**Aircraft Design**
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**Lecture – 37**
**Conceptual Design Contd.**

Good morning friends, today we will be discussing how to assimilate whatever we have been talking so far and add few new things. One of my students, he literally complain you do not be sir you give me an impression as if we are doing flight mechanics I do not see anything wrong in his statement. When you want to cover aspects of design, initially we cover the approach how you do the conceptual design without using much of a formula, more of physical understanding and statistical data.

Now, imagine aircraft has engine, you have to talk about engine. An aircraft have different types of engine from propeller to jet engine. When you talk about jet engine, you talk about the intake. It has fuselage as wings structured, it has a layout, cable layout. In the passenger who will be sitting that layout, the landing gears so many things. And each of this subsystem requires a special treatment. But in the first level course what we are trying to do is use understanding of the physics behind aircraft design and use as a complimentary statistical data, and see whether you can conceptualize an aircraft configuration or not.

Once that is done, then comes the analysis. And it goes on testing, revalidation, reconfiguration, it is a mammoth task right, but only those who would be able to handle this huge exercise who are clear about what they are doing both in terms of statistical data usage and as well as correlating those with a physics of the situation.

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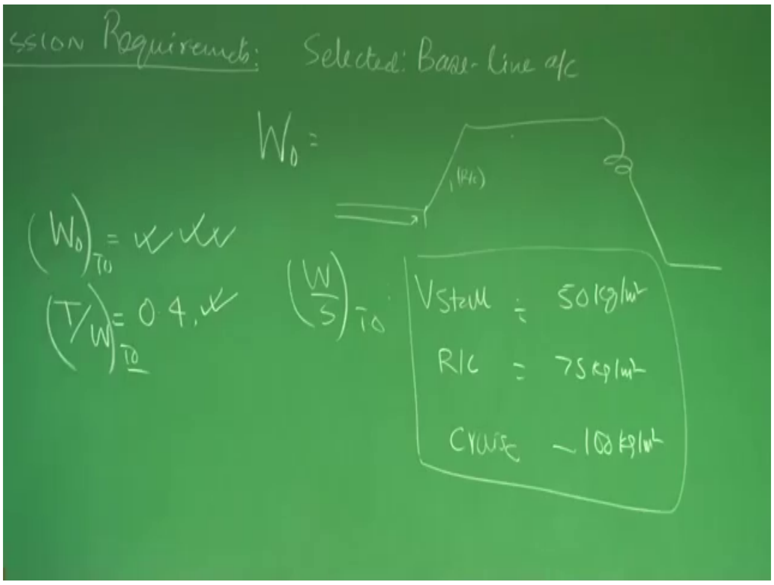


So, today I thought we will discuss few issues and the process we will revisit few things and we will also add some new things. Let us see what is our aim. We started from a mission requirements there are multiple mission requirements. And first thing we did was we selected or we should select a base line aeroplane base line air plane or air craft that is see from the history of aircraft available which aircraft suits your mission requirements. So, that will become your guide line aircraft, and you can cross check the mention which you are conceptualizing.

In doing that, first we estimated W naught, very gross estimation. What we did we said there are primary mission requirements, take off, climb, cruise, etcetera, etcetera. And then we said W naught take off is some number. And in this exercise, we also estimated what is the empty weight fractioning, what is the fuel fraction. And few we have taken statistically, few we have used physical understanding like for range, for rotor, for endurance etcetera we have done. And finally, we estimated W naught take off, the gross takeoff weight. And in that we ensure that whatever W naught available here W naught available here or required here, we translated back to W naught take off because we have to add that fuel which have been consumed, this we are expert in that. So, W naught take off we are estimated.

Our next question was on the thrust loading. Thrust loading also from two three criteria we found out what is the thrust load let say it is 0.4 some values we have already estimated and we have discussed about what should be our understanding to get T by W. Because T by W will play important role in accelerating the aeroplane from here to take off as well as for rate of climb. We also know that when I am talking about T by W when I try to right T by W take off I know very well as the aeroplane is climbing weight is going on reducing, even the thrust is going on reducing thrust value will because of density effect. And if it is propeller driven airplane the dynamic thrust, we have to talk about similarly here.

And again we have given the correction here. So, what should be T by W take off let say these number is known then we talked about W by S take off, and there we have different mission let say as well as V stall is concerned, climb rate of climb is concerned, let cruise is concerned right. So, let say we have got here 50 kg per meter square here, we have got 100 kg per meter square and let say here it is 75 kg per meter square. Now, the question was which were should I take, ideally speaking everybody will recommend you take the lowest W by S, lowest means your wing area relatively large, and it will support lifting characteristics.

But then you also understand if wing area is large drag penalty will be there right, turning will be another issue we have to look for which we have to look for or more than that what we look for is, when I am designing the aeroplane what this aeroplane is suppose to do for the maximum time. If it is a transport aeroplane while we give more weightage to the cruise the range and from that if I get cruise is around 100 kg per meter square then I am tempted to stick this value 100 kg per meter square. Why let us see.

