Aircraft Stability and Control
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Lecture – 26
Stick Free Stability

Yeah this is Kanpur, and winter season we are recording in extreme cold in Hindi we say, Halath karab hai right? We are talking about controlling an aircraft I wish I knew how to control this temperature doesn't matter, interacting with you gives me enough warmth and that makes me continue with recording so let's go back we have been discussing about controlling the aircraft and if it you recall.

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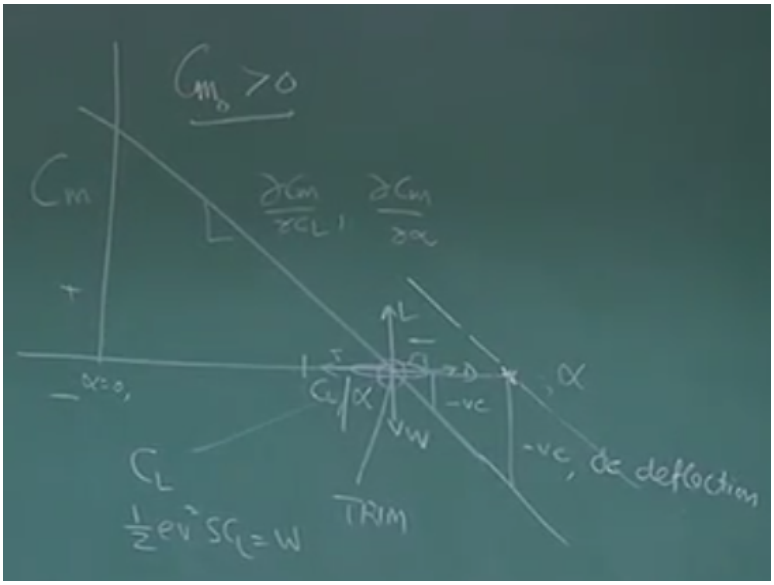

Your previous lecture you have seen what do you mean by controlling an aircraft is suppose this is CM and let say this is CL or Alpha whatever way you plot and you know that this slope is DCM by DCL or DCM by D Alpha depending upon in X axis. You are putting CL or Alpha what is our aim? Our aim is to trim the airplane at this point which is called trim point what is the meaning of trim point suppose the airplane needs to be flown at a cruise the cruise means the airplane is draw the airplane here so it would generate enough lift to balance.

The weight and enough thrust to balance the drag so if this corresponds to a particular CL then I must ensure half row V square SCL = W so, that will give you for a given W given decided speed given altitudes row and given wing area that will tell you what is the CL I should fly that means what is the CL? At which I will trim the airplane that further mean that what is that CL I will be flying such that there is no pitching moment it is CM = 0 okay?

Flying like this and this is the one of the equilibrium state and we have understood the slope is negative DCM by DCL is negative or DCM by D Alpha is negative accordingly you have decided to put CL or Alpha here and you know that if by some disturbance the angle of attack increases here if I talk about angle of attack to be this axis if angle of attack increases here then it will automatically generate negative pitching moment okay?

We got this CM, here is negative here is positive it will automatically generate negative pitching moment which will try to take Alpha back to the Trim Alpha and that is why we say it has initial tendency to back to the equilibrium so, it is statically stable so two things one is DCM by DCL should be negative or DCM or D Alpha should be negative and to Trim at positive angle of attack generally you should ensure that CM at Alpha, = 0 at or CM at CL = 0.

Since I am more discussing with Alpha CM at Alpha = 0 which is denoted as CM0 it should be positive generally that is the configuration which you want to fly now what is control? What we discussed was suppose, I want to trim the airplane at a different Alpha so, the moment I tried to take the airplane from this angle of attack to another higher angle of attack and still maintain lift = weight and thrust = drag what will happen?

That this gentleman because this statically stable it will generate a negative moment, it will not allow it to go that new CL or Alpha. So you have to forcibly nullify that and that is where you give a Delta E deflection in a manner that it generates a positive pitching moment and nullify this negative pitching moment and you can draw the line to be something like this that is what is the control part I am talking about elevator, only same thing will be true for the rudder and aileron we will see when if the lecture progresses and to formulate that we have seen.

