NOC: Introduction to Airplane Performance
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Lecture - 18
Estimation of Rate of Climb

We have seen how to estimate the drag polar through flight test. Now, we will also try to find out the rate of climb parameters like what is the speed for best rate of climb; how do one will find service ceiling through flight test.

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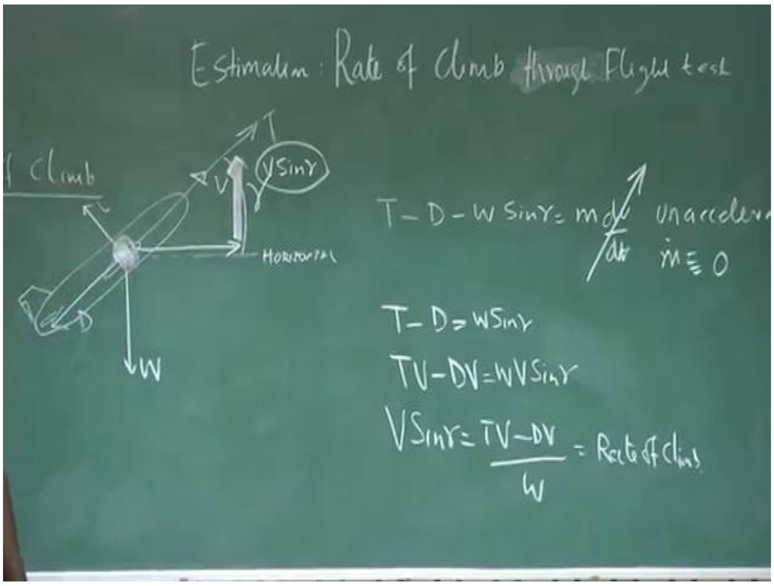

Before you do that, let us recapitulate what do you understand by rate of climb. And, so far, when we are talking about rate of climb, please remember we are talking about an accelerated flight at the rate of climb at constant velocity. If I again draw this diagram, diffuse the thrust, this is the drag velocity here. This is the horizontal. This is gamma fly path angle by now. And quickly, we can remind yourself that, thrust and velocity vector are generally not in the same line, but we are assuming that angle is very small. Also, you know this airplane will be acted upon by weight. And of course, there will be lift. And if I write equation of motion assuming point-mass model, we assume the whole mass is at the centre of gravity. I can write the equation like T minus D minus W sine gamma equal to m dv by dt. But, I will put this to 0 because unaccelerated and also I am assuming m dot is very negligible; that is, change in the weight, because change in the fuel. After all, fuel is consumed. But, we are assuming that is negligible.

And, what we did? We wrote this as T minus D equal to W sine gamma and multiplied by V; we found TV minus DV equal to W V sine gamma and V sine gamma. We expressed as TV minus DV by W. And, what is V sine gamma? V sine gamma is – if I resolve V, one is V cos gamma; and, this is V sine gamma. And, that is nothing but the rate of climb; which is how the altitude is changing per unit time. Who measures the altitude? We measure the altitude through altimeter. And, altimeter gives what? Pressure altitude; that also we should keep in mind.

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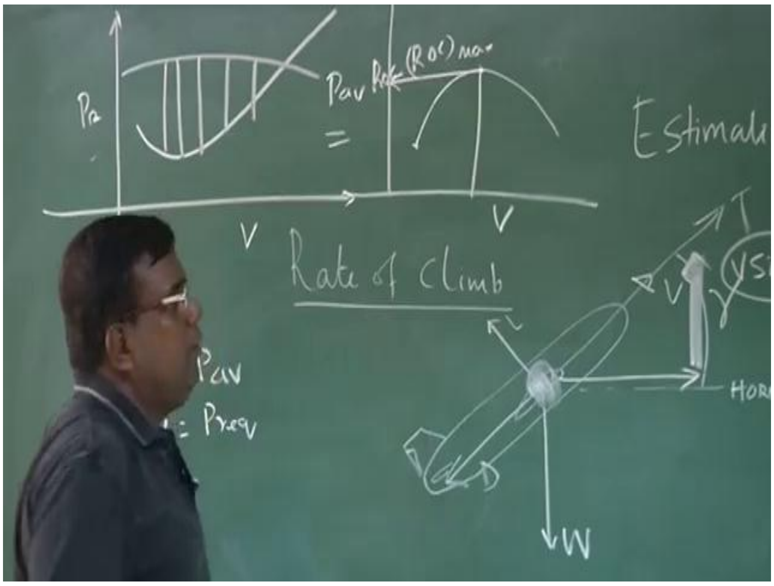

