Aircraft Design
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Lecture - 20
Tail Arrangements contd

Good morning friends, we are continuing our discussion on general appreciation of various characteristics of an airplane component; external component, mostly components which are contributing through aerodynamics. Yesterday, we have discussed touched up on tail shapes, which are historically being used. There are many types of tail you will see that, but we have discussed only conventional in a detail. You will find there is a V-Tail; inverted V-Tail. H-Tail so many things we used. We are not discussing all of these together because this discussion is to give the basic understanding and other things are just derivative of that and as and when required, we will talk about specific configurations.

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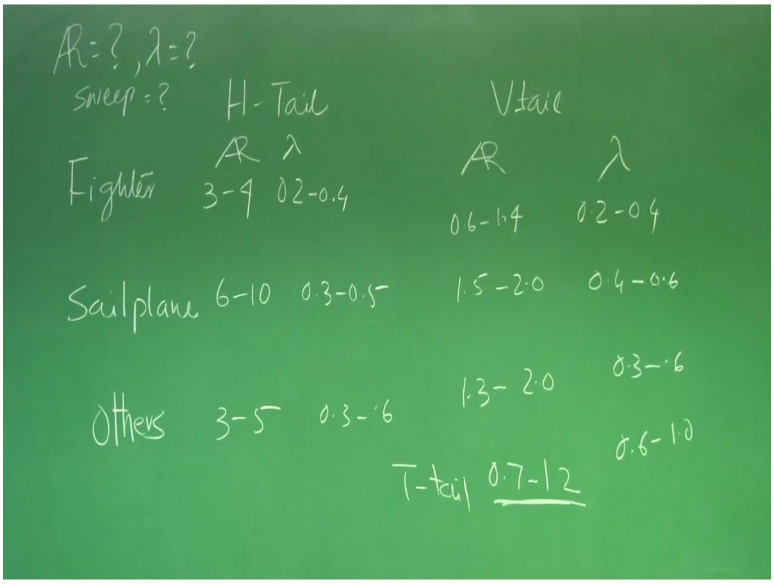

To complete the horizontal tail and vertical tail via some historical number; please have a note on this. If I write fighter sailplane and let us say others and if I here write horizontal tail what I am trying to give some numbers, where you will know what is that aspect ratio of tail or lambda of tail or sweep of tail historically being used. So, that gives a good feel for designer, please understand a chief designer need not understand every aspect of aircraft in detail, but he cannot have an excuse to know the first order effects otherwise he will not be able to converge into a configuration. It is expected that achieve designer has aerodynamics team, flight mechanics team, control team, structure team. So, they gave you the detailed analysis and a chief designer pick them up or aggregate them; he needs to have overall idea about what is happening and what is going to happen, how the design evolution have started and where it is going to; that is sort of a holistic knowledge, a chief designer needs to have.

That is why I give some numbers say again from Raymer; typically if I write aspect ratio and taper ratio, typically for 5, 10 it is for horizontal tail it is 3 to 4 and this is 0.2 to 0.4. These are some guideline numbers based on different types of aircraft in the market, it is not necessary that those numbers are very optimal numbers. For a sailplane it is; 6 to 10 and 0.3 to 0.5 and others will find varying with 3 to 5 and 0.3 to 0.6 and if you see the vertical tail; number shows aspect ratio and taper ratio, this is 0.6 to 1.4, 0.2 to 0.4, 1.5 to 2.0, 0.4 to 0.6 and it will be 1.3 to 2.0 and 0.3 to 0.6.

These are typical numbers and what you should notice that aspect ratio of vertical tail is much less compared to the aspect ratio of the horizontal tail. When it comes to vertical tail, if I am talking about T-tail; just putting some number here again; you see this 0.7 to 1.2 and 0.6 to 1.0; you could see that for T-tail; since there is end plate effect as I told you; this is a vertical tail and there is a horizontal tail here. So, there is end plate effect effectively it increases the aspect ratio of the vertical tail.

Hence you can afford to have lower geometric aspect ratio and that helps because the moment you make a vertical, it has to be thicker; it has to take the load of horizontal tail. So, if it is low aspect ratio means the weight will go down, so all these optimization goes on; it maybe vary delta plus but you know when you add delta 1, delta 2, delta 3; total delta may be really good worth. So, this numbers you need to have background to start conceptualizing a configuration.

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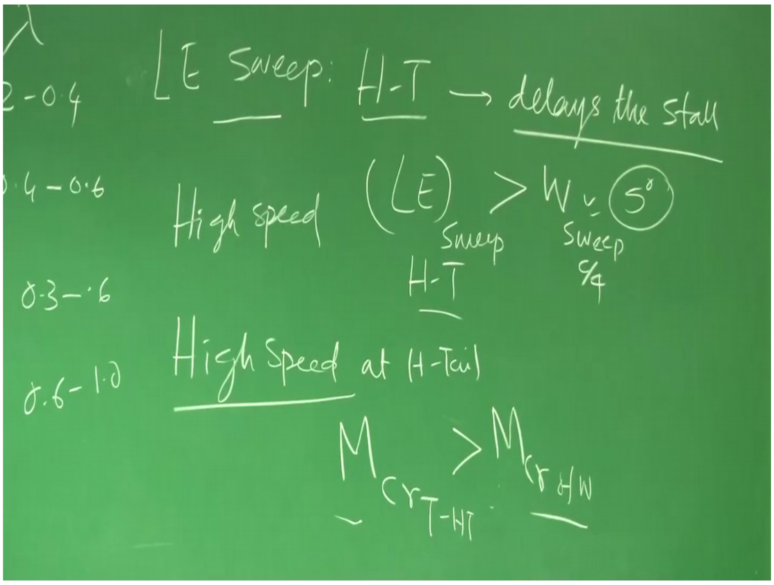

There is some salient point when you see the leading a sweep requirement; one of the point for leading a sweep is yes it delays the stall. For low speed, if you gives 10, 15 degrees your understanding is I have to delay the stall.