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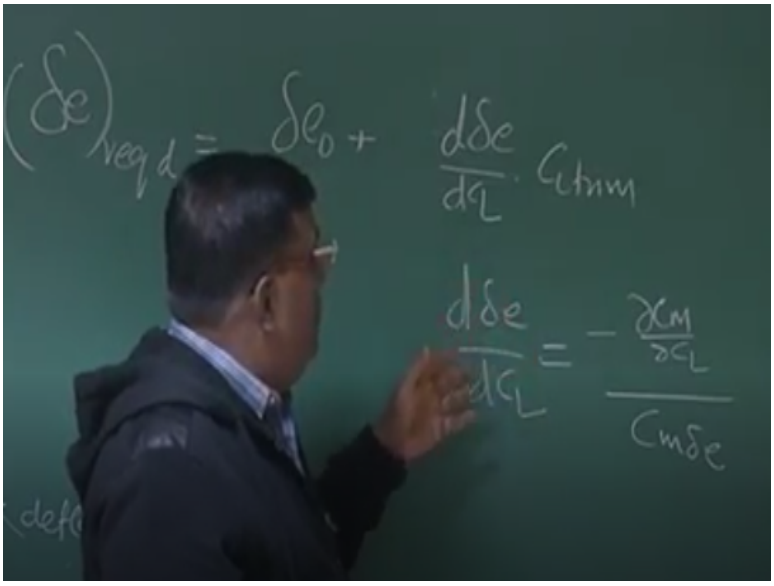

That what is that Delta E required to trim an airplane at a particular CL trim so we say it is Delta E0 + D Delta E by here I write D Delta E by DCL into CL trim and where D Delta E by DCL is nothing but - DCM by DCL by CM Delta E with some approximations, when we put okay? This is the neat and clean linear expression now what is the meaning of this? Meaning of this is that when I decide I need to trim at a particular CL I need to know what is the value of D Delta E by DCL.

Who decides that it is decided by DCM by DCL and you know, DCM by DCL has a relationship with static margin if static margin is largely negative or static margin is large then DCM by DCL is more negative okay? And also you need to know how effective is CM Delta E what is the control power? It is very obvious that if DCM by DCL is very, very large, that is highly stable then this value will be very, very large so Delta E required very, very large which conforms to our understanding that if an aircraft is highly stable.

So it is very extremely difficult to take it from 1 trim to another trim for simple reason, because highly statically stable, it will opposite so that is why this DCM by DCL is properly design in such a manner that all these deflections are physically possible either through pilot direct to pilot with all the older aircraft smaller aircraft, all through activators and boosters right?

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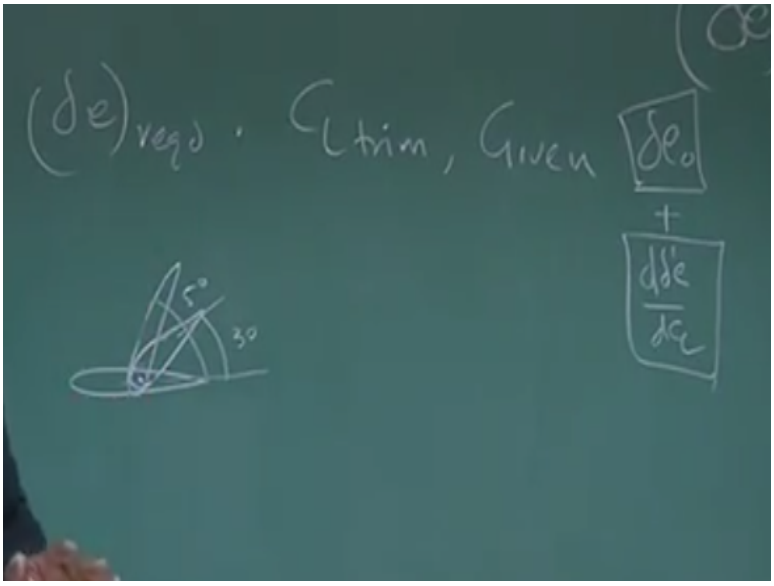

This is the understanding but what they in a nut shell what you understand is from this discussion and previous lecture. That there is a unique value of Delta E required for a given CL Trim given you are Delta E0 value and D Delta E by DCL values right? And you by know you know that Delta E0 is also related to CM0 which is the characteristic of the airplane, how you've let the tail how let the wing and D Delta E by DCL is nothing but they are related to static margin DCM by DCL.

And the control power so what is the understanding if I want to trim at a particular CL which is CL trim I have a unique value given this things which will not change one the airplane is flying. We assume that the derivatives are not changing with speed I am talking about low speed and also CG variation are negligible so, all the things remain constant so I need to know that the Delta E required which is unique value for a given CL trim okay?