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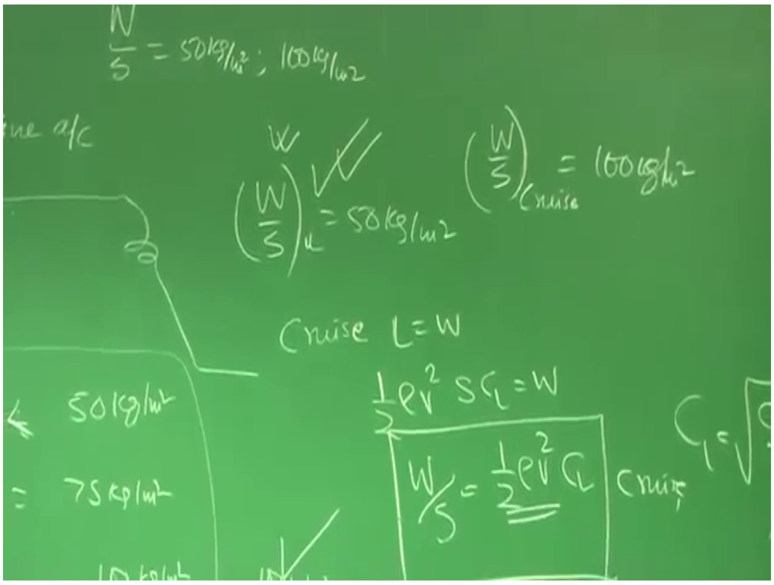


If I take the lowest based on the V stall criteria 50 meter per kg per meter square, and cruise says it should be 100 kg per meter square, what is the meaning of that let us see. For cruise lift equal to weight and so half rho V square S C L equal to W or W by S is equal to half rho V square C L, this is cruise. And when we have derive this 100 kg per meter square and the cruise let say we have assume that thrust required minimum is the condition for which C L was under root C D naught by K. And we have already assume some aspect ratio and C D naught typically you can assume are all to start with 0.021, 0.025. The problem is if I pick W by S equal to 50 kg per meter square which is come from V stall criteria that means what, that means, if I pick this then how cruise mission is going to be satisfied.

So, 50 kg per meter square if I put it here, of course you can multiply with 9.8. Now, if you see that I have to increase the dynamic pressure because C L is fixed C L is C D naught by K that interns tells me that I have to instead of 100 if I want to make it 50 kg per meter square. So, this will demand that you can fly at C L equal to C D naught by K at a lower speed at a lower dynamic pressure then you can maintain that thrust required minimum condition.

I repeat suppose for cruise W by S, we are getting here 100 kg per meter square for thrust required minimum condition, but we have taken 50 kg per meter square satisfying stall conditions. And if I use that it means now to have the same condition I have to fly at a lower dynamic pressure lower dynamic pressure means higher altitude and lower speed or both then you have to do a tweaking.

But instead if you do the reverse thing what you do you take W by S, the cruise value because you say my main mission is cruise, so I will take this W by S cruise 100 kg per meter square. Then what is its implication on this condition it means instead of W by S, which must 50 kg per meter square. Now, it is become a 100 kg per meter square, but please understand W by S you consisted you need to should be Newton per meter square you have to multiply by G.

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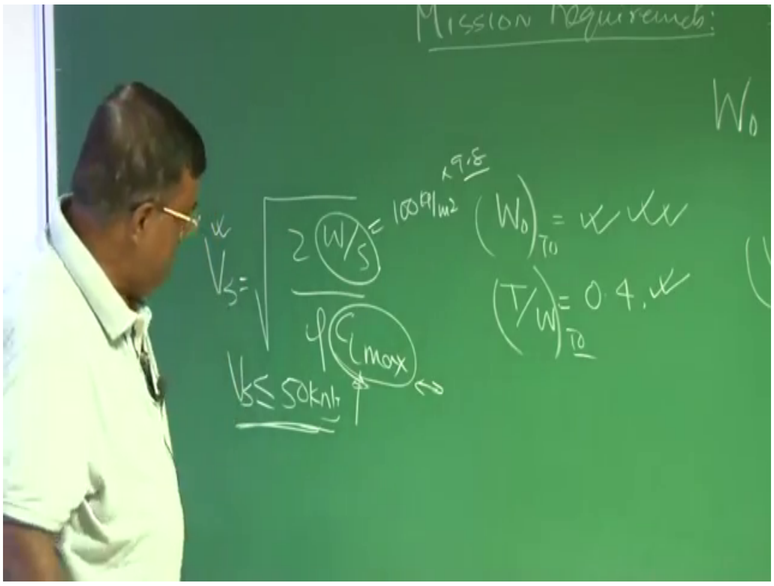


Instead of 50, we have taken 100 that means what that means, the V stall, which is 2 W by S by rho C L max. This condition of 50 kg per meter square was arrived with W by S 50 kg per meter square and V stall you got for a particular value of C L max because there is the restriction on V s. So, V s should be less than 50 knots or some number. If I now design the aircrafts with a W by S is 100 kg per meter square then your V stall will increase and V stall increases means V take off will increase, V landing will increase that you perhaps cannot afford to do it.