Generally we will find leading a sweep is greater than wing sweep that is sweep as c by 4; by roughly 5 degrees; that is horizontal tail sweep is 5 degree more rough number, more than the leading a sweep of the wing which is measured as c by 4. Reason is very simple that by giving leading a sweep to the horizontal tail, you are trying to delay the stall. So, your tail should stall later than the wing; these are all small small additions, but for high speed if you come, you have added requirement for high speed aircraft, you added requirement of sweep at horizontal tail. You want to ensure M critical at tail; horizontal tail is greater than M critical of the wing.

This is important because if the first point which happened to be on the tail becomes mach 1; stocks start forming the effective nasal go down, gradually increase; control power will be affected. So, these are the basic understanding to draw a initial conceptual sketch; how much it is, all these things should come from thorough analysis through CMD or primarily validated through internal testing.

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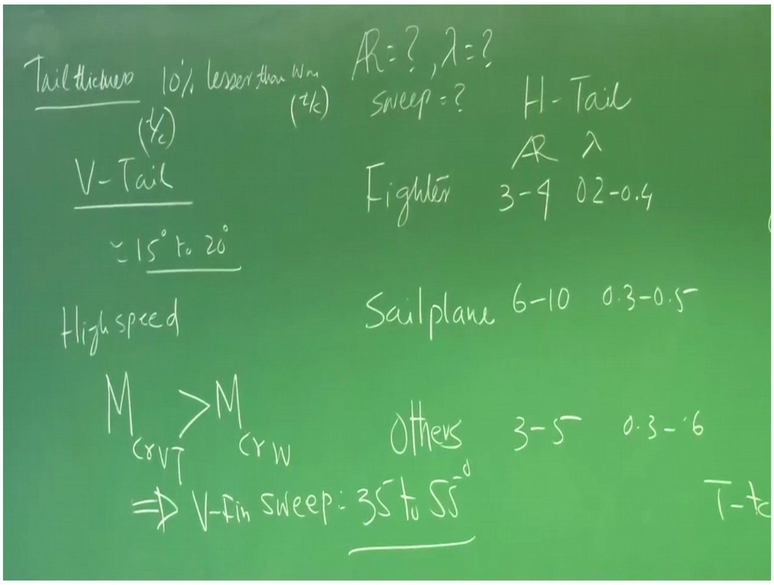

If we try to visualize similar thing for a vertical tail, there is no requirement of again any sweeped vertical tail when its low speed. We will find mostly around 15 to 20 degrees sweep will be there for a vertical tail, which is primarily for aesthetic reasons. But for high speed; again this criteria M critical, vertical tail should be greater than M critical wing. So, that demands that has resulted in vertical fin sweep order of around maybe 35 to 55 degrees in general. So, when you see a configuration these are the guidelines; you ask yourself am I designing a low speed, high speed, what sort of stall characteristic of the wing? So, you can pick those numbers and draw the initial sketch.

Another part we will see that as far as thickness ratio is concerned typically tail thickness will be roughly 10 percent lesser than wing t by c; I am talking about t by c, so tail in t by c will be 10 percent thinner as compared to t by c of wing; general feeling, but not the maximum thickness because maximum thickness depends upon what is the call. I am talking about t by c and mostly this horizontal tail; there will symmetric airfoil.

Again you can debate it out that t by c for a tail horizontal is thinner, this is guided by the understanding that we want M critical of the horizontal tail to be more than M critical of the wing. Because we know if I make the aerofoil thicker and thicker; M critical will reduce, so all those things are converged here and I thought; I will share these numbers with you. Yesterday, we were discussed something on very interesting thing and the difference between a good designer and average designer lies on the fact that a good designer knows how to configure his airplane to handle eventualities, the critical point, worst point in the flight stall is one of those, high side slip is one of those conditions.

For normal conditions; two airplane may look similar, but the moment you try to check them what is his performance during high side slip or high angle of attack, immediately you will find my god these two are different, so what the designers will do; without much affecting the weight or much change in the configuration, that is important and that is where designer role play and the important role; very very important role.

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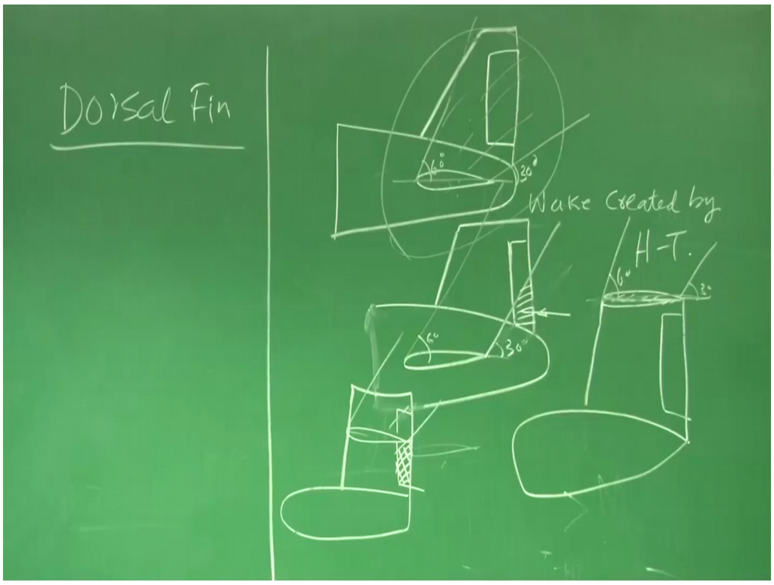

So, in that direction we will discuss something about dorsal fin; how this dorsal fin concept came? We were talking about are you sure we have designed our vertical tail and horizontal tail comfortably enough to avoid degradation or radar power or vertical tail effectiveness during spin. Spin means huge vertical component and rotation, so wing has stalled; we have only vertical tail and rudder to take care of the spin part, we have to come out of the spin, we need it only a movement we need u i movement.

So, we have to ensure that the vertical tail and rudder are effective even at high stall conditions. We started like that and then we said a simple guideline again based on Raymer it was; most of artistic guideline so that is if I draw my vertical tail like this and this is the rudder and if I put horizontal tail here and I draw 60 degree and I will draw here 30 degrees.

