Aircraft Stability and Control

Prof. A. K. Ghosh
Department of Aerospace Engineering
Indian Institute of Technology-Kanpur

Lecture- 34
Handling Qualities: Maneuvering Flight

We are continuing with stick force and if you see.

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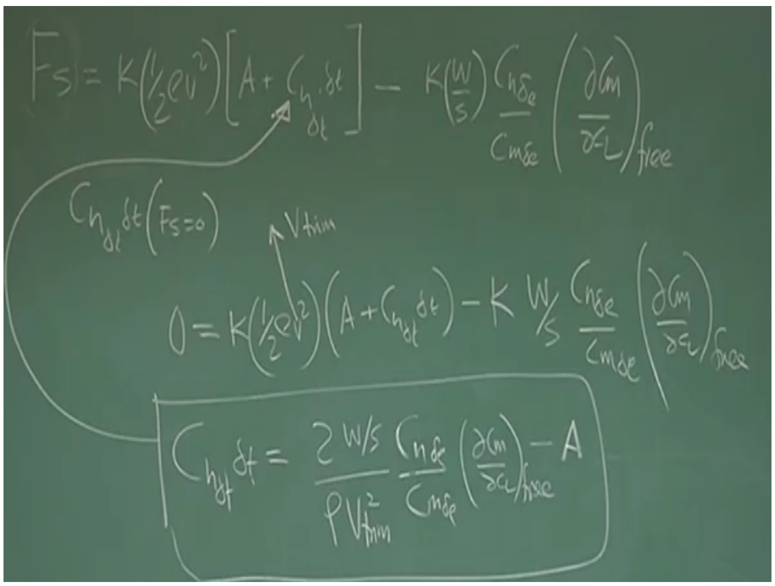

So far we have derived expression FS = K half ROW V square, into A + CH Delta T into Delta T so, and then - KW by S CH Delta by CM Delta E, This is also CH Delta E DCM by DCL free right, please understand 1 thing whatever derivation we have done, you should do once and you need to focus on something very important after you do all those juggleries we got stick force expression like this. So, you focus here many times you might have seen.

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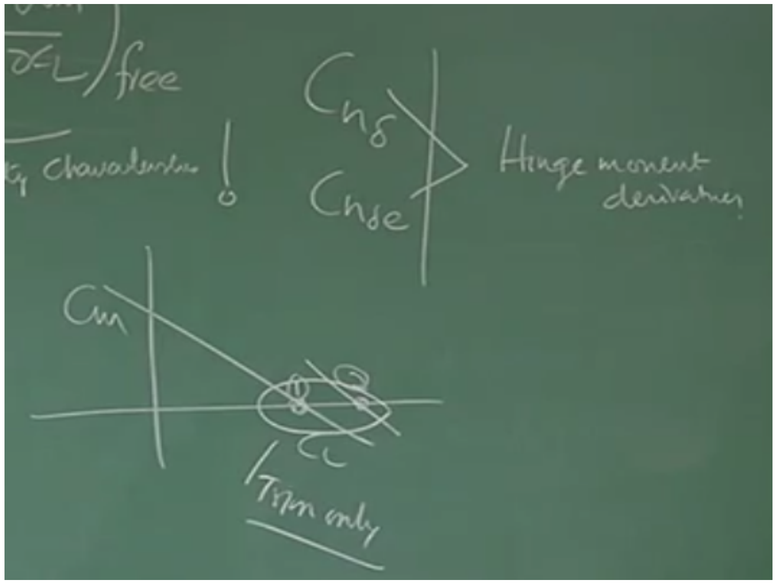

I write CH Delta, I may write Ch Delta E so, this are similar thing same thing's, actually some time I forgot to write Delta E or some time may be write in delequate Delta This are all this this is what is CH Delta E or CH Delta, this is the hinge elevator hinge moment derivative right. You know that CH Alpha T, CH Delta or CH Delta E are same thing now come back to this expression.

What does this expression tells you? It tells you the stick force applied or pilot require to apply the stick force will vary with dynamic pressure, and the first term we will only, we bothered about the speed, that is the stick force will be depending on the speed or dynamic pressure, and that contribution comes only from the first term, if you see interestingly the second term it is independent of V right.

So, stick force contribution towards changing with V comes from the first term, from the first term and not from the stability characteristics. This is something surprising right. So, we meet to again ask our self a question whenever we talking about stick force, what we are doing actually we should know this very clearly, I am applying the stick force to change the trim of the airplane from 1 equilibrium to another equilibrium, or 1 trim to another tr.

That is if I have CM and CL here, I was flying here I want to go from 1 trim to another trim 2 okay. So, far me the force requirement, or the slope of force with speed or the gradient of the respective speed, as well a force is concerned I should be more bothered about the trim only, And common sense says, if airplane his highly stable, highly statically stable then this gradient will be large, right because it will always resist. So, now to get that understanding explicit, we will steady the case at trim right, Okay.

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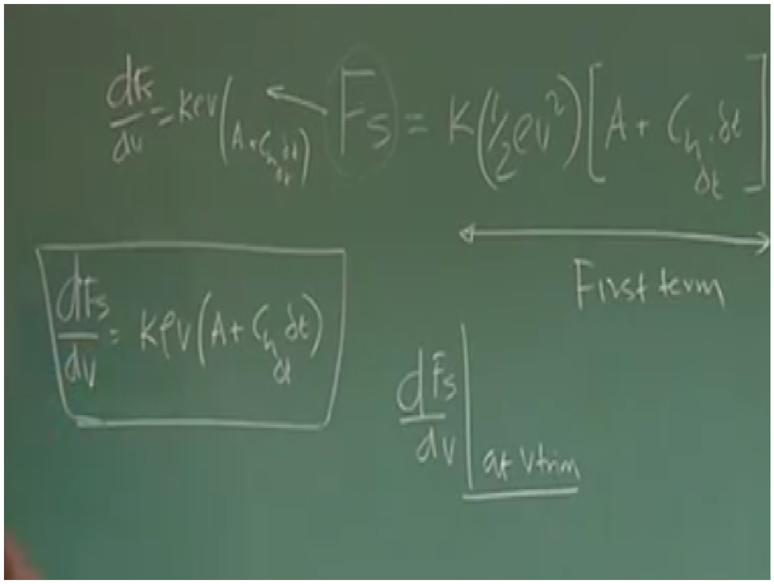

That is why we will now go for DFS by DV, will try to find out at V trim how does it function, how does it vary it clear? If you take DFS by DV here we will get only this term, with 2 will come here, for example if I do it here, I will get DFS by DV as K ROW V into A + CH Delta T into Delta T. that's all this term will not contribute.

