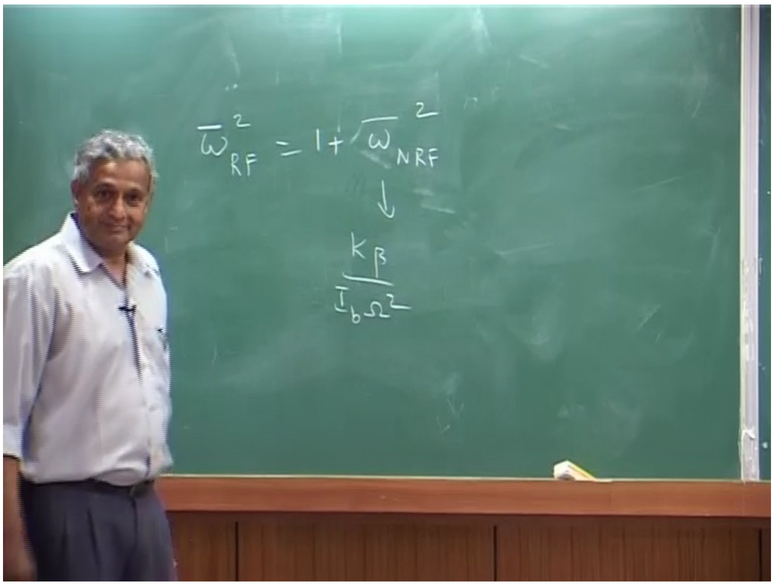

So, this is my rotating flap square is 1 plus omega bar two sorry and this is K beta over I b omega two that is all. So, if you put a spring my natural frequency in flap has increased because become more than one. Now, this is where the industry real problem how much more than one you can keep it is a very very see that is where I said we introduce now two terms. One is this lap number another one is the rotating flap natural frequency this is natural frequency please understand. These are the two new parameters actually, you will find the industry in selecting the rotor system rotor blade this is where the major effort goes on what should be my flap frequency it is a real challenging.

Because this is going to affect my performance control characteristics my loads hub moment many quantities, that is why the flap frequency is a very very dominant frequency there is a first flap natural frequency, first natural frequency we will come to that influence part later.

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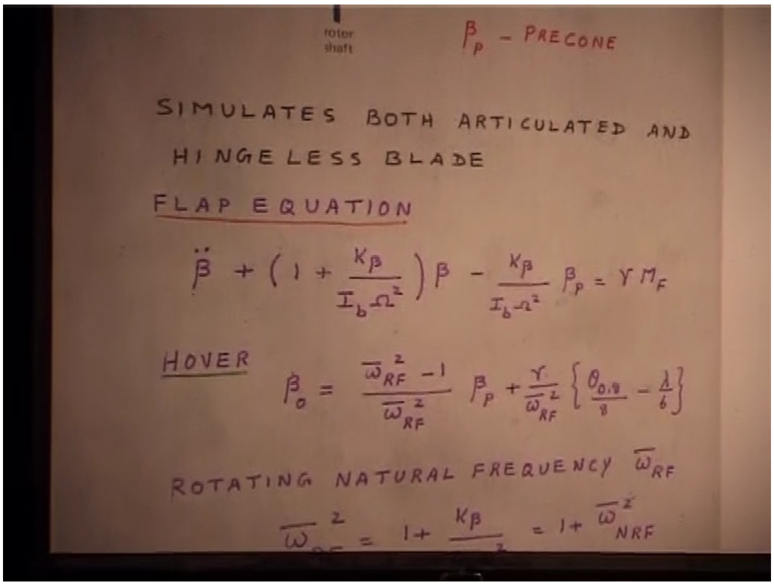

Now, I have modified now i have to get again beta equal to beta naught plus beta 1 c plus beta 1 s all those things. I should solve for beta naught 1 c 1 s again I do the harmonic balance may be I will write that part.

