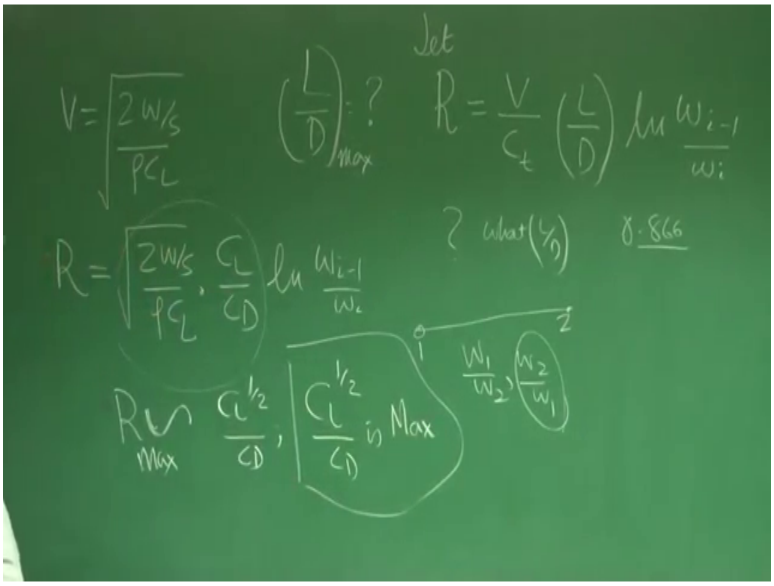
Aircraft Design
Prof. A.K Ghosh
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture - 09
Range and Endurance: Jet-driven Aircraft

Good afternoon friends. In the last class I left an exercise for you.

(Refer Slide Time: 00:25)

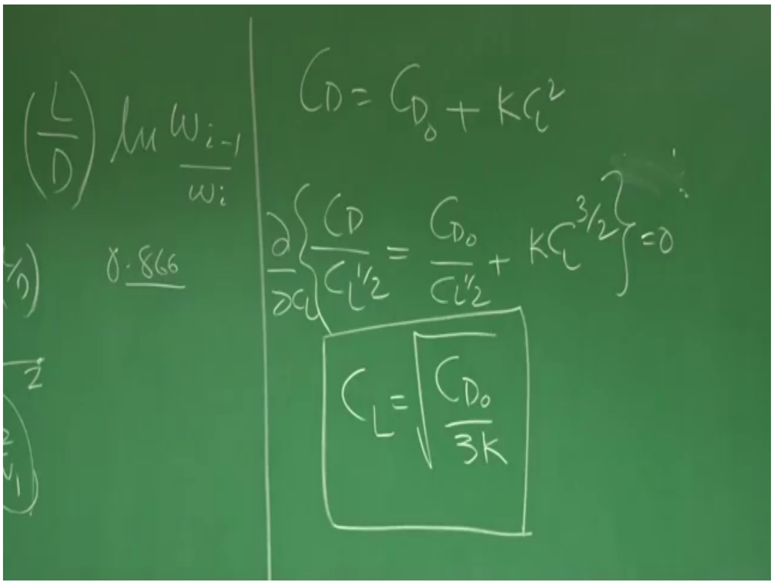


And what was that, remember, we are trying to look for what L by D I should select or. In fact, L by D max, I should select at the initial stage of the design. Which should meet our design requirement, and in that we have talked about range and endurance, and we left this exercise for you and I hope you have done it question was if this is the expression for range, for a jet driven airplane, to ensure I get maximum range. What should be the initial number for L by D? That is at what L by D at what L by D, I should configure my airplane to be capable of. And to understand that we will use a similar approach, which we did for earlier cases and you have seen the magic number of 0.866. When first time I read book I was also wondering what is this number right.

So, I thought let us discuss now, if I will do some simple rearrangement R is v. So, V, I can write 2 W by S rho C L, and the root because we are talking about range and the cruise mission we are analysing. So, for range I can write this equal to 2 W by S rho C L into for L by D, I write C L by C D and this is L n Wi minus 1 by W, I to get a designer perspective when I write, i minus 1 means suppose the cruise starts from here ends here I am essentially looking for W 1 by W 2 or W 2 by W 1. So, that I know if I know W 2 by W 1 and if I know the value of W 1. I know how much fuel is consumed in traversing from point 1 to 0.2.