Now, from here we realise that, TV is a power available and DV is basically power consumed – power required – power required. So, once I plot, this power required versus speed – if this is this graph like this and this is the power available, we know this is the axis power; and, rate of climb is directly proportional to the axis power. So, if I try to draw, rate of climb versus speed, I will get something like this. So, there is a velocity at which rate of climb is maximum. So, that is our understanding. Now, we want to fly the airplane and actually climb and see whether whatever our understanding is there; they are ok or not; that is our motivation.

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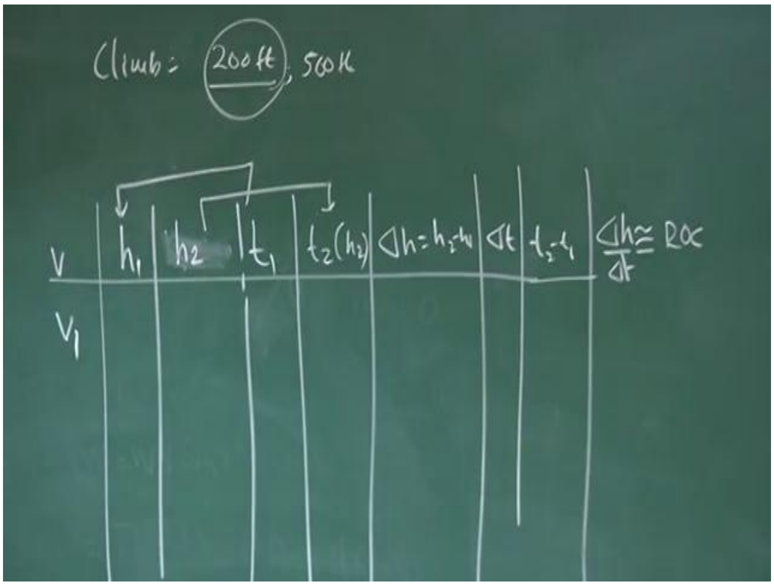

Let us do the experiment. So, what do I do? I again take the weight of the airplane. And, I say let us go for a climb. So, before I do the experiment, I do the weighment; I take the weight of the airplane with passenger, fuel and the pilot in command. Now, the pilot will go and establish himself at particular altitude. So, while the pilot says yes, I am happy; I am at cruise altitude of this much of speed; you check with the altimeter for your own learning – what is the pressure altitude there; you check the speed; you check the outside air temperature. That should be your routine thing. Whenever you are flying for experiment, keep your eyes there – altimeter, air-speed indicator, outside air temperature, turn back indicator. So, that will give lot of insight what this airplane is doing. This pilot is hands off; he says I am at a cruise altitude of ((Refer Slide Time: 05:50)). What is our aim? Our aim to do rate of climb experiment. Now, you discuss with the pilot; say let us climb… Let us say for 200 feet or at the max 500 feet; say I am cruising at the altitude; I would negotiate the pilot – sir, let us go to 200 feet or 500 feet. Why I am saying 200 feet, then 500 feet when I am saying until the air pause? Because I do not want to change the altitude so much that, there is a large change in the density. So, it is better if I try to manage my experiment within 200 feet; it is a good number.

