Introduction to Flight
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Lecture 08.1
Steady Level Flight

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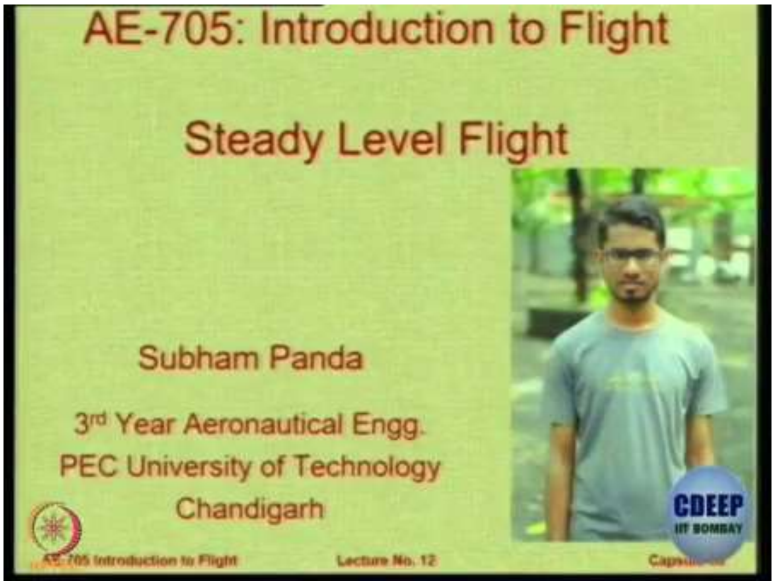

So, welcome to the 12th lecture of this course which is the 2nd of capsule number 6. Today we are going to move on to basic exposure to flight performance and the most basic activity in flight performance is indeed the steady level flight. So, our task today is to get familiar with the issues regarding the steady level flight both from the point of view as a performance engineer in the beginning, so we will derive some expressions and then we will wear the cap of a pilot and try to understand how pilots are trained to maintain steady and level flight. This particular presentation is based on the content generated by an intern called Shubham Panda. First let us get an idea about what exactly is steady and level flight.

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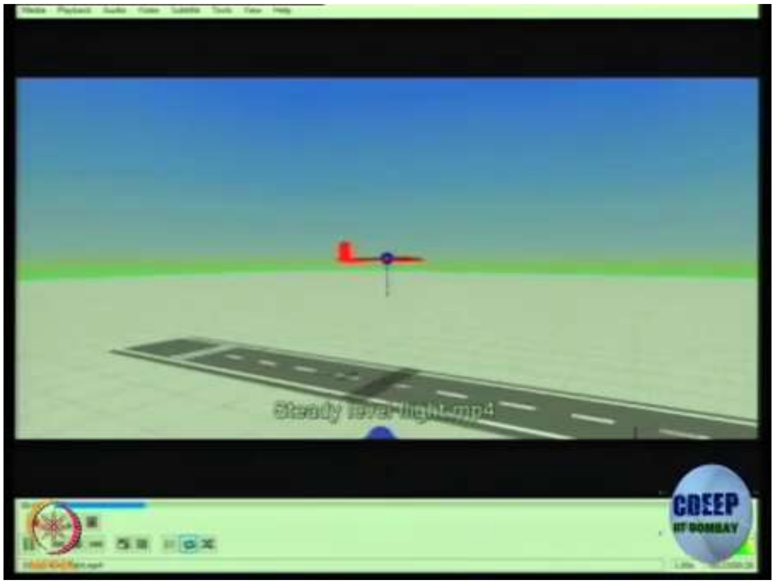

There are two words here steady and level, so let me first show you a small simulation of a steady level flight on a simulator. So, what do you see when you see this simulation? Ok, what do you observe in this particular simulation? Or in another words, how can u say that this flight is steady in level, yeah anybody? Well, you have in front of you a simulation, what do you observe? Yes.

Student: Sir, the rate of climb, flight over there is not climbing it maintains the same level.

Professor: So, you said something about rate of climb being zero and what else?

Student: I think it is moving at constant velocity.

Professor: Constant speed, right? So, what about the altitude?

Student: Remains constant.

Professor: Remains constant.