So, what is the thought process come, I will keep this 100 kg per meter square suitably converted to Newton per meter square I multiplying by 9.8, but then I have a restriction of V S to be less than 50 knots. So, I will change the C L max value, I will increase C L max value; that means, I have to look for an aerofoil whose C L max is higher and we have to look for another highly devices which can enhance the C L max locally during the take off and (Refer Time: 12:32) back.

So, all this combinations we will be trying right and that is how you compromise every factor and find out ok, this is optimal form me or adequate for me. So, this sort of way conflict will come and the designers job is how to give weightiest to different, different segments and come back to a compromised or all people will agree, ok this is fine right that is what first I will explain you that.

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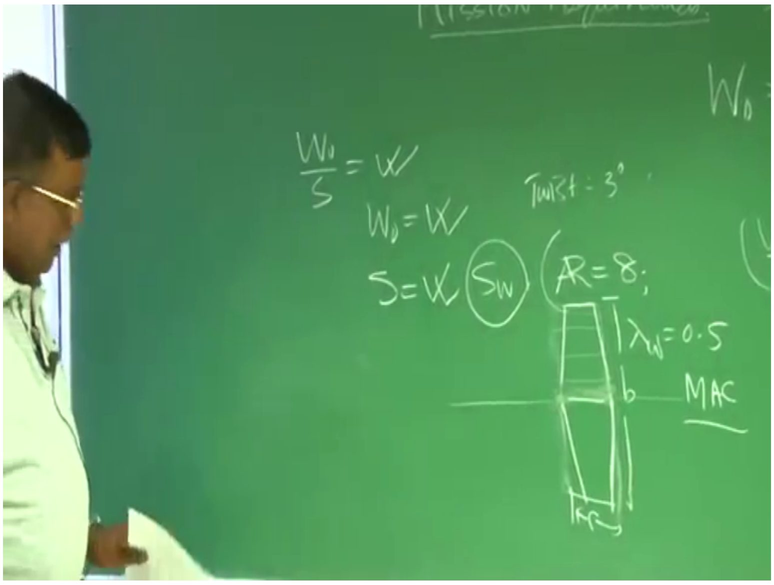


So, there after W naught estimated and once you have frozen and give a justification W naught by S I picked up a number and I have already picked what is W naught. So, I know what is S. So, I know what is S wing, which is known to me. And remember when we were calculating W naught, we also assume some aspect ratio of the wing. And let say that aspect ratio I have taken around 8, just giving a number which already you have used while calculating the fuel consumption during lighter or during range estimation. Once you know the a aspect ratio 8, then you just start doing what should be the span, what should be the chord, these are all conceptual. And then you ask yourself I want to reduce the induced rank. So, my wing should have some sort of a taper ratio where the taper ratio of the wing, I will keep around 0.5 at the conceptual level not a bad assumption.

Then at a conceptual level, I will know that I need to design a wing. So, that I ensure that the root part stall earlier than the tip part. So, I may give a wash out that is I will if some setting negative angle at the tip we let say that twist roughly twist may be 3 degrees down these numbers come from the historical data right because you are not doing analysis. Now, please understand these are your starting numbers then you will do analysis as whether 3 is required or 3.5 is required or 4 is required or 2 is required or at all not required. Because you have another option you may select different airfoils at different section having different C L max an alpha stall characteristics then also you ask yourself am I really giving a sweep, if it is a sweep then to avoid tip stall what do I do all those question you ask here.

So, in a nutshell at a conceptual level you have got a idea about what is the wing area and what is the min aerodynamic chord right you know that how to calculate min aerodynamic chord once we know the taper ratio. Now, you are wing area aspect ratio etcetera is conceptualize.

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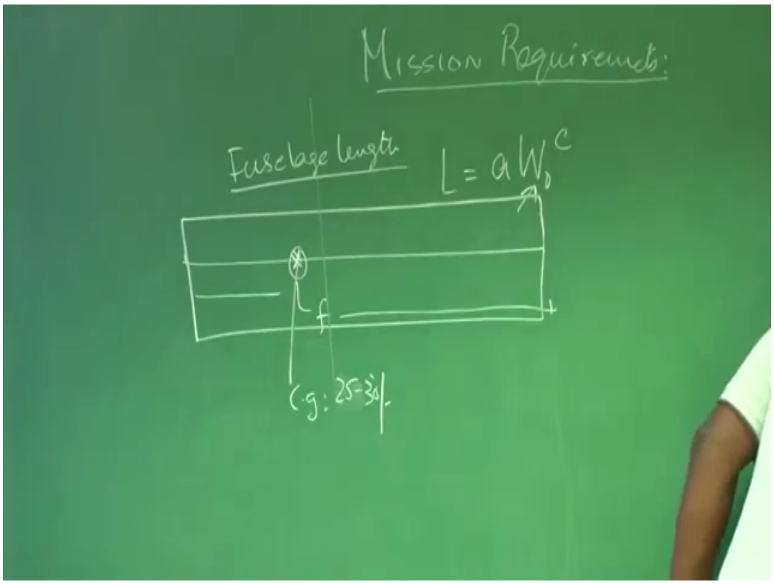