So, now, you have an agreement with the pilot and this is the v. So, you start climbing. Note down at what height you have started climbing. Then, as soon as it becomes h 1 plus 200, the pilot stops climbing. So, that is, you are aiming at 200 feet of increase in height. But, in actual practice, what will happen? It is too much stringent condition for a pilot to make it exactly 200. So, what is better? You give him an idea – approximately 200 feet and then note down that altitude, where pilot says – yes, yes, I have gone up by 200 feet. It could be 210, it could be 195 feet. So, you do not mind. But, when you are doing this experiment, also note down one thing – what is the time when you have started climbing. You have a stop watch; you start; climb from that time. And, when it has finished, that is, when you reach h 2, what is that time? So, what you have now? You have delta h equal to h 2 minus h 1. Also, we have got delta t, which is t 2 minus t 1. So, now, for approximately, you have rate of climb – delta h by delta t is rate of climb. Why I am writing approximately? That you have to answer; I am giving a hint – this height change is actually measured by an altimeter which senses pressure altitude, not a geometric altitude. So, you have to make some correction to get true rate of climb using the ratio of density at sea level and density at that point. That is why I was telling you density should not change much. So, with this hint, you try to think how can you correct. So, you take the reading. Similarly, ask the pilot to repeat at least 5 to 6 x.

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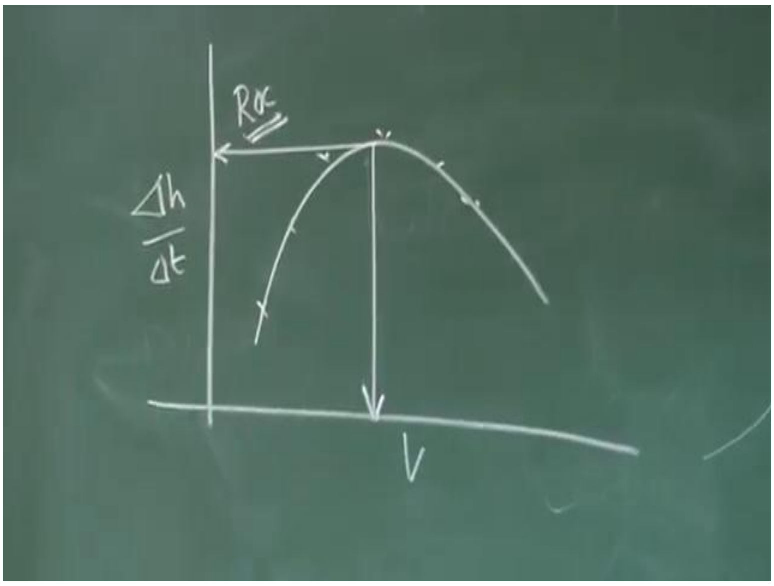

Now, comedown and you plot delta h by delta t versus speed; you will get points scatter like this. Join them; and, this is the velocity or speed at which you will get maximum rate of climb. This you are generating from experiment. But, what is our aim? Our aim is to see whatever theory we have understood, whether I am able to validate those three experiments or not. So, my job is not over here. What I should do now? Now, I will again use the understanding – whatever we had in black board in classroom teaching, there we know how to calculate power required.

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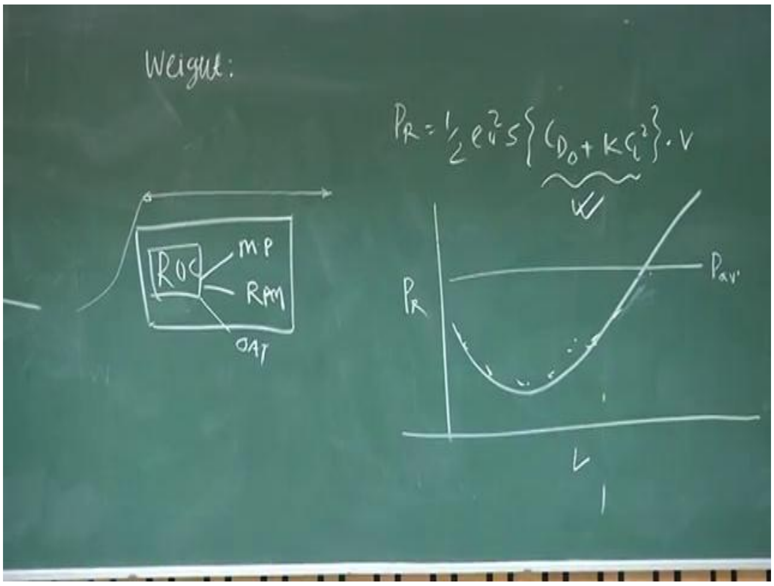

