Aircraft Design
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Lecture - 19
Tail Arrangements

Good afternoon friends. So far we have made an attempt to glance through wings, the aerofoil plant form of wing, and their importance. We have also talked about typical shapes of wing tips and what are their merits and demerits from designer's point of view. We talked about canard, when you are talking about the aspect ratio; canard that linkage is primarily we are talking about lifting canard. There are canard which are not supposed to be predominantly for working as a lifting surface, they are like a control surfaces.

Their aspect ratio may not be that high; at this point we have just glanced through those and while coming for stability air control design, we will take each of these items precisely and see who qualifies for a particular configuration.

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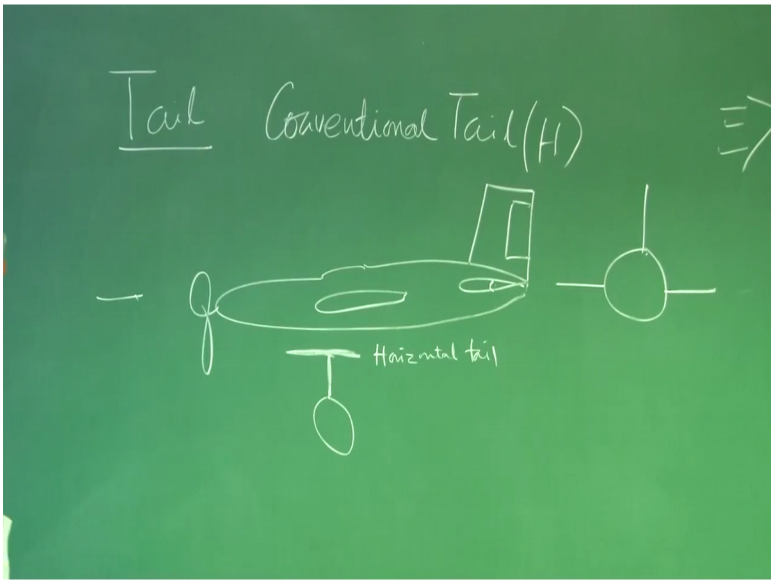

In continuation to that; we will also quickly go through most popular tail configurations. To start with; I will not talk about various types of engineer's tails, but I will primarily talk about conventional tail and a T-tail and try to highlight what are the merits and demerits and why it has evolved like that. Any other configurations, we will be talking or discussing as and when required.

When I like talk about tail, when I say conventional tail here tail I mean horizontal tail; you understand when the aircraft; or a conventional aircraft is a horizontal tail which is horizontal stabilizer and this is a vertical tail, which is vertical stabilizer. If you see for a conventional tail, the airplane will be like this, there is a vertical tail, there is a rudder, there is horizontal tail, there is an elevator and there is a wing and maybe engine here and if I see the long preview, it will be look like this; this is typically a conventional tail.

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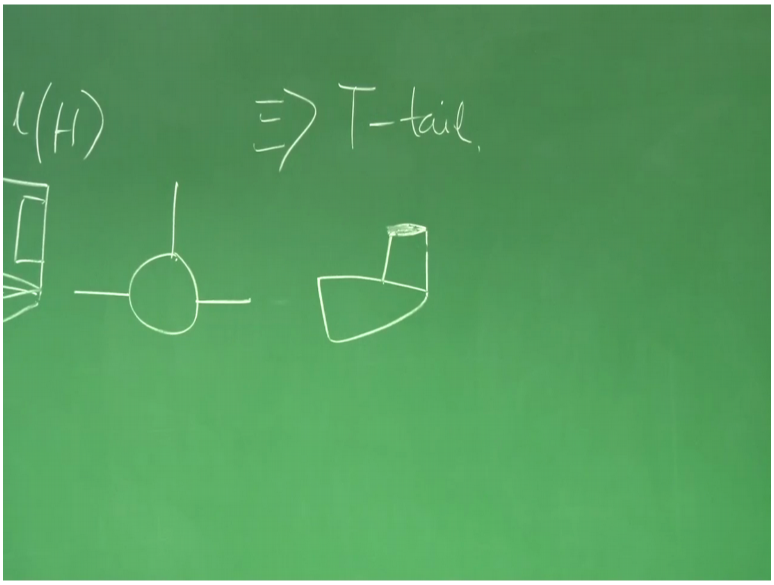

You find among the youth or also you can see in the design evolution; the stylish tail is T-tail that is typically if this is my empennage, I will write the vertical tail; this horizontal tail will be housed here. So, it gives from the front if I see; from here if I see, I will see this is the vertical tail and over that this is the horizontal tail. We are all familiar with this; first of all let us ask our self a question, why do you need horizontal tail? And once you know; why do you need? The next question is how much we need? Who decides?

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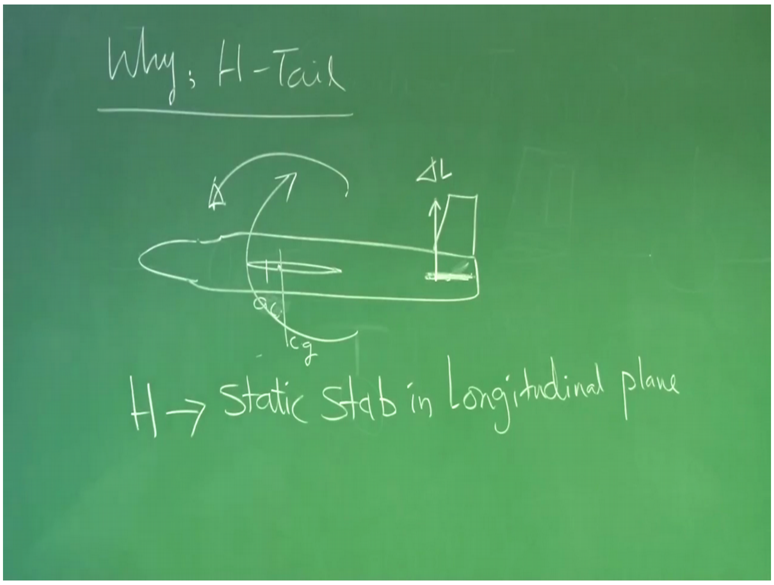