So, this is the situation when the airplane is at high angle of rudder, it has come near the stall ordinary stall. So, if you draw like this you see the whole rudder and vertical fin; they are coming in the wake created by horizontal tail. This should be avoided then your rudder is not effectively available to apply rolling or u i movement. So, what is suggested is you find out a configuration, trying to see the location of let us say this is vertical tail and you put the horizontal tail little ahead and draw 60 degree as required here and draw 30 as here and perhaps; this is 30 degree is this plot to scale of course.

What is the message is; you locate the horizontal tail and vertical tail in such a manner. So, when I draw 60 and 30 here I have larger area which is out of the wake created by horizontal tail. So, if this is a diagram which is not to scale, so you know this much portion is available from the rudder to be effective. Generally, 70 percent is available you are happy about it; then with this understanding, if I now see a T-Tail; T-Tail means the one is here, another T-Tail could be mid T-Tail; if this is the vertical tail and I have put T-Tail here; this it is location of T-Tail is different this is at the top conventional T-Tail, I can puts the T-Tail here as well.

Now, you could see here; here if I draw 60 degree here and 30 degree here my rudder and vertical tail, they are out of the wake because of horizontal tail. So, it is very very effective as far as influence because of horizontal tail is concerned, but do not forget when I am talking about T-Tail, it should not come into the wake created by wing; we are here talking about horizontal tail. It should not happen already the airplane stall because of wing this gentleman has come into the wake of the wing. So, all these things we have to test analytically, computationally a final through internal test; you generate data.

So, nearly here is mid wing you could see if rudder is something like this, then here and here if I draw this much portion is available; which is not part of the wake because of horizontal tail. Please understand this when I am talking about; I am avoiding rudder to come inside the wake created by horizontal tail; this is fine good. When you talking about horizontal radium location, but when I am trying to justifying for T-Tail; yes it is indeed if it is a T-Tail, the rudder will not effected by T-Tail wing, but you should forget there is a wake coming because of wing; this gentlemen may be very very ineffective there may pitch of tendencies, but rudder will effective that is more important and when I am talking about stall or spin, where the (Refer Time: 17:25) is not at all effective, I want rolling movement, I want u i movement, I am more concerned about rudder power; rudder effectively, vertical tail effectively.

That is why; this is generally a conceptual level if do like this; you are actually hinting towards that, you are preparing yourself so that design is as a initial beginning for a good spinning recovery characteristics; that is important. So, at conceptual stage you should know where do I locate my horizontal tail? How far vertical tail and what x location vertical tail that is why I am sharing these, I am repeating this today; I started with dorsal fin, so we will come to dorsal fin here.

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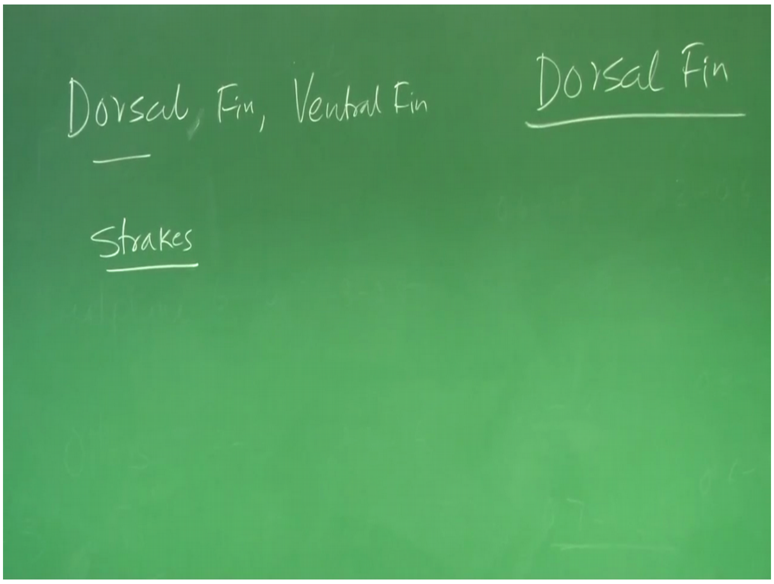

Remember, dorsal fin and ventral fin two types of strakes we discussed yesterday; this was dorsal, I am repeating those things with little more detail. Dorsal fin; (Refer Time: 18:36) I will talk about ventral fin also because you see an aircraft; you will find these things are there. When yesterday I have discussing about dorsal fin; I gave a statement this dorsal or a ventral, they are basically strakes and strakes are regularly used. They are used in fuselage to create vortex which helps in attaching the flow, gives more energy to the flow via vortex.

So, whether dorsal fin or a ventral fin they are all actually strakes; their property scattered by strakes property; that means, they are basically vortex generator that is important.

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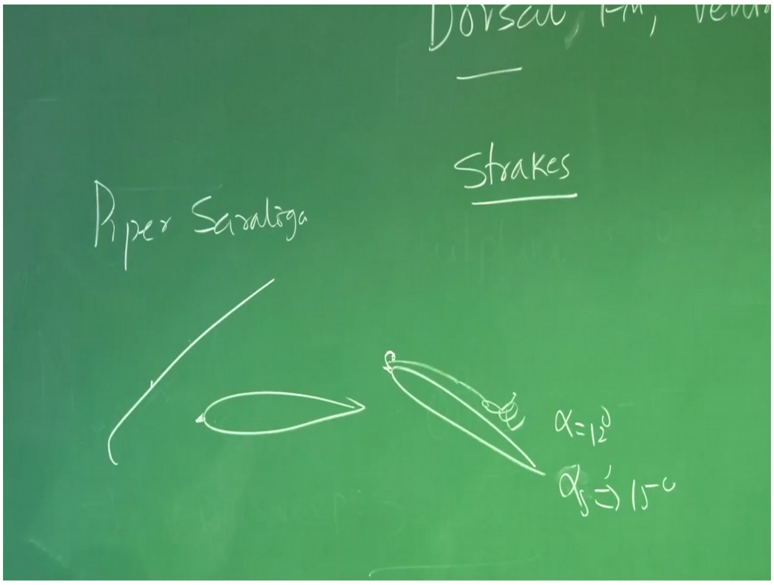

For example, if you see our piper Saratoga airplane; the leading edge some part we will find; if I draw the leading edge for some part not all through, some part there is a verge installed at the leading edge; which is like leading edge strakes. What is the advantage of it? If this airplane, suppose to stall at 12 degrees; this is a alpha 12 degree.

