Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Introduction to Experiments in Flight

Lecture-16
Steady Coordinated Turn

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A good morning, last class we discussed about recall it was Steady side slip and how do you define a steady side slip, suppose a plane is moving like this straight like this then factory angle is 0 and if the airplane is instead moving like this we have a positive side slip that is if I draw a diagram. If I flying such that relative air speed is coming from the right that is I am moving like this so relative air is coming from the right if I see from like this lady where should come from the right okay.

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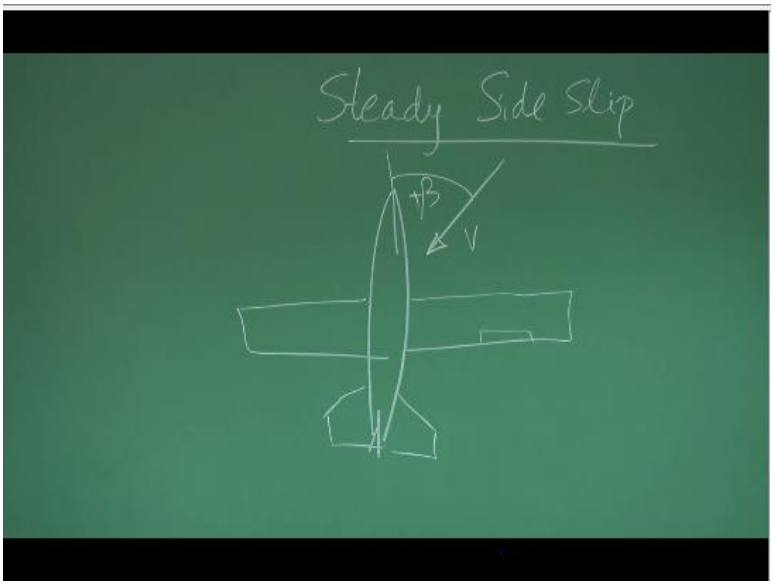

So this is a positive side slip angle, and we have seen to execute a positive side slip angle I need to give a null deflection I need to give another deflection and we have seen how their reflections are related, and also we have seen that I can use studies actually maneuver to estimate some aerodynamic parameters. Especially C and beta right, and you can do it for estimate a few other parameters as well. By doing experiments by using some subset of internal data the basic philosophy is to in this course is to educate you how to conduct explain how to think.

The second part today what we will be doing is basically we will be doing steady coordinated turn; steady coordinated turn that is what to do will be giving a brief. What is the steady coordinate turn see earlier we are discussing about the airplane let us say having a cruise it is going like level cruise is going like this right. For a steady sight sleep airplane is going like this but for the coordinated turn steady coordinator turn I am turning like this and that I can do if I have some bank and I am using some other deflection.

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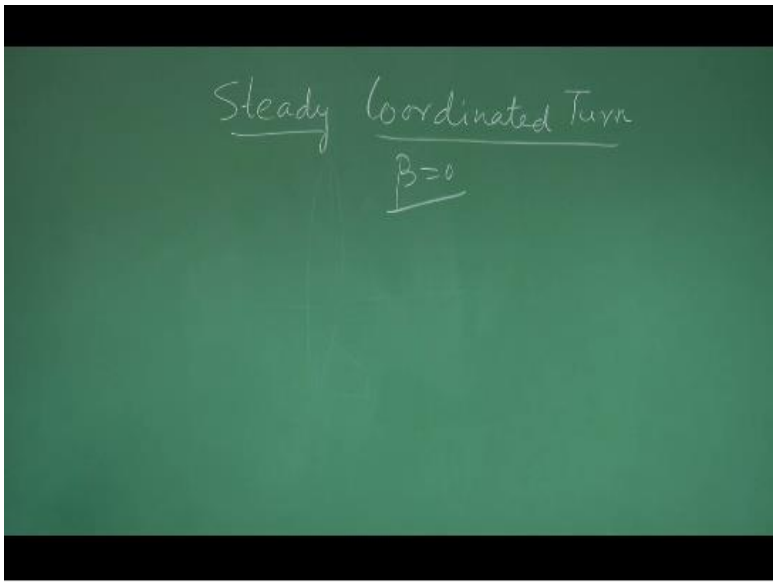

I can as well do it like this just give another deflection but the problem is as I get on a deflection you could see this left wing will see a larger velocity because of this turn so there will be more

left or it will try to bank so you use both rudder as well as a lid on and you turn it like this so that beta is zero all the time. That is very important in a steady cornea terms beta is 0 and of course you are ensure that you are not losing the altitude, but if that is agreed that I am executing a maneuver using a lid on and others and some throttle setting.

Such that I am turning, such that beta is equal to 0 then how the sixth of equation will get modified the first thing we will see right because when you will be doing experiment and will be putting their data I should know what is a mathematical model I am going to use which will be a subset of a 6 12equations of motions right. So let me take up that for the steady turn.