The first question I am addressing first; why do you need a horizontal tail? If you revise your stability and control lecture, we will immediately will be able to answer; if this is my fuselage, if this is the wing; let us say this is some are at C G or let us say this is aerodynamic centre, some are it is CG and this is horizontal tail, this is vertical tail; horizontal tail will be require primarily for static stability in longitudinal plane.

And also we know that horizontal tail is extremely important for a conventional airplane because it has to house elevator. In fact, part of the horizontal tail or whole horizontal tail could be an elevator; which is required to pitch the aircraft up and down. If I put this elevator up, then the aircraft will rotate about central gravity and this direction we call pitch up, so one is static stability and when I talk about static stability.

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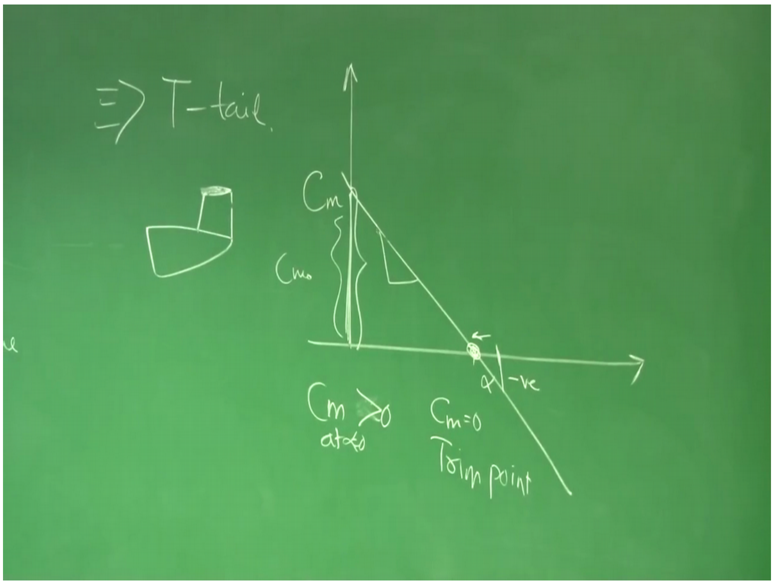

If you recall that pitching movement C m versus alpha, the variation for small angle, if I tag is like that where this point where C m equal to 0 is the trim point you want fly at this alpha, but it is at a given altitude; moving at a particular speed, you have decided your alpha so that the enough lift is generated to balance the weight and why do say static stability because if for some reason; alpha changes, then it automatically generates negative movement which tries to take airplane to trim alpha.

Who generates this negative movement; the primary responsibility is from horizontal tail it whatever additional angel of attack changes, the lift force was generated here and that gives you goes down moment as dictated here.

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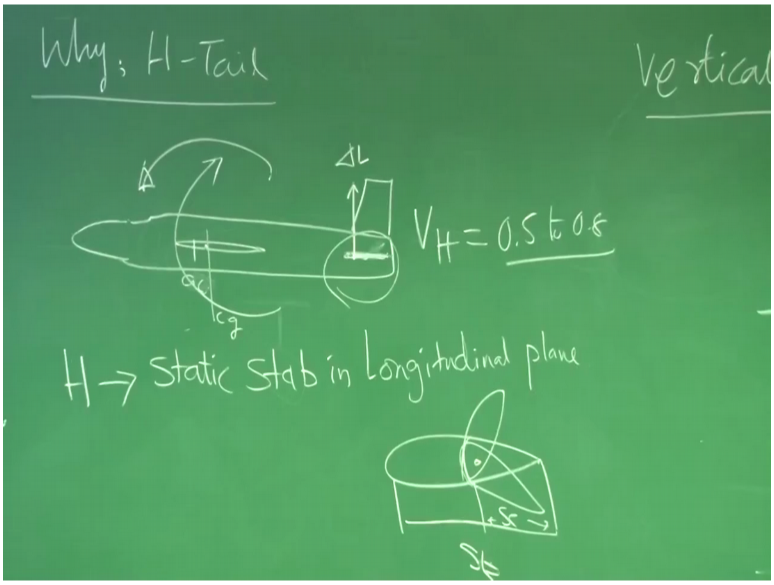

So, horizontal tail is extremely important from the static stability point of view and also it has to house elevator with horizontal tail; part of it can go down, can go up and it acts an elevator and the elevator effectiveness depends upon, the ratio between elevator area or the tail area S t and elevator area.

Of course there are planes which does not have tail; like typically flying wing. For a flying wing, if you want to fly you need to have ensure that it has to reflects aerofoil. So, that this gentleman is positive as well as aerodynamic centre of the flying wing is behind centre of gravity. So, I am not digrancy in towards flying wing, but I am talking about conventional aircraft. So, coming back to conventional aircraft you see that; if I want to fly at this trim, I need to ensure not only the slope is negative to the magnitude I designed, but also this C m at alpha equal to 0 should be greater than 0 and to be honest; it should have a definite value for a given slope to have a trim at this alpha.

So, C m naught has be positive and to ensure that C m naught is positive we heavily depend upon horizontal tail and you know that if this is the horizontal tail.