So what is that I will get? Let we write clean DFS by DV will be = K ROW V A + CH Delta T into Delta T right? that's why I was telling if this gradient does not bring the inside it terms of stability, which comes through DCM by DCL free, it does not come directly, you cannot see immediately of something is happening here. So we will do a trick, since we know that all this DFS by DV we talking about a trim, so we will analyze DFS by DV at V trim okay. Let us see what happens.

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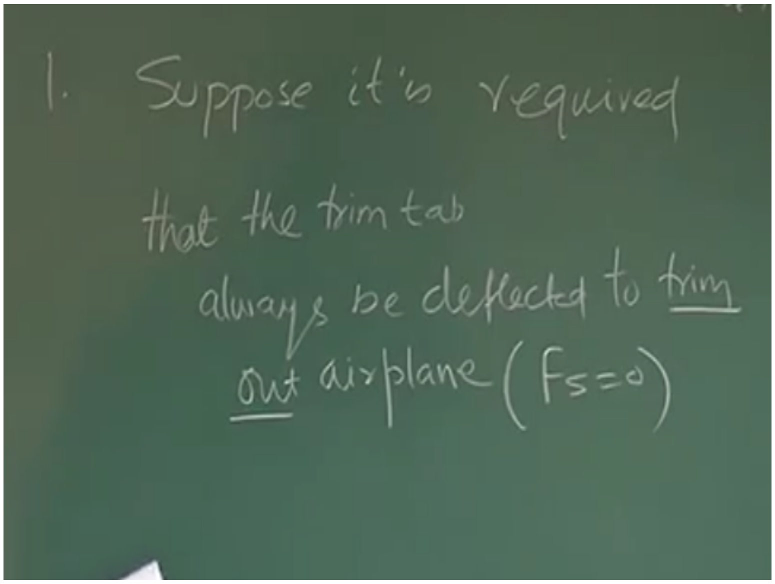

So, I write the statement like this suppose, it is required that let me write this, that the trim tab always be deflected to trim, trim out the airplane this is the language pilot will be using, remember he is the most important person for us right. And this are language you see the pilot will say I have trim out the airplane, that means it's hands off FS = 0 no stick force is required, you can fly like this and this job is done by Delta T all the time okay? and you know how it is done?

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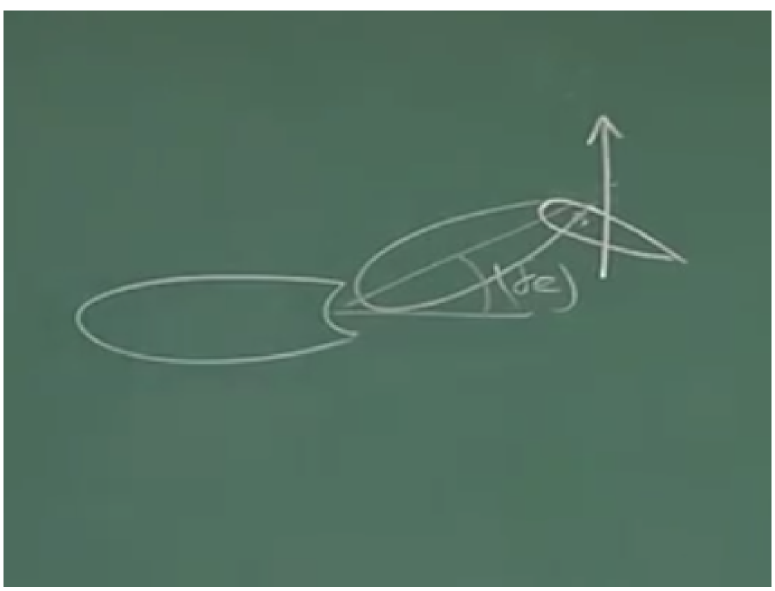

The mechanism we have already discussed suppose the elevator has to be kept at this angle for trimming at the particular CL, and you want doing it by pulling the stick, you are trimming at lower speed. The lower speed so the elevator go up, but then has long as you hold the stick okay? This gentle man will be like this, the moment will release the stick because a reversible system, then elevator will also try to go back, so how to hold it without applying the stick force?

Let's put a trim at this tab and this tab will generate a hinge moment, and which will. Ensure that this is kept at this position so, in a language we say assume that, Delta T is rolled so, that trim is achieved okay, Correct. So, that is what language is trim tab, so that FS is 0 which is trim or in pilot's language it is trim on the airplane. It's apt in the trim all the airplane okay, now with this understanding let us see how to formulate so, using this equations will try to find out what is CH Delta T into Delta T, to ensure that FS = 0.

Take this is the statement that always be deflected to trim right? So always Delta T is deflect such that FS is 0, I want to know what is this contribution. so from here if I put FS = 0 then I get K half ROW V square into A + CH Delta T into Delta T - K W by S CH Delta E by CM Delta E into DCM by DCL free. If I do this I get CH Delta T into Delta T you should do this simple derivation will be 2 W by S okay? By ROW V trim square right.

Now all is happening this V is becoming once FS is 0 V is nothing but V trim. So this will be ROW V trim square CH Delta by CM or Delta E CM Delta E DCM by DCL free right? - A is here okay? And know the expression for A so what is this? Let us have interpretation what is the interpretation of this.

For a given stick free stability, given hinge moment coefficient given elevator control power for a given wing loading, and at a V trim I need to deflect Delta T such that CH Delta T into Delta T is = this. Then it will be trim FS will be 0, no stick force is required so we are flying using a trim tab okay. Now what I do this CH Delta T into Delta T I substitute here correct. Then what I will get? For a substitute in this expression then I will get FS = so please derive yourself.