If I put a strake here; this stalling will alpha stall may become 15 degrees because the vortex which is generate the vortex, which carries energy and gives energy to the fluid; so delays later, so that is leading edge strakes. Now, when I am talking about this sort of a lateral characteristics; maybe stall, spin; the best way to see that our rudder and vertical tail is effective is to supply this area with some vortex so that its effectiveness increases; if we stalling at side slip angle of 12 degree; let us stall at 15 degrees.

So, I should generate some vortex which should impinge on the vertical fin and energies it and delay the stall; that is the philosophy.

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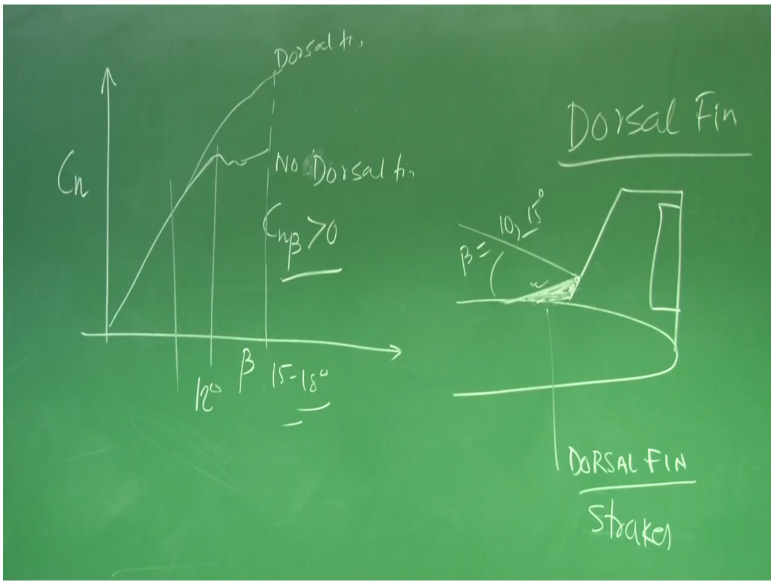

And in that philosophy, we find if this is vertical fin and rudder this is the strake; if this is strakes which is typically known as dorsal fin. You will see its further effect I will discuss and if I try to give some historical description of dorsal fin being used; types of dorsal fin being used, as I was telling this dorsal fin they are basically strakes which creates vertices or vortex which impinges on the vertical fin specially when beta is high at 10 or 15 degrees, 12 degrees.

When a airplane is being huge side slip; that is the time where at that side slip angle, the vertical tail may become very very ineffective because it is nearing the stall. So, that time this gentleman dorsal fin will generate vortex, will get impinged on the vertical fin and delay the stall. So, the vertical fin effectiveness will increase and hence rudder effectiveness also will increase. So, what leading a strake was doing for purpose Saratoga dorsal fin is doing the same thing, but for the lateral direction, lateral stability, the restore stability.

So, when I talk about directional or lateral stability; more importantly lateral stability I talk about beta that is Cn beta should be greater than 0, if an airplane is directionally stable and if I show you typical plot this is mu dorsal fin. If you put a dorsal pin generally; it will be that is with dorsal fin. So, if you see this angle could be around 12 degree; so, this gentleman goes up to 15, 18 degrees depending upon how you have designed the dorsal fin, depending upon how effective is your dorsal fin in terms of what is this length? What is this angle? What is rough shape? To decide what sort of help it is making in delaying the stall on the vertical plane, when the airplane is going in a high side slip.

Yes, it will indeed increase drag but please understand these are the situation during high slightly which is emergency situation, you need to ensure that your vertical tail and rudder is effective. So, this dorsal fin plays an important role and they do not make much difference when the beta is small, whether the dorsal is there or not there, if beta is small; it does not make much of difference; their important is when the airplane is flying at high side slip angle.

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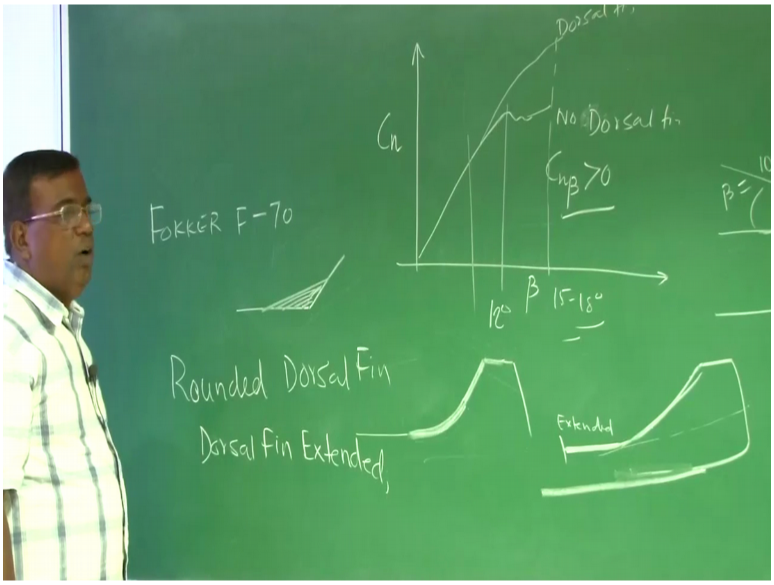

If you see this set of a concept being use in Fokker F-70; you will find if you see Google search, you will find rigorous use or in most of the plane they are doing using dorsal fin like this. There are some set of called rounded dorsal fin, so basically if this is dorsal fin itself is part of it; here it has been rounded like this and extended and there are also dorsal fin extended; all these concept please understand, this is what the designer has liberty. The concept is you have to somehow generate what is vortex here, which gets attached to the vertical surface and delays the stall, but designer will see I do that, but you should not unnecessarily increase the time.