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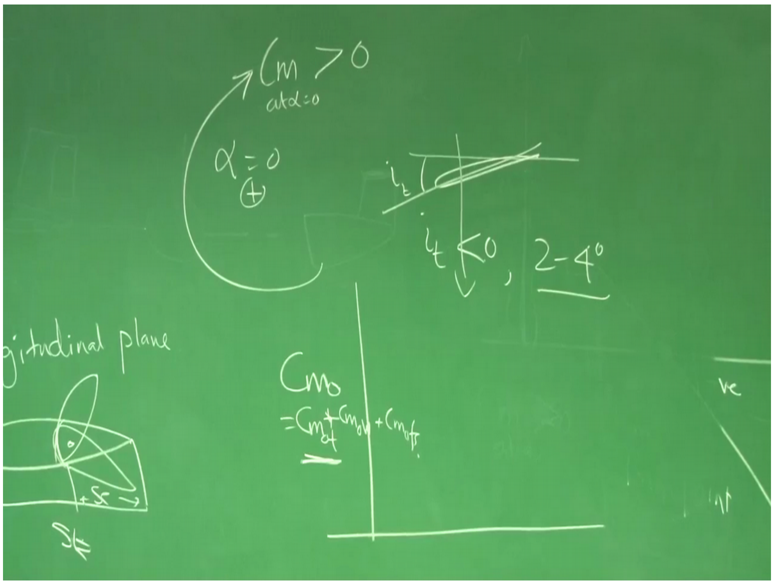

We try to give a setting angle to the horizontal tail i t; which is negative maybe order of 2 to 4 degrees; typical numbers. This is done to ensure that even the if alpha equal to 0, it has a force here and cg suppose is here it gives you a C m at alpha equal to 0 or C m naught greater than 0.

But depending upon whatever C m naught you require, you can set the setting angle. You also know that when you talking about C m naught; here C m naught can come from C m naught tail; primarily C m naught wing and very small C m naught fuselage. So, message is maximum C m naught comes from tail setting angle.

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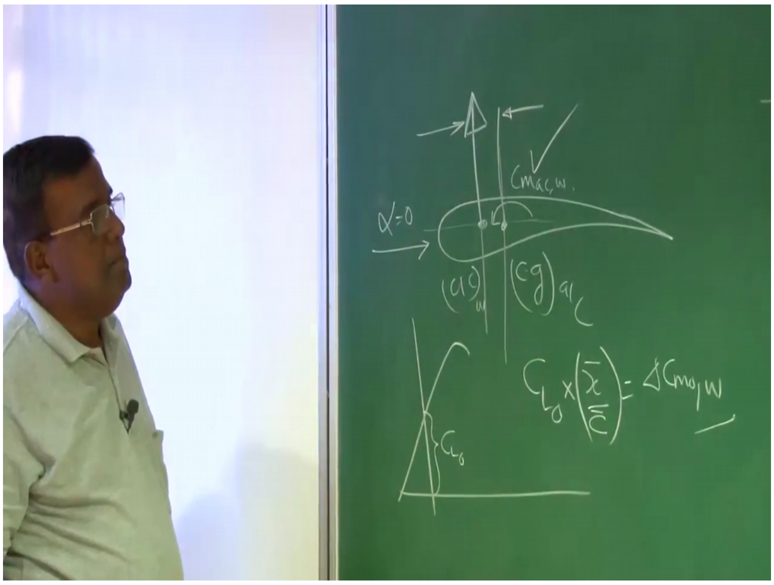

You can also get C m naught positive from the wing. If I have a cambered aerofoil wing what I do if this is the cg of the airplane; I ensure that ac of the wing is ahead of cg. Since it is a cambered aerofoil, so there will be some negative movement C m ac wing, so I want C m naught wing to be positive; we see at alpha equal to 0 because cambered aerofoil. So, there will be CL naught, which will act here and CL naught into this things the cg and the ac of the wing that is a x bar non dimensionalized with (Refer Time: 11:15).

So, this will give me additional C m naught which comes through wing, so message is if you only use tail setting angle to get C m naught desire and tail setting angle become very large; it is always advisable whenever you are using cambered aerofoil would the ac of the wing little ahead of cg of the airplane. So, you can effectively handle negative effect of C m ac wing through tail setting and ac of the wing location together. This we know in stability control, but just to complete the discussion; I thought I will mention this, but today since we have focus through horizontal tail, we are more focused that tail setting angle is required which is negative to ensure that we get some sort of a C m naught which is positive.

So, we will find most of the airplane is having tail setting angle negative and in fact, you may adjust the tail setting angle depending upon what is the flight regime you are going to operate.

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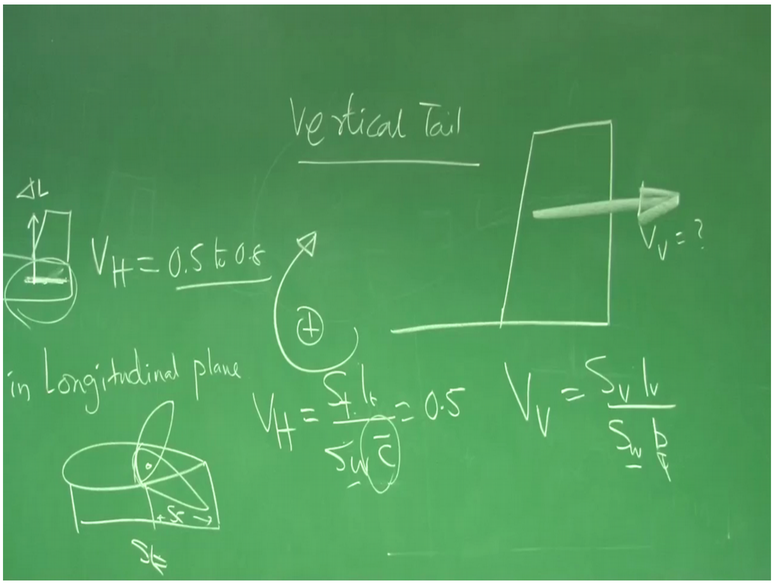