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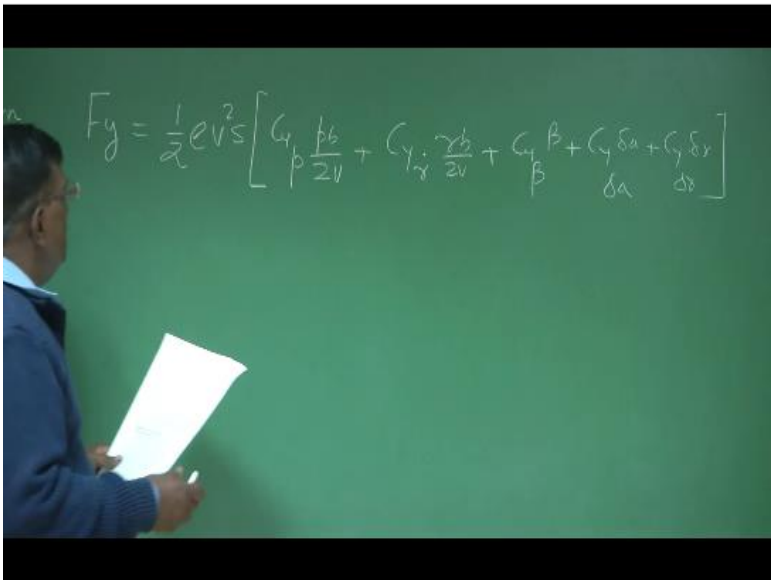

Let the FY equation from a six off you are aware it is half Rho v^2 is to C_y into p b / 2 v plus cy r into r b /2 v plus cy beta into beta cy delta A into Delta A Cy Delta r into Delta r this is the aerodynamic force. Which are coming because of chill in the sixth off if they roll it is a unit if there is a beta if there is a alone deflection greatest another deflection. Of course the FY will have some component because of the bank will be compared of the weight right that tell me that mg generator with mg cos theta sine five.

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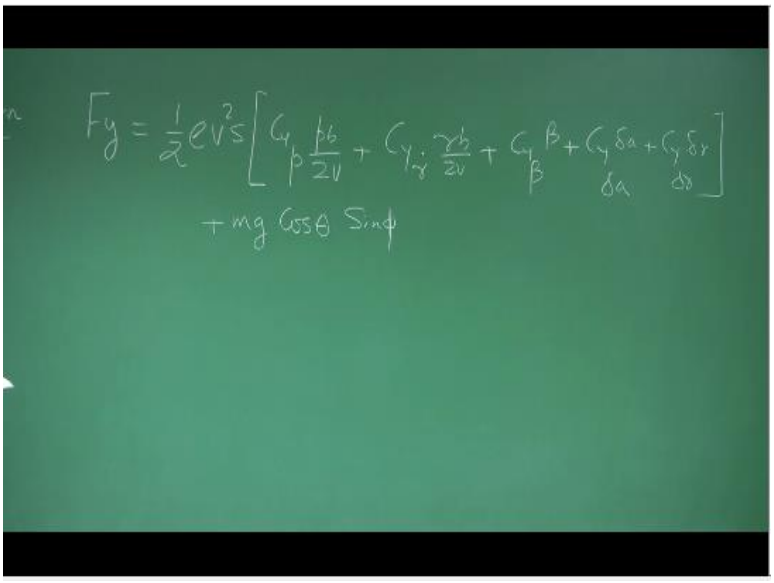

So this is I think knew I have written this is part of the one of the equations of the sixth of model you should understand before you do an experiment that this part is aerodynamic force and this part is because of the gravity and theta is the pitch angle okay. Now the question is we are talking about study coordinator turn I like to investigate which of these terms will contribute for it steady coordinated ton .What is CY please let us understand what is the CY be it is that side force let us say if I take the axis system which conventionally follow this is X this is Y and this is Z.

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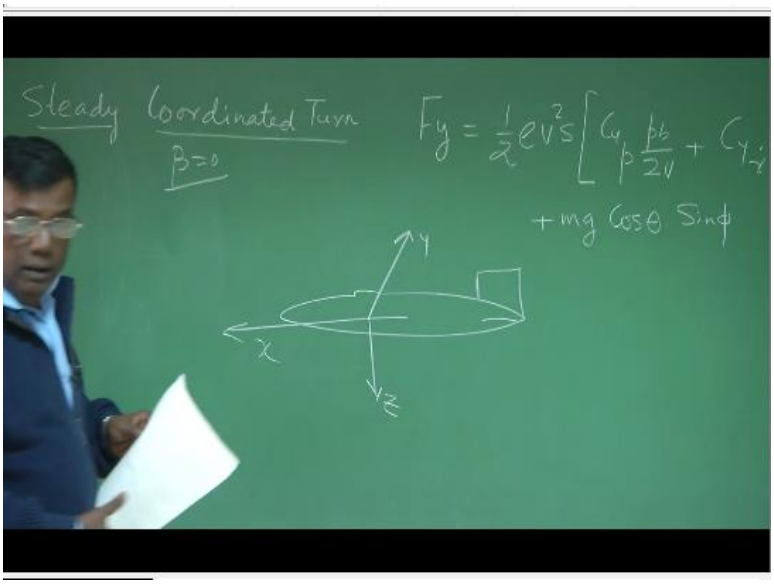

So if I use this as if I assume this aircraft then if I am moving in this direction you know x axis is this y axis is towards view and z is downward right X Y Z said right and now what is beta positive beta positive is the wind is coming from the right so this is the beta positive direction and if the wind is coming from the right and there is a vertical tail which way the vertical tail will experience a force it will be in the opposite of y direction is it clear.

If I see it like this is X this is y and this is z and positive beta wind coming from here and this is a vertical tail so vertical tail experience force towards me and this direction is opposite to positive y direction ok. So for a positive beta CY which is a non-dimensional coefficient of FY will be

negative that is I say CY beta will be negative well, right ok. And by diagram wise if I write this is my Hooks law this is the tail this is the wing if this is positive beta let me draw an effort if this is positive beta.

I know my convention this is X this is Y and then Z is inside the board for positive beta this vertical tail which is here it will also see closer to positive beta, so there will be a reinforce in this direction and this direction is opposite to the positive y direction.