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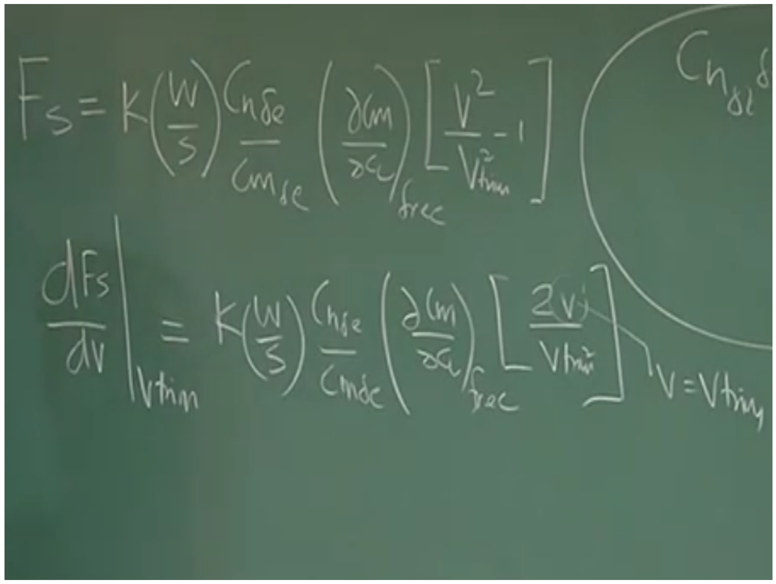

FS will be = KW by S CH Delta E by CM Delta E into DCM by DCL free into V square by V trim square - 1. You may get a confusion that, we have put FS = 0 from there we have got CH Delta T into Delta T so, if I put it here then it should be become 0, no if I put it here this FS will become 0 only 1 V = V trim is it clear? I repeat you may get a confusion that FS = 0, I have put here from there I have got CH Delta T into Delta T.

Now this gentleman I am putting it here, so FS should become = 0 answer is no, this I have got at V trim but I am talking about in general V, that is why once you substitute that you get expression like this is it clear? Everybody okay, or should I do it now I will not do it, you can do Yourself just put this expression here, and you will get this expression and if you are finding it difficult, which you should not write in the forum will give the detail derivations but,

I will be disappointed if you cannot do 1 are such derivation right? I am sure you are smarter than me we will be able to do it. So this is FS now what is DFS? by DV at V trim that is our question we are looking for, so you could see first if I find DFS by DV, so that's the KW by S CH Delta E by CM Delta E DCM by DCL free, and here I will get 2 V 2 V by V trim square, I know that I am valuating DFS by DV at V trim.

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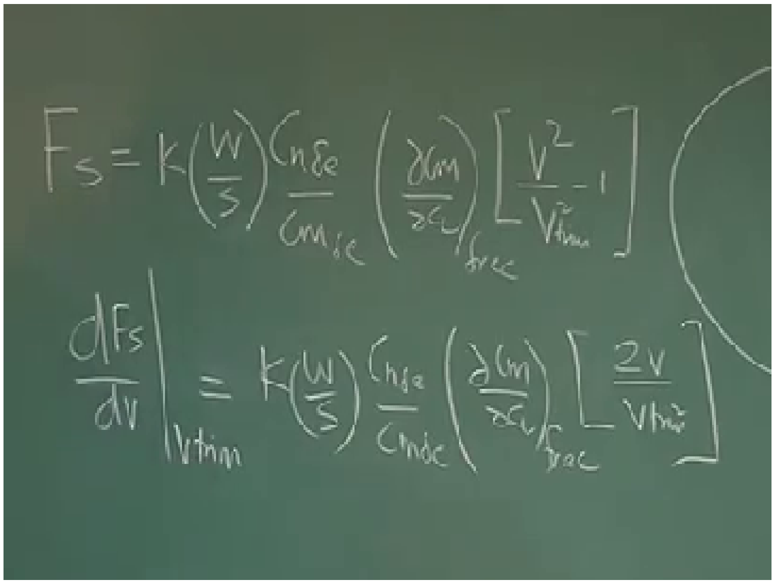

So I will put here also V = V trim, so if I put here V = V Trim then V trim and V trim square 1 V trim will be there, and you will get the expression DFS by DV at V trim = which I am going to write now.

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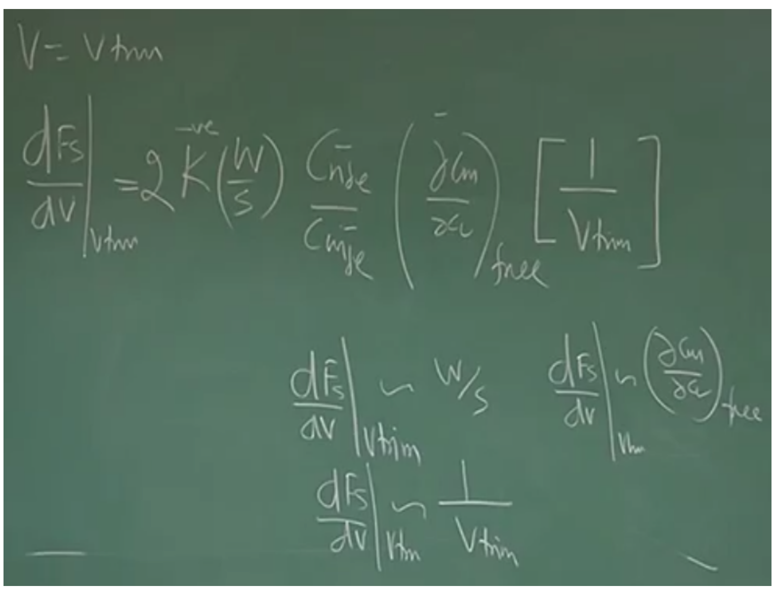

So, at V = V trim we will get DFS by DV at V trim will be = K W by S, CH Delta E by CM Delta E DCM by DCL free into 1 by V trim or I put 2 here, this is the expression so, what is the physical interpretation of this. If I want to find out this gradient, then I know that for a lightly loaded airplane that is whose wing loading is less like gliders and all, DFS by DV also will go down okay. Also you know that.

It where is for other 3 D when it is constant it varies inversely with V trim, if you are trying at to trim lowest speed DFS by DV will be larger okay. Also you could see if we make so, I let me write down this DFS by DV at V trim okay. Will be proportional to W by S very important parameter wing loading, also I see DFS by DV at V trim is proportional to or inversely proportional to V trim, that is if I am trying to lower speed DFS by DV will be more.

Of course inversely and also another see which we are looking for DS by DV at V trim is proportional to DCM by DCL free, so you could see that, if I take CG forward then DFS by DV it slope will gradient will increase. More stick free stable more the DFS by DV okay. So this are the understanding from this expression, now if I just plot it the FS required by the pilot so if I see before a K I know is negative, this is positive this is negative this is negative so this becomes positive. This is negative so total this DFS, DFS by DV at V trim SIN is positive.