Similarly, you have got vertical tail and question always comes how high the vertical tail should be like; similar question will come here how much tail size and you know that we try to answer that by using a term tail volume horizontal tail volume ratio at the value as well as (Refer Time: 13:19) from 0.5 to 0.8 as a initial number you are making a good beginning. We will come to all these things in detail design, but I thought I will mention it. For a vertical tail also we will have some sort of a ratio, which we will discuss only difference is when I see V H tail volume ratio horizontal it is S t; area of the horizontal tail l t distance from the aerodynamic centre of the tail to cg of the airplane by s wing c bar.

So, this typical value let us say 0.5 when your eyes try to see the number for vertical tail volume ratio, it is S vertical l vertical; S wing into span of the wing. So, you can assume that lt and lv; lv is the location of aerodynamic centre of the vertical tail from cg. So, they are almost same; s wing is anyway same, the difference is major difference is c bar and b; b is fairly large that is b is c times aspect ratio for a rectangular wing. So, naturally you will find the vertical tail volume ratio as per number is concerned will you much less compared to tail volume ratio.

It is primarily because the non dimensionalization has been done; for vv by b not by c bar. So, do not think if the number is 0.2, 0.3 is we are talking, we are not giving lot of vertex to vertical fin, it just matter of how we are non-dimensionalize it, so this is important for a designer.

Now, question is if I go on increasing this vertical fin what are the problems? Yes, you know vertical fins are required for direction on stability because it plays important role in lateral stability. So, if you do not want to make an airplane highly sensitive if you go on increasing the vertical tail; then if it becomes highly directionally stable, it becomes very sensitive to wing anywhere immediate it correction this figures increases you do not like it.

But the same time one point what do we missed generally, please understand if I am increasing the vertical size because we are afraid. Then actually I am encouraging drag due to vertical tail or vertical fin, I am encouraging it to become more and more and the cg will be somewhere here; this will give a nose of movement. So, if you are having a vertical fin I am necessarily a put larger size as you try to accelerate, you may have a pitch up tendencies. So, that also need to be careful you are going to do the finer design, finer evaluation, so at this stage this thing should be clear in your mind.

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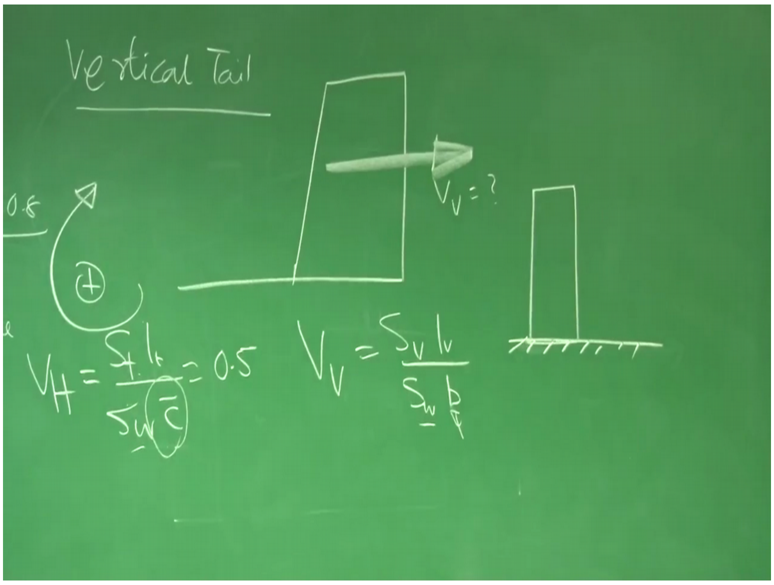

Another part also you should see when I talk about vertical tail, the vertical tail has a end plate effect that is not like a horizontal tail or both the span asymmetry are open to more sphere. So, generally if you read books and all you; do not know how much should I take as initial number for the vertical fin or vertical tail span, roughly if you take 1.3 times, one of the horizontal tail.

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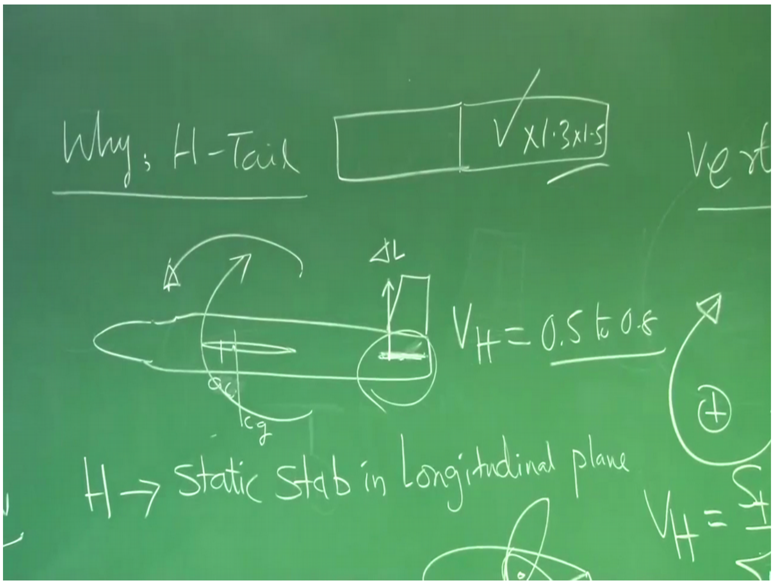

For example, if you should have horizontal tail like this you take this area multiplied by 1.3 or 1.5 and that can be good initial estimate for vertical fin. We will talk about exact this, but this is just to give an idea how to start thinking in terms of conceptual sketch.