Now, see here you could easily see the range proportional to C L to the power half by C D. So, keeping everything constant, if I want to maximize range for a jet driven airplane, it tells me I have to fly such that C L half by C D is maximum. We have seen for propeller driven airplane, and jet driven airplane for a range case we had various condition like C L by C D maximum C L 3 by 2 by C D maximum.

(Refer Slide Time: 03:38)

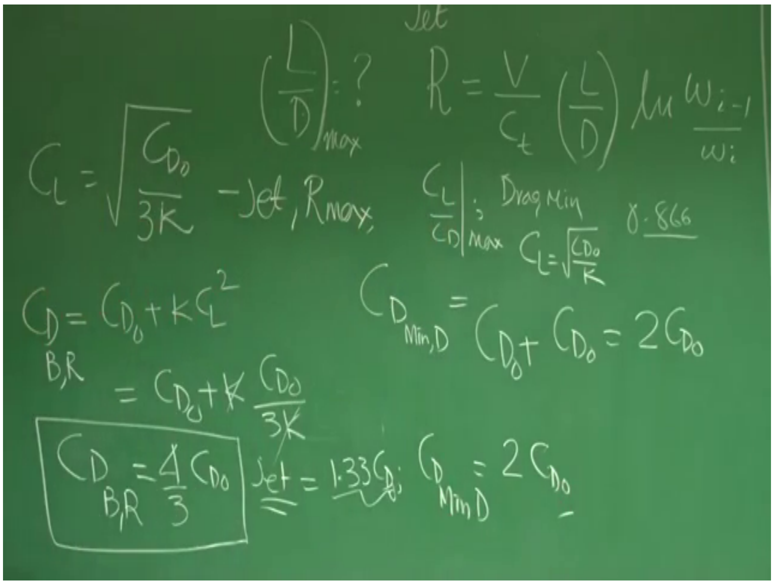


But here we are talking about jet driven aircraft and which we have done in performance course it means C L half by C D should be maximum, just to revise what does that mean you know C D equal to C D naught plus K C L square. So, I can write C D by C L half is equal to C D naught by C L half plus K C L to the power 3 by 2.

Now, you know, if I want to find out what is that C L for which, C L have by C D S maximum which is a condition here, indirectly I can tell I can look for mathematically. What is that C L at which C D by C L to the power half is a minimum right? So, it differentiate this with respect to C L both side and equate it to 0, and it was check that second derivative it will be positive right. So, the stunning point if I find out, I will get the condition C L equal to under root C D naught by 3 K.

So, what is the massage here? Messages if you are having a jet airplane, if we are designing a jet airplane, and if you are looking for maximum range you need to fly at an L by D. For that L by D should the C L should be C D naught by 3 K, that is the message and if I understand that message right.

(Refer Slide Time: 05:12)



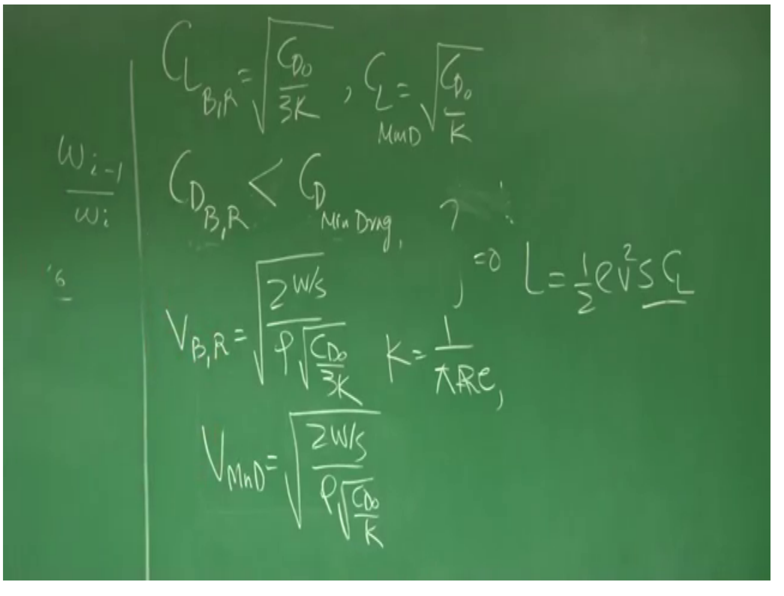
C L equal to under root C D naught by 3 K, it is for jet R max, by 3 K sorry the messages the moment a writes C L is like this is the C D for best range. So, I write best B R for best range will be C D naught plus K C L square and which will be C D naught plus K, into C L square means C D naught by 3 K and K (Refer Time: 05:57) this C D for best range will be equal to 4 by 3 C D naught. This is for jet driven airplane this is important.

