Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Introduction to Experiments in Flight

Lecture-02
Cruise Experiment

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After women is over we now go for a cruise experiment it has been the physics behind so that we understand what you are doing and what you are looking for.

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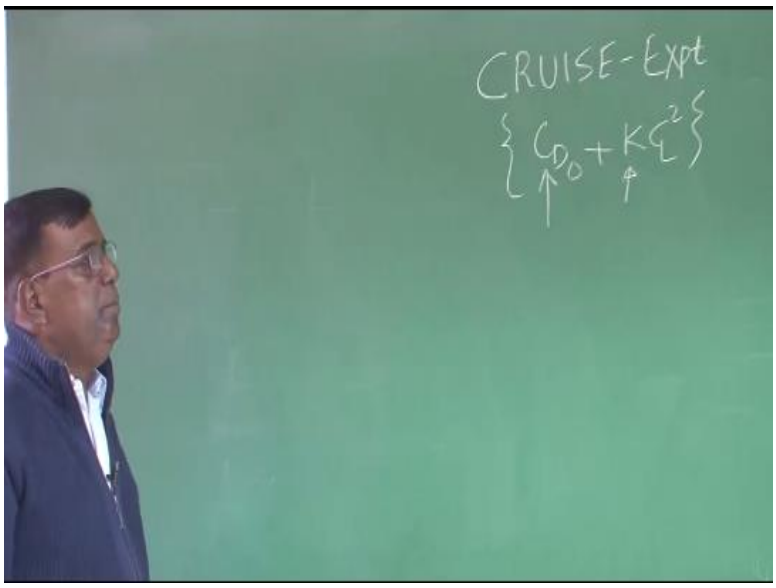

And you know we want to estimate the drag polar C_D knot $+kc_L^2$ essentially we are just image C_D knot $+kc_L^2$ and as long as for the low speed we are playing this parabolic equation is valid form is valid we will put the C_D knot $+kc_L^2$ as a drag polar of the air plane, that is the purpose for the screws experiment. And why this is important you can understand that depending upon the

value of C_D knot K the drag experienced by the airplane at a given altitude and given speed will vary.

You always want t C_D knot to be as slow as possible k should we ask you as possible for a given here right. You also know that, this C_D knot is because of pair is called Paris Hydra because of shape and the speed etc. However this is primarily, this is the induced drag which is because of lift, and there is a lift linking vertices which causes Windows track if you lifting to strike. So this is primarily because of shape and this is family because of the lift. Now we want to estimate the C_D knot and you want to design an experiment which is known as in our terminology cruise experiment.

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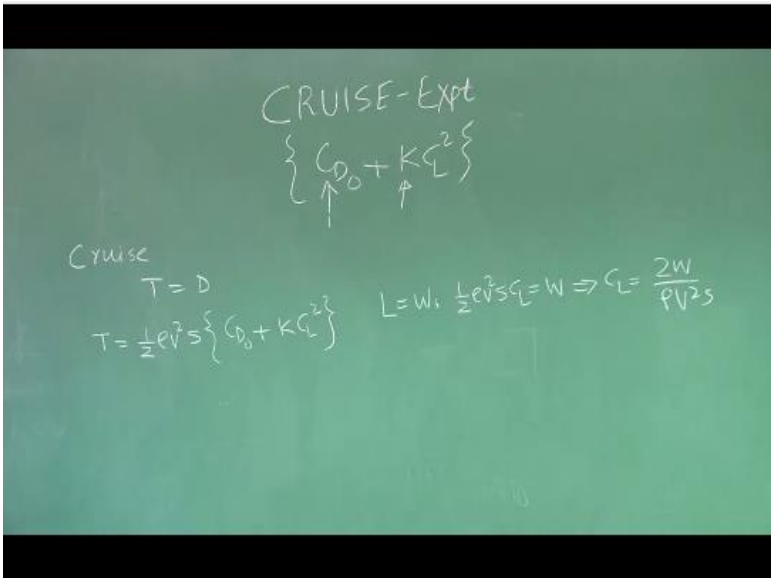

Let us develop the physics behind it, you know during cruise thrust=drag so what I can write trust= half Rho v^2 is C_D knot $+kc_L^{2,}$ no problem set forward. Now what is CL you know lift=weight, so I can write half Rho v^2 SCL=W this implies C_L= 2w/ rho v^2 s. At least what I am cruising lift=weight, So this equation I have written this will tell me how much C_L are flying at a given altitude at a given speed for a given weight of the airplane at cruise that is important right. So now what I do I write this as T=half Rho v^2 s C_D knot+ k for C_L I put it 2w/ rho v^2 is

whole square, Ok.C_L^2 for C_L I put this expression, now I expand trust from the engine is equal to half Rho v^2 is C_D knot + half Rho v^2 is into k into $4w^2$ / Rho^2 V to the power $4S^2$.