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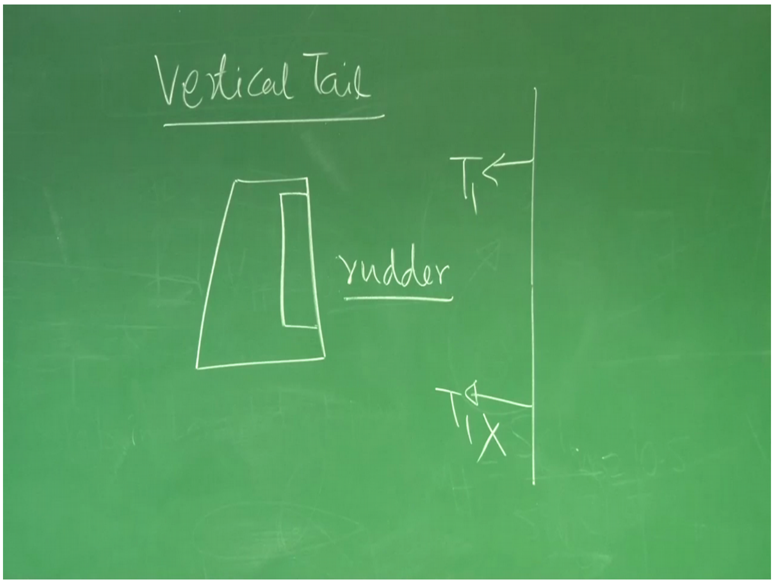

When I am talking about vertical tail; this is a vertical tail and this is a rudder; the primary role of the rudder is for yaw control, role control and also extremely important when the aircraft goes into stall and your analogue will not be effective rudder, then place an important role to adjust the spin. Also you realize for a twin engine airplane which you all know, if twin engine airplane is there and one engine is here, another engine is here; if one of the engine fails, it will immediately give yawing movement. So, my rudder should be enough powerful to balance that yawing movement which is coming because of asymmetry of engine power.

Most of the aircraft twin engine aircraft are designed primarily based on whether the rudder is efficient or not to handle this asymmetry power which you link to engine failure and also whether that is enough powerful to handle the spin.

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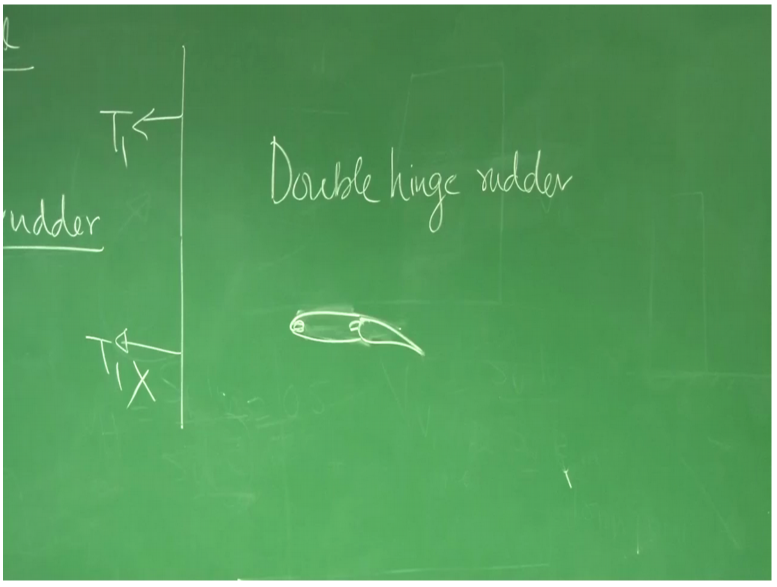

We will find in modern airplane, there are double hinge rudders are there to increase the effectiveness; you might have the top view, in which to the top view you will find a two location maybe 30 percent or the 50 percent, 55 percent, the locations where rudder can be operated; so it is found that it does help to increase the rudder control power.

Another way people increase rudder control power is through all moveable tail then the whole vertical tail moves, then the whole horizontal tail moves increase the elevator power. So, if you see different, different evolution you will find a lot of work was done on double hinge rudder, I strongly recommend as have been doing for all the lectures; please Google and see what are the airplane they have design this, read a read article, read research articles. How much percentage? How do they quantify whether it is in good or bad or ugly.

So, this I was touching on horizontal tail and vertical tail keeping conventional aircraft in mind, but as I promised to start with we will talk about T-tail some features of the t tail.

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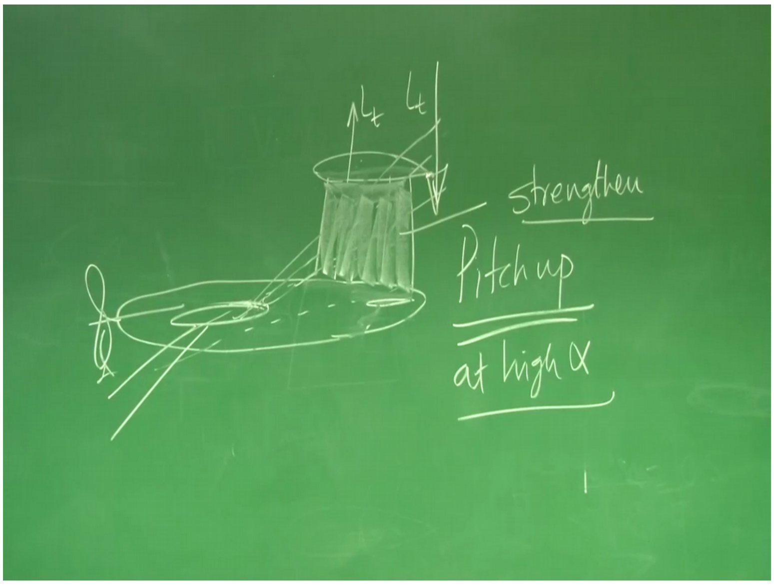