But we also know C D for minimum drag, what was the condition for C D for minimum drag? That was C L by C D should be maximum right. That was the condition for drag minimum. And that was equivalent to C D or minimum drag the C L will be C D naught by K. This is not well known to basically it corresponds to C L by C D max. So, I can now write C D for minimum drag will be C D naught plus K C L square. So, this again will become C D naught. So, this is 2 C D naught.

So, what is the observation C D for best range will be 1.33 C D naught. Whereas, C D for minimum drag we have seen here that C D for best range for a jet airplane is 4 by 3 C D naught which is 1.33 C D naught. And you also know C D for minimum drag is 2 C D naught. So, this I write 2 here I will write C D naught please correct it 2 C D naught. So, clearly you see that the C D for best range is less compared to C D for minimum drag.

As a designer sometime it is misleading that you think best range means C D should be lower right. Or C D should be higher if it is lower range. But if you think that C D for best range is 1.33 C D naught and C D for minimum drag as 2 C D naught. So, that drag here will be lesser compared to this that will be a blunder because what is drag has dynamic pressure. And dynamic pressure means that is where the designer has to be very disciplined, you cannot go for a telescopic conclusion right. Every step as a designer you have to check.

(Refer Slide Time: 08:46)



This is fine C D for best range is greater than C D for minimum drag. So, default best range is less than sorry less than C D for minimum drag. This is fine because we are seeing here C D for best range is 1.33 times C D naught, and C D for minimum drag is twice C D naught. But if you think here it means the total drag to achieve best range will also be less than total drag experience for minimum drag that has to be checked, what is that. Why I am saying this? Please understand whenever you are designing an airplane the dynamic pressure plays an important role make it a habit of taking along with your dynamic pressure. Because even lift when I write lift equal to half rho V square S C L.

I have seen most of us psychologically gets lock to what is the C L value I (Refer Time: 09:53) what is the wing area right. But as a designer you have to give due respect to dynamic pressure half rho V square right. We have C L will be 0.2. But still you will be able to take 1000 kg airplane in the air because of dynamic pressure primarily. And also why dynamic pressure I am telling that this dynamic pressure will give you an idea how strong how stronger your structure should be designed for which is C L will not tell right.

So, let us do an exercise here, if you see V for best range will be what we have seen C L for best range is under root C D naught by 3 K. And we also know C L for minimum drag is under root C D naught by K. First of all, if you want to get feel for number immediately if you understand that when I am flying at C D for best range I am flying highers with higher speed compared to when I am flying with C L for minimum drag, because this C L is more than this C L right. At the designer this should be immediate that is how you develop feel for numbers this thing should automatically come to you.