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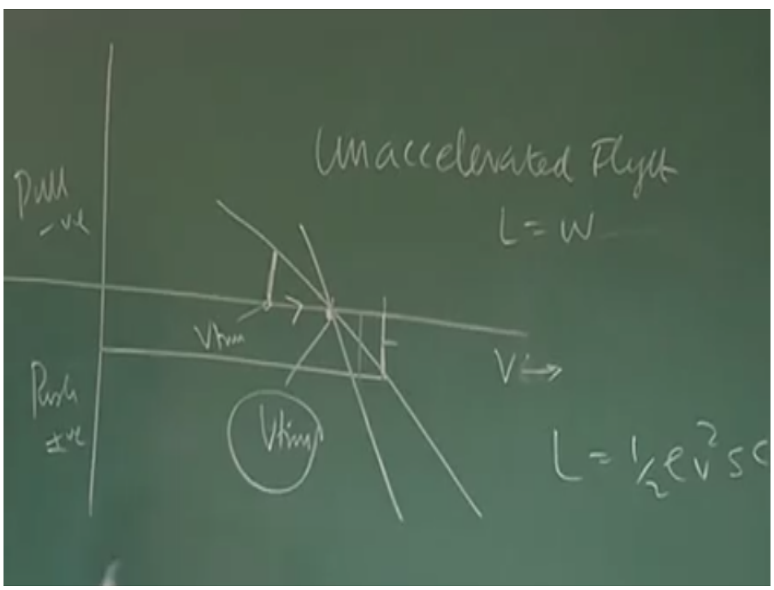

But we have seen that we have taken push force as positive, while plotting we are putting it here pull, which is negative and push here positive, so you see this will be something like this, V trim speed. And at trim this is V trim what is this say, if you want to increase V trim from here to here, we have to apply a push force so consistent, so push force i am increasing the V from V trim, V trim 1 to V trim 2 or V trim 2 is more than V trim 1, and increase in the speed for trim.

I am talking only about trim not transients please understand, similarly if I try to trim the airplane at the speed lower than this V trim, let's say here it says i have to pull it. Which is also consistent and to reduce pull, you got to increase push, now what is happening here? if I come back here, if I want to increase the trim speed and you trim at a higher speed, remember these are all un-accelerated flight this you should not forget, that is lift = weight.

What we are trying to do? And lift you know what, lift = half row v square SCL that is = weight. Now if you want to trim at a higher speed you are pushing it, you are pushing here that means you need a push force, as per this diagram and the push force will do what? As I push elevator should go up or go down? Check from here if I am increasing the speed, to maintain the lift to ensure it is = weight CL has to go down, so if I push,

Elevator should go down, so that angle of attack is reduced, if I want to pull say it elevator should go up, so these are all linked, okay lets now you say when I am pushing elevator goes down, when I am pulling elevator goes up, all these things get connected, 1 thing you understand suppose you are at a V trim here, and you have applied a pull force now you have Trimmed the airplane at this V trim, and now release the stick, because it is reversible you will find it will try to come to back to this trim.

That is where your stability and respective speed comes, and you could see that if the slope is very large, larger the slope then external disturbance will not be able to alter the V trim; it will take larger DFS by DV whether pull or push okay. But there is a limit how much gradient a pilot can handle, so that decides the handling qualities of an airplane okay. This part is extremely important and you must understand this carefully okay thank you.

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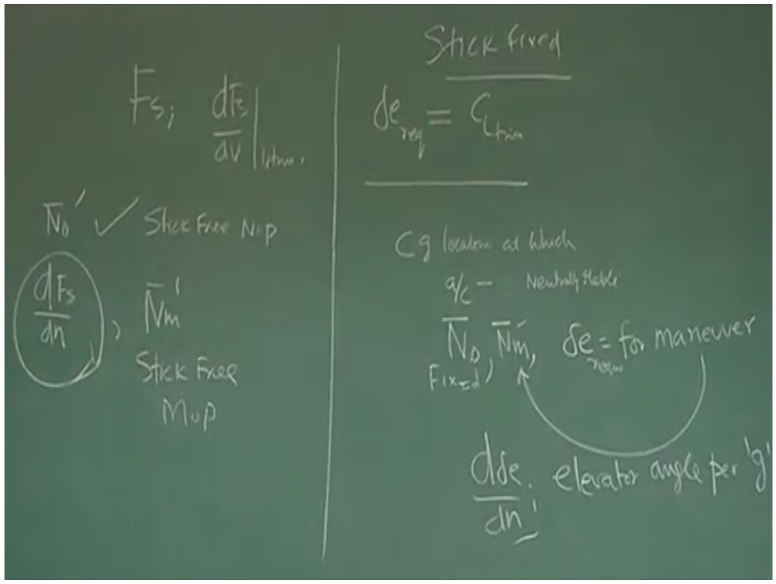

Let us now thing think what we have done, we have calculated FS, we have calculated DFS by DV at V trim, and sometime back we also calculated what is the Delta E required for particular CL trim, right okay, and from here we realize 1 thing, from this concept that there is a CG location at which aircraft become statically neutrally stable okay, so from there we have defined neutral point, then we have done maneuvering flight and there we have defined.

NM maneuvering point these are all stick fixed, right these are all stick fixed, that is we have not allowed the elevator to float, then we have also calculated what is Delta E required, for maneuver, from there only we got maneuvering point, we have also computed some expression like, D Delta E by DN and we try to interpret this as elevator per G okay, elevator angle per G requirement right, which comes that is exactly we used.

We told that the CG location at which D Delta by DN 0 is allowing maneuvering point stick fixed, if you see in similar way we want to find out DFS by DN, this gradient this is extremely important gradient, this is what pilot will be feeling right, and also we want to know what about stick free neutral point, which we have already derived expression to find out, what is the stick free neutral point, so our aim now will be to develop an expression for DFS by DN.

We have already developed expression for D Delta E by DN, through which we define something called maneuvering point, and which is what is the maneuvering point? it is that CG location, at which D Delta E by DN = 0. That is beyond that you won't be able to really accelerate the airplane, G then it is its going to have a structural failure okay, so what we have Calculated there is maneuvering point, using D Delta E by DN expression we put D Delta E by DN = 0.

And found out what is that XCG location at which D Delta E by DN was 0, and that is the maneuvering point. Similarly we will now try to find out DFS by DN, and we will try to find out stick free maneuvering point, which is called a stick free maneuvering point. Like this was called a stick free neutral point. And what was this? Its stick fixed neutral point and this is stick fixed maneuvering point, when you talk about stick fixed, we are talking about Delta E.

And N Delta E and CL, when you are talking about stick free we are talking about stick force, N and stick force and CL we will see it how we build it out. Then also we will try to have a lecture on, how to find various neutral point through flight test okay.