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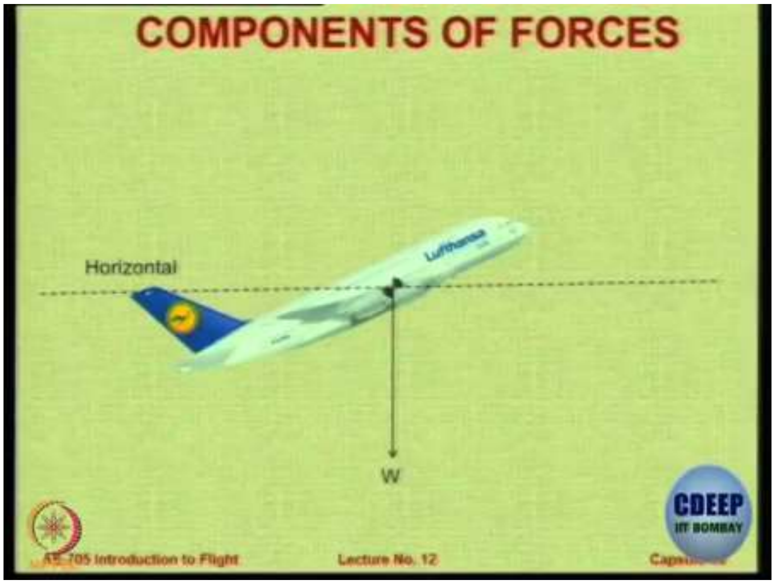

So, steady level flight is when you are operating at a constant speed at a fixed altitude. But whatever be the situation, whenever the aircraft is flying, there are a few forces acting on it. So, today we will start by looking at the components of the forces acting on the aircraft in a steady level flight. So as you can see, let us assume there is an aircraft now in this animation or in this figure I have shown purposely the aircraft at a very high angle. Normally, aircraft do not fly at such high angle in steady level flight, but this is just for the purpose of illustration. So, you have an aircraft which is flying and we assume that the flight is steady and level. So, there is a center of gravity of the aircraft which we assume is at that point shown in the figure.

So, that is the point at which the net weight of the aircraft will be acting vertically downwards. The aircraft does not go on the horizontal flight path; it goes along a particular flight path which is at an angle θ with the horizontal so that is the flight path angle. In other words, the aircraft is going to move horizontally but along that particular line. Now, in this case it is not necessarily in steady level flight this is in general, ok. So, in general aircraft is going along a path where the angle is θ. So, there will be a lift force acting which will be perpendicular to the flight path, ok. But, there is an angle called as the angle of attack which is the angle between the flight path and the chord line of the aircraft or the main reference line of the aircraft that angle is α, ok. There is also drag acting on the aircraft which is along the flight path and there is also the thrust force acting on the aircraft which in general is at some angle α_T compared to the flight path. Is there any other force acting on this aircraft? That is all, the four forces which act on it.

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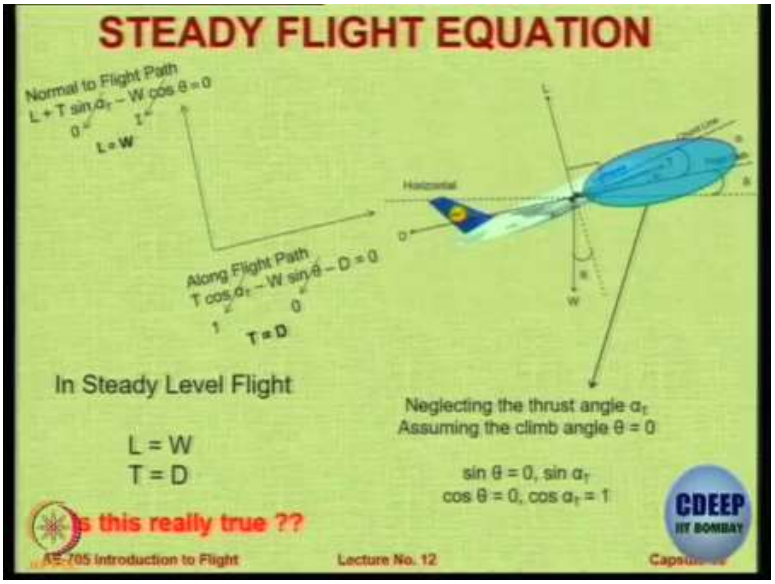

Let us look at now the equilibrium of these forces in steady flight, the same picture I am reproducing here. So, if you resolve the forces along the flight path, then you can get the thrust into Cos times the angle of mounting of the engine minus weight times Sin θ. These are going to be or minus drag force will be equal to 0. And similarly, normal to the flight path you will have a balance of the lift force, a component of the thrust force which will be acting upwards in this case and it will be oppose by W Cos θ. In other words, now if we look at steady level flight, let us neglect two things; let us neglect the angle of mounting of the engine just to make the equations a bit simpler for you.