So, there this tricking goes on and extended means what we will see in that; yes, there is some sort of a; here there instead of rounded it here; it is tended with little bit of thickness. So, this is extended, rounded here and normal like this. So, little thickness we continue for a longer length rounded and then merges with the sweep of the vertical tail. So, all this concepts are used as dorsal fin primary reason is to ensure that high; at high side slip angle; it should be able to generate vortex, it should help in delaying the vertical tail stall.

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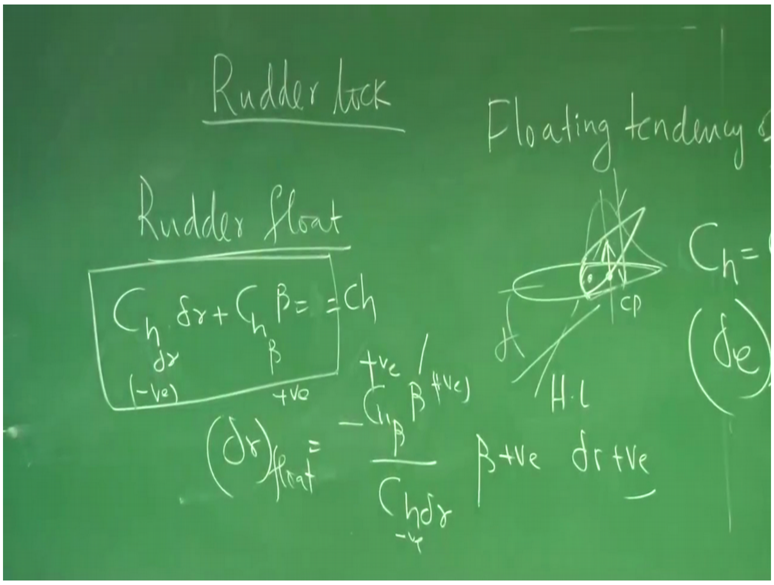

I am just continuing the advantage of dorsal fin or how dorsal fin have been used. You know this is something called Rudder lock phenomenal; some point of time, it was really a serious challenge, when airplane is to be flown with less actuators or other mechanisms. You have when exposed to the concept of floating tendency of elevator; for a conventional reversible airplane.

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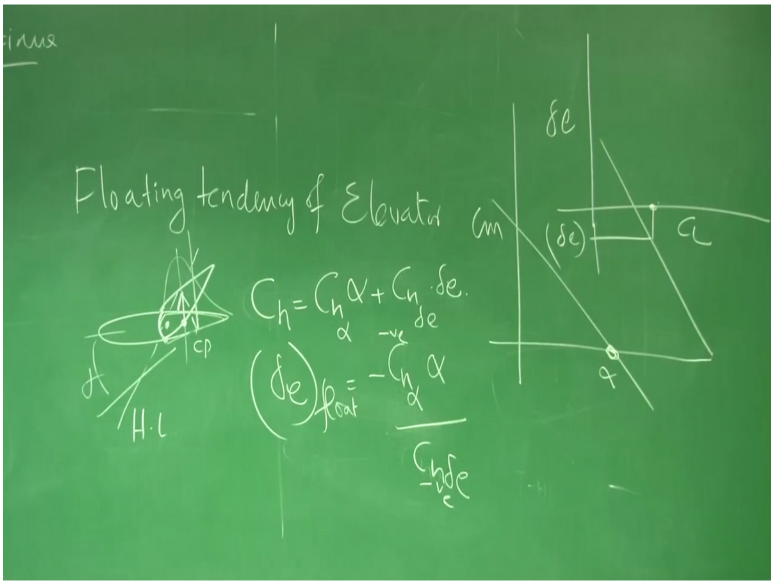

So, this concept I am talking about mostly on reversible type of airplane; that is you pull that stick elevator goes up or down, you put elevator up and down the stick will goes forward or backward, so this is reversible. Nowadays, it is not reversible that actuator etcetera, so scenarios are different but the fundamental issues first understand; what was floating tendency of an elevator, if this is the horizontal tail and this is the elevator edge line, if there is a angle of attack alpha.

So, you can say that there is a pressure distribution over it and aerodynamic center or center pressure over the elevator is here. So, it will try to float this gentlemen elevator up, but as it goes up; resisted by the force is experienced here and there is a equilibrium; we explained that Ch; non dimensional hinge movement co-efficient can be expressed as Ch alpha into alpha plus Ch delta e into delta e; of course, we assume Ch naught is 0.

So, delta e float can be easily moduled as minus Ch alpha into alpha by Ch delta e and you know that this man is negative, this man is negative. So, for a positive alpha; elevator will be negative, floating elevator will be negative; it will automatically float because over the elevator, the pressure distribution of a such, if the center of pressure observed pressure distribution is behind hinge line; it will try to float it up with alpha.

So, message was if you really want to trim an airplane for a particular alpha; Cm versus alpha, graph we will tell you how much alpha is required to trim the airplane, such that lift is equal to weight. How do get that alpha? You want to pitch up, so use elevator and pitch it up, but because it is floating tendency reversible airplane; the aircraft automatically will float by this much.

Now, imagine suppose your delta if required to maintain the airplane at a particular trim. If you see this diagram; delta e versus C L diagram from the like this suppose you are flying at you want to fly at this C L, it tells you I need this much of delta e. So, you have to pull that stick to get that much of delta e; elevator deflection, but imagine the situation; you have designed the elevator such a way that values of Ch alpha, Ch delta e is such that without doing anything at that alpha, automatically it floats to this point or when you direct take it to that alpha; it further gets floated by this angle, both the things are possible.

The dynamic says at any alpha, there will be a floating tendency unless you lock it. So, actual efforts put by the pilot will not be what dictated by the absolute delta, you have to take consideration of how much elevator has floated; that is the understanding. Similarly, if you see for rudder floating again for reversible rudder float; which is happening at longitudinal, it will happen at directional also. So, in that case I say Ch delta r into delta r plus Ch beta into beta will be equal to 0.