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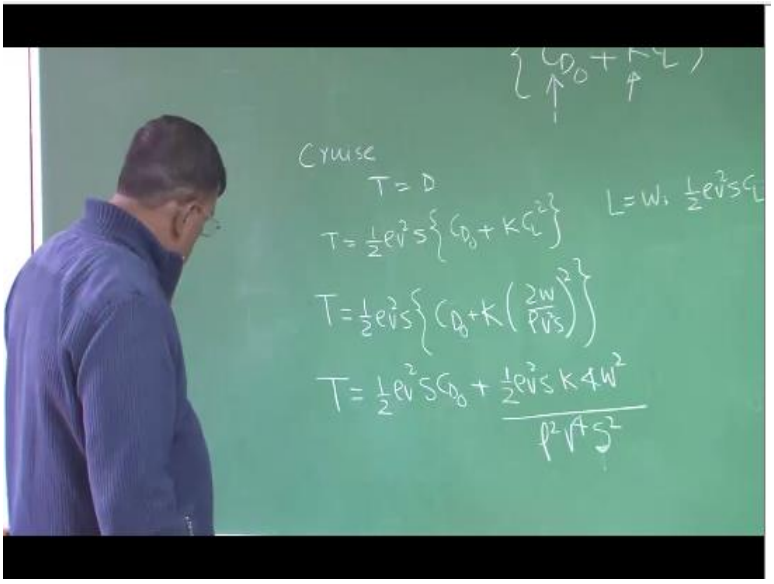

Right, now do some simplification, if I do some simplification, and find that let me write this thrust= half Rho v^2s C_D knot plus so this four and two becomes two, row is row1 V squared + V squared X1 so this will be 2 k w^2 / 2 k w^2 / rho sv^2 .Right we see this what is this T is the thrust available from the engine that it was equal to drag experienced by the airplane that cruise trust is equal to drag experienced by the range. Now what I do I multiply both sides by V what I have half Rho V^3 s into C_D knot+2 k w^2 /by Rho s v^2 into V.

What had but this gives me T into V is equal to half Rho v q is C_D knot+ 2 k w^2/ Rho s v, correct. What is T into V, this was t was thrust available from the engine T into V at during cruise means power available, right and this equal to half Rho v q s C_D knot+ 2 k w^2 /Rho s v.

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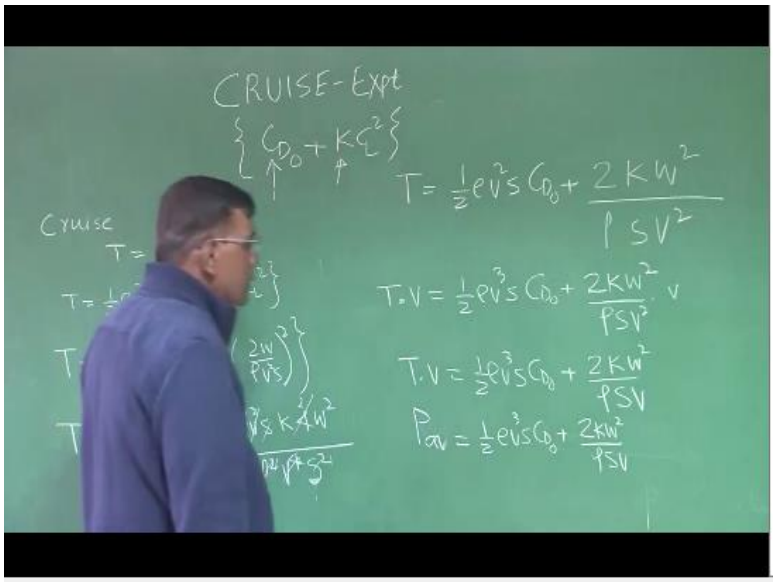

So let me write this here, so I write p available is equal to half Rho v q s C_D knot+ 2 KW ^{2}/ Rho S V , just to make with familiar notation for power available I use a word letter BHP brake horsepower allow me to write BHP for power available to give it a understanding that it is coming from the brake horsepower from the engine .So this will be equal to half Rho V^3 s C_D knot + 2 k w ^{2} /Rho s v. Now what I do I multiply left-hand side and right hand side by V again so I get half Rho v half Rho s C_D knot V^{4+} 2 k w^2 /Rho s.

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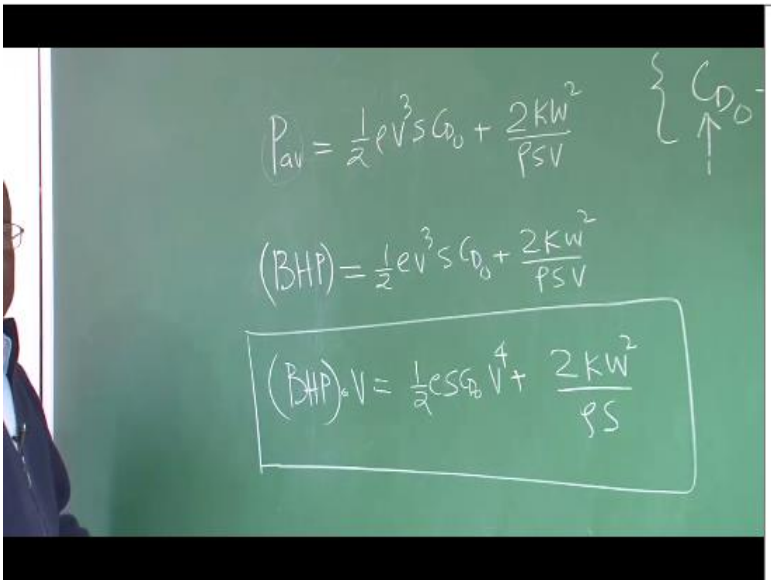

