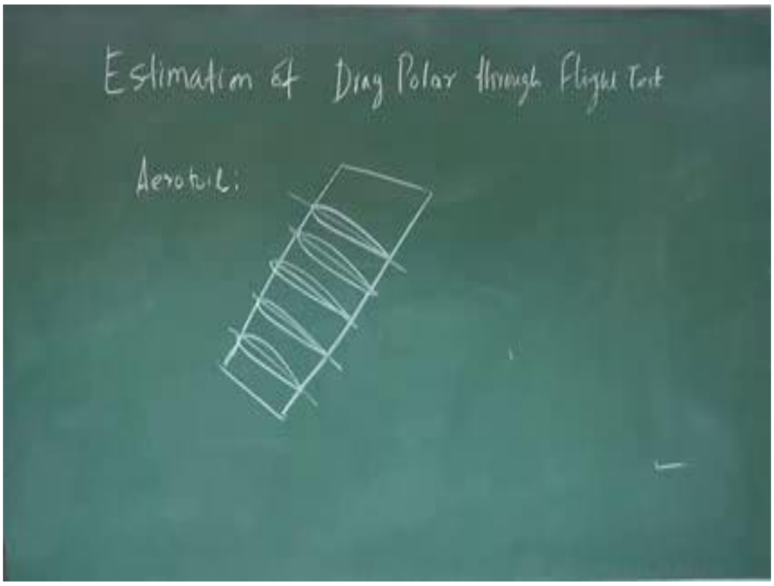
NOC: Introduction to Airplane Performance
Prof. A. K. Ghosh
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture - 17
Estimation of Drag Polar Through Flight Test

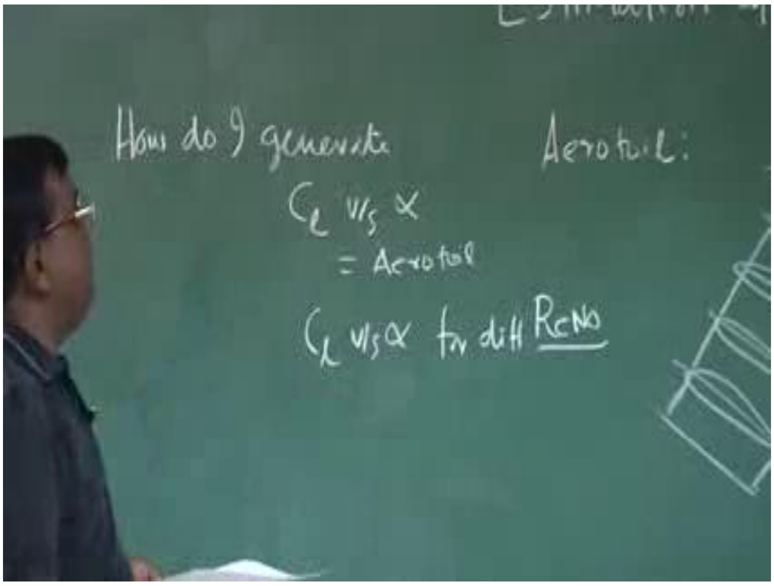
Good morning friends, now again fly the aircraft and try to understand, what about we have designed, what are the configurations we have, let out aircraft, an aircraft is flying. Is it possible to validate? Whatever you have designed, you are achieving the same or indirectly or directly, I am asking a question, can I estimate the drag polar of the airplane through flight test that will be the thrust for this lecture.

(Refer Slide Time: 00:42)



Before, we do that, let us recall, we started with aerofoil, they are basically contours with an infinite span, infinite aspect ratio to ensure the flow is always along the chord and wings are composed of, if you take any cross section, we will get the aerofoil shape. Please also understand that it is not necessary that CM aerofoil will be used at every location along the span of the wing. We will try to know, if time permits, how do I decide, where do I put, what type of aerofoil.