Next question comes what should be the fuselage length that is next question comes to you what is the fuselage length. And you know last class we have shown a very good correlation fuselage length as a W naught to the power c very good correlation with a gross weight. And we have demonstrated for cessna 206 and sinus 912, how accurately it predicts and you know by that you have got some fuselage length. So, roughly you know this is the fuselage length, I will be operating. Next question comes out of this fuselage length where will be the expected CG.

Generally I have shown you in the last class of a conventional airplane, it is not a bad idea to assume the CG to be around 25 to 30 percent the total length from here. Because this CG is extremely important because whole of your airplane installation of wing, tail everything will depend upon why the CG because it has to define some stability criteria which is satisfy some stability criteria majority of the work, majority of the iteration works out here, because at this stage you do not have idea about what sort of weight distribution will happen. So, once you conceptualize then use approximate correlated data from statistical data and see where the CG should be, but not a bad idea if you take instead of a percentage of CG total length. Now, once I do this now what are the information I have got let us see.

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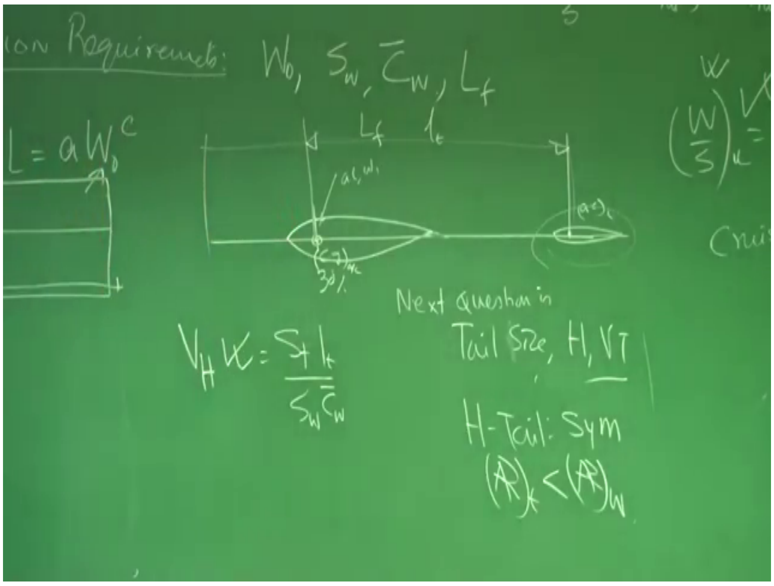


We are all talking about conceptual design. So, we have we know what is W naught. We know what is the wing area, what we know what is the wing aerodynamic chord. And next question will be and also I know what is the fuselage length. So, let us say this is the fuselage length and around 30 percent I have kept the CG. What I prefer to do I let say I am designing a symmetric wing. So, initially I will try so that the ac of the wing and CG are at same location that means, this wing will only be responsible for producing lift I have taken symmetric wing. So, there are no C m ac which are negative right I make it as simpler. I have put ac of the wing and the CG of the aircraft at same point, so this wing lift will not create any either a destabilizing or a stabilizing moment.

Next question is how much is the tail size both horizontal and vertical that is our question, tail size as well as where do I locate the tail. Do not forget that we know now what is the fuselage length, we know the chord, we know the wing area. So, to have an idea about what should be the size of the horizontal tail to start with and its location, we have given you some guideline where we all know by understand the physics the tail volume ratio which is S t l t by S w and C bar that place very, very important role. And you have seen very cleverly I have put ac of the wing and CG are same point, so that wherever I am putting the tail horizontal tail, the ac of the horizontal tail and this distance which is CG of the aircraft as well as ac of the wing, so this I am defining as l t. Theoretically, conventionally l t is the distance between ac of the tail and cg of the airplane.

Now, before I talk about V h and all I decide as for as horizontal tail is concerned we use symmetric aerofoil for wing we use mostly cambered aerofoil all the example I am giving symmetric to so that there are no other complications to start with, but horizontal tail it is symmetric. And also in horizontal tail the aspect ratio of the tail should be less than aspect ratio of the wing that you know the reason is because we want that the wing should stall earlier than the tail so that there is a some control left here. And as aspect ratio decreases, the self induced downward also increases so its stalls later all those understanding you have got. So, let us say I take from historical value I take aspect ratio of the tail may be 4 or 5 correct.