Watch out for this expression, what is BHP the information comes from the engine how we get V where from I get the V that is a question comes from your airspeed indicator right, okay and you know that in the Air speed indicator you get equivalent airspeed and what was equivalent air speed you know that it is that speed or we write ½ $Rho_{SL}V^2_E$= ½ $Rho_{air}V^2_T$.

How do you define equivalent air speed the suppose an airplane is flying at 10 kilometer with some speed V it is experiencing some dynamic pressure which is equal to half Rho altitude into V true there but if I want to fly the same airplane at a seal standard sea-level condition duplicating the same dynamic pressure it was experiencing a 10-kilometer then that speed was with the equivalent air speeders.

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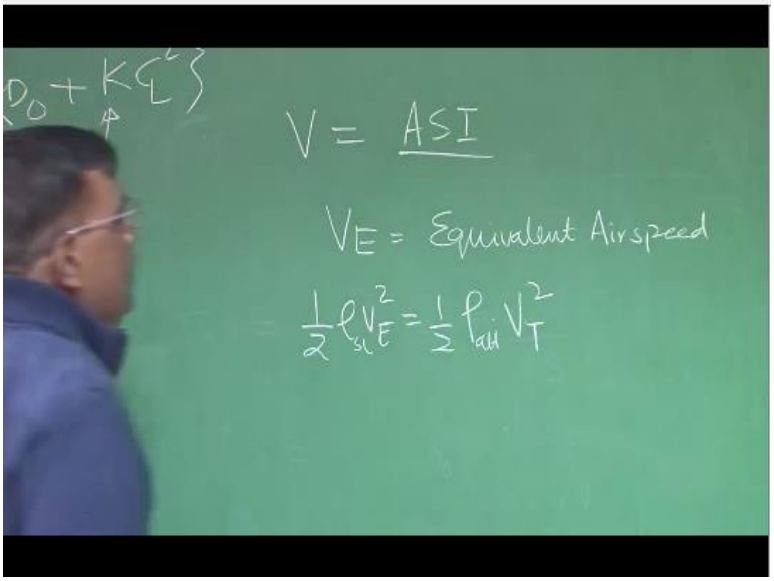

I am equating the actual dynamic pressure have seen by the airplane equal to the dynamic pressure at sea level condition standard sea level conditions and what is the speed equal speed that is that v e are equal in speed, but we will be working with V true so I know that V true equal to Rho C level standard by low altitude under root into V_E. My Airspeed indicator gives me air speed indicator in airplane gives me the equivalent, but I need to use the true here so I will be using this relationship to get what is the true speed for that low altitude.

As I told you once you have outside air temperature which you are recording then using P equal to Rho RT and standard atmosphere you will be able to find out the Rho as P / RT and pressure comes from the altimeter reading because altimeters are calibrated based on the static pressure atmospheric standard atmosphere right. So no problem BHP comes from the engine and I told you the beginning most of such engines which we have propeller-driven IC backup engine these parameters that will be useful forgetting what is the actual power delivered by the engine under that condition using the engine chart or a correlation.

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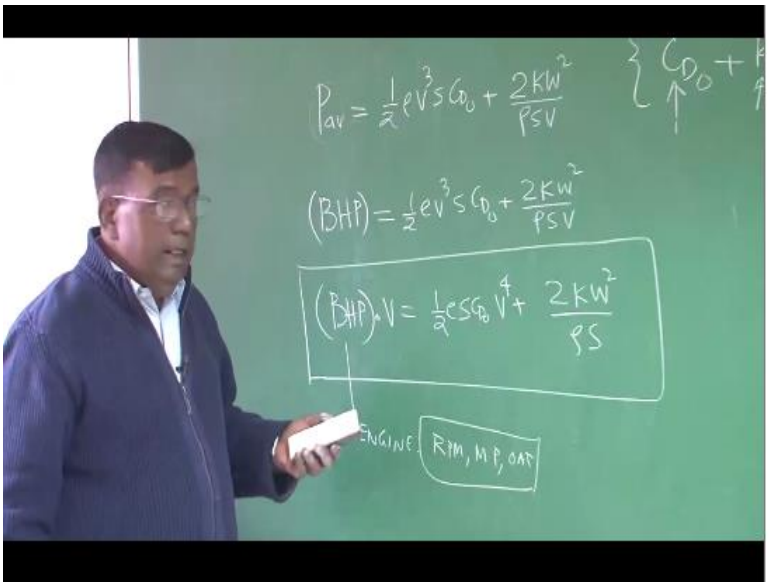

We need to or just measure RPM manifold pressure and outside air temperature while doing the cruise experiments for rpm less rpm indicator or the manifold pressure the manifold pressure indicator for outside air temperature this outside air temperature indicator in cockpit. So you will get all those information right, so no issues on the BHP and no issue on of the V Rho also you are smart so most of the thing w you know how to take the weight now I have to use this relationship to get the value of C_D knot and k so how do I plan my experiment to use this relationship to get the value of C_D knot and k let us focus on that.