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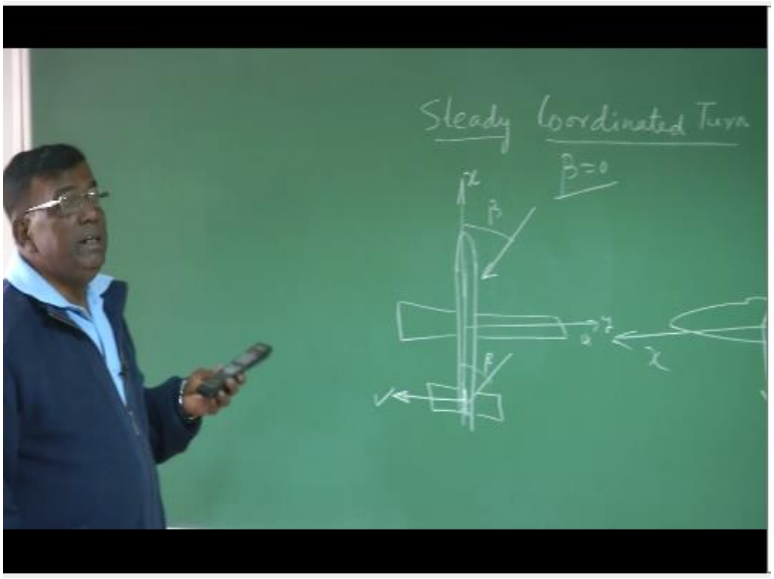

So this FY because of the beta is negative always say d cy / d beta which says per unit beta how much CY will change direction wise that is negative. We understand it back; now let us talk about $CY_{P.}$ What is CY_P ,CY_P is suppose this is the airplane what is p+ p positive is right wing going down that is the right wing going down this P+ so if I roll this airplane positive like this now imagine with a vertical tail here so as it rotates the vertical tail also rotates in same direction it pushes their towards positive Y so it also experiences the force in the negative y direction is it clear.

So they repeat again Let us assume I am repeating this for your clarity let us say this is a vertical tail all the vertical tail as I will be positive p right wing going down this tail is pushing there so there will be a reaction on the tail in this direction and this direction of force is opposite to the direction of positive Y, so CY because of P also will be negative as the major contributor is the vertical tail. So I said this negative, sometimes you sign my changes because of sweepback of the wing kind of high-wing aircraft because of the fuselage.

But I am not giving you a general idea how to find that component I see like be negative and actually meaning this contribution is primarily because of vertical tail right normal aircraft you may find because of sweep because of a fuselage effects design may not be what I am Telling your numbers may not be what I am telling. Similarly Cy_r if you see what is Cy_r and if you recall your earlier class are r means you are you are it that is yours is positive is right wing going like this she or it positive.

Imagine this airplane is taking a you are at about center of gravity it is turning like this so again this tail is pushing the air this direction so it will experience a force in this direction and incidentally now for the positive or eight the force experienced by vertical tail is in the positive y direction so Cy_r because of vertical tail if it is predominant which is generally true will be positive right .Now I come to see Y Delta R for time being I neglect this I said he is not much if I talk about CY Delta R let us see what is the sine of CY Delta R .

Again I come here Delta it means other this is the rudderless say if I deflect it towards left which is a positive radar deflection, I repeat towards left when I look from the top is a positive rather deflection by convention so if I have deflecting towards left and moving forward then the force will come in this direction which is the positive direction. So CY Delta R will be this sign will be positive this much understand you need to have or you are doing experiment at least times we should know from the first principle that is why I thought I will explain you this then we come back to our experiment.

So this is the expression of a FY which are essentially I return the forces and the kinematics part if I now they could we see the signal equation this term whole of this term will be equated to

M(v.+ru-pw) v dot is a component of V along from total v which is half Rho v ^{2} capital u^2 number that V along the local y direction.

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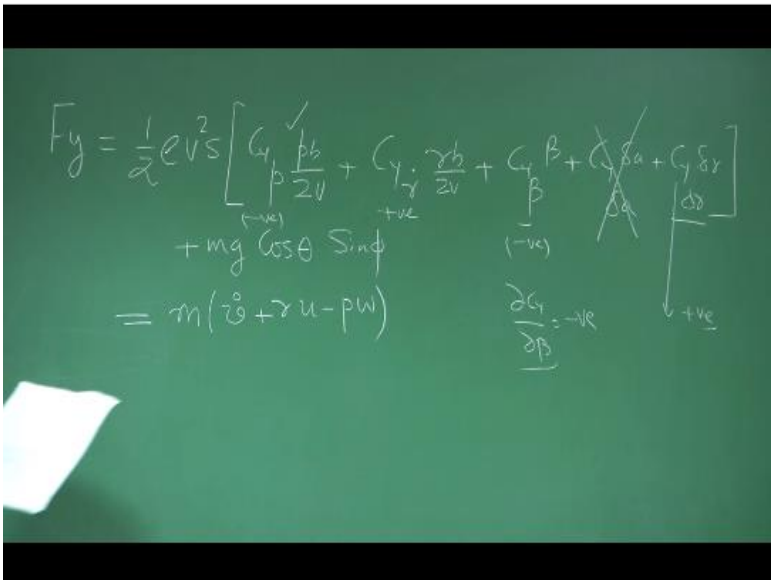

And u is the component of total V along X direction local X direction and local z direction is w that is aircraft people is moving like this and then suppose this is a relative air speed he had a component along X along Y along Z that same aircraft is moving like this unless the velocity is still the exits in the parallel to the ground then the component will change so that is why I am saying but you know that VW u VW are the component of total velocity along local body axis XYZ direction right and V dot is of course you understand is the rate is acceleration along that direction.