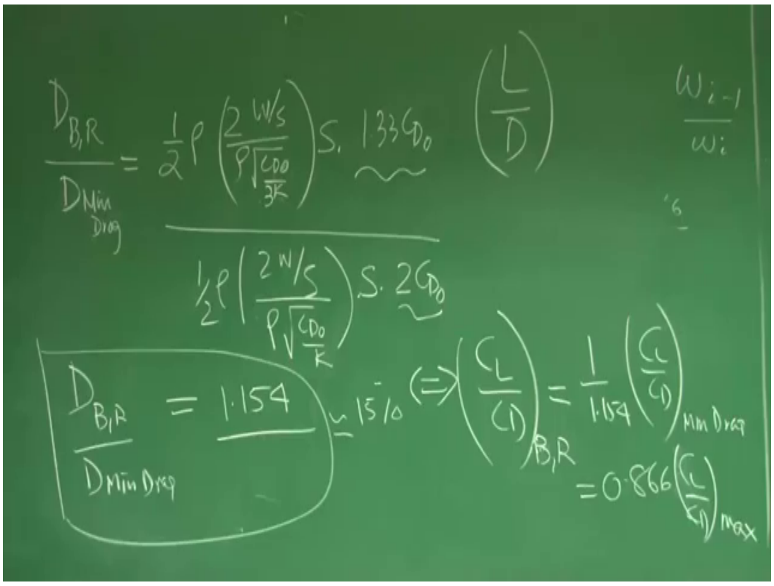
The moment you know oh yes here I have to fly faster immediately dynamic pressure will come to your mind faster means dynamic pressure more for a given altitude. So, what will happen to structure all those thing will come. So, V B R for V for best range will be 2 W by S rho C D naught by 3 K, and V for minimum drag will be under root 2 and W by S rho C D naught by K. Why these numbers are important please also see from designer perspective, you may not allow your airplane when you are designing to fly at any speed if this speed for best range is very high right. You at that point you said, no, no I cannot do that.

So, you start looking at W by S, if I reduce this this man reduces right. I tried to look at C D naught tried to look at K, means aspect ratio right. You know K as one by pi roughly pi right.

So, these are the numbers where a designer will have a holistic view he does not see only the speed this is if I reduce W by S, I can reduce it because more of V B R, if I require somebody has to give you power you need a engine it does not come out of free. So, designer will not wait a most of the book I have seen they give me the algorithm right. I do not appreciate such way of a design course exchange; design means every number a designer should have a field.

For example, you can ask an aero dynamist tell me what is the stall angle he can do CFD everything he will be better person to tell you what exactly the stall angle for the aerofoil he is good at that. But if we want to use that information you as a designer should understand if the stall angle is 16 degree or 18 degree. How it is going to help or not or may not help for when I much everything together that is why the designer every expression every number you write you should ask yourself, what does it mean in terms of speed in terms of dynamic pressure, that is why I give lot of weightage to my way of understanding things. So, this is clear.

(Refer Slide Time: 14:22)



Now, So, if I compare a drag for best range and drag for minimum drag, this will be half rho V square means 2 W by S, rho under root C D naught by K. That will be V square half rho V square S into C D naught is 1.33 C D naught right. Divided by here is half rho 2 W by S or this is not C D naught this is C D naught by 3 K. Please note this correction we know that the velocity for best range is to W by S rho C D naught by 3 K, and here it is rho under root C D naught by K into S, into 2 C D naught. That you have seen we have already shown that what is the effective C D for best range which is 1.33 C D naught and C D for minimum drag has to C D naught.

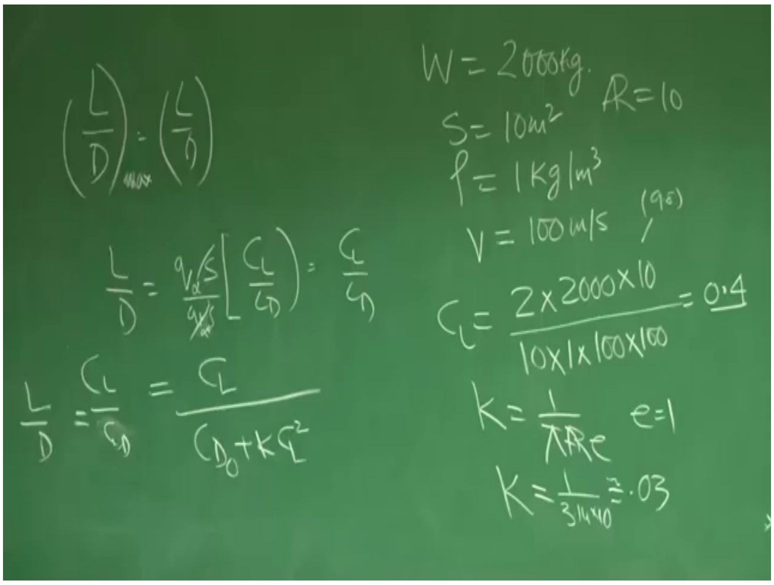
If I do the further simplification, I will find this to be as 1.154. So, what is the interpretation, I hope you will be able to get this number, W by S W by the cancels C D naught cancels 3 is there K, will cancel rho will cancel. So, you have 1.3 then 2 here, and then you will get this number 1.154 what is the designers interpretation of this number.