This is the cruise experiment, so we start from that we have come to this point and started cruising, so this is record as you start cruising I take down what is the altitude note down the altitude from the altimeter reading and also seeing the outside air temperature indicator I note down the outside air temperatures reading. Now what happens you have to cruise the pilot will do, he will cruise at a speed V_1 and you have to note down RPM and manifold pressure, so once this cruise over aspire to say I will go for another cruise at a different speed so again you have to note down RPM and manifold pressure again V_3 like this five or six points pilot will give you.

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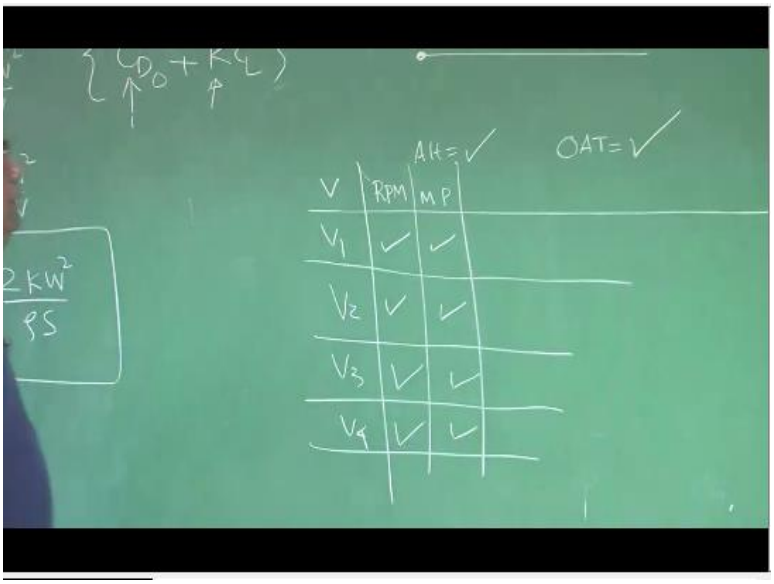

So what are you going to do with this again comeback here I need to know BHP or the power available from the engine I need only information RPM manifold pressure and outside air temperature and there are engine correlation supplied by the manufacturer I can use that and find out how much power the universe delivering the horsepower black horse power available. We know from airspeed indicator but you also know that is equivalent air speed so we are converting into the true airspeed okay.

Now if I know these measurements what I will do that is more important watch if you see that equation if I plot V^4 and BHP into V what sort of relationship it will have BHP into V I call it y. V^4 I call it X ,so half Rho s C_D knot into x+ this I call C.

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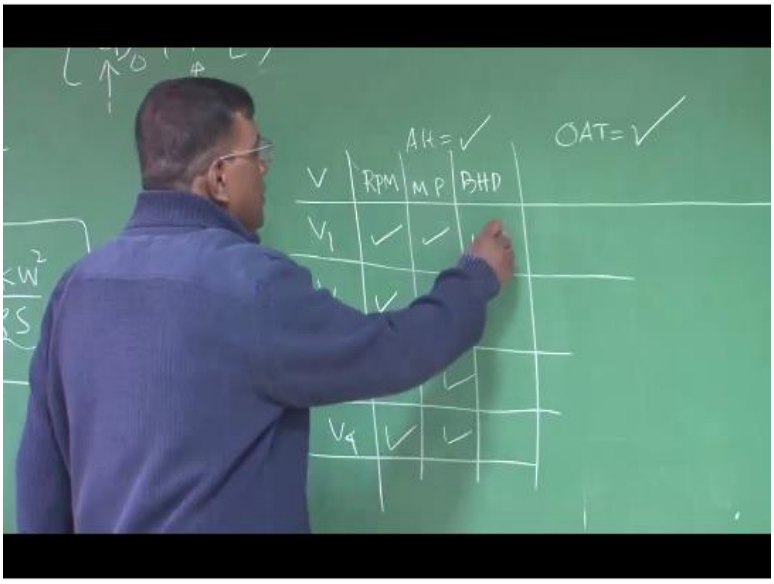

So this is typically y equal to MX plus C, so if I plot BHP into V and V to the power 4 then I am expected to get straight line is this part clear, okay. So what we will do I pick up v_1 I will take RPM and manifold pressure and I will compute BHP using outside air temperature also.