Okay this is the part which I am taking out from the sixth topic of motion which you have already done you know one of us postage and you are aware of it. Now I put some atoms I am assuming that theta is zero that means what I am conducting the experiment so that the pitch angle is very small pitch attitude angle please under this theta like very small ice that is why I am taking zero and also assuming that the bank angle is also very small where was in 10 degrees.

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If I do this some Back angle side greater than equal to 15 degrees I would say 10degrees when I do the experiment. Once I do this I make an approximation that this term mg cos theta sine Phi I can now easily write it to be mg Phi. No objection, right.

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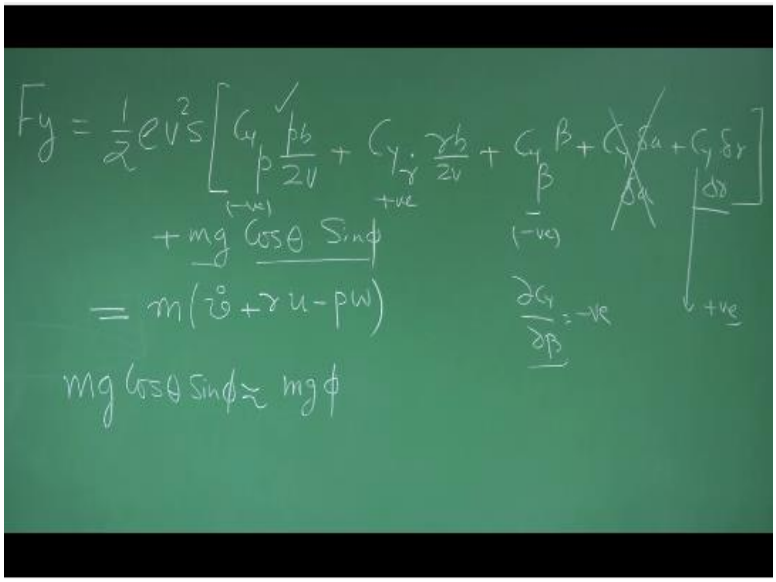

Now once I am doing a steady coordinator turn that which I know that there is no beta these gentlemen those for steady coordinator run because in a steady coordinate time I am Telling like this every time we tied 0 latitude is aligned towards the velocity vector okay, similarly when I am doing steady coordinator turn what is the value of P it is not doing anything like that it is only

turning like this so p is also 0 so I drop this term so long steady coordinate kind of proclamations what about R can I drop it you cannot drop it because R is there it is turning like this right. For this stage and then delta R is there this also stays and we have any approximation that see y delta is weak.

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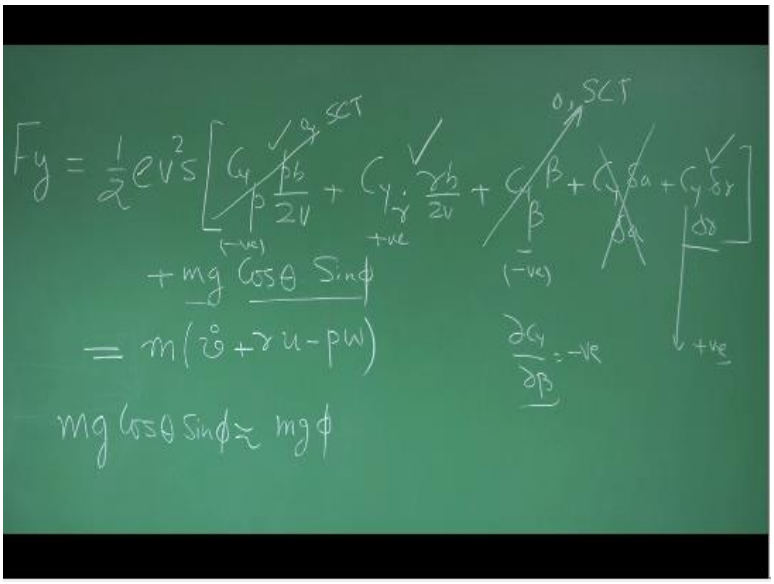

So I am not adding that into the expression, so finally what happens if I do this assumptions then my equation becomes M G Phi plus half rho v^2 s into cy r into r b / 2 v +CY Delta R into Delta R this is equal to M. Now V dot it is a steady coordinator return so we got automatically goes there

is no role p so the speed of loose on these goals because steady coordinator turn there is no role for these also goes.

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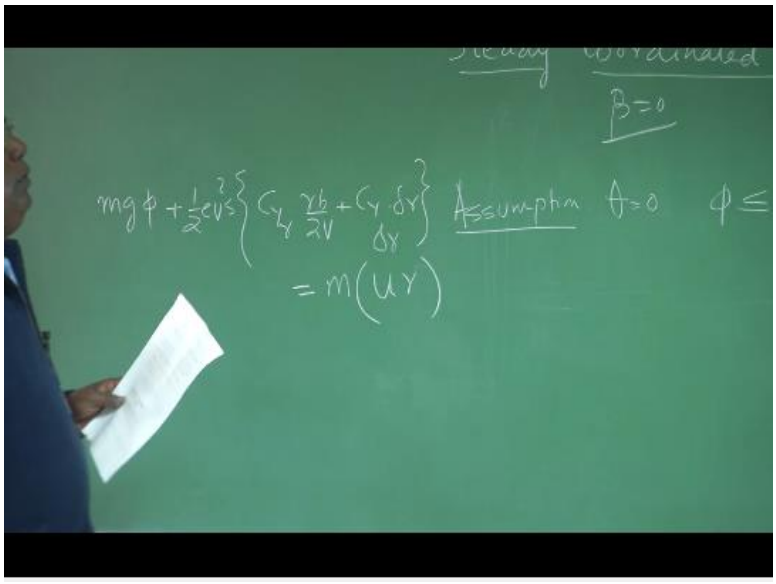

So what is remaining now is m and U into I right and it will easily understand when I am doing a static or a turn like this and I will not be very much in corrective file at V equal to U and I am moving like this every time align to the velocity vector an exception align so I can replace this U / V second right mg phi plus half rho v^2 square and to CY RB / 2 B plus CY Delta R into Delta R equal to MVR.