Typically, the horizontal tail etcetera they are not cambered, they are symmetric. Now, you could see why do you want a T-tail; one of the reason for this was that at angle about that little bit a higher angle of that; there will be wings. Wing wake will be there and if the horizontal tail is in upper side, it is the angle to come into the wake of the wing and that may reduce the effectiveness of the horizontal tail.

Already found that, if you put this at the centre it is good enough, but to be doubly sure at high high angle of a tag; which is corresponding to take off and landing, it is possible that you have shifted this wing from here tail from here to here and you are claiming that it is not covering under prop wash or wing wake; this is fine. So, I am happy with T-tail, but as you go for higher angle, what will happens the wake will go in this direction and that time what will happen; the T-tail effectiveness will reduced at high angle of tag T-tail effectiveness will reduced.

That means earlier whatever T-tail was generating a lift force at tail; now L t is reducing; it means now enough lift force will not be there to balance the airplane; so, airplane will try to pitch up. So, for a T-tail when you are designing please ensure that at high angle of a tag, it should not generate pitch up; this is one of the serious issues with T-tail and one has to be very very careful, one should do exhaustive tunnel testing and see how the location is addressing the problem of pitch up at high angle of a tag.

Also you could appreciate that because now this vertical tail is also taking load of horizontal tail, so the vertical tail has to be strengthen more to the weight penalty comes. So, you are having weight penalty because down the vertical tail which is carrying horizontal tail all the loads trace and all. So, I have to strengthen it so the weight will also increase, so these are the flip side, but as I told you as a designer; we have to see how 1 plus 1 gives you what result you want.

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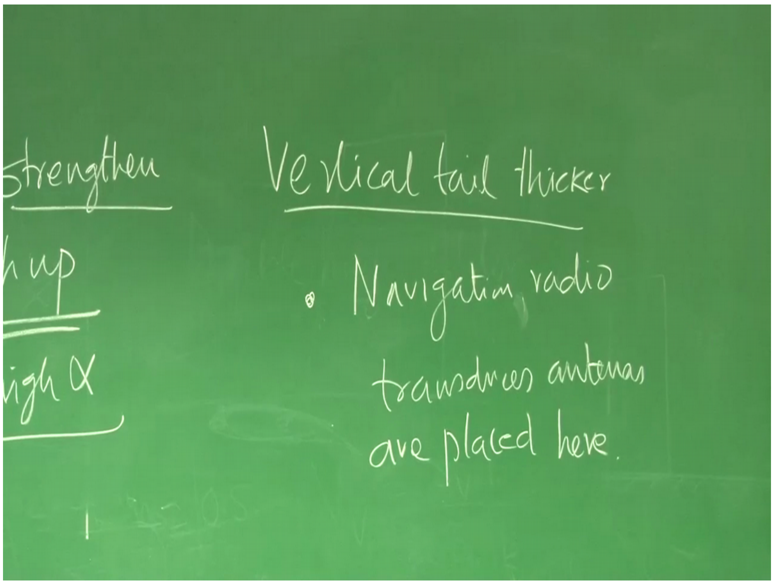

Generally, you will see the vertical tails are thicker; for simple reason, you will find navigation radio, transducers antennas are placed here. So, it is not that it is thicker; a designer will try to use that, that space available. For an aircraft designer, the layout designer always look for a space; whatever space come he will be say ok I accommodate this in this space and the flight mechanics man will tell; do not put it there, the cg shift will be there.

So, that is sort of a interior designer, flight mechanics designer, aerodynamics they quarrel. So, the chief designer takes the decision in consultation some time we vetoed some aspect because he has the final goal; what are the mission requirement he has to achieve.

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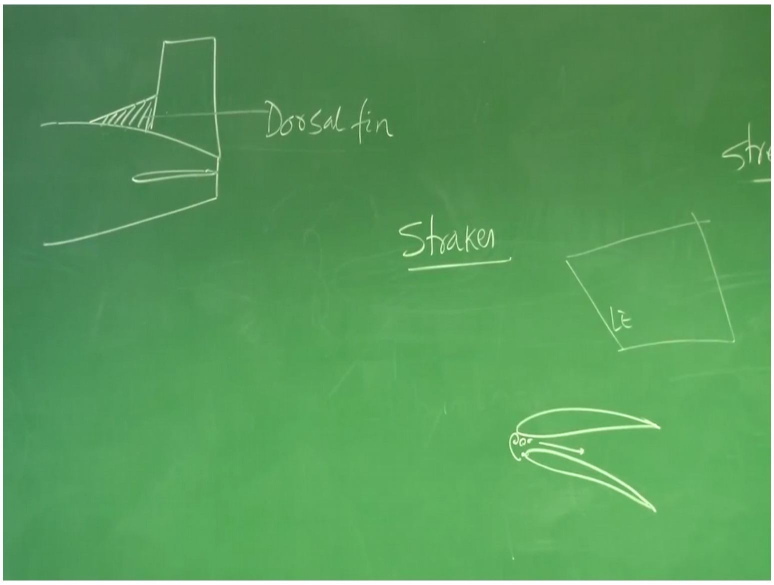

Also, you might have seen them peonage the part where all these vertical fin etcetera are housed. So, there are something likes this we call it dorsal fin; these are basically strakes, these are basically if you want understand from the aerodynamics language; these are strakes. What are aerodynamics strakes? What is their role? Their role is to generate the vertices; vertex so that there is an higher speed in the lifting capability.