So what is the meaning of that? Suppose this is your elevator I start measuring from here for a particular CL trim I need to go to let's say 3 degrees for another CL trim I need to go to 5 degrees like that these are fixed depending upon value of D Delta E by DCL Delta E0 and CL trim correct? So, whatever we are talked in terms of stick fixed stability so far it assumes that here I start from here and I put it here lock it nothing to move it will not be allowed to float it will not be allowed to float.

This is new word I am now adding because I want to come to a new topic now what is this meaning of float let us see, but remember there for a particular CL trim you need a unique value Delta E required right? How do you go it how I achieve that is the matter I am going to discuss now in one case whereas stick fixed case I am saying it was Delta is like this I need 5 degree take into 5 hold it, I am not allowing any floating of the elevator, what is the floating of the elevator.

That is exactly where we will be discussing now let us have a closer look on the tail.

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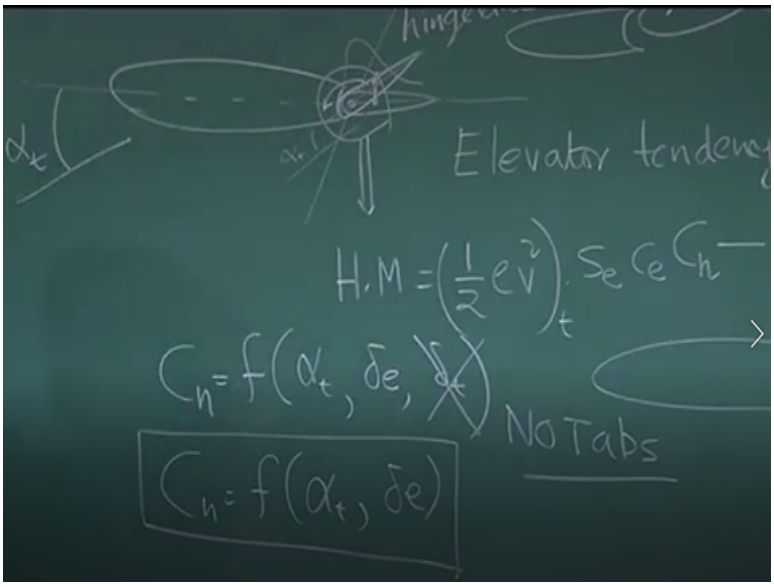

With a horizontal tail since I am talking about longitudinal stability and mostly talking about horizontal tail and let's say this tail is seeing some angle Alpha T Alpha tail and as you know this elevators are hinged through a hinge line and they are free to rotate about the hinge line okay? You have become enough aerodynamics to understand that the moment, there is a Alpha T angle of attack it also sees Alpha T so there will be some pressure distribution across this elevator also and that.

Also will have some sort of Centro pressure and if the Centro pressure behind the hinge line what will happen? the force will act like this and this will give a moment like this elevator will try to float, you say elevator is floating that is for a particular Alpha T the elevator by itself will float as long as the overall center of pressure of the elevator is behind the hinge line which is mostly the cases right? So if I want to model that how do I model and why do I model.

Because I told you Delta E required is a fixed unique number in first case stick fixed case, what we did we said okay, If it go 5 degree I don't care of the float or not I will not allow you to float I simply take elevator from 0 to 5 then hold it I will not allow it to float because if I allow it to float now it will get some other angle that is why stick fixed okay? So, this is very important that elevator will have a tendency to float what is this float means?

Now understand this I am focusing here I call there some hinge moment HM which is hinge moment I model this is hinge moment as as I am modeling pitching moment I write it s half row V square at tail into S elevator C elevator into CH which is the hinge moment coefficient is this clear? I am defining hinge moment as half row V square at tail S elevator C elevator and CH is the hinge moment coefficient like we have pitching moment coefficient that CM right? What is C?

C we have defined it like this if this is the elevator and this is the hinge line then from hinge line to the trilling age this is defined as CE elevator chord, this is the elevator chord please note that by convention we're define it from the hinge line to trilling age of the elevator and AC obvious the area of the elevator correct?