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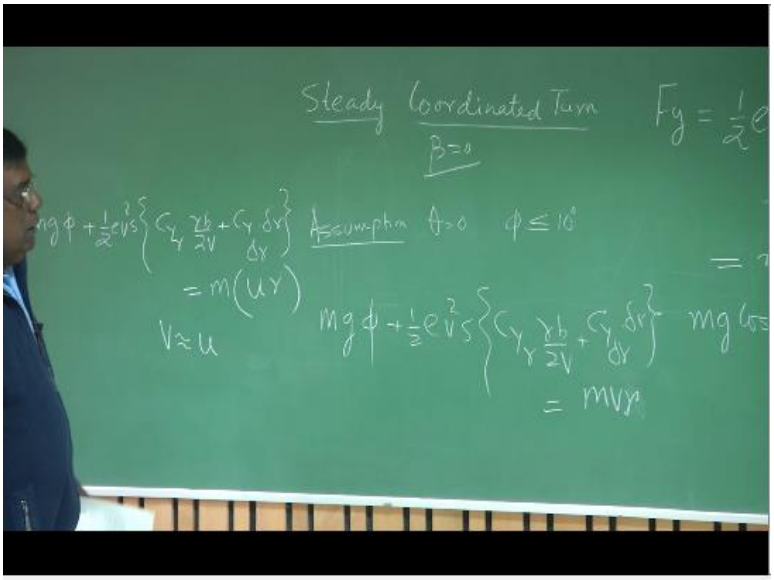

Where our location wise I am using this so let me or is I or it. Now see what is this MVR, MVR is angular rate MB omega relate and mv^2 upon X centripetal acceleration okay and you guys true if they have the plane turning like this it is like a stone being turned by a string so some force must be making it happen to give a centripetal acceleration in the circular path. So that is the effect MVR which is a centripetal acceleration who is causing it, for a stone and rotating a stone is the string the tension the spring causes that so somebody must be causing this acceleration who is causing it primarily mg Y component of the weight and a dynamic force this, this is clear right.

So now what we will do will do further little approximation engineers are always in famous for doing approximations many a times or sometimes something very realistic comes out if I do an approximation he let the aerodynamic force contribution is negligible anyway you could see that ladders are designed to give moment is a large momentum not force, forces from the wing side so this is a force component from the runner and this is there because of cross because of rate the side forces coming.

So we cannot a bad idea to see what happens if I say gentlemen this force component is not very appreciable competitive back to the force coming because of the weight component which is at a bank angle of Phi so if I neglect this if I neglect this then what I get is minus I am getting is sorry right mg phi is equal to MVR or R whatever additional writing nor I can rank mmk gets cancelled so I am writing that minus VR plus b phi equal to 0 or proceed G equal to vr/ five.

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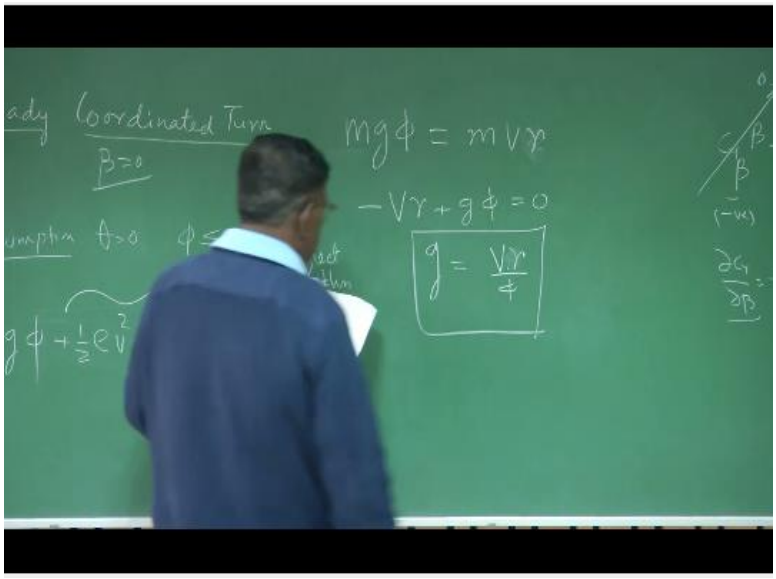

So how do I use this information and get some enrichment to experiment what I will be doing I will actually go for a steady coordinator I will take stopwatch I tell the pilot take a turn of 90 degree on 180 degree depending upon mutual agreement. I have a stop watch and I know how much time it has taken to turn from there I will get the value of R. It will be how the total angle turn divided by total time so I know R we I know from a speed indicator phi I know from the turn back indicators so I will measure accurate those data and find this ratio and if it counts we are not between nine point seven to nine point eight something like that and which should remain constant.