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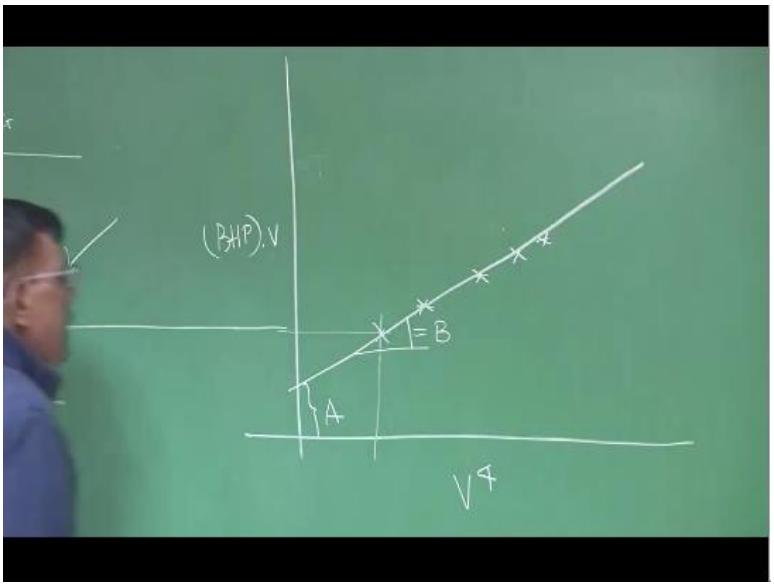

So this is available this is available this is available to see available so for a particular v I find how much is this BHP into V that is important one point will come here and one will come here and we will come here something like this happen and then you have you know it will be best wicked by straight line because that is what the physics tells you it will be best fitted by straight line.

So do the best fit straight line and this intercept whatever you get that will reflect the A and the slope whatever you get to measurement let us say this B then I know A is equal to whatever I get from the graph is equal to 2 K W^2/ Rho S and B equal to the slope which is equal to half Rho s C_D knot correct please understand the A and B we are getting from the plot right after plotting the experimental results there.

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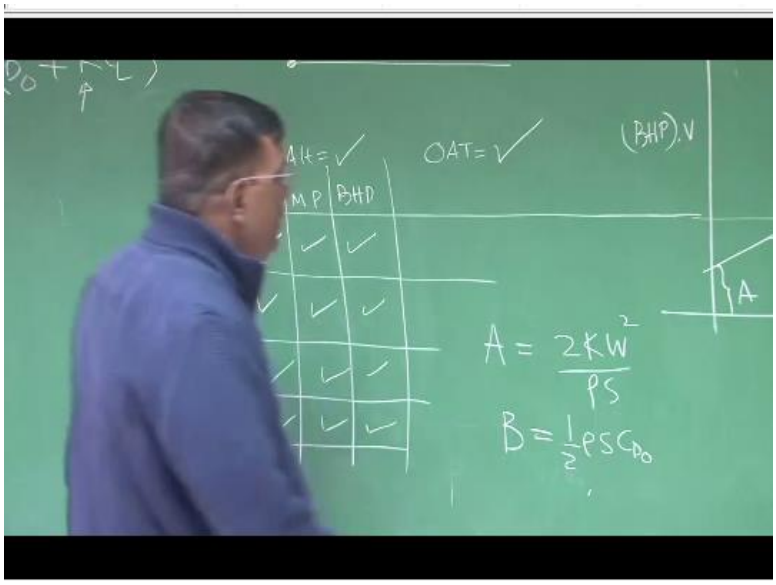

Once I know this my aim was to find k so k will be A Rho s / 2 w^2 and C_D knot will be equal to 2B/Rho s ,as simple as that. So get the value of K you get the value of C_D knot so now you postulate the drag polar of this experiment is or the airplane is C_D knot+ k C_L^2 where you have estimated C_D knot and k by going through this experimental procedure clear.

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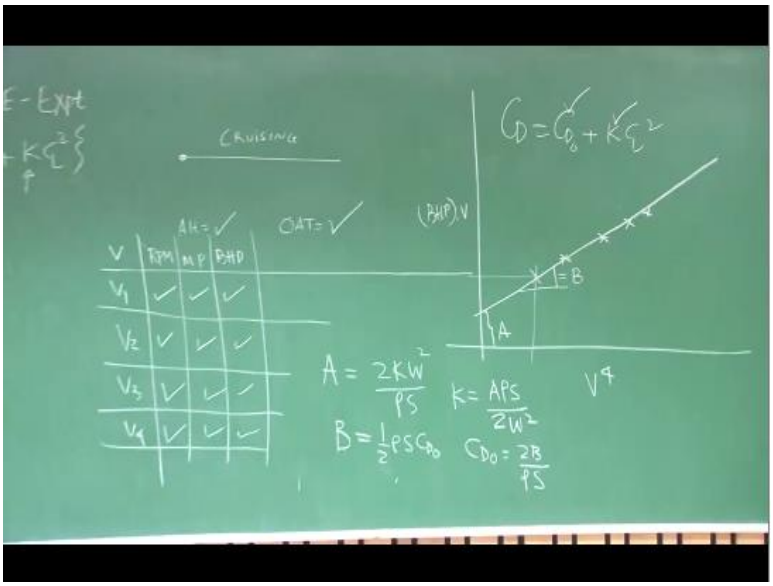

So this is what is the first cruise experiment and also understand, once I know the C_D knot+ k C_L^2 that is once I know what is the drag polar of the airplane through this experiment I can easily calculate power required at different speed and that is given as half Rho v^2 s half Rho V^3 s into C_D knot + k C_L^2 and C_L equal to 2 w/ rho v^2 s so what you can do offline you can easily plot power required versus velocity or speed please understand.