For example, if there is a wing and this is leading edge; after certain angle if I lets say this is a leading edge and this stalls; let us say at particular angle, if I put a sharp strakes on the leading edge then that will generate vertex which will delay the separation and also increase the lifting efficiency. So, primarily all strakes is to do that only to generate vertex which adds up energy to the flow and in turn you get a efficient aerodynamics as required for the airplane.

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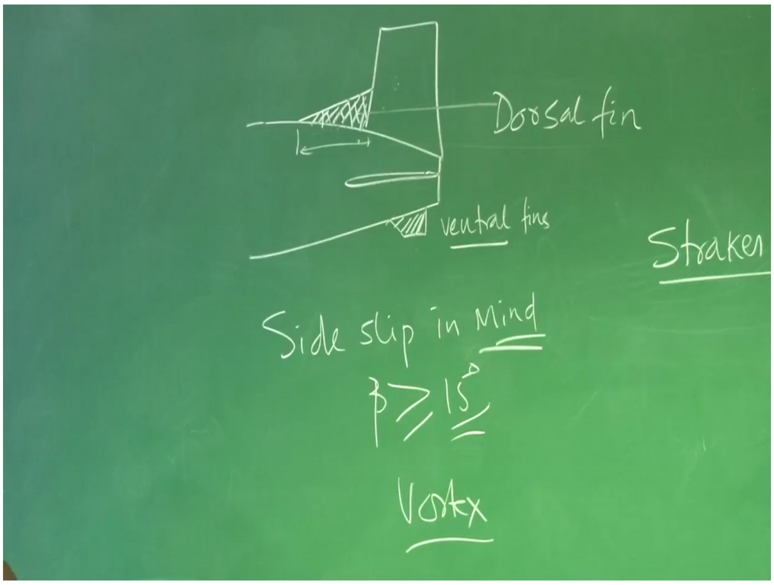

Now, this the dorsal fin; this is primarily required slip in side slip in mind. Suppose a airplane because of some reason has gone into high side slip; could be it has made an entry into spin, I see side slipping very fast and the moment the side slip angle, let us say this is more than 15 degrees and there is every possibilities of vertical fin may stall. A vertical fin stalls; rudder also will be ineffective; so you will not be able to control.

So, there this dorsal fin is purposely kept here because dorsal fin is like a strake; it generates vertex which imperious on the vertical tail and give more energy; additional energy, so that delay and effectiveness delay stall and effectiveness is much more effective. So, that is the primary role of dorsal fin; there are lot of work is being done or how much should be this angle, what should be this length; this is the part of your research work and lot of data is also available.

But for a designer, he takes the initial cue from the existing airplane and definitely when he goes for winter (Refer Time: 28:54) testing, he tries three four such dots of fin configurations to ensure that for his aircraft, this is quite sufficient. Also, you will see ventral fin; fin something here. Like dorsal fin you will also find ventral fins; they are also like strakes at high alpha, beta combination, they also generate vertex which helps in improving the directional stability of an airplane.

We will be talking about this in detail as we progress into design of stability and control for the airplane; that is important at this point that you at least know man this is what this dorsal fin, this is ventral fin; they are basically strakes.

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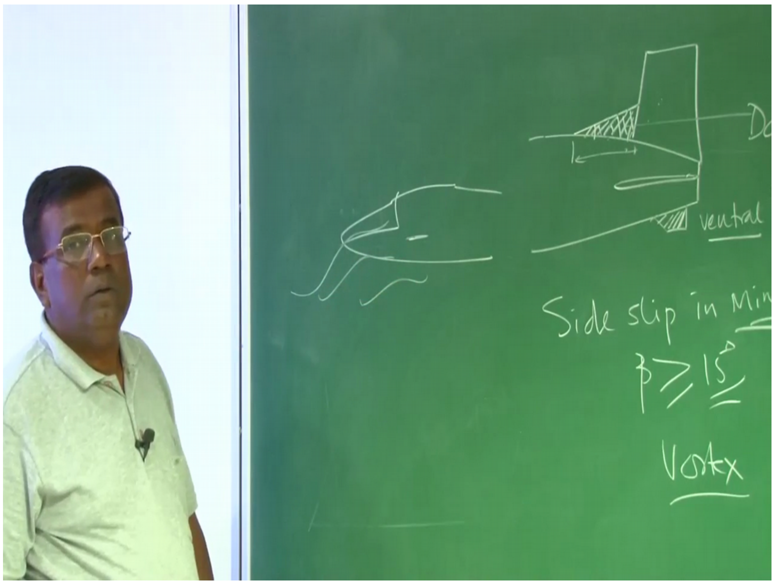

Similarly, we will find if you see the fuselage of airplane; there are strakes here also. Now, you will ask me why there is a strake. See after all air comes from here in every region to get the air decelerated, the energy loss will be there. So, now these strakes will generate vertex that will energize the following field. So, all these are small small things, but they are calibrated in a tunnel for simple reason that; fundamentally we know this going to help and from fine to finer design, this strakes place an important role. So, we will be taking about this, how to design this as we progress, but at this stage we need to know this.