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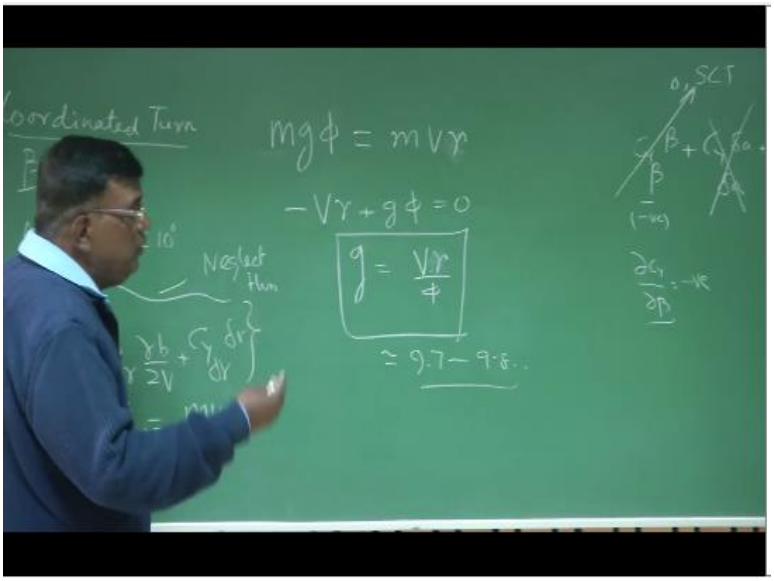

Fairly for that altitude so you know that yes this ratio has to be closer to the value of G so then you are understand whatever sixth term equation you have understood you have applied it correctly and their assumptions are realistic. If this value goes off then the assumptions are wrong ,for example if you are banking at a60-degree and you are having a some positive theta values and your rudder is very powerful then you need to be careful that the value of U lot come that means your experiment who are designing is not correct because the G equal to Phi will only come when theta equal to 0 and Phi is very small right and this indirectly also tells you how go do your sig Tau' s model, right.

So this would be also all of the experiments and this is a theory of building it up then we will be going for a session will actually demonstrate how to do this experiment clear then but not forget for a steady coordinate and you are supposed to measure you are eight but if you tell the pilot I want to take a turn after 90degrees or 180 degrees you should have a stopwatch as you start taking a turn ensure that is doing a coordinated turn no loss of altitude the speeder should remain same.

And this is the stop watch you find what is the value of r you are it you stun bang indicator information to get Phi use airspeed indicators to get the value of V and offline you see this ratio or there is coming closer to G or not if it coming closer to G the assumptions are fine because

you assume the equation of motions to be perfect right okay. Now so this is one part for this experiment now let us see what more information you could get out of this experiment.

Let us watch out for rolling moment coefficient in a rolling moment coefficient I can again write like cl and expand like Cl_p and P B / 2 V + Cl_r into RB / 2V+ CL beta into beta plus Cl delta A into delta A + C_L delta R into delta R.

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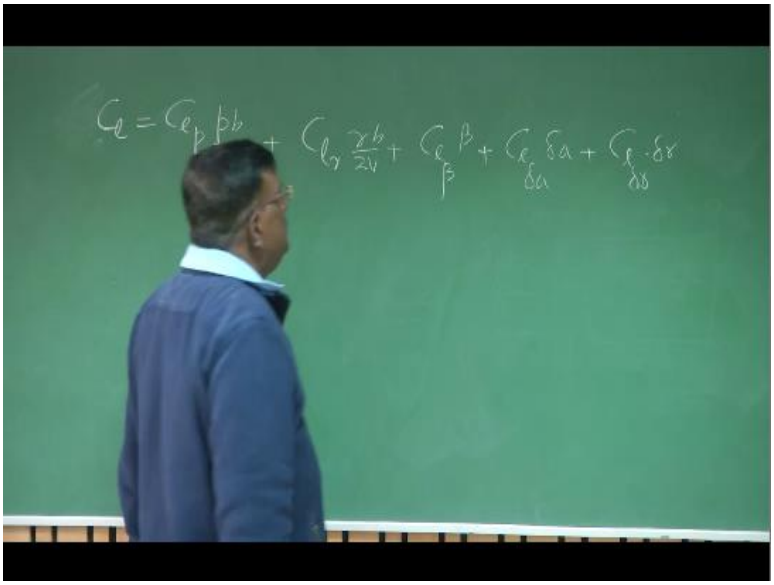

Alright so when the airplane is doing the pilot is executing a steady coordinate turn like this what is the value of cl, cl has to be zero there is a positive value here it will turn like this or turn like this since it is just making a coordinate turn so CL is no rolling moment is there for CL is 0 so it must satisfy cl is equal to zero. When I put this zero equal to CL_P into P B/ 2 V and ask myself a question whether this contribution of rolling movement will be there or not.