Now the C_D knot value and k value you have already estimated from that experiment so you know this C_D knot and k for different different altitudes where ever you want a different speed you can plot for required versus V and you will see it will follow this sort of a trend which you have studied in your classroom right.

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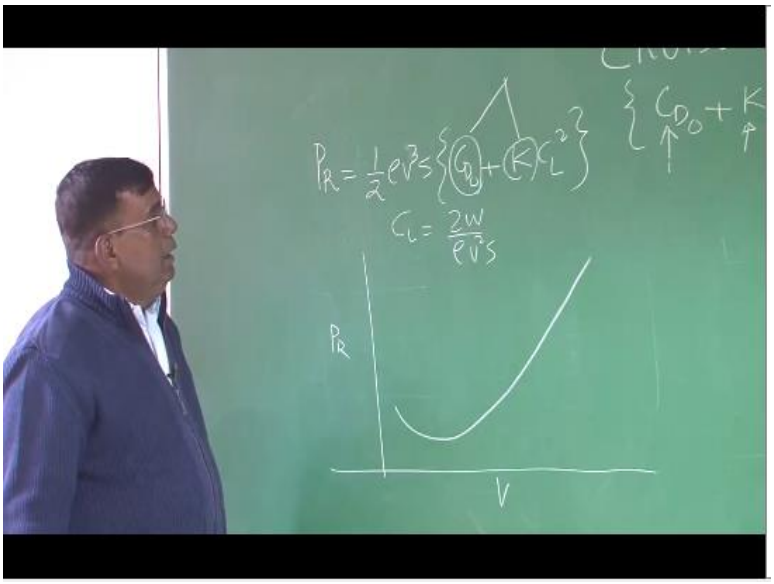

And then if you want to find out if small available was this let us say of a engine if this is power available then you can find out what is the speed at which rate of climb will be maximum, I repeat again a C_D knot and K you have estimated from flight test now you are finding power required and the plotting the power required here, now for different engine setting you want to check how much rate of climb it can have so I can easily use this plot to find our rate of climb and how to do that what is the physics behind this.

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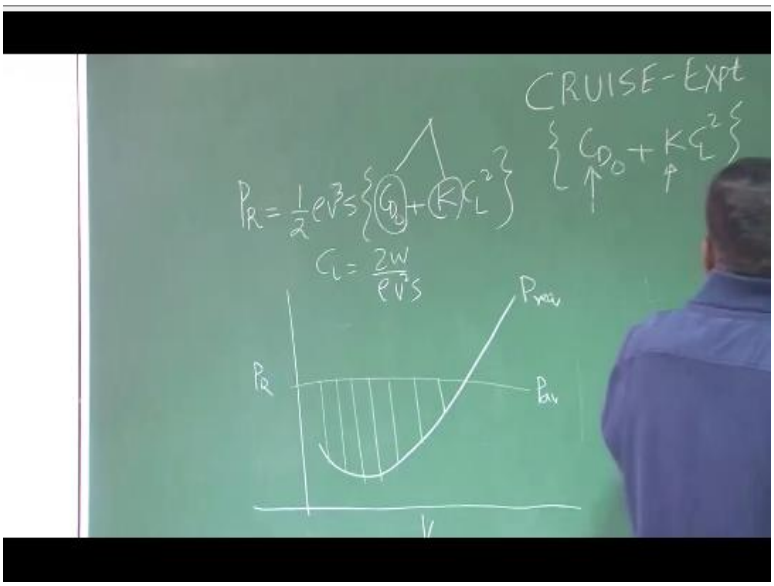

Let me discuss so that you are comfortable, I am sure you have done all these things and this things will be on your fingertips. Remember this diagram this is the air plane, this is the trust this is the weight the lift and drag so we wrote for a steady climb that is climbing at the constant speed, I write the equation like this along the V direction. This is V direction T-D-W sine gamma equal to M DV/ DT for gamma you know the flight path angle but for a steady climb this gentleman will become 0 ,so I write this equal to zero, so what you get T- D is equal to W sine gamma or T into V minus D into V by W is equal to v sine gamma.