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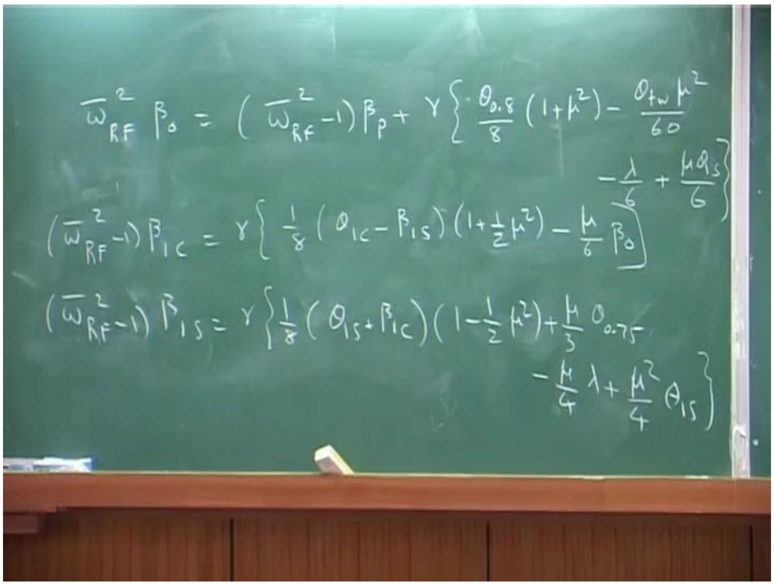

This is omega bar R F square beta naught equals minus 1 beta p this I will send you also plus gamma I have d1 some simplifications here, theta twist mu square over 60 minus lambda over 6 plus mu theta 1 s over 6. This term is identical to I think that earlier term only thing is I have put some point 8 I added because that comes, because here this is the gamma part is almost same because 60 you add point 8 location. So, you will get 1 plus mu square you take out in this, because you add 1 over 6 minus 1 over 6. So, that is how you get that mu theta 1 s over six minus lambda by 6, but then the next two terms is omega bar this is a little different minus 1 beta 1 c is gamma 1 over 8 theta 1 c minus beta 1 s into 1 plus half mu square minus mu over 6 beta naught.

And then the next one is omega bar R F square minus 1 beta 1 s is gamma 1 over 8 theta 1 s plus beta 1 c into 1 minus half mu square plus mu over 3 theta 0.75 minus mu over 4 lambda plus mu square over 4 theta 1 s, n f p is mu square minus that expression any mu square theta. Now, this is just a modified form you have to solve this equation now, if you are looking for you will see there is a modification in the beta naught beta 1 c beta 1 s, because of change in the flap frequency. Now, you have to solve this equation to get your theta naught sorry beta naught beta 1 c beta 1 s.

Now, if you take the hover case because again I am coming to simple flight condition which is the hovering flight condition, because then you said mu is zero. If you do that let us look at the only the beta naught part that is the coning beta naught becomes I am because your mu will go up all the mu will go up.

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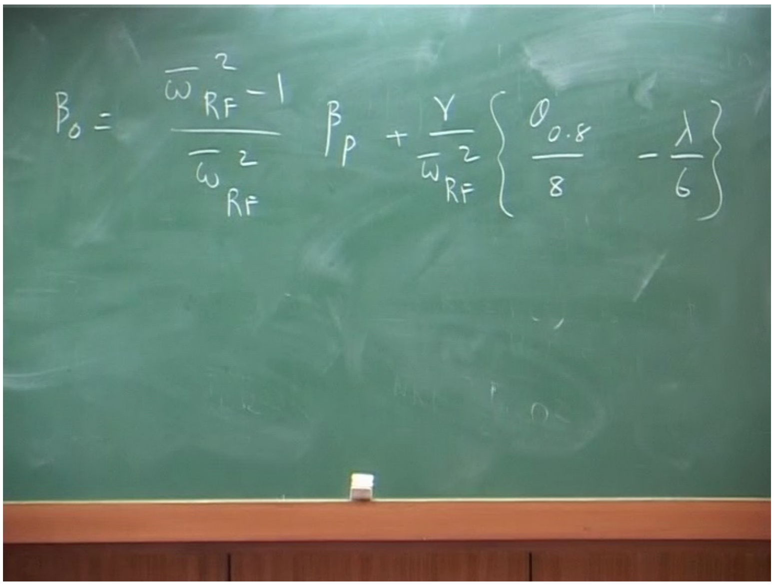

You will have omega bar R F square, because from here you get a very interesting result divided by omega bar R F square into precone, because this is a precone term is there plus gamma over omega bar R F square into you will have theta 0.8 over 8 minus lambda over 6. Now, there is something called ideal precone that is what should be my how much I can set, because I said that initially blade I attached it at that location what angle I would prefer. If you put at that angle the blade will not experience any moment at the root even though I have a spring, but that is set for only one particular flight condition this is called a ideal precone why you want to have a ideal precone?