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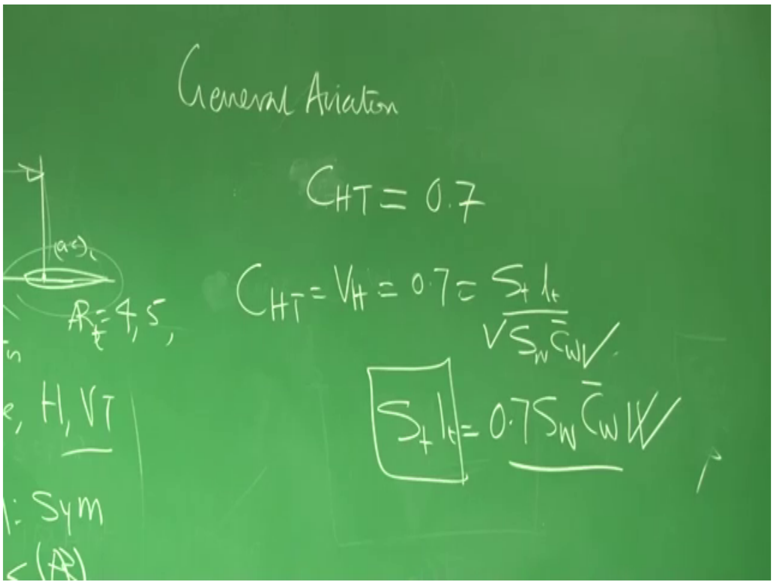


Once we understand the importance of V H, I use statistical data and check for what type of aeroplane I am designing and let us say I am designing a general aviation. And if you see my last lecture for general aviation the V H which is in the Rammers book it is C H T this value is around 0.7 little higher side, but at the conceptual stage you must use this higher values. So, what is the meaning of this C H T which is nothing but basically V H that is 0.7, so that is equal to S t into l t by S wing C w wing. What is our aim, our aim is to see what is the tail size, but I by now you know this values you have estimated this you have estimated you now need to estimate s t into l t, you get that value as point seven into S w into c w bar. So, this value is also known to you how much is s t into l t.

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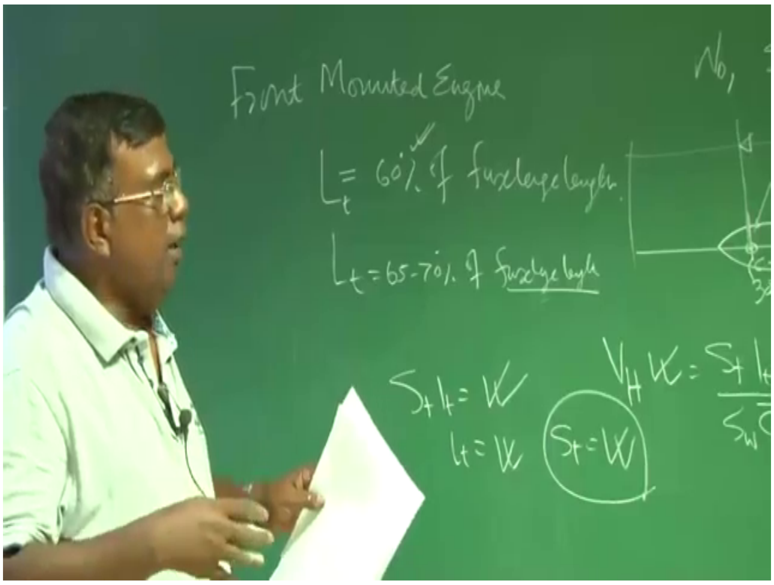


And for L t you have another guideline there is a statistical data refer my last lecture says for front mounted engine L t you can take as 60 percent of fuselage length. Similarly, for wing mounted the variation 55 percent is there, but when I do I take L t as simple as 65 to 70 percent of fuselage length. So, you can this say 60 or 65 percent, 70 percent. In fact, you should have various combinations. So, I pick one of this number and you know fuselage length already you know that, so L t is known to you. So, S t into L t is known, now L t is known, so you get S t. So, now, you know where to locate the horizontal tail and what it would be its area at a conceptual level. We are not doing analysis at this point right this is where the starting point.

So, once I do that then natural question comes what will be the vertical tail size. Please understand, again and again, I am repeating these are all conceptual numbers, we are not doing analysis I will tell you how to graduate from here to the analysis, so that you are perfecting your estimation.