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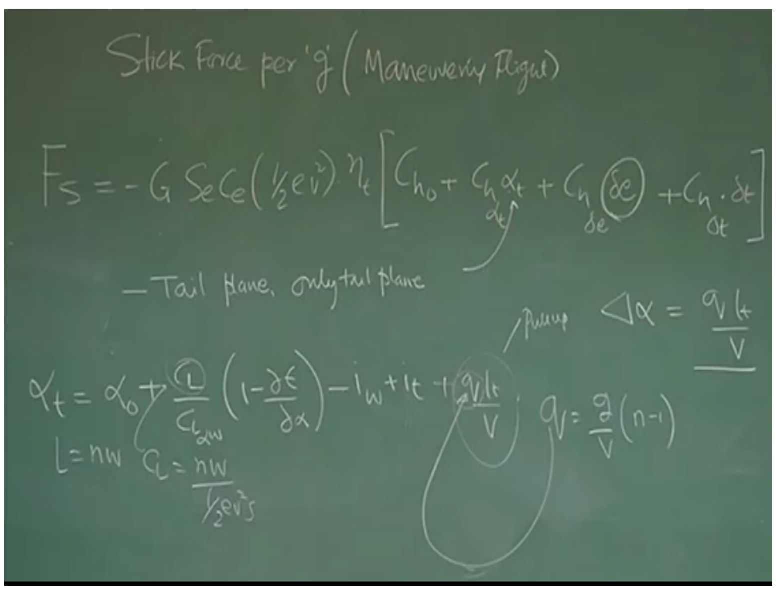

Let us focus on DFS by DN so the title will be stick force per G, for stick fixed case it was elevator deflection perch okay, so now let us write first this big expression, FS is - G SE CE half row V square into Neeta T. And you are expert now CH 0 + CH Alpha T into Alpha T + CH Delta E into Delta E, + CH Delta T into Delta T that this is general expression where CH Alpha T and CH Delta E are the hinge moment coefficient which are negative for most of the cases because hinge line is a head of now center pressure over the elevator and CH Delta T is also negative and Delta T is the tab deflection okay.

This all we know by now what is RA? RA means stick force per G that we are talking about maneuver what sort of Maneuver we have discussed 1 was pull up and another was turn okay. And we know that

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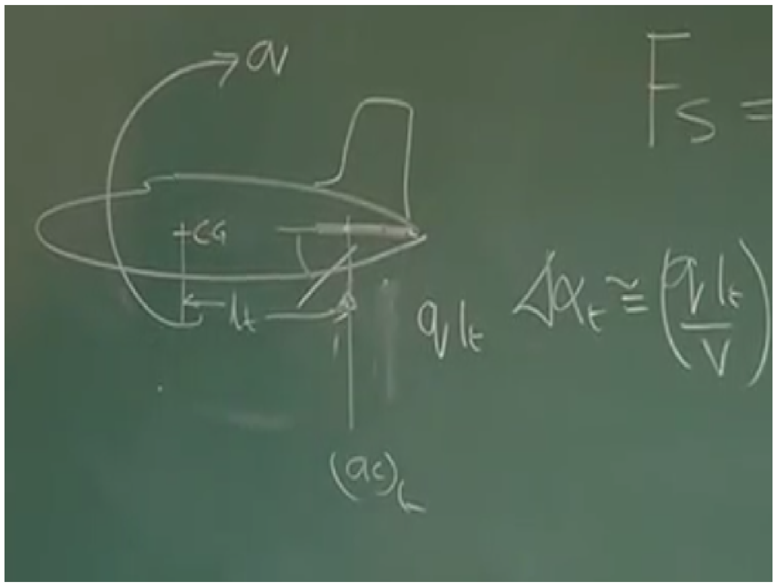

if I see this diagram if this is airplane is going for head pitch up Q or pitch rate you is reduced per second and if this is the AC of the tail and this length is LT by convention we all agree this is the tail momentum horizontal tail momentum then you know that because of this there will be let if her velocity at SE.

Which is resultant type let see at is we are taking this this will be Q LT and that angle of attack at tail additional because of Q as it is going down if this airplane going down it is tail it's going down so, this is the QLT relative velocity and moving forward should Delta Alpha T will be Q LT by V approximate and then you need to understand 1 thing that means the tail plane because of him pitch rate maneuver we will see additional angle QLT by V which will give and nose down moment right.

And that is why we have to give a different elevator deflect that we have done already in stick fixed case but there is a difference they understand what I am try to leave this tail plane angle of attack is increased by this only tail plane we are no multiplying 1 point 1 here when we are doing correcting for Delta E they are we have multiply 1 point 1 I will explain that has we progress as okay.

So, what is happening now? Alpha T I will write has Alpha0 remove this was CL by CL Alpha wing into 1 - D epsilon by D Alpha - I w + IT right? This was for level acceleration that is level flight okay? Now we are talking about maneuver in flight so, let me write here maneuvering flight during maneuver what you know L = NW so, CL = NW by half ROW V square S when it was level flight that term we replace CL by W by half ROW V square S.

But it's maneuvering flight so, load factor is more than 1 so, I have to replace CL by NW by half ROW V square S so, what this expression will turn out to be now Alpha T = Alpha0 + N W by half ROW V square is divided by CL Alpha wing into 1 - D epsilon by D Alpha - I W + IT if you listen to my explanation you should be able to do all this steps at ease okay?

What we are discussing here we are discussing here maneuvering flight we are trying to find out our model FS for a maneuvering flight and we have this expression okay. Here Delta E is sitting here what is Delta E for maneuvering flight what is that maneuver I am talking about we have already done.