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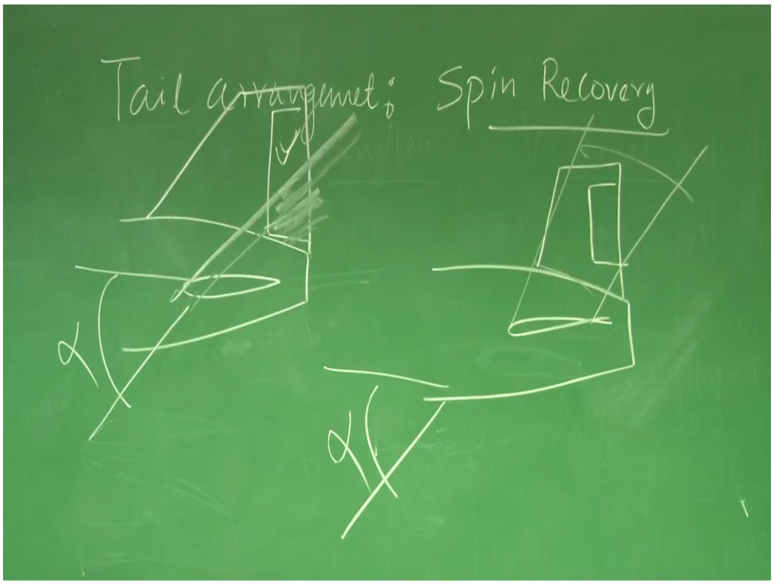

Just to end today’s discussion; this is another important aspect for tail arrangements; when you look through spin recovery. When the aircraft goes into spin, it has stall, it has a large vertical motion and also precisely; it will spin also like this. All these combination is the characteristic of a spin to ensure that initially when you are thinking of conceptual sketch, there are few care one can take to ensure that you have done enough at a conceptual sketch to make the aircraft worth enough to come out of spin or having enough spin recovery capability and that is if this is a empennage and if this is the horizontal tail here.

And if this is the vertical tail you have designed, you could see at high angle of a tag that is why high angle of a tag we are talking about because we are talk talking of spin vertical contour stall. So, if I just extend it you will find rudder is here, so all these portion will be blanketed; they will come under the wake and the rudder will lose it effectiveness. It is also possible that if this is empennage, if you have not careful design the tail and this is here and everything comes into the wake of wing at high angle of a tag.

So, this is dangerous situation here at least some part of rudder is available. So what is done generally is, it is better that you put the rudder here fine and then take the horizontal tail little ahead of this.

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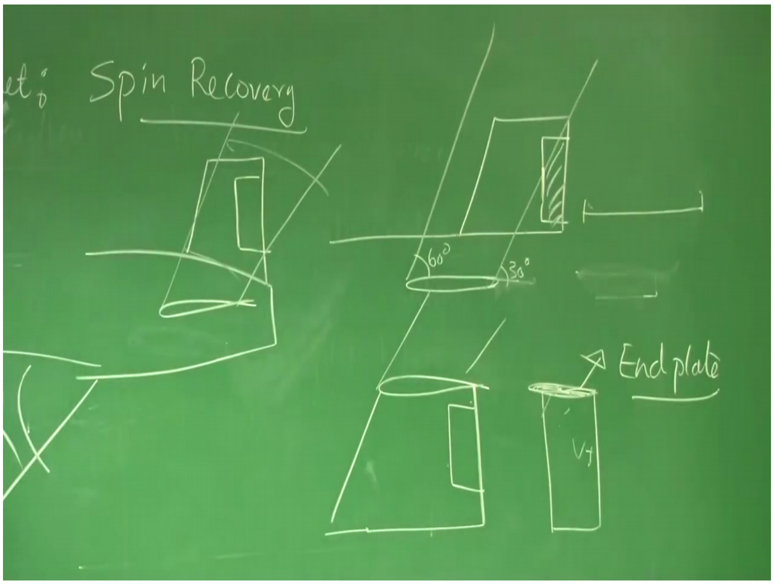

So, what will happen if you take it like this? Major part of rudder will be least effective because this much will be not affected, so you have enough rudder power. What is the done is; generally you draw these are empirical these are all 60 degree here, around 30 degree here. This is again from Raymer and see the placing the location of rudder and all how much area is getting blanketed or come into the wake. If your 75 percent of the rudder is out of the wake, you should be happy.

Now, see the people who volunteer for T-tail; they say simply and if it is a typical T-tail and rudder is here. So, rudder is not at all being affected because of wake, because of horizontal tail. So, (Refer Time: 34:26) that is why T-tail is better, but again for T-tail we should know that it has a inherent tendency for a pitch up at high angle of a tag. There is another content goes on for T-tail is because of end plate effect that is; this is a vertical tail and you know end plate effect if this is the wing sorry when if you put somewhere here, effectively I am making the wing two dimensional except towards that because I am not allowing flow from the bottom to come over the top or effective the aspect ratio is increasing. If you say with end plate effect means it is actually increasing effectiveness of the wing or the fin.

So, by doing this actually this horizontal tail gets advantage of end plate effect, it become more efficient. So, it do not require that much of size if it did not have the end plate effects, so size reduces. Similarly, vertical tail also gets advantage of end plate effects and in turn you say vertical tail also becomes very effective. So, I can reduce the size of the vertical tail, so there is as reduction in the weight.

So, what was the logic; we said because vertical tail has to take load of the wing. So, it has to be strengthened, the logic is the debate is because of end plate effect; now they become more effective so I can operate with a smaller size, drag reduces and because of lot of space here; I can use it for housing radio antenna etcetera, etcetera. So, why not I go for a T-tail; I can handle the pitch up.

So, this sort of a thing the debate goes on notwithstanding the comment that detail always looks elegant, stylish. The youth they prefer detail, but yes you can use any style as well as you know, but it is affordable or not. So, I think with this I have tried to glance through the features of an airplane wing and tail as I look through and which enough to start drawing a conceptual sketch.

Thank you very much.