If this is true? Then what is happening let us see we need to know how CH will vary CH will be function of Alpha tail obviously CH will be also function of elevator deflection, that will generate different pressure distribution of the elevator and CH also will be function of Delta T if there are some tabs I will discuss about tabs if time permit if this is the elevator and there are some tabs here also, which can float can we say down or up and this is the this is for trimming final trimming,

And also that will see that that will do the hinge moment effort for the pilot we will discuss about tabs but at present to understand the physics we'll say there are no tabs note down this we'll come back to tabs once you understand this simplest formulation adding tab effect, will be just reveal okay? So this CH is function of tail angle of attack and elevator this you must understand and will do a simplification which may not be true always will assume that CH can be expanded as a linear combination of Alpha T and Delta E.

Where we are actually assuming that whole effect is linear in practice, you will find it may not be linear but for our understanding we are taking doing this simplification and in fact what are the efforts are put the internal testing to get actual value of hinge moment coefficient okay? Now, why all these before I go deep into it,

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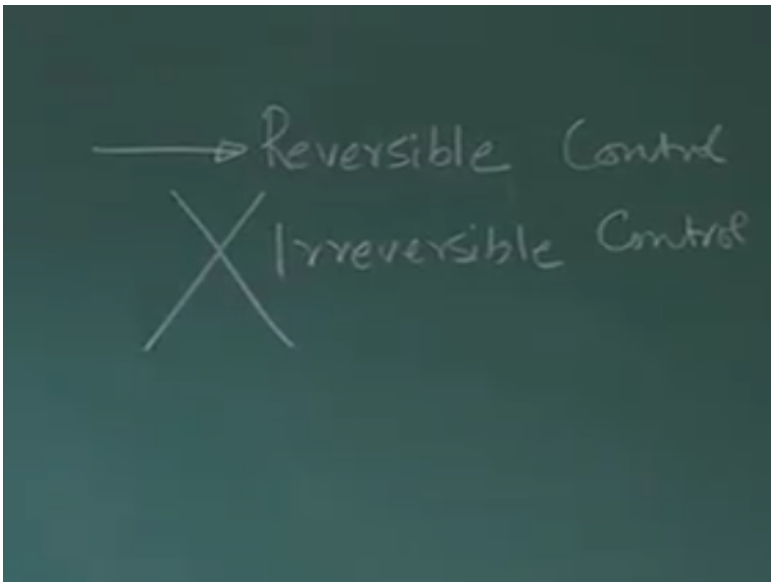

Let us understand there are two types of control will find one is reversible another is irreversible what is the meaning of reversible control I write control here for that you remember this is also control what is the reversible control? Suppose, this is the elevator right? There is a stick in the cockpit if I move the stick then the elevator will move up and down depending upon how it is designed similarly if I move elevator up and down the stick also will move forward or backward right? Generally, the one conversion is followed if I am pushing the stick right?

So, I am try to accelerate the speed so I need lesser CL to trim for the same weight okay? So if I am pushing the stick and I am increasing the speed so I need lesser CL so angle of attack has to be reduced so you will see the elevator will go down and reverse it will go up but for a reversible if I move the elevator the stick also will move so they are linked directly like that however, for an irreversible control there are boosters right? So, if I move the stick elevator will move but if we move the elevator stick will not move right?

So next part of my lecture whatever we'll be doing will be talking discussing mostly focused on reversible control not irreversible control and that is how we will be developing a model what is the nature of stick force the pilot has to apply, for flying the machine one thing is very clear for a particular CL trim he has to have a definite unique Delta E value Delta E required value that's no debate on that but when he is flying if he is flying with the stick for a reversible control airplane like all small aircraft even nowadays that also is becoming irreversible.

We're trying to model how much stick force he has to apply for a deflection of elevator or if you want to change the speed how much stick force he has to apply that is important to understand, one thing handling qualities of the airplane so you cannot design an airplane where pilot has to put put all of his weight to pull the elevator or push the elevator okay? Right?