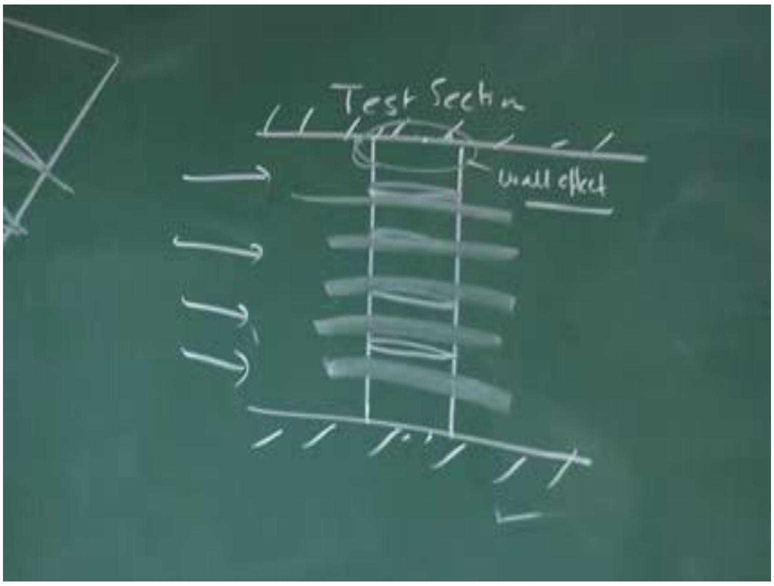
(Refer Slide Time: 01:37)



Now, suppose you ask me a question, how do I generate, how do I generate C L two dimensional C L versus alpha for aerofoil. Do you think you have to ask me a complete question, is it a correct question. It is no, it is not a correct question, question is not complete, the question should be, how do I generate C L versus alpha for different Reynolds number. Reynolds number, this is important, because we know that C L depends on Reynolds number also and very importantly, yes.

So, if you now ask me second question, how do I generate experimentally, because after aerofoil are infinite span as I try to explain. But, remember, why do you saying finite span? We saying finite span, because we do not want any flow to go like this or any flow to come like this, that is why I have seen modelling infinite.

(Refer Slide Time: 02:55)

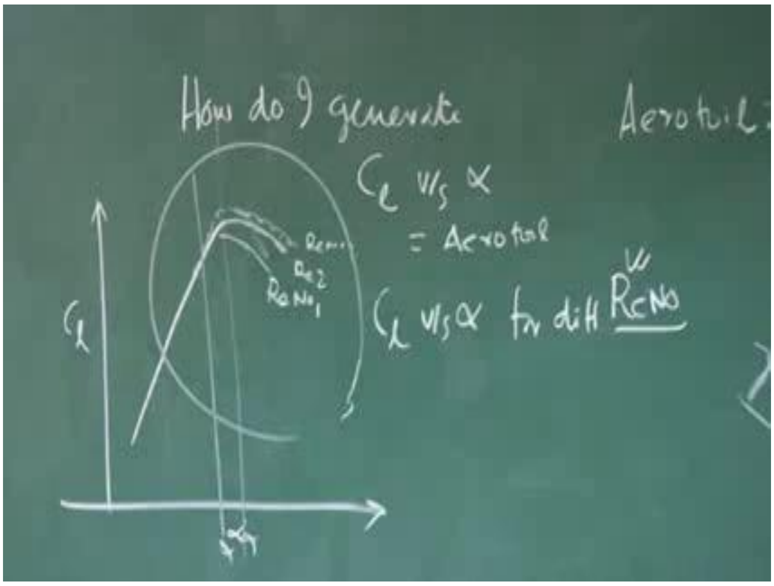


What is the practical pragmatic way of doing it is, go in a tunnel and end-to-end; you put a wing, which is having shape like this. So, contours decided by the aerofoil and now you made the whole wing, it is just touching the wall of the wind tunnel. This is the wind tunnel test section. And air is going like this, if the wing tips are not touching the wire, then it would have behave like a finite thing, there is a gap, flow will come like this.