Because usually all the blades there are not hinged like this they have a spring spring means, it is a it is again an idealization real blade will be different, but it can be made equivalent to this type of blade. Because if I give you the flap frequency of a blade rotating flap frequency you immediately can find out what should be my K beta, if I know the mass of the blade if it is centrally hinged assumed that it is centrally hinged, if you know the rotating flap frequency you know what is my K beta. So, you can get that this kind of equivalence you should be able to handle it easily now if you give a precone what is the effect of that precone?

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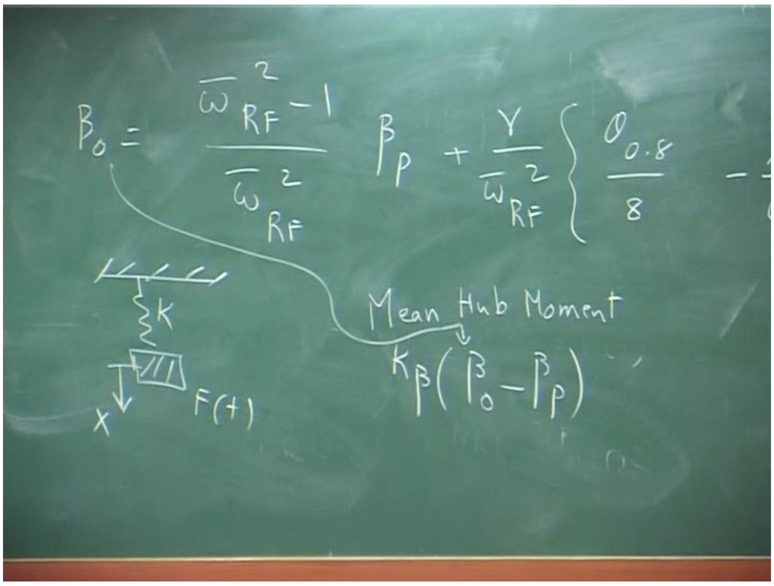

That is let us look at the what is the hinge moment that comes that is if you have a system spring mass and F of t. What is the force that here? The force that axis is only k x that means; the moment that acts at the hub please understand this is the flap moment. Flap moment acting at the hub is I am taking mean value, because beta naught 1 c 1 s I am not taking otherwise I have to take K beta beta minus beta p I mistake like that here I am taking only the mean part of it 1 c 1 s (( )). So, the mean value mean hub moment is K beta into beta naught minus beta p, this is the mean hub moment now I substitute this beta naught here.

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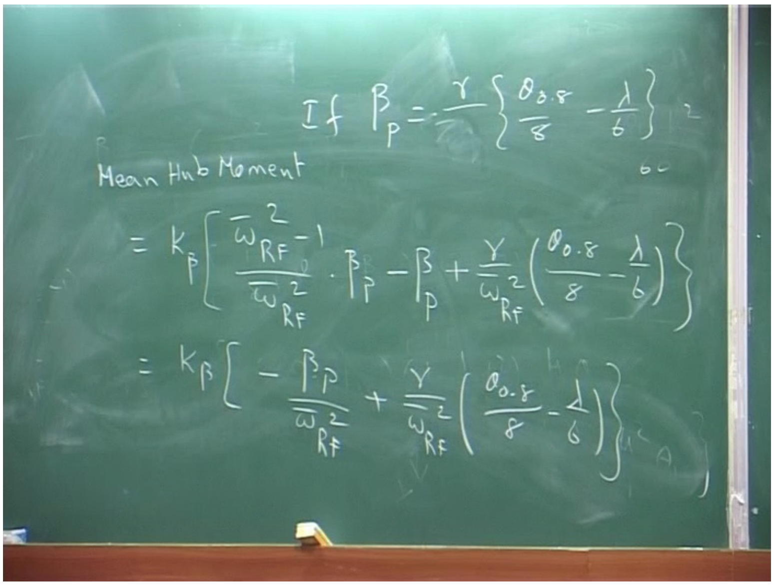

If I substitute that my hub moment mean hub moment will become that is K beta you will have omega bar R F square minus 1 by into beta p 1 minus beta p then of course, the other term plus gamma over into theta and this it is a beta p because a beta p over this beta p only that is all. So, you subtract this will become K beta minus plus this value into theta 0.8 by 8 minus lambda over 6, because this is minus beta p. Suppose, if my beta p is equal to gamma into theta 0.8 over 8 lambda over 6 if, that means, my moment is zero. Even though I have a spring my mean hub moment is zero, but I will have some beta 1 c and 1 s they will ask later that means, what I am doing is in my design.