For example, this is your rudder; this part I just so this is the hinge line, as there is a beta coming like this there is a pressure distribution over it and it is a central pressure of this pressure distribution when the beta is passed in like this behind the hinge line, then that will give a force towards me which will give me ion movement of the hinge line nose going towards. Is that clear? Again, you see if this is the rudder; there is a beta like this, there will be pressure distribution here and if that point is behind the hinge line which is indeed, it will be ion movement going towards right. So, the Ch beta will be positive and Ch delta requires similar check will be negative; this is the hinge movement because of beta and delta r.

So, delta r float means; what is that value of delta r, delta float where Ch equal to 0. So, this is actually equal to Ch; 0 means it is floating, so I put 0 here. So, that will be minus Ch beta into beta by Ch delta r; I denote Ch beta is positive, Ch delta automatically negative. So, delta r float will be for a positive beta, delta float will be negative say negative and this is Ch beta is positive; negative, positive; negative and this is negative positive, so delta r will become positive.

Yes, so beta positive is delta r positive what is the meaning of that? If you want to fly at a beta, let us say if you want to fly the airplane at beta.

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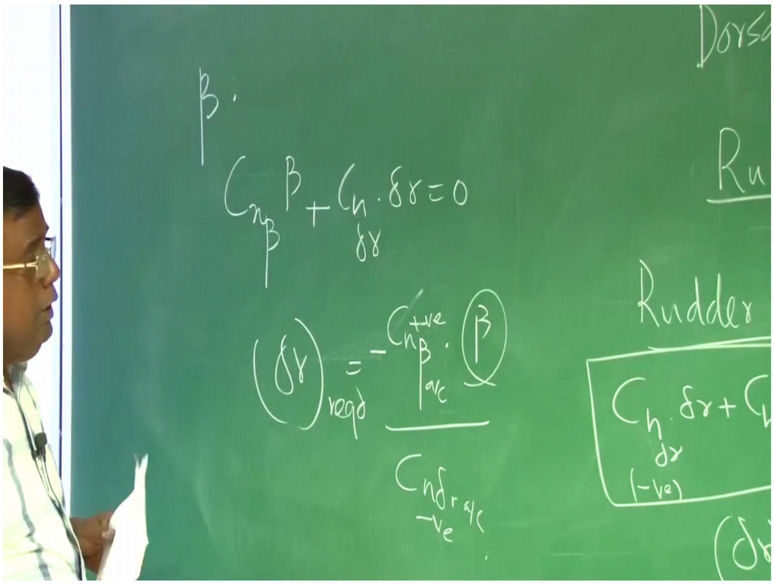

Say I want to fly the airplane beta, then I must ensure that Cn beta into beta; this is the ion movement coming because the airplane is directionally statically stable; that has to be corrected by Cn delta r into delta that should be equal to 0. So, delta r required will be minus Cn delta of the aircraft into beta by Cn delta r of the aircraft. This you know like cross wing landing, but delta r float is giving me this. So, for a positive beta; delta r is positive, but here you see Cn beta is positive, Cn delta d is negative. So, for positive beta any positive again delta d is positive.

So, I want delta positive some value, but by float already it is having some positive values, so what is the problem?

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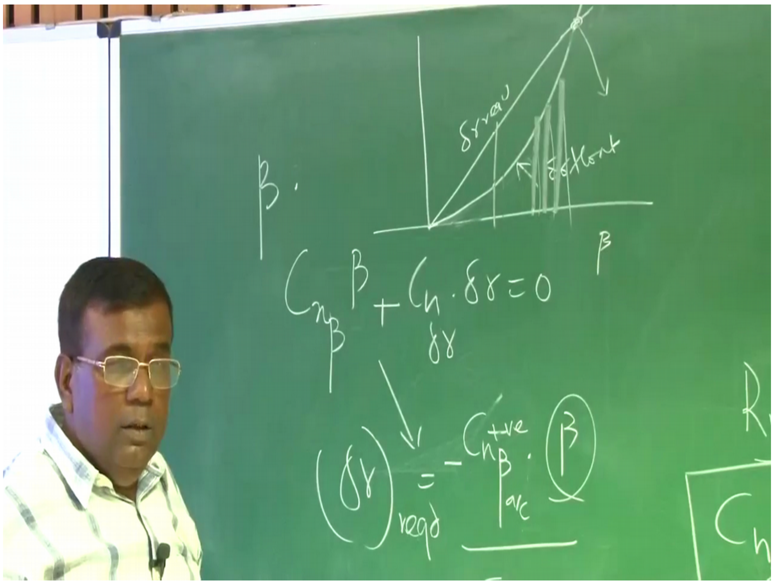

See the issue what will happen; that let us say this is delta required which is coming from this equation for a given beta and delta r float, this is delta r float; what happens at high angular beta delta r float becomes very very sharp, why it become very sharp? You can understand; the point here where delta required and delta r float they converge, so pilot cannot fill anything and beyond that delta float will be always higher than the delta required. So, pilot will not be able to do anything; he has to do something reverse; all this time delta required was more than delta float, so he will be using the peddle.

But after this point the sine changes, so this point you call rudder lock; the pilot who is not able to handle it unless he does the thing reverse where on, which is typical stall characteristic. What happens? As increase beta, this delta r float increases abruptly; what is the physics behind it or some understanding behind it that rudder lock will happen when Cn beta of the vertical tail reduces and Cn delta r of vertical tail increases or increases or strong.