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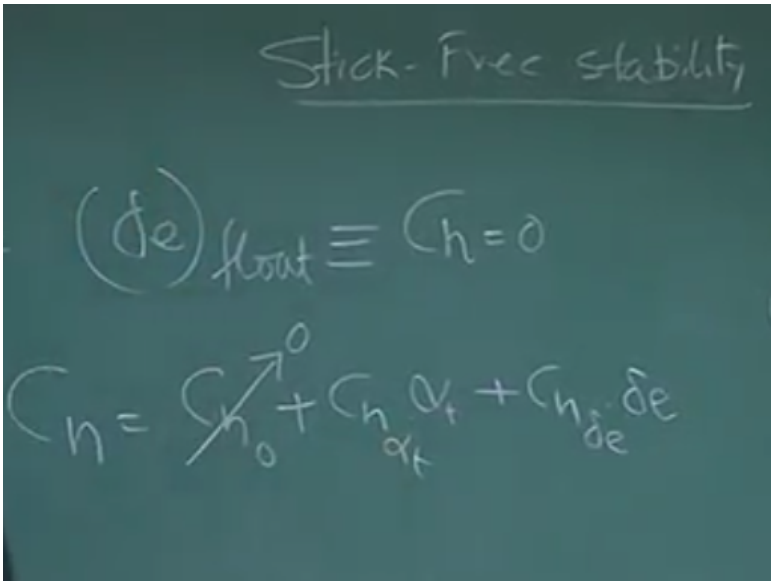

So, from that angle there is a concept mostly books are not mentioning that but we will be talking about that in some perspective this called stick free stability. I repeat so far previous to this lecture everything was focused with the concept of stick fixed we are not allowing the elevator to float, whatever 5 degree 5 degree then lock it so it cannot float but you know if I leave the elevator free then it will have natural tendency to float how much it should float how much it will float can I model it or not that is what we are now attempting okay?

By simple common sense you understand that this elevator for a given Alpha T will float till that time. When the hinge moment coefficient becomes 0 naturally till there there is a hinge moment coefficient is there, it will go on floating so what is that Delta E float is the Delta E float corresponds to when the CH becomes 0 and what is CH how do I model CH as I told you will assume that it is behavior is linear then I write CH as CH0 + CH Alpha T into Alpha T + CH Delta E into Delta E.

Let us not forget one thing what is CH Alpha T these are the partial derivatives, that is Delta CH what is CH Alpha T. Please understand this concept once for all nothing but Delta CH by D Alpha T that means it is the change in hinge moment coefficient for change in Alpha T keeping other constant so these are partial derivative similarly CH Delta E Delta CH by Delta Delta E keeping Alpha T constant so, it is typically a partial derivative we will concept and typically we are using that advantage of assumption that it is linear okay?

Will further assume that CH0 is 0 let say the aerofoil is symmetric and the construction is very symmetrically made but in practice you will find even if you push symmetric aerofoil the construction will have some sort of asymmetric so CH0 in fact will not be 0 a small number but for our purpose CH0 we are assuming 0 because if there is CH0 value we have to only add the mathematics, which is as simple as that so nothing new physics you will get out of it.

So to have the physics clear? Where at is CH = CH Alpha T into Alpha T + CH Delta E into Delta E. One of my request to all of you I will be writing this equation every time, I will try to go physical meaning of though since you should have a pen pencil and a notebook with you and you should do it yourself okay?

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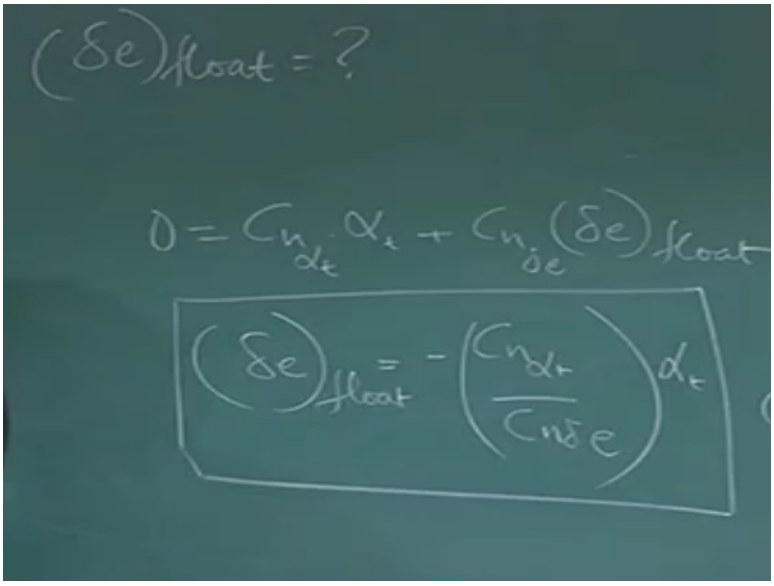

So now see Delta E float is what? How do I find out we have understood by applying our common sense that Delta E elevator will flow till that time when CH is 0 so now I put CH = 0 Here so 0 = CH Alpha T into Alpha T + CH Delta E into Delta E I write here float so, what is Delta E float Delta E float is nothing but - CH Alpha T by CH Delta E into Alpha T very important relation how your mind getting excited now?