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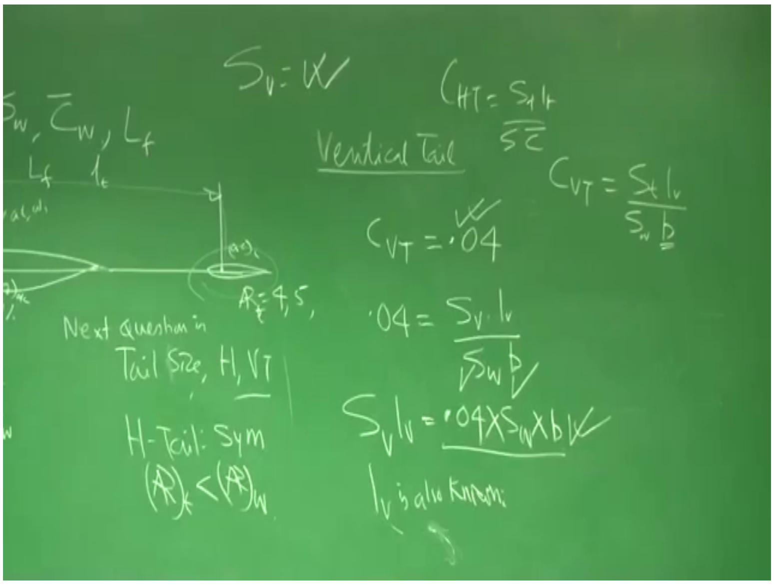


For vertical tail, we follow the same. There we use the coefficient C V T which I have given you last class say for general aviation it is 0.04. Please also understand when you define C H T or tail volume ratio we defined as S t, L t by S c bar, but for vertical tail we defined as S t l vertical tail by S wing into span of the wing right, so that is why the order of magnitudes are different right. So, once I know C V T, so I write 0.04 equal to let say I have pick 0.04 that is equal to S vertical tail l vertical tail by S wing into span. And you know that I know S w, I know span of the wing, so I can get S v, L v equal to 0.04 into S W into span. So, this number is known. So, I know S v into L v.

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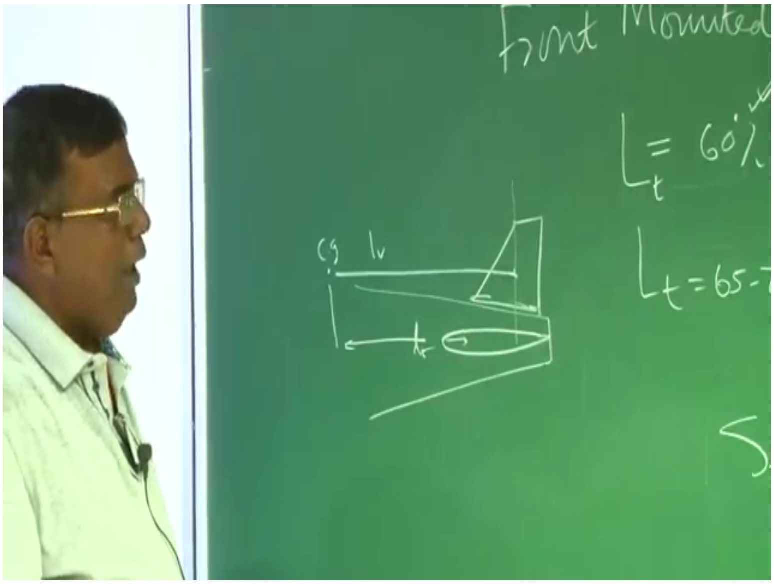

Now, the question is L v equal to L t we could see that for an aeroplane if this is the empennage some configuration will have horizontal tail here and vertical tail is starting from here. Naturally, if this is the ac of the vertical tail and CG is here then l v and l t are not same right, but at a conceptual level we will say both are same, I will not bother much. So, in a sense I am telling l v is also known. So, I easily get what is S v vertical tail area also is known. Once I get this number by this then we cross check for a given aeroplane, what is the vertical tail area ratio with respect to the wing area that is what is the ratio of vertical tail to wing area, what is the ratio of horizontal tail with wing area. And I must see that for this type of aeroplane whether this ratios coming closer or not. We have spoken about horizontal tail and vertical tail.

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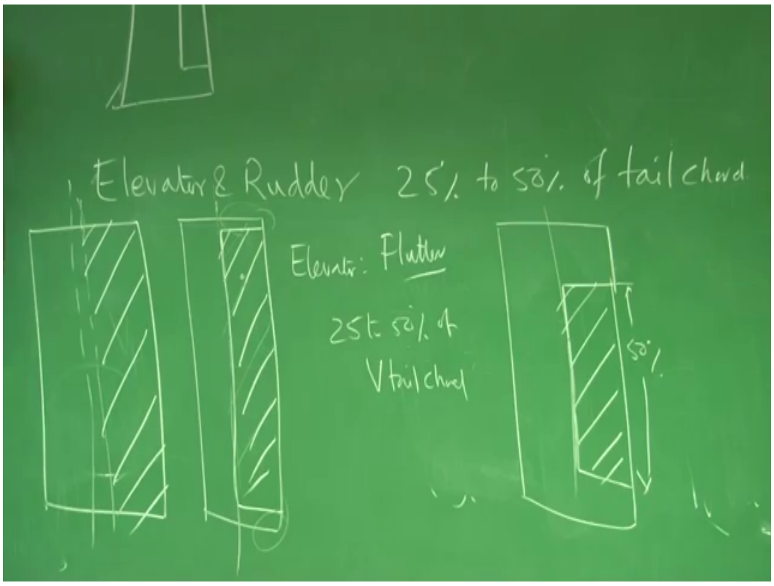