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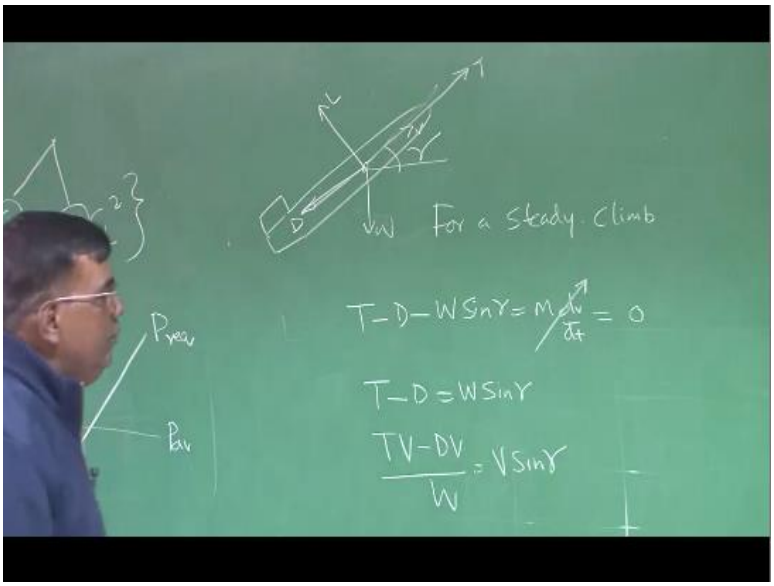

These are all stuff I am sharing with you multiply by v and then divided by w what is the sine gamma if you recall if the gentleman is going with v here V sine gamma is the vertical component so this is typically is the rate of climb okay ,right. So now I can write the rate of climb is equal to TV minus DV by w so now here you see TV minus DV, DV minus DV is what its power available minus power required so from this graph you could see this is all available power required so at different speed this excess power which is difference between power available and power requirement is going on changing in fact it goes on increasing comes to maximum then again goes on decreasing right.

So with this graph you should be able to see what is that speed like the v-star activation to the excess power is maximum so that time you should give this v-star should crush on to rate of climb maximum and that will take you this part are clear.

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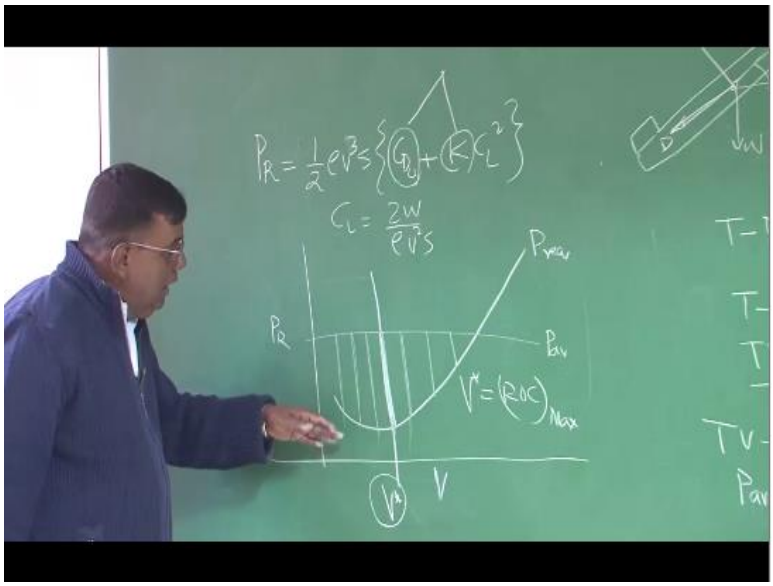

This is the excess power and you can see this excess power is gradually increasing then again decreasing so there is a point v star where this excess power is the maximum as his excess power related to rate of climb for this v-star respond to a rate of ground maximum for that attitude okay these are understanding.

So you do it offline now we experiment which I call climb experiment will essentially see how to get this v-star through experiment. Again once cruise is over, we say now going for the climb experiment as a ritual note down the altitude note down the outside air temperature, now this is a V unless the pilot says I am climbing so note down the is H1 note down what is h2 once he says that my climb is over.

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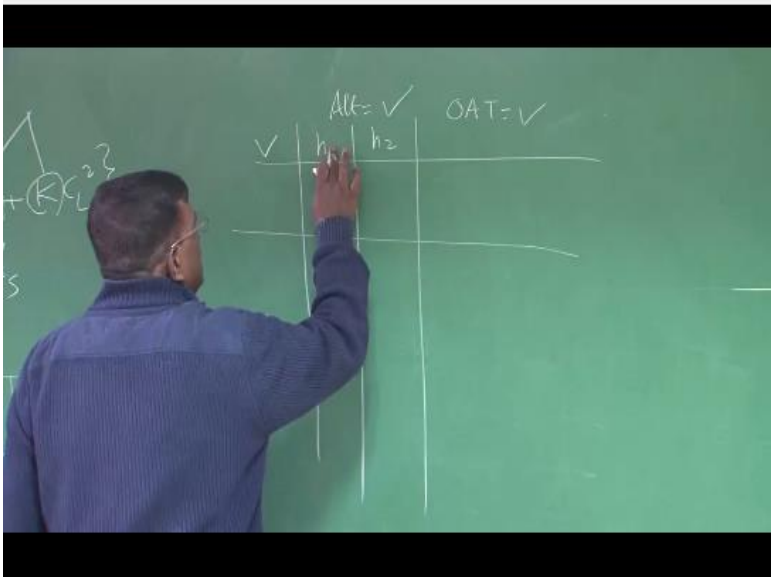