See whether Delta E float will be up or down who decided that let's say Alpha T is positive for a positive Alpha T whether Delta E that is the elevator will go up float up or float down, who will be deciding that that will be decided by the this sign of CH Alpha T CH Delta E and with - here if this number comes - that means the float up if the total number comes + it will go down for a positive Alpha T let us see what is CH Alpha T and CH Delta E as per their signs.

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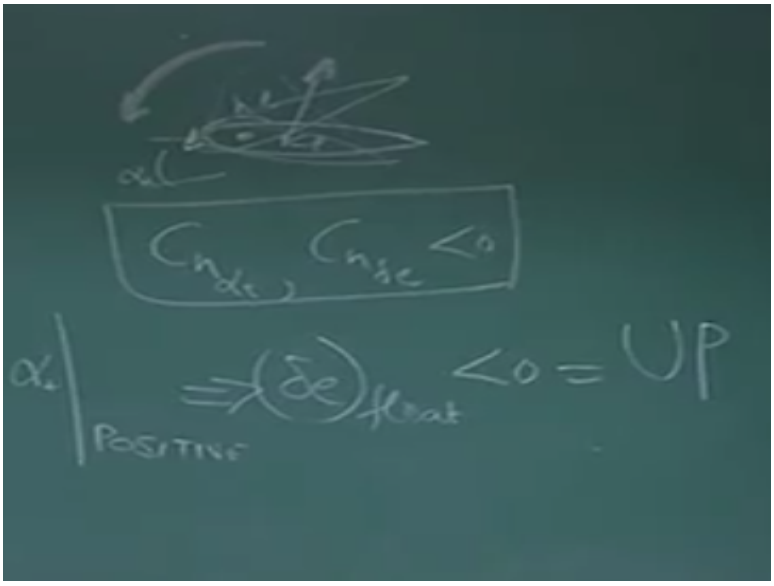

Are concerned and initially I told you this is the elevator and this is the hinge line and because of fresher distribution generally Centro fresher line behind the hinge line or hinge line is adjusted Most of the airplanes it is ahead of the center of pressure over the elevator so naturally you could see for any Alpha T it will give a moment in this direction so, CH Alpha T will give a nose down moment so, it is negative right?

Similar thing happened you could see because of Delta E also if there is Delta deflection again force will be like this which will again give nose down moment so you see as long as hinge line is ahead of the center of pressure of the elevator right? So, CH Alpha T and CH Delta E and less than 0 this is very important okay? Now if they are less than 0.

Then this is negative, this is negative this is negative from here so for a positive Alpha T if it is positive what do you get? It implies Delta E float will be negative that means it will float up is this clear? And most of the airplane this is what the tendency So, what is the message you got? Most of the airplane whether hinge line is for ahead centre pressure of the elevator or let's say center of the elevator which have almost same for the symmetric aerofoil, for the positive Alpha T the elevator will try to float upward okay?

This is first mathematically, second is what? Second is suppose you want to take the elevator 5 degree one is stick fixed case take 5 degree hold it but if you are talking about hands off that is I

leave the stick and it will really go to 5 degree then you have to very careful you know that at 5 degree if I leave it then because of Alpha T at 5 degree elevator will float further up So, it will not be 5 degree it will be more than 5 degree okay?

This is one is this is the second thing, if the pilot has to put a stick and to the stick force the elevator will turn like this so one should be smart enough to know that pilot should put that much of effort to take it to that much of difference in angle because already by elevator by itself will float by some degrees so pilot should put effort only for the remaining angle let's say 5 degree is the aiming angle for elevator by float it is going to 3 degrees so pilot effort will be only for 2 degrees okay?

Because anyway it will float but only problem causing modeling is the floating angle. Changes a different different Alpha T so it becomes little complicated okay? But in actually understand that floating up you must know, how much it will float and you should try to use this concept to define mathematical model which will relate stick force and CL trim for a reversible control right?

That is the catch word reversible control because for irreversible control there are boosters in between so, the pilot force and actual deflection relationship is over reading by the activators and the boosters, so we cannot give tied feel of course artificially they are simulated but that is not our purpose these are Delta E float Thank you.