But if you see horizontal tail, there are elevators question will be how much would be the elevator size for a given horizontal tail area, this is horizontal tail. You will find for most of this aeroplane this elevator and rudder, rudder you understand if this is the vertical tail you have a rudder some over here. So, typically elevator is rudder are 25 percent to 50 percent of tail chord that is the meaning is if this is my horizontal tail we will find to the 50 percent line. So, around 25 to 50 percent area is kept for elevator right there are finer things which you will see once we analyze it, yes, I am taking lets I am taking 50 percent of the horizontal tail in terms of chord. This part is my elevator I may have elevator something like this, and the use only 90 percent of these as an elevator, because I know there are tip loses here I may not use it right and there are other issues in elevator you will find such that it is something called flutter at high speeds.

If you see that if this is the elevator which is suppose to move about this CG line if CG is behind, so it will have tendency to do like this. So, for that we also do some other balances called aerodynamic balance, mass balance, in the sense we want to see that this effect is neutralized. We will talk about those things. We have spoken that in our stability classes earlier, but this is for a conceptual, you need not bother about those things. You are more bothered about how much would be the elevator area I should keep once I have got a horizontal stabilizer area that is all. So, the answer is simple you take a 50 percent line the chord should be keep in 25 to 50 percent. So, initially you take around 40 percent how do it matter or make three configurations one is 25 percent, one 40 percent, one 50 percent and then anyway will be getting analysis to see which one is better suit.

Similarly, for rudder you see that for high speed rudder high speed aeroplane rudder will be around this will be around 50 percent of the span. And after the chord is concerned that is whatever I have told you earlier that 25 to 50 percent of vertical tail chord, but (Refer Time: 31:43) for high speed around 50 percent of that vertical span is used of a vertical stabilizer as a rudder. In a rudder, there are many other things will be discussing how to ensure that it has better spin recovery qualities which comes to you the final design or a second stage design at a conceptually stage I need to have those numbers.

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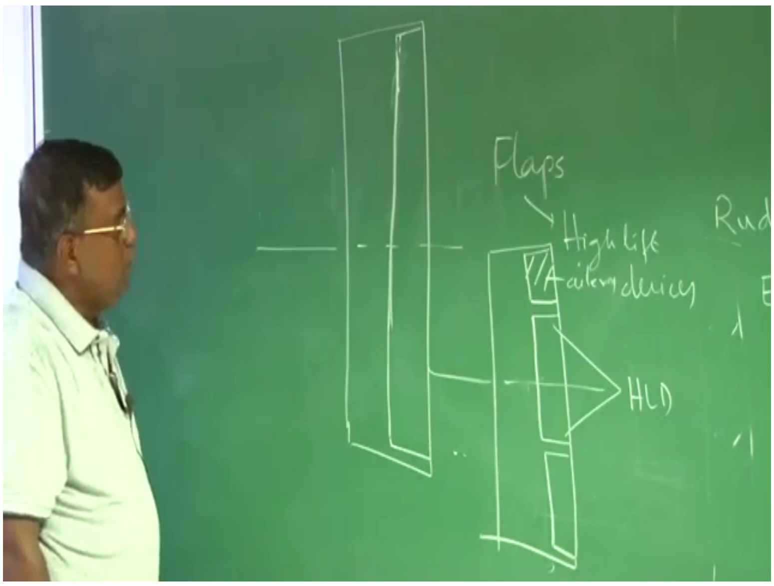

Now coming back to other control surfaces at a conceptual stage, we have wing and you know roll control is done by aileron. And in aileron, we will find the aileron span would be 90 percent total 90 percent you have might be seeing aeroplane were 90 percent of the span is used as aileron. This percentage is again not used because of you know there are tip stalls, so vertices will be there. So, effectiveness may not be good. But you will also remember, you need to have space for flaps which were high lift devices which were high lift devices. So, now, then what happens then your wing lay out changes which you say in centre some portion you are using for highly devices in the flaps and rest portion you are using as aileron. So, this is aileron and these are high lift devices.