So, $\alpha_T = 0$, similarly let Cos θ be a very small angle. Let us say α_T is not zero, α_T is very small, let us say couple of degrees. And let us also assume that θ is also very small 3, 4, 5 degree. So, therefore the Sines of these angles are going to be equal to 0 and the Cosines of the angles are going to be, ok. So, Cos θ will be 1 actually, not 0. So, this equation will become very simple, lift will be equal to weight and thrust will be equal to drag. If that is the case, then in steady level flight, it is a very simple expression that lift will be equal to weight and thrust will be equal to drag, but is this really true? So, if it is not true then what is the real story? Do you agree with this? Because many of you were nodding your heads when I was deriving this expression, which means you agree with this explanation. So, now I say that something is wrong. So, let us see what is wrong, let us see how the forces are balance ok.

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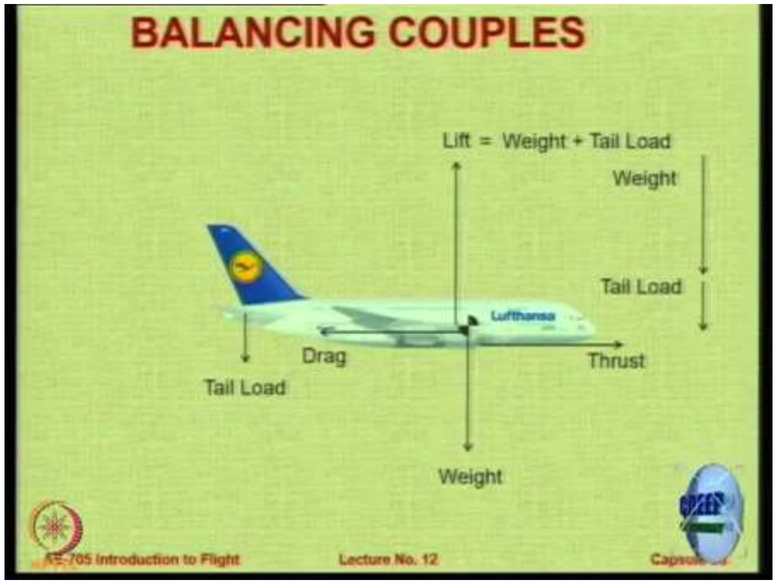

So, once again now, because the aircraft is in study level flight, I am not showing any angle. So, the first force I will talk about will be the drag force which will oppose the flight. To cancel that we need to have that thrust force which will be equal to drag because if thrust is more than drag, you cannot get steady flight, you will get level accelerated flight. Weight is a force acting vertically downwards, but the lift force does not necessarily act at center of gravity. So, the lift force typically will act at the quarter chord of aircraft or at the aerodynamic center. Therefore these forces are going to create a couple ok that couple has to be balanced by a force acting on the tail.

In this case the orientation of lift and weight is such that there is a moment in the nose down direction, so there has to be a down load on the tail to give a moment. So, this down load on the tail means the lift has to be more than weight otherwise, the aircraft will start sinking. In other words, the lift force generated by the aircraft has to be equal to the weight of the aircraft plus whatever is the tail load to balance the aircraft in level flight.

Now, in case we have a situation where the center of gravity is behind the place where the lift acts, then the direction of the lift force or the tail load might reverse in which case that is going to help in which case lift will be less. Similarly, if we use the canard which is a tail mounted in the front, then the nose up or the nose down between moment can be cancelled only by a vertical load on the canard. So, that much lift can be subtracted from the lift of the wing and that is one reason why we use the canard because it allows you to manage with lesser lift requirement, because the tail load in this case the canard load is helping you in carrying the aircraft up so therefore in reality, lift is not equal to weight. Similarly in reality, the thrust and the drag forces also they do not act along the same line so they also create a moment that moment can cancel or oppose or support the other moment.

So, it is a very simplistic assumptions that lift equal to weight, thrust equal to drag, and we will live with the assumption because if we do not do that then the equations become little bit more complicated, ok. So, from now on we take this statement with the pinch of salt, ok.