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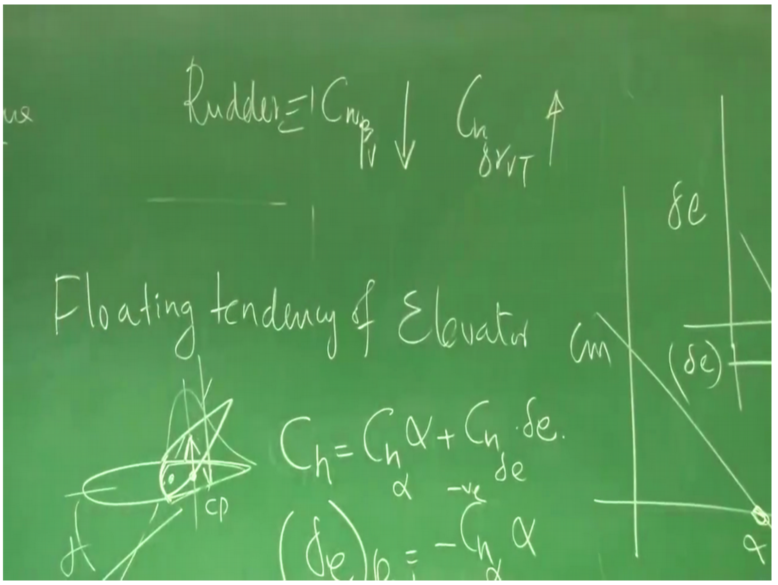

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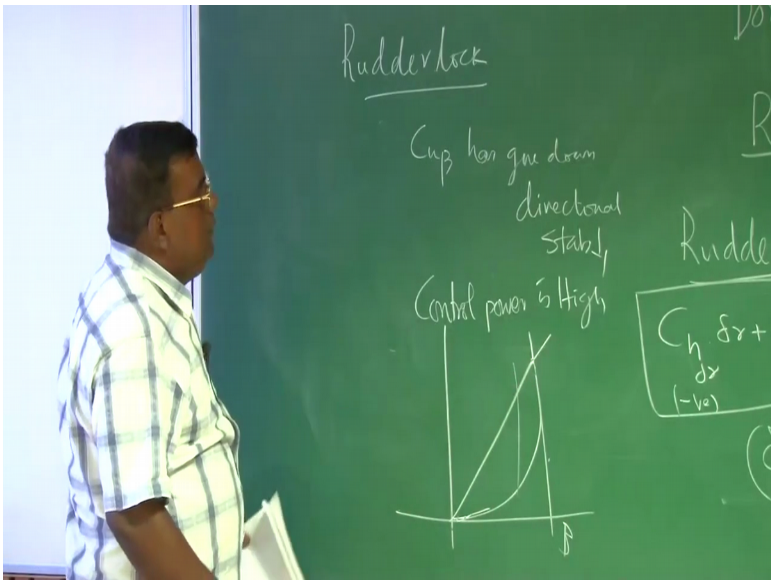

That is whenever loosely you understand that rudder lock will happen, when Cn beta has gone down. Has gone down means its direction over stability has gone down, but rudder control power is high; that is why when you say like that this is 1 and this is this. At high beta, this problem of rudder lock will come; if is a delta float; this is Cn beta by Ch delta; Ch beta; this is not Ch, Ch beta by Ch delta r; what does Cn beta has gone down means what?

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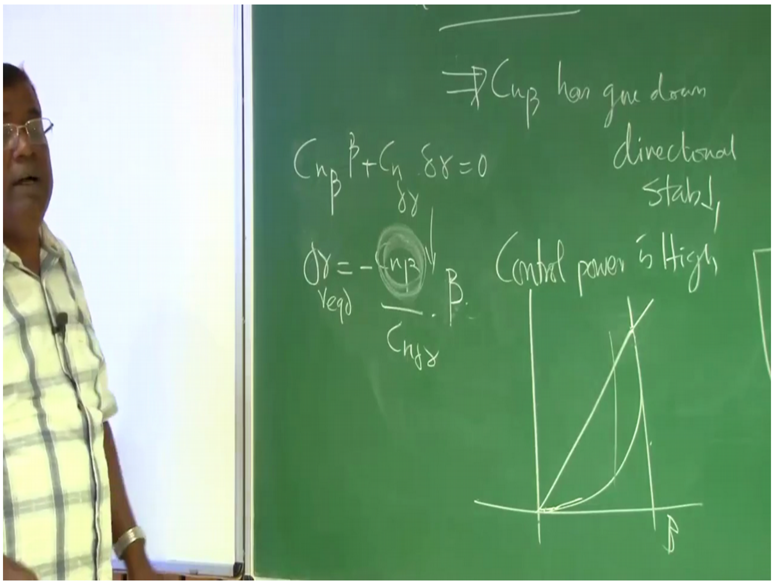

Let us see this statement carefully, if I trying to trim at beta then I know Cn beta into beta plus Cn delta r into delta r has to be known. So, delta r required will be minus Cn beta by Cn delta r into delta r or into beta sorry into beta. So, now if Cn beta has relatively gone down; that means delta's requirement will be less, delta required will be less; relatively physics n beta has gone down, why Cn beta has gone down? Because vertical tail is stalling, the effectiveness going down; so, delta required will also go down, but delta r float, will not change that much.

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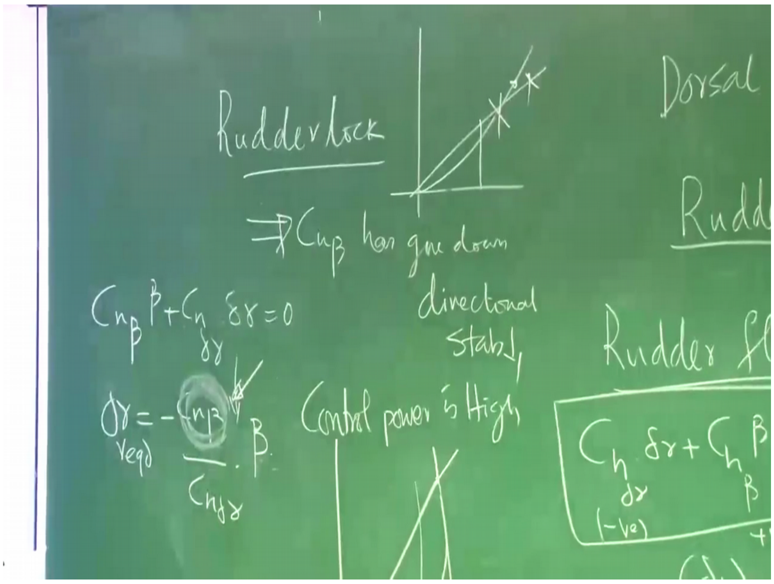

So, delta r float will float fast; so, it will cross this point it will come to this point; that is where rudder lock phenomena likely to happen. So, what is done? If this is the culprit, the Cn beta is going down, why it is going down? Because vertical tail is nearing stall; so what do we do?