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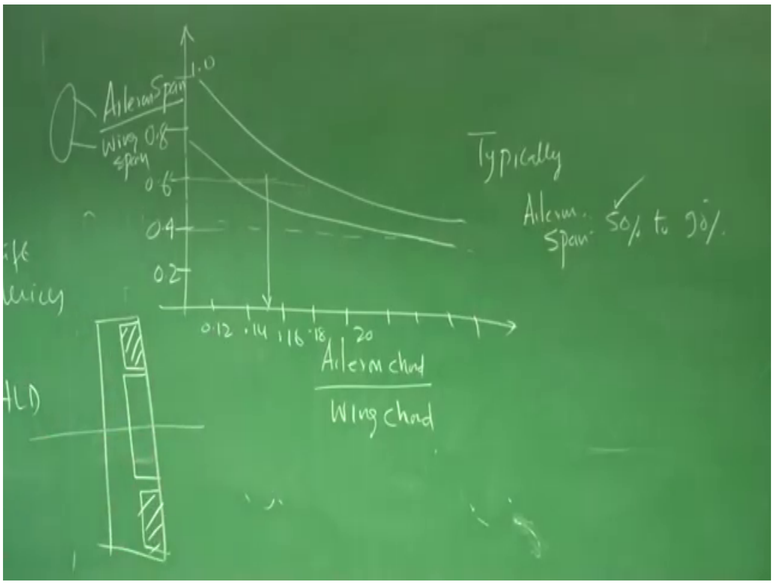


Question is how do I decide they are at a conceptual stage, the aileron size. You can use historical strain it again from Rammer's, I will be giving you some number for typical aeroplane you will realize then. So, if I let me draw this 0.2, 0.4, 0.6, 0.8, this is aileron span by wing span and this is aileron chord by V chord. The historical strained is something like this. How to use this of course, these values are please refer those charts from book of many other literature here, what we were looking for how do I size my aileron if this is the wing, one thing I decide first what should be the flap space to be kept once that is done. So, we have got this much of space for the aileron. And typically we will find typically aileron span will be span will be 50 percent to 90 percent. When I say 90 percent you can easily understand that means there are no high lift devices 5, 5 percent left here full is aileron. But when I am using flap we are more close to 50 percent if I have that aileron span to wing span this ratio I will be knowing. Once I pick a number from here, then I know this ratio and I can easily suppose the ratio still 0.6. So, I come here and some over here I see what is the ratio of aileron chord to wing chord

And since I know wing chord I can also find out what is the aileron chord from here. This also gives in a quite a good estimates at the conceptual stage. Also understand well high speed aeroplane, if you are using a conventional aileron like this at high speed it may happen that you are giving a deflection down here, up here to bang like this but because of high speed this wing may twist downward right, it may generate twisting moment. And then instead of banging towards left, it may turn banging towards right we call it aileron reversal.

So, for high speed aeroplane, you see people use spoilers. Spoilers are of course, required for spoiling the lift conventionally they are use for landing, but now you could see that if I reduce lift on one side of the wing. So, I will be able to generate a bang angle and we will avoid high speed aileron reversal. So, all this combinations are used and generally this spoilers are installed if this is the wing.

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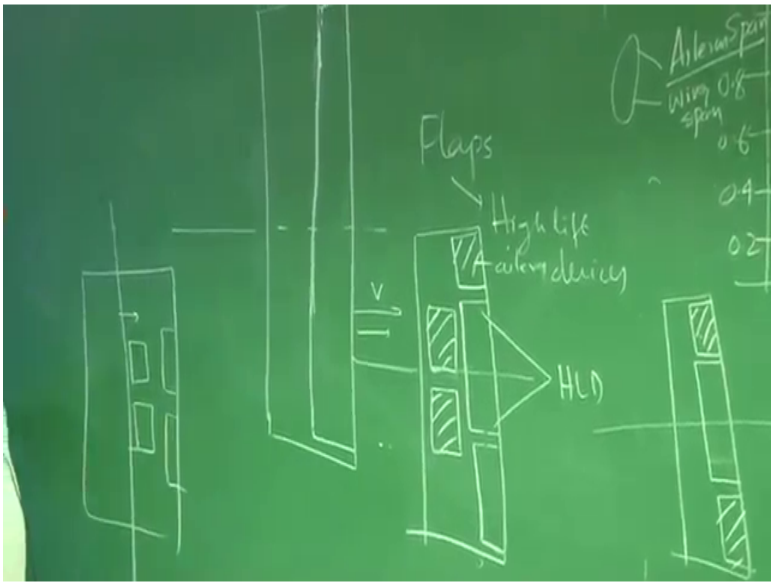


And this is the line of maximum thickness the spoilers would be installed aft of the pointer maximum thickness. So, all those details we will be talking later. However, you must understand since the physics behind spoilers giving a rolling moment is based on spoiling the lift that effect is non-linear. So, theses are for small, small corrections; one has to have very good flight control system to manages smoothly.

My today’s lecture I tried to summarize at a conceptual level how can you think of an aeroplane without having much of a formula right, but same time you should understand I need to also know how effective should be my elevator or rudder so that I can trim the aeroplane from one condition to another condition. What should be my elevator size, so that I get right type of elevator control power. So, this part I will talk tomorrow, I will start with an example an numerical problem and then come back and try to see how you can translate this to understanding into the design of an elevator, similarly rudder as well.

Thank you very much.