So I said V1 is climbing ,this is h1 this is h2 where he says I stop climbing and now you note down what is the time taken to go from H1 to H2 .Does he stop off nor does people use the mobile so you could see that rate of climb approximately will be equal to delta h by delta T if you see my earlier notes this is approximate values it is not very accurate because the altimeter is calibrated instead most fears so because refer back to my notes there is a correction of ratio of densities to be applied but mostly we had conduct experiment within thousand feet so that difference is not much but fundamentally should know I refer back to my performance lecture.

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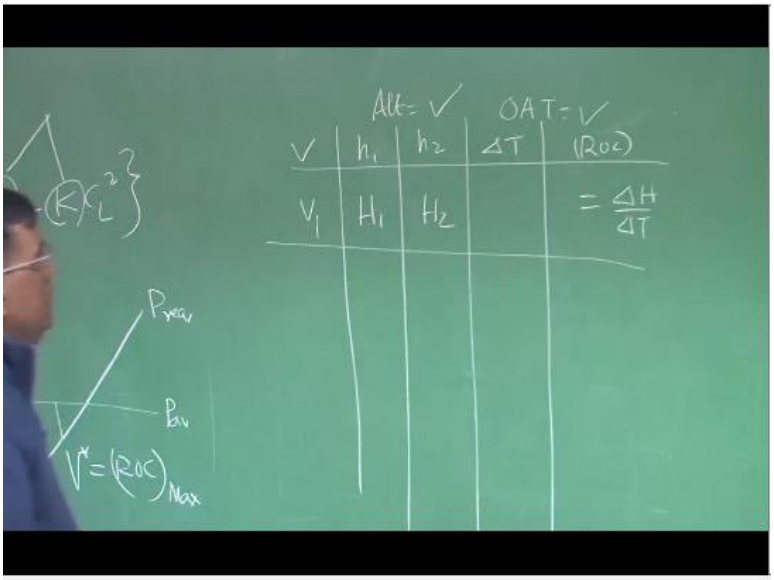

On this similarly pilot again will carry out another climb at different climb defendant speed so have delta H by delta T different values of delta H by delta T for corresponding to different speeds once you have that, once you have that life is simple what you will do we will just cross the plot rate of climb which you have obtained three experiment to this column.

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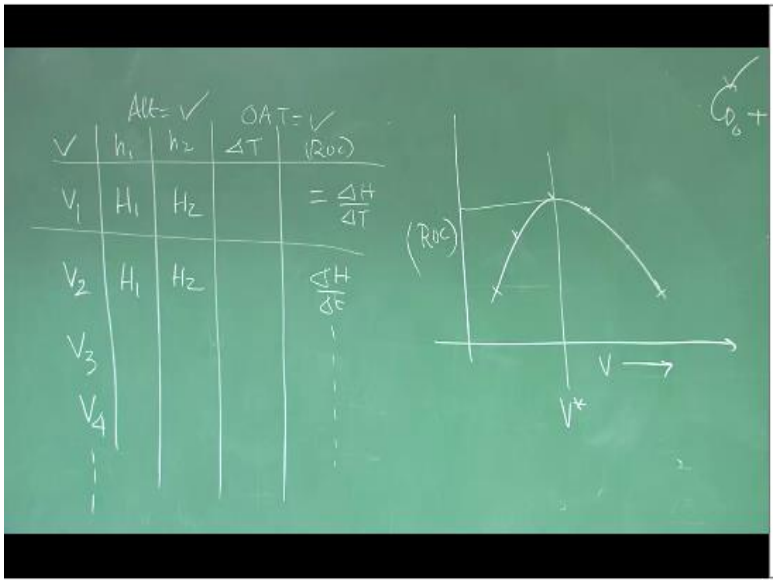

And we plot this plot will come like this and join them and this is the point if you see where rate of climb is maximum cycle exist are and to that experiment whatever v star you get and through this theory whatever you get this v-star are and that v- star should be closed. Then yes whatever physics we have got that is getting validated. So this is one of the experimenter are called to climb experiment you can conduct these experiments at different altitudes and then find out service selling okay but we do not do it here but you should know this you can do extend this experiment to get service selling etc. right.

I hope I have made it clear what we will be doing after this how to take away that the physical demonstration where students from MIT Chennai will be conducted be participating in web and experiment similarly will be doing some cruise experiment some videos will show you how to take the readings and how to do the calculation this is I told lose 10 hours module just to warming you up how to conduct experiments. And once you are happy will try to see that as you present return to invite to all of you here and do the experiment yourself thank you very much.