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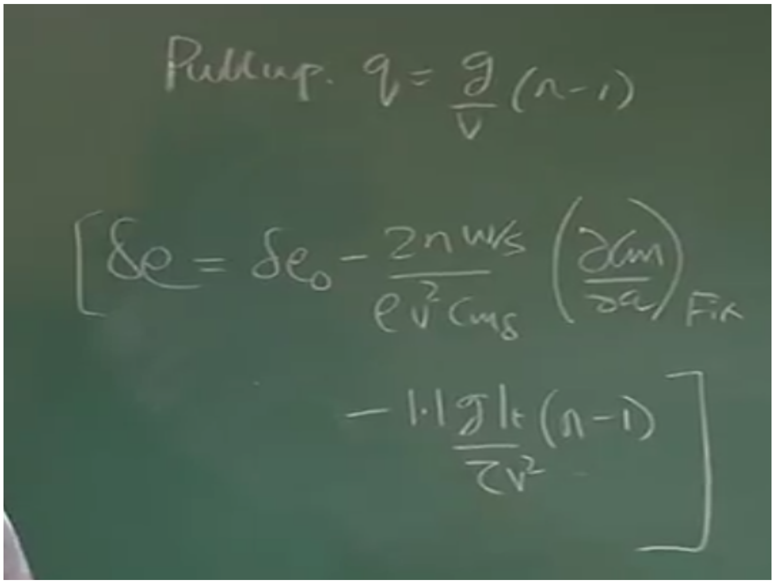

For a pull up we know Q is nothing but G by V N - 1 okay. I will take the case of pull up and I will write the general solution for turn which we suppose to do it they are do it yourself all will do through. Simmons if will consider pull up case where Q is G by V N - 1 what is the meaning of that if I want to generate at this much of load factor N at a speed V then the Q the pitch rate should be given by this relationship and then what we said because of this Q I have to be careful I have to ensure that elevator is corrected DCM by DCL fixed then - 1 point 1 G LT by TOW V square into N – 1.

We have already develop this in earlier lecturer you have seen this a Delta E require for a pull up value maneuver okay. I was mentioning please take here when I am try to see what is the Alpha T seen here I am very very clear that when I am talking about Alpha T and this is the Alpha0 + this is this is this is of CL is NW this are because of Q there is in increment in Alpha T and that Alpha T Q Delta Alpha T was Q LT by V no 1 point 1 factor put here has per as tail angle of attack is concerned.

This 1 point 1 came here because we are taking about the damping effect because of the position a head of the wing what required right. What actually happen you see as I am going like this there is an increment in angle of attack here so, it gives stability has it position goes up front position so, they hit be like this so, they also try to discourage it give nose down moment so, they also act to some sort of stability and we have to take care it take care that reflected by elevator.

That is the ten percent increment was there to counter the fuselage effect right. From Delta E perspective but as per Alpha tail is concerned it is only increase by this much value where Q has to be put equivalent to Q pull up or Q turn we are considering a case Q pull up what is the understanding this Delta E which is there we ten percent increase because of fuselage effect this Delta E will come here but when you come to Alpha T what's will be the Alpha T expression let us write it.

This was Alpha T for N = 1 it was like this so, far with load factor N CL replace by this this - hydrate by IT what will happen what I have to add I have to add this Delta Alpha right. Because that is the amount by which tail angle of attack is changing so, I will add this is as Q LT by V so please be careful we should be very very clear what we are doing here at this point I need to know what is the Delta E for maneuver.

We have already done if it is doing a maneuver of load factor N this for a pull up case Delta E required is this we have already done in your earlier classes now because of this Q the change in the tail angle of attack by an amount this so, I have to put the value of Q also so, that Alpha T I will put substitute here so, what I will do let me clarify we trying to find out what will be the Alpha T we know for N = 1 Alpha T is given by this we have already derive this.

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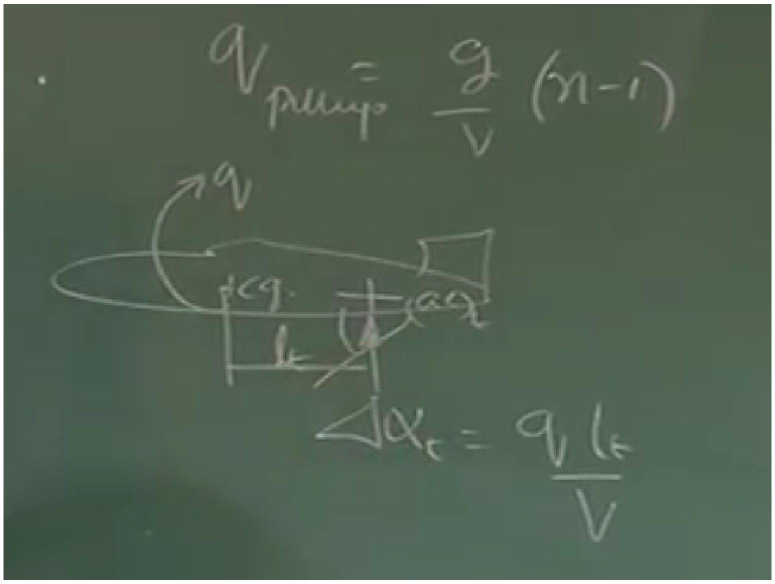

What is happening if airplane is doing a pull up with Q and you know Q for pull up is given by G by V N - 1 so, what will be the Delta Alpha here Delta Alpha tell will be Q LT by V where from here to here this is LT that is from AC of the tail to CG is LT Q LT by V typically is this already we have done that so, now tail angle of attack has to be modified by this factor so I will add 1 is Q LT by V this is coming from pull up what more?

See here it is CL what will be CL now for maneuver you know L = NW so, CL will be = NW by half ROW V square S so, this change is will come in Alpha tail notice that we have not multiplied by 1 point 1 1 point 1 multiplication are required for Delta E expression because that Some damping was coming from fuselage also but here we only solving talking about change in angle of attack at tail okay.

If this is the expression was Alpha T Delta E0 already Delta E expression already we have understood Alpha T have to put it here put this whole expression here but remember what we have to do I have to replace this Q by what Q have to write let has G by V N - 1 so, what are the steps you take this value of Q put it here L for L here put NW by half ROW V square S take this whole.

Alpha T put in this expression so, 2 things we have done we have put elaborate expression

For Delta E which takes care of the pull up and Alpha T which also takes care of pull up these 2 things we have to put in the FS expression clear. So, now 1s you put that what happens.