Because if I get root moment my design has to be properly made, because it has to resist the sheer force and the bending moment like a cantilever beam, if you are taking a beam you design what is my root every section you design for shear and bending moment. If my bending moment is there I have to design it a little thicker I can reduce the mean load only mean load I can reduce it by giving a precone now you know why rotor blades are given slight precone. If it is a only when you have a if it is a root moment because the pin there is no that moment is zero centrally hinged no problem, but the moment you put a spring which is like it is like a cantilever first (( )).

So, you want to give a mean moment slightly bring it down rather than otherwise my blade has to be designed little thicker at the root. So, the whole idea of putting the precone is reducing the mean flap moment acting at the hub slightly less. And this is called this angle because please understand you will not eliminate the moment at all flight condition because this is valid only for one particular value. If you start flying at a another speed forward you will have different flap then you will get a moment usually, the precone they give about two degrees 2 or 2.5 something like that that is all whereas, the flap angle may be of the order of around 5 degrees.

So, whereas, if it is fully tilting to 5 you all of you to tilt only through 2 3 degrees rather than full the 5 degrees, because then the design that is why all are very very important, but it has a effect on damping also that part we will come later. The stability and other aspects right now the precone is given to relieve hub mean moment slightly otherwise you have to design a bigger (( )) because the centrifugal force you will try to bring it down in the aerodynamic force we will try to take it up. If it these two moments are equal it is kept at the same location that is all. But if it is slightly up that is why you can have if it is fully up it will try to bring it down, if it is like this it will take it up.

So, that is why usually you do not look at flap deformation because it depending on the flight condition it can come down it can go up anything. Because you can have a if the coning is too much that means, your lift is very large because that is why going up if the coning is very less means my lift is less. So, the coning angle is changing with your weight condition, that is why all this are just give some two degrees you relieve the hub moment it is purely from a designed structural design point of view. Of course, air aeroelasitcally it will have an effect that part will come I hope you will be able to do it or otherwise you will forget aero-elastic effect of beta p on the blade some stability etcetera.

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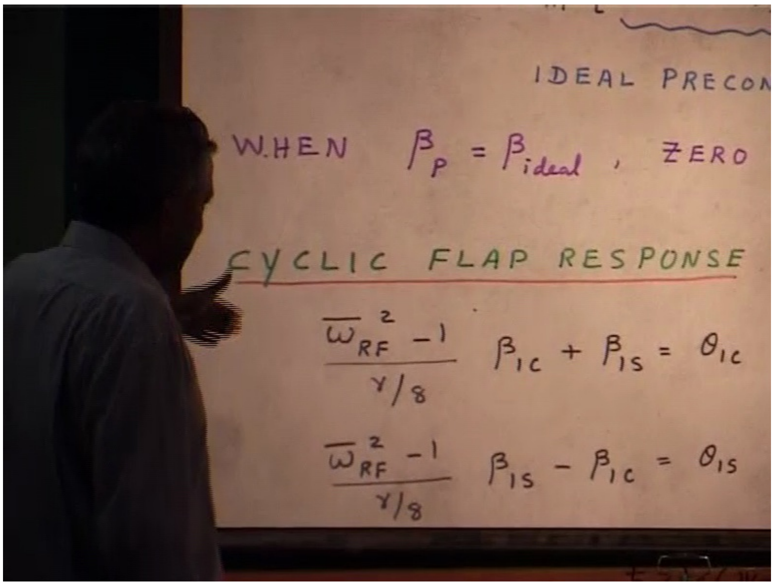

Now, I think I will leave you now because this is the next part. The phase shift how much because now you have change the frequency what will be the change spaceship that part we will do the next class.