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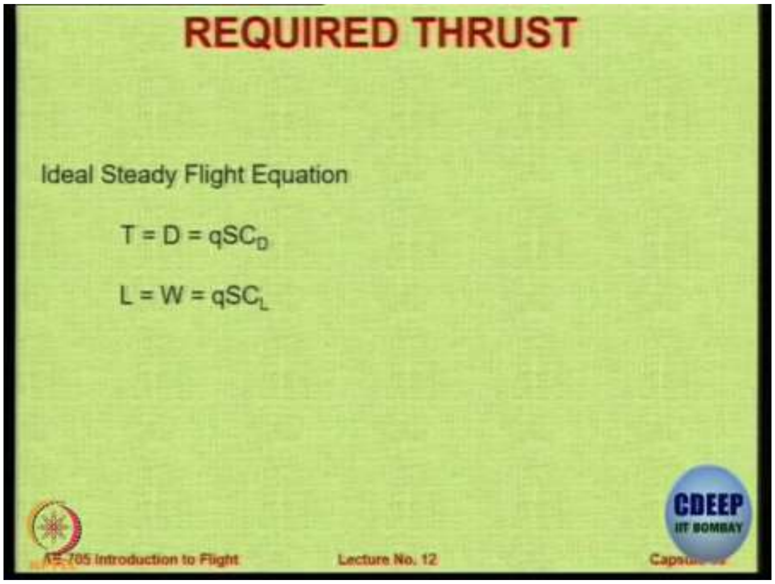

Let us see how much thrust is required if you want to fly level, the answer is simple it is equal to the drag that is created. So, the drag that is created is equal to the dynamic pressure $\frac{1}{2}\rho V^2$ or q times S being reference area times drag coefficient Cd,

$$T = D = q\ S\ C_D$$

$$L = W = q\ S\ C_L$$

q is again $\frac{1}{2}\rho V^2$ dynamic pressure. So, with this you can easily get an expression, that the thrust required will be nothing but the L/D of the aircraft during the level flight divide by the weight of the aircraft.

So, you get a very simple logical understanding. If you want to fly at a particular speed at a particular altitude which means dynamic pressure is fixed, speed and altitude are fixed, therefore q is fixed. And if you want to reduce the thrust required, you have one of the two options, one option is make the aircraft lighter or reduce the weight. What should you do if you want less thrust required? But can you change the aircraft weight? That is something which is already fixed and aircraft with a particular amount of pay load, particular amount of fuel is going to have a particular weight. So, you really cannot arbitrarily change W, unless you add fuel or dump fuel etc or being very cruel dump people and add people. So let us not touch W, therefore you have only L/D available to you, but can you change the L/D of the aircraft? Lift over drag ratio of the aircraft. Is it possible, what do you think?

What does it depend on? For a given aircraft, the angle of attack at which the aircraft is flying. So at different angle of attacks, the aircraft with different L/D. so, if you want to fly at a condition where the thrust required is minimum, why would you do that because you would like to consume less fuel. The pilot will then choose an angle at which the L/D is $\left(L/D\right)_{max}$ and for a given aircraft weight that would be the condition or the operating situation at which the thrust required will be minimum. Yes, take a mic please.

Student: Should it be L into D?

Professor: Should it be?

Student: L into D.

Professor: Why should it be L into D?

Student: D into W is equal to the D into L.

Professor: So, you see it yourselves. See, if T equal to D and L and W are same then I can multiply. So, do you think that L by D should be more or less?

Student: Sir, in the formula it should be L into D upon W.

Professor: You are right; there is a mistake in the formula. Correct, I did not realize. There is a mistake in the formula. So, this formula we will correct, ok.

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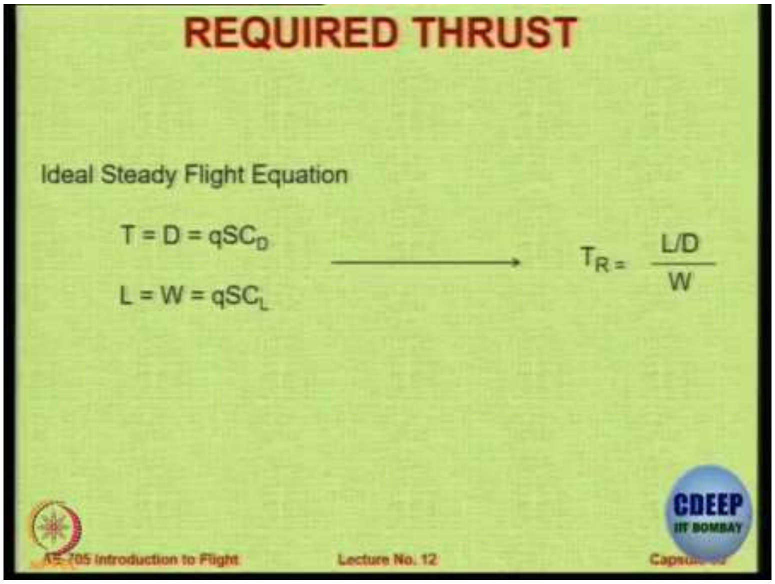

So, basically it will be the other way around, 1 by L by D. So, when L by D is more, T required is less, ok. So, whether you say it depends on where you take it so, I want to bring in L by D because L by D is more important. So, as the L by D increases, the thrust required is going to reduce, ok.