Please understand what we are looking for we are looking for what should be the L by D is not it, we started all this thing because that Brevard equation for jet has L by D, and we are looking for how much should be the L by D and we have seen if I am flying for best range is in jet, then I have found out the ratio that the drag for best range will be around 15 percent more compared to drag experience during minimum drag flying you seen contrast to the C D interpretation. See here C D if you think from here it tells C D during best range is less than C D minimum drag. But actual drag which is directly proportional dynamic pressure, we will see here that drag during best range is more than drag during minimum drag by 15 percent roughly, which immediately tells you for a given C L, C L by C D minimum best range will be one by 1.154 C L by C D minimum drag obvious because the drag is more right. L by D, C L by C D.

So, now if you see this one by 1.54 again this is 0.866 L by D or C L by C D max. So, what is the message? So, again this number 0.866 is coming. So, messages somehow you first guess what will be the L by D max, you are designing for or aiming for. When you are trying to calculate what will be the range for the jet, you just take 86.6 percent of that L by D max if you are planning for endurance you should have shown you take hundred percent of L by D max right similarly for propeller driven airplane.

Think you are at the era of wright brother's right. You do not have any airplane data much of airplane data, and if you somebody gives you a task, what how do I visualize the designer what should be the L by D max right. How will you think you will starts thinking, like a designer rest what is happening today? You need analytics people where this database they will use some number. But that is not the purpose of this course, purposes you should able to think have an issue as a designer do have experience of getting maximum number through minimum information right.

(Refer Slide Time: 19:39)



Let us see we are talking about L by D max or say L by D. What is L by D? L by D, I can write as dynamic pressure in base into C L by C D. So, this case this is you know C L by C D. And what is C L by C D; C L is C D naught plus K C L square right. This is I can write L by D or C L by C D, I can write that L by D also. What will be the typical value of C L you would like to fly, how do you get a feel for that number. As a designer you are in the flight level you have. So, many aircraft here their weight class is 1500 to 2000 kg. So, let us take some sort of a number, let us say I will I am tiring to visualized through an airplane which is 2000 kg, let us say S is around 10 meter square.

So, what is the wing loading here, what is the wing loading?

Student: 200.

200 kg and then let us say for simplicity, I am saying I am flying at an altitude where density of air is one kg per meter cube right. And I am flying at a speed let us equal to hundred meter per second right. I am purposefully I have taken a speed and then altitudes. So, that the flow is subsonic right. If I want to find out C L, C L will be what that will be 2 into W that is 2000 into 9.8, I am writing 10 for 9.8 divided by 2 W by S 10 rho is 1 into V is 100 into 100 2 W by S rho V square right. How much is this value?

Student: 0.4.

Point?

Student: 4.