So, by ensuring that they are touching that test section wall, we are avoiding that, but warning some effect here, near the wall, which is wall effect, which can be handled through calibration. Mostly the flow will be along the chord, a two dimensional flow and it is what is consistent to our understanding of an aerofoil. So, I will put a load balance, I will go on generating measuring C l for different, different angles.

But, since it is for Reynolds number, so I must ensure, what is that angle and what is the Reynolds number. So, I can go on generating different values of C l for a given angle, I go on changing the Reynolds number. I can change the Reynolds number by changing speed, by changing density of inside such tunnel, too many combinations are there, I can change the Reynolds number.

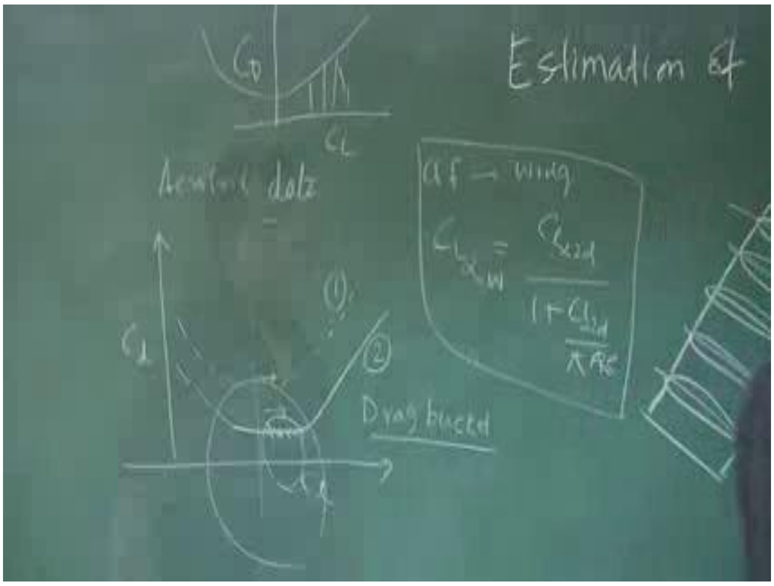
(Refer Slide Time: 04:47)



So, typically if you see database of aerofoil, which will give you the C l, C D characteristic for different aerofoil. There means generated through experiments and each aerofoil is nomenclature depending upon, what is this known radius, what is these thickness to chord ratio. You and there are this is termed as nomenclature; we will try to adjust that nomenclature, before I come to some aspects of design.

But, if you see this C l versus alpha graph for any aerofoil you pickup, you will find this given like this and here for different Reynolds number 1, Reynolds number 2, Reynolds number 3. So, you will find same alpha, but depending upon Reynolds number, the C l value go on changing. So, this is very, very important to capture and make you understanding very clear.

(Refer Slide Time: 06:11)



Once, you have knowledge about this aerofoil, aerofoil to wing or finite wing, we know how C l alpha of the wing is related to C l alpha 2 d of aerofoil, this is something by C l alpha 2 d by pi aspect ratio e, this is already we have done. So, we do this correction and try to find out the total C l of the airplane by taking, estimating C l of other component as well. I am only focusing on the wing and same thing can be extended directly for tail also.

But, we are talking about drag polar, so we will try to understand little bit on drag part also, very small part, very important part. If you see 2 D aerofoil data aerofoil data, we also see data sheet or the database gives C d versus C l something like this. Some are something like this, depending upon what type of aerofoil we are using; that is depending upon what type of contour you are using.

What is the maximum to tails, what is the leading radius, all such issues are there and you can customise your aerofoil. But, what is important here, if you see as C l is increased let us say this, if I concentrated this part, I am saying there is an increment in C d. Almost, like it may be may not be correct, but almost like a quadratic, but it is not a correct statement, but train wise, you may see, it is a almost quadratic.