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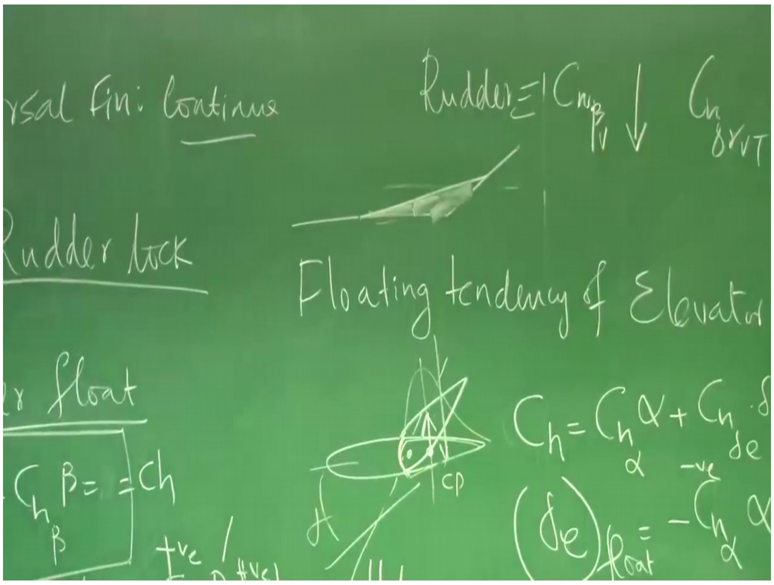

Again you say; dorsal fin, you help us. The dorsal fin, the presence of dorsal fin create vortex, delays the stall of the vertical tail and hence the Cn beta does not drop and you still can operate somewhere here; avoid this point or this point. This is a very fast explanation you must read, this is a very complex phenomena.

Easy to say the beta float increases beyond a degree aerodynamics no more linear, it is non-linear, but this is the general physics and this has a context that; as long as you understand rudder lock will happen, when Cn beta goes down and Cn beta delta r; rudder lock will happen when Cn beta has gone down and directional stability has gone down and the control power is high. So, to avoid rudder lock; you ensure c beta better then go down, so ensure that delay at high side slip angle; delay in the stall angle is there.

You increase the stall angle during high side slip of the vertical tail; ensure if Cn beta does not drop and that can be done through dorsal fin; one of the another advantage of the dorsal fin. If you find some difficulty in rudder lock we will take; again we will come back to this. This is my way of teaching; I introduce a concept and you are supposed to read and come to the forum and I also see the videos. if I find you know in need to talk more on this then I come back again, but since our discussion is on design; I am avoiding to go into all these equations at this stage, but still these are unavoidable because you understand this equations.

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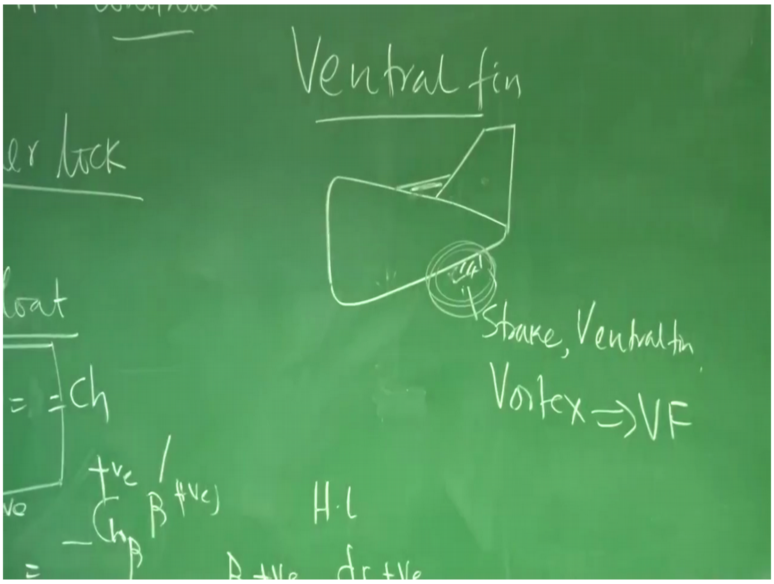

Like dorsal fin there is something called ventral fin; put a dorsal you know ventral is also doing the same thing. We will find this is the fuse large, there is vertical in the dorsal fin, there is some location here. If you also strake, they also generate they call ventral fin; they also generate vortex which impinges on vertical fin to delay the stall or make it more effective.

This is indirectly helping the directional stability of the airplane also at high side slip angle because this gentlemen; this one, this one will generate its vortex at high side slip angle. At the high side slip angle, either decaying the vertical tail effectiveness because it is nearing stall, so generation of vortex from here and here that enhances the vertical tail effectiveness in terms of delaying the stall and also increasing the dynamic characteristics.

So, many places where only dorsal fin is not that effective people may put ventral fin. The advantage is at high angular attack, this ventral fin does not get blanketed because of wing wake because we are talking about side slip angle. So, at high angle of attack dorsal fin and this may get blanketed, but dorsal fin will not get blanketed. So, you add that also this is important and that is where the designer takes a call depending upon type of situation he is flying, type of speed he is doing.

You select dorsal fin or ventral fin both or one of these; mostly you will find dorsal fin will be a mandatory; ventral fin depending upon what is all the speed range, what is all angle of attack manure; all these decides its combinations, but you should know fundamentally what are the role of these, what is expected of this. There is lot of research paper on dorsal fin and ventral fin, you can Google it and see how aerodynamic characteristics changes.

Thank you for today, we will come back with a new area now, a new topic that most probably it will be thrust loading and wing loading.

Thank you very much.