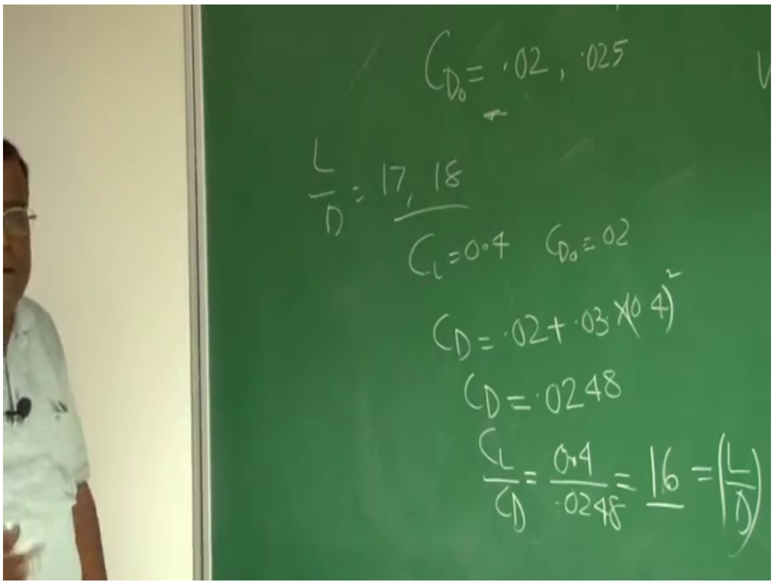
0.4 the moment you get C L equal to 0.4, and if I want to see what will be the value of K which is one by pi aspect ratio p and I take e equal to 1.

So, roughly how much is the K value see I am taking rho of value, because that is how a designer should work to get a feel for number this is one, by pi that is 3.14 into aspect ratio 10 let us say I have taken aspect ratio ten. So, K is how much 1 by it is 0.03 roughly.

Student: (Refer Time: 22:50).

Right. The moment you are writing aspect ratio 10 more than 7 or 8, you are actually going giving more weightiest to the gliding performance if you want to design a high speed airplane, you try to come at on 7 for our transport airplane like that. So, 7 is. But if you are thinking of gliding performance if you want (Refer Time: 23:08) to be less then you need to go for high aspect ratio. The problem of high aspect ratio is structurally it becomes more demanding the weight may go up right.

(Refer Slide Time: 23:30)



What will be the typical value of C D naught, we have done airplane performance course. And we have seen if you see that C D naught typically 0.02, 0.02125 like that, even dreamliner and all the latest aircraft they have tried to make it less than 0.02 0.018 and that is how they claim that the fuel efficiency has increased they have reduced the weight dreamliner by using composites and they claim that it is performance as enhanced right.

So, these are the marginal thing goes on. But as a initial number C D naught, point 0, it is not a bad number right. So, if C D naught is 0.02 then what I am getting C L is equal to 0.4 and C D naught equal to 0.02. So, C D equal to C D naught 0.02, plus K C L square K is 0.03 into this is 0.4 square. So, C D will be roughly equal to how much point let me check this is typically 0 0.0248.

Now, if you want to see what is the C L by C D that will be 0.4 divided by 0.0248 that is equal to.

Student: 16 point (Refer Time: 25:01).

It will be around 16. So, I can I could see that L by D is 16, what is the message messages you take historic numbers which are genetic number 0.02 order of magnitude. And all these are very historic numbers. And you find that L by D comes to around 16 right. So, if I am a designer and I am ambitious designer, what I should do? I want to do please understand when you are making a product 99 percent will be what have been done same sensors same reliable sensors material perhaps. But you have to add one person new, so that you can market it. So, you have to add some ambition into your performance.

So, one of the most important ambition is can you somehow reduce the fuel consumption, nowadays it has come can you make it green fuel right. So, if it is L by D and I know L by D aerodynamic efficiency. So, I will be tempted to design for L by D maybe 17, 18 right. To start with little more right. Because why what I know the designer I know that already dreamliner, and latest aircraft they have been successful in reducing this value 0.02 to 0.018 already material development is happening, where weight can further go down. So, why not I take the advantage of what is happening, and I pick L by D 18 or 18. So, this is my preparation.

Now, I should see historical data that is what the difference I want to present do not just see some handouts and go on picking those number that does not help that is why many design courses happen. But few aircraft new design comes out what is important you prepare yourself. So, that pictorially whatever information is given you are able to pick the right one, and that is the purpose of building this in the next class, we will actually use some design charts.

Thank you very much.