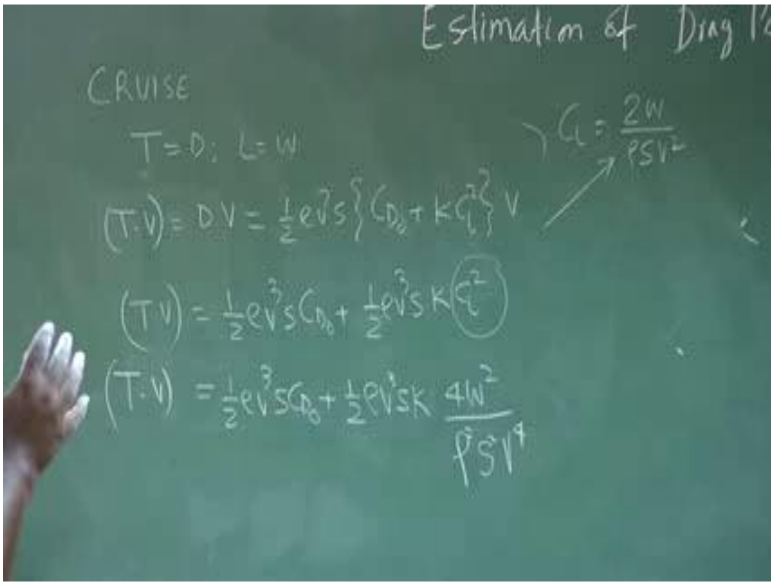
So, what do you think, is it the because of induced drag, that is my question, is it because of induced drag; that is my question. Please, understand I cannot talk of induced drag, when I am talking about aerofoil; be very clear, because this is an infinite span. So, there is no question of finite wing effect. So, this train of increase in C d because of increase in C l should not be interpreted as contribution, because of induced drag.

For 3D for a wing, we have seen C D and C L graph go something like this, you know and this part all these seen as increases, because we talked, this is because of K C L square term C D naught plus K C L square; that is the drag polar. But, when I see a 2D aerofoil, the caution is this increment is not because of induced drag. This is primarily due to the flow separation and this is a complex field and people are working in this, I have been talking to one of our honoured researcher.

So, and I could get this feeling that, yes, lot of fundamental work is also going on into this. This is one, second part, you will see some aerofoil data where C d versus C l have a bucket type shape, we call it drag bucket. What is the significance of or importance of drag bucket or how can I use this? Using one thing, if I am flying the machine C l close to this drag bucket zone, then there is hardly increase in C l because of this.

But, if I am flying somewhere here, then I will have unnecessary increased in C d, because of increase in C l; in addition to induced drag; that is of the different. So, a good news an aerofoil try to select the C l, so that I am operating somewhere in this drag bucket or if it demands the standard aerofoil, it is not able to fit that requirements, then you customize your aerofoil. Knowing this now, we want to estimate drag polar through flight test. Now, it is something like this, you are given an aircraft, you are a pilot and this told to you, go fly and find out tell me, what is the drag polar of this airplane.

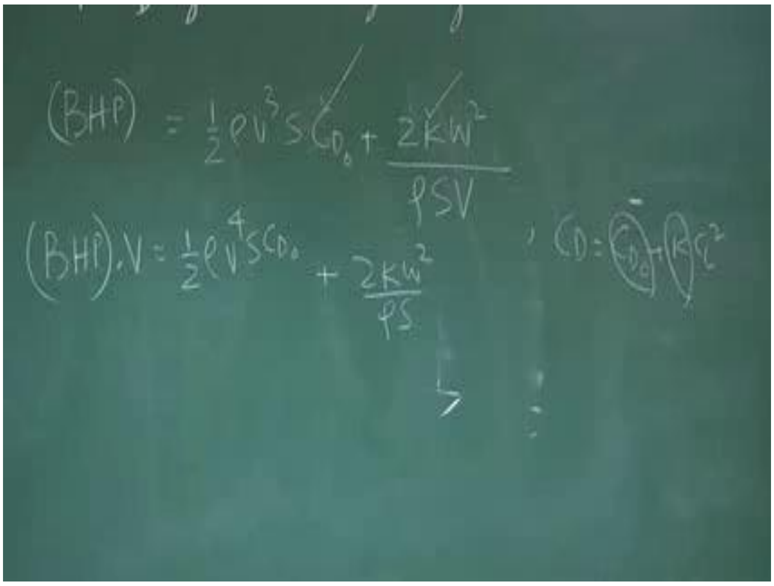
(Refer Slide Time: 10:59)