And, how to calculate power required? Power required was half rho v square s C D naught plus K C l square into V. Already from the first experiment, you know the drag polar for this airplane; you have already estimate C D naught and K. So, what you do? Using this expression, you plot power required versus speed – different speed – whatever you are flying, you can extend it also and plot power required versus V. Now, you know what was the thrust available from the engine recording. When you are doing climb and all, you have an idea about what is the power available and you draw it here. Please understand – when you are doing rate of climb, it is also important that you note down – when I am doing rate of climb, please also note down manifold pressure and RPM, which I have not listed in the table. That will give you an idea what was the power available. Is it clear? Which I have not mentioned in the table. So, you must measure, note down manifold pressure, RPM and the outside air temperature, which any you are taking outside air temperature. So, this should be kept in mind. And, from there, you can draw this and from here you find out what is the point v, where excess power is maximum; and, check that velocity v star – it should be equal to whatever you have measured through experiment. Then, your all this theory gets connected. Is this clear?

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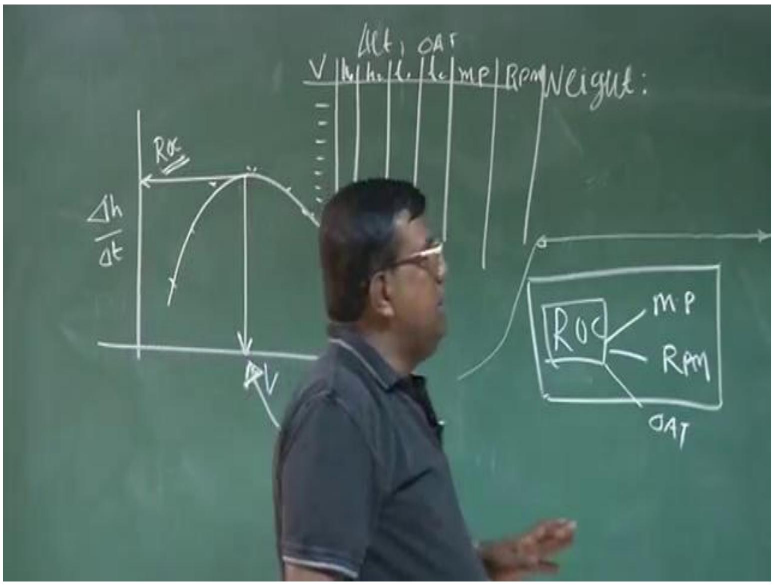

How do you do rate of climb experiment? I repeat again you go to an altitude for different speed; you note down h 1, h 2, t 1, t 2, and also which I missed. I note down manifold pressure and RPM. And of course, you will always note down outside air temperature. I will repeat this experiment for 5 to 6 sets of reading; then, by using this expression, you find out the power required graph. This is because you know that, already you have estimated drag polar using C D naught plus K C l square. And then, draw this power available and find excess power and see that V star and V should be close.