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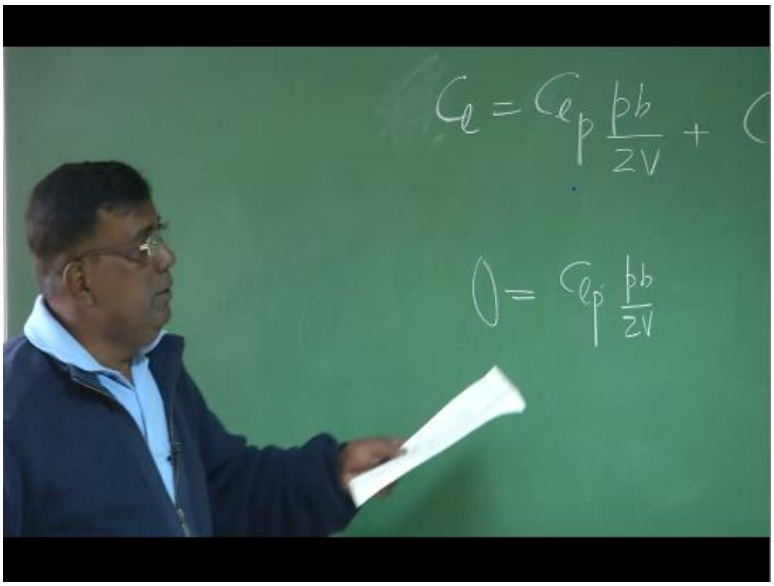

I we get to see that when I am doing steady coordinator in a return there is no p they are not all right so this gentleman goes off. Then plus cl_r similar story with cl_r if I say will you be correct no ,no because there is the R and I have taking a study coordinator turn there is a you are it so I cannot drop on this stage what about CL beta into beta for a steady coordinator turn what is the value of beta we have seen beta is 0.So this man also goes well of course cl and delta which is coming from Ellen on and plus CL Delta R CL Delta R means.

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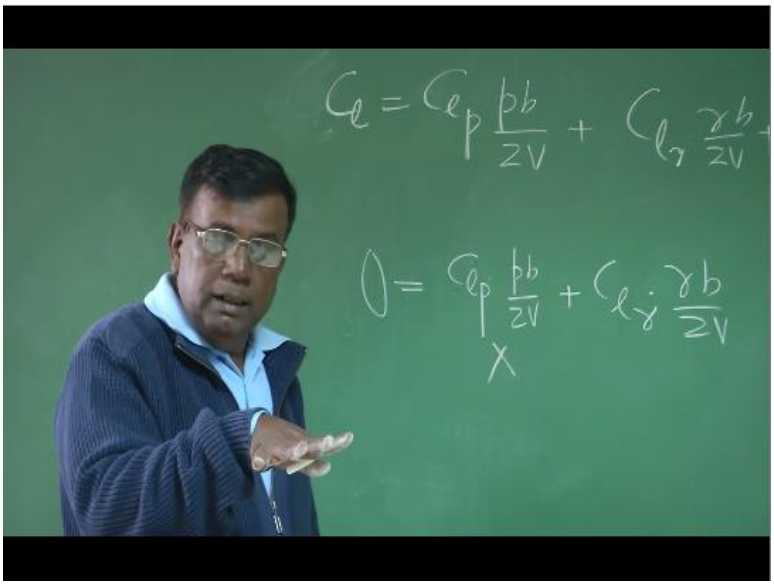

When I deflect the rudder if I deflect the rudder like this it gives a young moment plus they the force in this direction that will give a rolling moment also that is why you have CL Delta R. So if this is true then what do I do I write simplified equation 0 equal to CL r into r b / 2 v plus Cl delta a into delta a + CL delta r into delta r .

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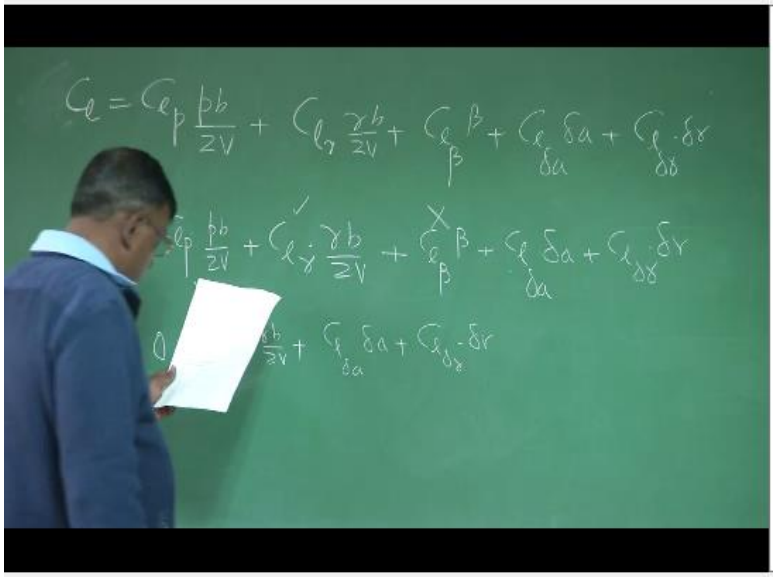

While we are doing further approximation we will see if we study between these two terms CL delta and into CL delta t which control surfaces primary responsible for giving rolling moment by design it is the al anon from rudders it comes as a second effect because rudders are useful direction of motion for turning the plane our should also remember that during stall rudder is our best friend. But in general designed when you are not going to stall and all the primary rolling moment comes from the ell anon and that he is designed for aeronautics for rolling motion.

So I again do an approximation as a junior I said between these two terms this contribution is predominant so I say thank you very much you also go ,so now you have 0 equal to clr to RB by 2 V the CL Delta A into Delta A do not forget to bring this equation what are the assumptions we have made. And also you know that from the earlier equation you have seen R equal to G Phi by

V then if I now substitute this R here what will happen then it will show that CLr into r is defined by V into B /2 V because I am replacing the expression for R by this, this expression of R came remember for the study coordinator turn and others assumptions.