So, what we should do, we know one thing that, if I cruise, this thrust is equal to drag and lift is equal to weight, we are so much using this. So, I multiplied both side by V, T into V equal to D into V, which is nothing but, half rho v square S into C D naught plus K C L square into V. So, again I write T into V is half rho v cube S, C D naught plus half rho v cube S into K into C L square.

What do I do now? I now know that lift equal to weight. So, C L is equal to 2 W by rho S v square. So, what I do? I replace C L square by using this C L. So, I have now expression half rho v cube S C D naught plus half rho V cube S K into 4 W square by rho square S square v to the power 4. No objection, everything is fine. If everything is fine, try to understand what is T into V. T was what? T was equal to drag or thrust require equal to drag. If you going to cruise, I must ensure my engine is providing that much of thrust, what was T into V then, T into V is power available.

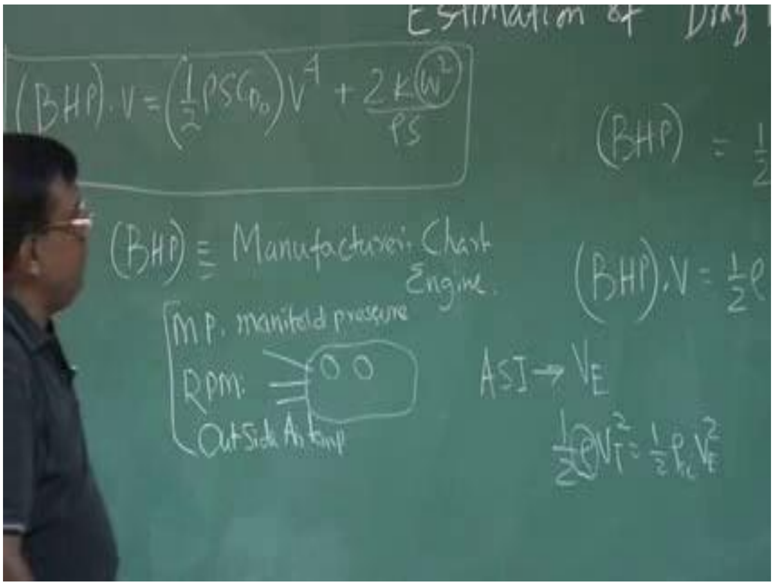
(Refer Slide Time: 13:05)



So, far our understanding will be write T into V, so that we do not get mixed up and as break our power, keeping in mind that, this is available for the engine, this is equal to half rho v cube S C D naught plus 2 K W square divided by rho S V. Now, what is our aim? Let us not forget, we want to estimate drag polar; that is C D naught plus K C L square. That if I can estimate K and C D naught from flight test, then I can express the drag polar as C D naught plus K C L square; that is a simple question.

So, my aim should be fixed to know clearly that, my aim is to estimate C D naught and K. Now, we do little bit of more arrangement, what we do multiply both side by V. So, what I have BHP into V is equal to half rho v to be power S C D naught plus 2 K W square rho S. But, if I do further rearrangement, I can write, let me write separately.