Please understand – whenever I am drawing this power ((Refer Slide Time: 13:17)) this is typically for a cruise you know – half thrust into V. Actually power required for climb is not only this power, it requires power to take the weight also. So, that sort of an error will be there. So, if you expect, this V star will be exactly equal to V; if you are getting through the experiment, there is something wrong you are doing. Revise a lecture on power required; that will tell you. These are the beauties of experiment that you will learn more when these two do not match. If they do not match closely or if they do not match exactly, then you know you should not match exactly, because when I am deriving the expression, I had some assumptions, which are not duplicated during the flight test; and also, during the flight test, measurements have their implicit error. So, never expect whatever theoretically predicting, they will be exactly matching with the experiments. But, it should be well within a bound, which is explainable. I can justify this. Once we have done this experiment to find out what is the speed at a given altitude for best set of climb, I can use this experiment; extend it to find service ceiling or absolute ceiling of the airplane through experiment. How do I do that?

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Please understand first theory what was absolute ceiling. We know that, this is power required and let us say this is power available. And, as the altitude increase, we know that, this has a tendency to come down, because density of x and this has come up to tendency of go up and goes towards right. So, what happens as I go higher and higher, this man comes down and the gap between them goes on reducing. Finally, the situation comes when it is something like this. And, this is the situation where the excess power is 0; that is, rate of climb maximum is 0 that time. And, that is where we define absolute ceiling. If this is the understanding, how can I do this experiment to generate absolute ceiling data.

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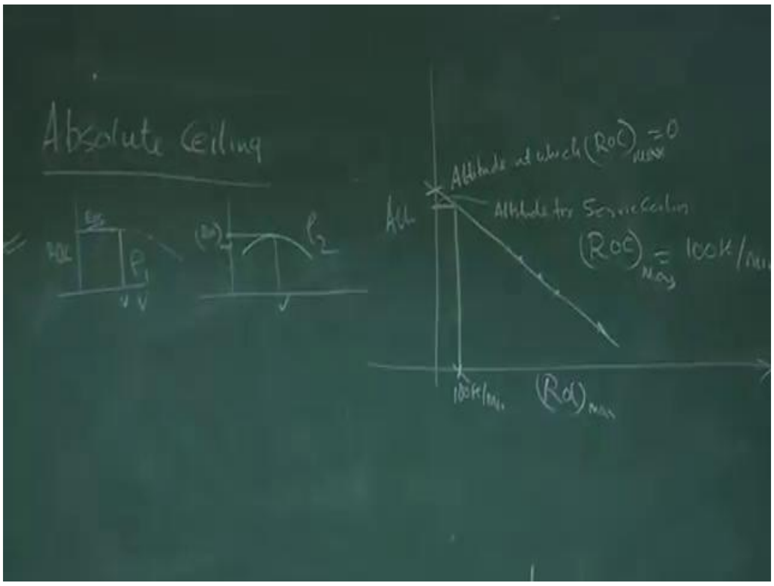

See we are flying at an altitude let us say where densities – rho 1 and do this rate of climb experiment and generates data – rate of climb or I say ROC versus speed. And, I have generated rate of climb and V – rate of climb maximum and V for that altitude let us say rho 1. I repeat this experiment for an altitude rho 2. And again, I generate this data. What is the rate of climb maximum at that altitude? I go on repeating with different different altitudes; I go higher and higher. Then, I plot. I plot altitude versus rate of climb maximum. So, you know that, as altitude is increasing, the rate of climb will maximum will reduce, because the excess power goes on reducing. So, we will get some points like this and then just extrapolate this.

You are not required to fly, where the rate of climb is 0. Maximum rate of climb is 0. So, you do some experiments at comfortable altitude, where you find you are comfortable and then extrapolate it. And, wherever it starts, this is the point altitude – altitude at which ROC max is 0. So, that becomes the absolute ceiling; you want to find service ceiling. So, you find here what is this point, which corresponds to 100 feet per minute; you take that point and go up and see what is that altitude. So, this is the altitude for service ceiling, where ROC max is 100 feet per minute; that is all; your job is done. So, now, you have an airplane, you have a pilot; you conduct this experiment and generate this altitude versus rate of climb plot; find out absolute altitude, find out service ceiling, find out absolute ceiling.

Thank you very much.