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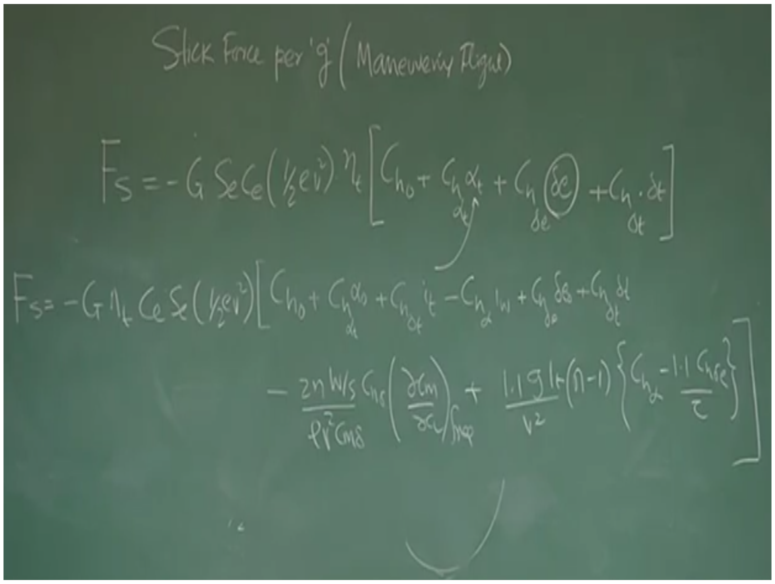

Once you put that what happens once you put you will get the expression like this FS = - G Neeta T CE SE half ROW V square CH 0 + CH Alpha T into Alpha 0 + Ch Delta T into IT - CH Alpha into IW + Ch Delta E into Delta E 0 + CH Delta T into Delta T - 2 N W by S ROW V square Cm Delta into CH Delta DCM by DCL free + 1 point 1 G LT by V square Into N - 1 in bracket it is CH Alpha - 1 point 1, - CH Delta E by Tow this will be the expression. This is very mechanical

As I told you if you put those expression for Delta E and Alpha T here then you can manage this nothing to you will really get worried about it, so once we have this expression now we do a trick. We are again try to come back to a trim condition, which I call trim means when the FS in 0. Now we want to use the definition of Trim at N = 1 which lift = weight, so what we do we say.

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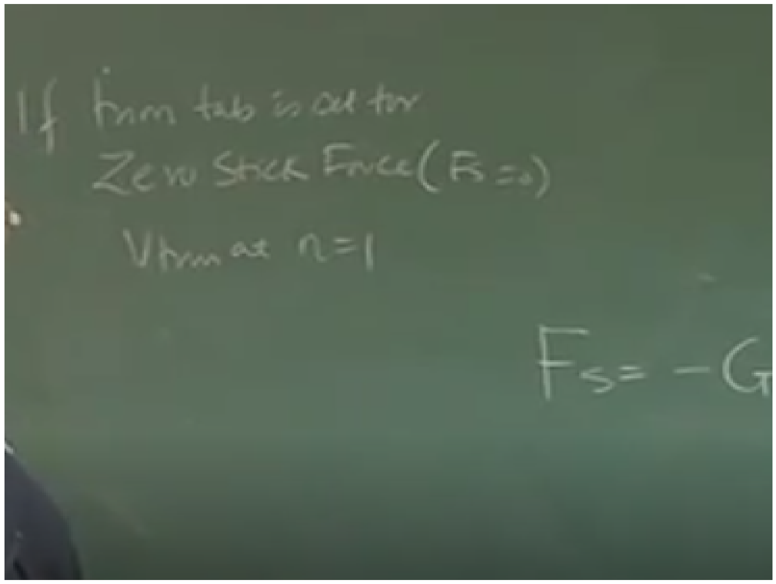

If trim tab is set for 0 stick force, that is FS = 0 V trim at N = 1 why this is important, how do I do pull up? I have a trim lift = weight now I am doing a pull up okay so I am assuming that, when I have trimmed the airplane. At level flight the stick force is 0, and which corresponds to N = 1, from there I am going for N greater than 1 or N other than 1, and we are trying to find out what is the DFS by DN.

It also says we want to find out DFS by DN about the trim, and trim for this case is lift = weight clear. Now if put this condition if trim tab is set for 0 stick force, that is trim at N = 1 I repeat because how we are doing the pull up. Your trim is at lift = weight N = 1, right? And from there you are doing the pull up. I am trying to find out DFS by DN which is at the trim at N = 1. Trim means lift = weight from there I am doing the pull up, so I am trying to find out DFS by DN about the trim, when I am changing from that trim okay.

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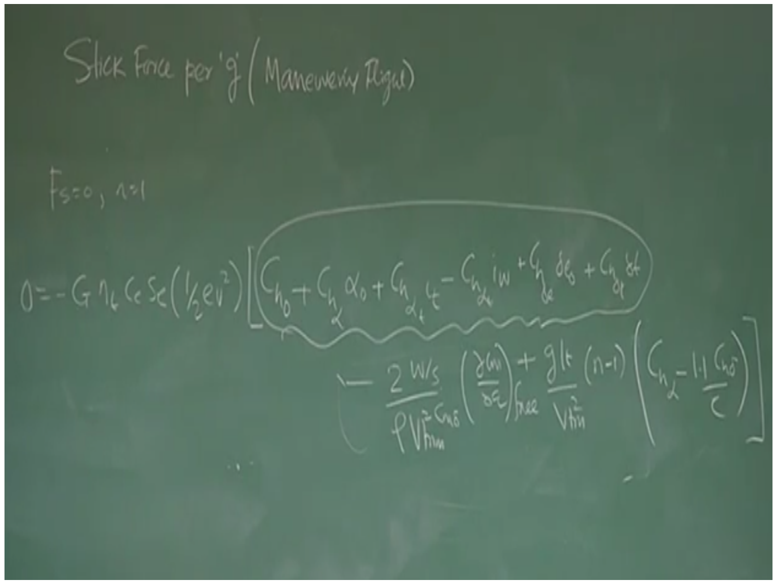

So, I can always write to find that condition FS = 0, and let be N = 1 that is at trim I will put 0 = - G. Neeta T CE let me write this because it is very lengthy term, you do not get mixed up Alpha0, + CH Alpha into IT - CH Alpha into IW Alpha tail then + CH Delta E into Delta E0 + CH Delta T - 2 W by S Row V trim square okay? This is important CM Delta DCM by DCL free + GLT by V trim square N - 1 into CH Alpha - 1 point 1 CH Delta by Tow bracket to be closed okay.

Now see here if I put N = 1 then you will see that this whole will correspond to a case where at level acceleration same term will come here right? That is that shows that we are in right direction that is stick force called level unaccelerated slide when I put N = 1 those term goes to 0 Exactly that expression will develop for level flight unaccelerated which is cruise flight you can check yourself.

Okay if I put this = 0 now what I have to do from here I can find out this + this + this + this + this all of these right? That will be = this term right? Divided by this term because as 0 so, I take this term to a right hand side and I divide the right hand side number this then I get this then I will get this expression and the whole expression in actual stick force expression pull replace them by this expression okay. That is what I am try to do will see this we see if this = 0.