(Refer Slide Time: 14:37)



Because, we will be planning our experiment based on this expression by have BHP into V is equal to half rho S C D naught V to the power 4 plus 2 K W square by rho S. Let us ask ourselves, what are those variables, I can measure, what is BHP; BHP is engine parameters. So, engine manufacturer gift chart, they give calibrations. So, if you know, what is the temperature outside, what is the RPM, what is the manifold pressure. Manifold pressure means, the roughly it is the pressure at which the mixture is taking place.

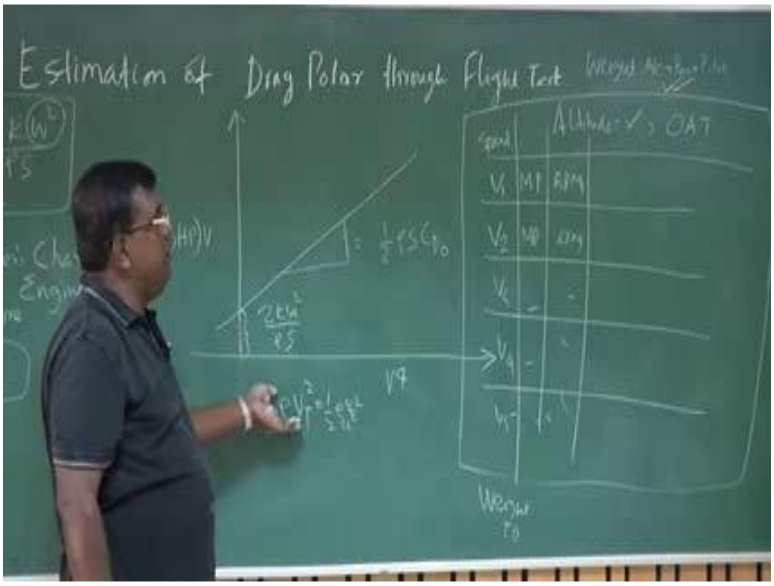
As far as the BHP is concerned, I can get it easily through manufacturers chart, engine chart we call it, engine chart, which essentially tells you, if I know manifold pressure, this manifold pressure, if I know RPM, I know outside air temperature, then using the engine chart, I can easily know, what was the power available from the engine at that speed. If you see here all this information in the corporate, you have seen in the corporate, there are instruments which will give you readings for a manifold pressure R P M and outside air temperature.

So, this is in my control, S is the wing area which is known, what is V, V is the true air speed, how do I get V, I know by now that we have air speed indicator, which gives me V equivalent. Remember, we write half rho V 2 square equal to half rho C level V equivalents V square; that is how the air speed indicator where calibrated. So, if I know V equivalent using this relationship, I can get what is V true.

But, for that, I need information about the local density there, I know outside air temperature. So, I can use this again, again I can find out rho, I can find a true air speed. The another important thing is W weight, the issue of weight is, when I go for takeoff, I will take the weight, passenger, fuel, etcetera, etcetera. But, when I am doing the cursing, actually some fuel is consumed and when I am doing cruising, fuel is continuously getting consumed. So, which one should I take, so best way to do is, what I do, when I try to do experiment, I find out how much time has elapsed.

And from air, I use the fuel consumption chart and see, how much fuel is consumed for that time and detached that much of fuel-form the weight. This is one way I find out. Second, what I do, second approach, what I do, when I land, again way the machine with all the passengers and then, take the average weight and if I will not come very off. So, this is how I get this information, but so what question is, I can measure all these things.

(Refer Slide Time: 18:39)



So, how do I find C D naught and K; that is the question, if I plot graph between BHP into V verses V to the power 4, what set of graph, we will get see BHP. So, I say Y equal to this is I am telling X, I call it m and this is plus C. So, what set of graph I should get, I should get straight line and this should be my 2 K W square by rho S, because that is intercept and the slope will be equal to half rho S, say C D naught.