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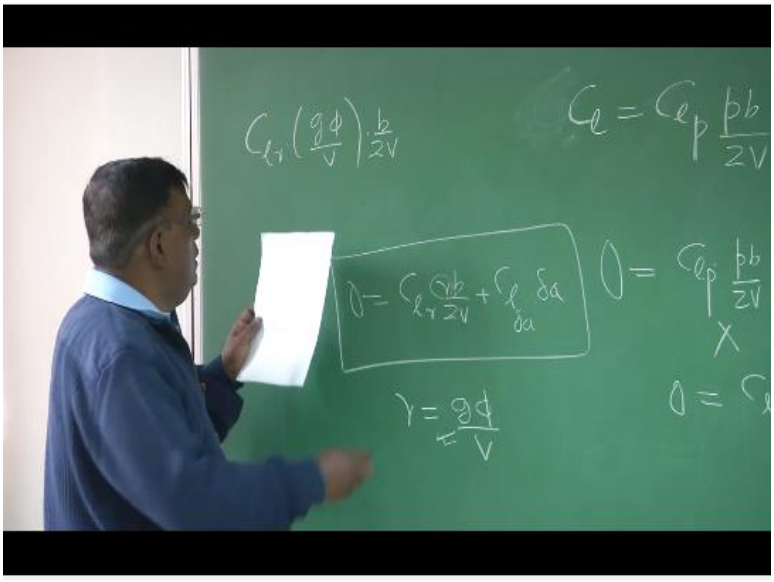

So I am simply in this equation I have substituting the expression for R this plus cl delta A into delta a is equal to 0 .So CL r into r is this into CL r into r b / 2. So this is fine now what I do I do some manipulation I could show that right clr into g phi by V into b/ 2 v same expression plus CL delta a into delta a equal to 0. So I can write clr into v Phi / 2 is to be by v ^{2}square v v have taken their 2 have taken a to have taken inside the bracket is equal to minus CL Delta A into Delta A, no issues this is the expression you understand.

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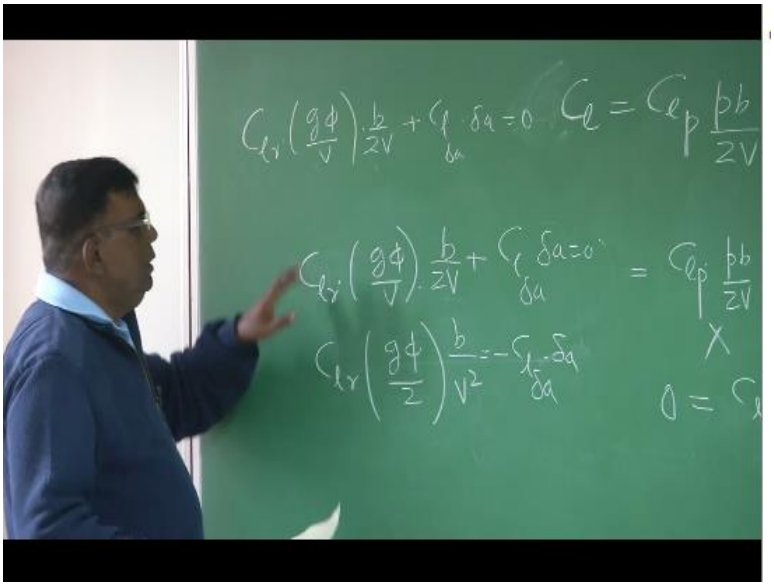

Now here from here to hear nothing great we have done the two we have taken inside this g Phi to this V has gone outsides of v^2 and this is .So you could easily see that Delta a by Phi varies with 1 by v^2 very extremely important of the vision Delta a by Phi values with 1 by v^2 what is the meaning of this. As you are going to make a back angle change and we do a later on you will find that the as I increase the speed is a she will go on decreasing right it goes inversely so this is easily can check from your experimental results because you know you have the data available around deflection you have Phi through done by indicator your V from airspeed indicator and we are from this expression has come it has come from a fixed off and go on adding those simplifications right.

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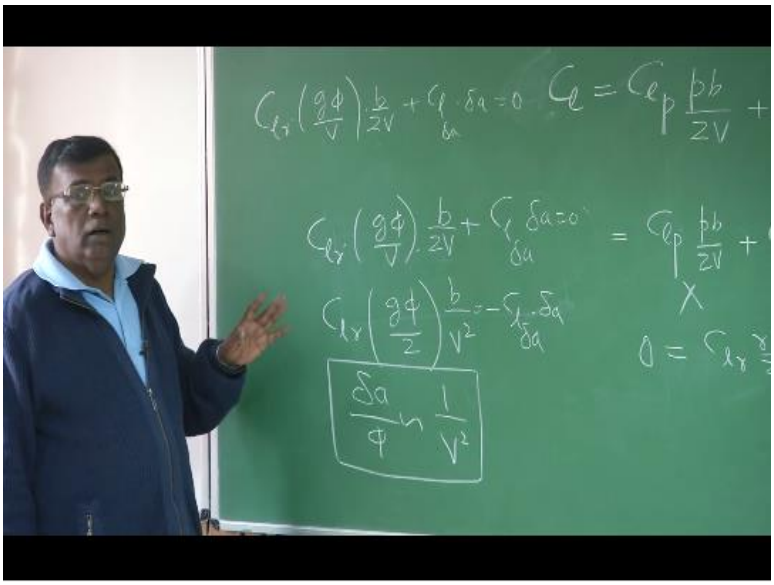

And if you get something closer to this you will understand oh my sixth of my understanding is correct my assumptions are correct a meaningful which will help you in understand the equations of motion this expression is extremely important and this will tell you how to design when you are designing the control controller or an airplane to make the pilot have a good handling qualities it should be very, very carefully the delta A / phi will go inversely with V^2 okay that is extremely important okay thank you very much.

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