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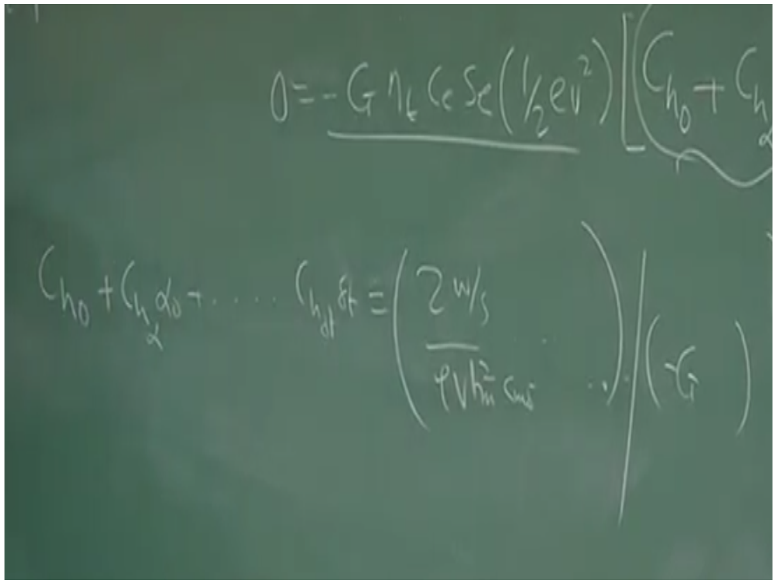

Then I can write CH0 + CH Alpha Alpha0 + dot, dot, dot CH Delta T into Delta T this term or this term will be = 2 W by S by Row V trim square CM Delta right. This whole divided by this term okay, Clear. By doing this manipulation let us see finally after all this thing what do we get too expressions let us. What we get and what sort of physics we are going to attribute to that.

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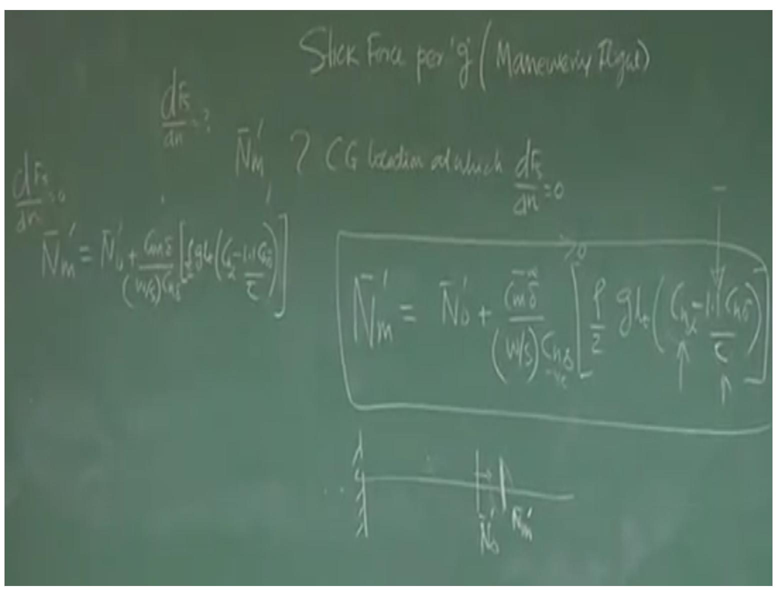

We will get interesting expression FS = - G Neeta T SC CE W by S CM Delta E CH Delta E and DCM by DCL free into V square by V trim square - N of course it is not end of story - G NT SC CE G LT Row by 2 N - 1 into CH Alpha-1 point 1 CH Delta by tow huge expression will get now what do is if I try to find out DFS by DN I have to differentiate this.

So, I get expression DFS by DN for a pull up will be = G Neeta T SC CE W by S CH Delta E by CM Delta E and DCM by DCL free then - GNT SC CE GLT Row by 2 CH Alpha - 1 point 1 CH Delta E by tow this will be the expression for DFS by DN and this is DCM by DCL free what is our aim? Our aim is to find NM prime that is what is that CG location.

What is that CG location? At which DFS by DN is 0 so, I put 0 here and I know DCM by DCL is XCG bar - N0 prime so, DFS by DN if I put it 0 this XCG becomes NM prime is this clear. DFS by DN focus on this expression okay? DFS by DN is coming like this where DCM by DCL free is here and DCM by DCL free XCG - N0 prime.

And if I want to find stick free maneuvering point which is NM prime what I have to do is put DFS by DN = 0 and whatever expression for XCG you get that is nothing but N 1 prime because that is the CG location which DFS by DN is 0 so, if I put that 0 so I put DFS by DN = 0 then I Get expression for malingering point stick free as N0 prime + CM Delta by W by S CH Delta into Row by 2 GLT CH Alpha - 1 point 1 CH Delta by tow erase this.

This is or the form if you want this expression further right. In a Neeta form this is = N0 prime + CM Delta by W by S into CH Delta Row by 2 GLT CH Alpha - 1 point 1 CS Delta by Tow now if I ask you a question. If this is stick free neutral point so NM prime will be here or NM prime will be here if I am measuring from this case 1 obvious way of answering this question is during maneuvering this aircraft become more stable so NM prime should be somewhere here more stable so, you can travel CG more and now if check on this expression see this is negative this is negative so negative positive.

If I ask which way N0 NM prime would be respect N0 prime you know, this is the maneuvering stick free neutral point so, by our own understanding should be aft of N0 prime if you see the expression this is negative this is negative and here between CH Alpha and this term this will dominate ad there will be - sign given so overall this term will become greater than 0 so NM will be more than N0 prime and CG somewhere here again see this by understanding since it is maneuvering.

So it will be more stable so, whatever stick free neutral point was here because of maneuvering the stick free maneuvering point will be aft of stick free neutral point and that you could see from here this is negative this sign is negative this become positive and the sign is decided by this sign of sign of this generally this factor is more than this factor and the - sign dominates here that becomes that makes it positive so most cases if I NM prime will be aft of N0 prime.

I advise to all of you all these expressions you go through once or get the final expression understand what I am telling you that's more than important right? You should not get lost into big big expressions this is simple expression we derive and you derive once derive once only remember the final thing I would not expect any memory I do not want you to remember this formula all these big big thing no no question and these are available to you.

You need to know physical interpretation so that you can utilize it for design purposes right. I do not want to waste your time in memorizing all those big big expressions so feel relaxed only my request is sit with the pen and pencil and derive this expression the way I told you okay. Thank you very much will finally conclude this section by telling you how to calculate neutral point maneuvering point using flight data or through flight test okay.