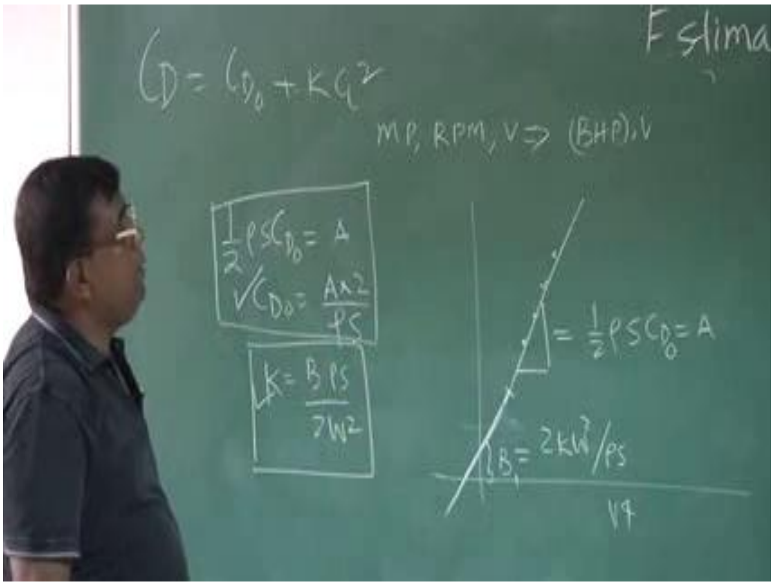
And once I measure this intersects and slope, I can find out C D naught and K, this is a understanding, but how do I do it through experiment, try to understand. So, what we should do, we will go for a cruise flight and then, we note down the altitude, who will give an altitude, the altimeter, it will give us pressure altitude, do not forget that. Then, I note down the outside area temperature, again we have a gauge to measure outside air temperature.

So, I take this ready, now I ask pilot to maintain a cruise with the speed V 1 and why should I not down, I note down this is speed and I note down the manifold pressure M P and R P M of the engine. These two I note down, once the pilot is with the cruise at V 1, we check the air experiment indicator, whether the speed is same or not, what you are looking for, you check the altimeter, but the higher is constant or not.

You check the bank indicator result level or not, once you say yes, note down what is V 1, note down what is manifold pressure, note down what is RPM. Then, again you request pilot to cruise at a speed V 2, again you note down, what is the manifold pressure, what is a RPM. You do it for 3 to 4 or 5 readings, take like this reading and then, you come down and take the weight touchdown. Of course, before you went for the experiment, you must take the width of the aircraft plus passenger, please note down, the aircraft plus passenger plus pilot, total weight and ticket.

A wiser man will note down the time will carry stop watch also, because we like to see, what was the time during, which I was not cursing, so he will try to find out the fuel weight and reduce from total weight. So, I know all this things, now it is simple for me, I will use a manifold pressure RPM outside temperature to find BHP, I will use equivalent air speed density to find V by using relationship half rho V 2 square is equal to half rho V square, rho C level, V square. Rho I will find out through outside air temperature and standard atmosphere table.

(Refer Slide Time: 22:40)



And now I will plot, what I will do, so what is done, you know manifold pressure, you know RPM, you know V, so you are calculating the BHP into V. So, this is V 2 by 4, you know V of this point and whatever BHP do V I got get this point like this, some points and then, the straight line. Because, you know that, they will follow straight line. Some time, you have to find the best statement, because there measurement error. Once, I do that, then you take the slop and this equal to half rho C D naught.

Let us say this slop is a and this intercept is get is b and that should be equal to 2 K W square by rho is, so I know half rho S C D naught, this is C D naught equal to a. So, C D naught will be equal to a into 2 divided by rho S and K will be equal to b into rho S by 2 W square. So, from there, you now know, what is the value of C D naught, what is the value of K.

So, you postulate C D equals to C D naught plus K C L square; that is how you can get drag polar, estimate drag polar through flight test, is it not wonderful. If you are happen to come to Kanpur, you are welcome send me an email, will give an opportunity to conduct this experiment.

Thank you very much.