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Right so, in an attempt to reduce the thrust required in flight, one way is to reduce the drag and aspect ratio is one parameter of the aircraft which allows us to reduce the induced drag. So if you increase aspect ratio such as in this particular aircraft it has a very high aspect ratio of 12.8. The L by D increases and hence the thrust required reduces, ok.

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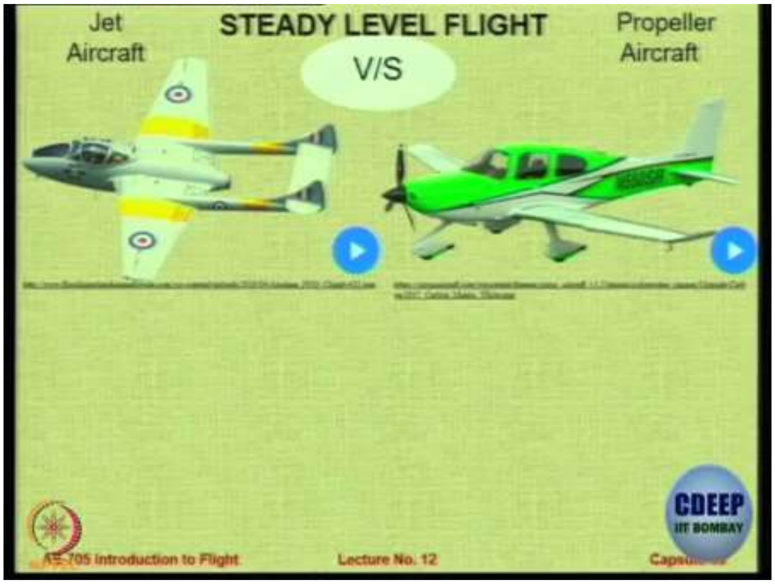

Let us compare the level flight of a jet engine aircraft such as the one shown versus that of a piston engine aircraft so, first let us have a look at the two. Is there any difference visible in the way they fly? Let us see.

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So her is Jet engine aircraft in level flight.

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And here is the piston engine aircraft, so is this aircraft actually in level flight, we cannot say because we zoom so much that we are not able to see the relative location between the horizon and the aircraft, ok.

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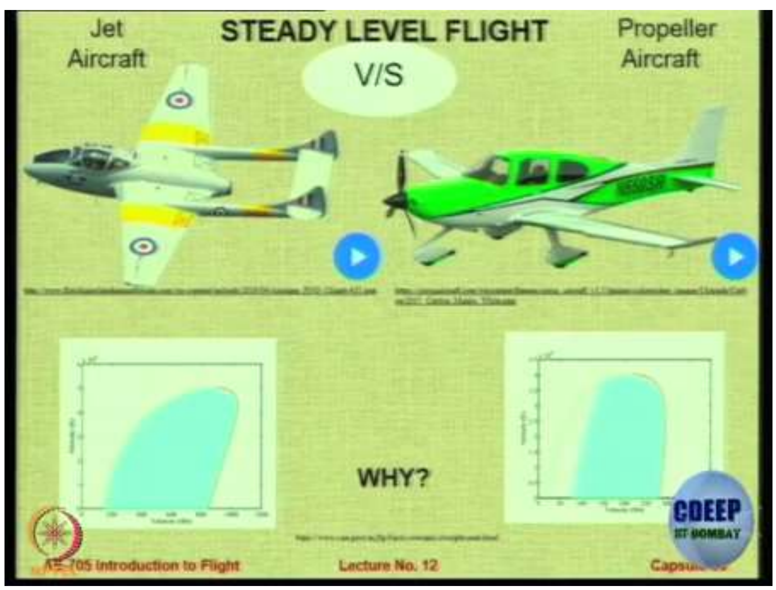

So, we see that if you draw the operation graph or the operating envelope of these two aircrafts, we notice that the range over which speed can be maintained or the range over which the level flight can be maintained is much, much larger for one aircraft type and smaller for the another aircraft type and also the effect of altitude and Mach number is also a bit different. So, let us have a look at why there is a difference in the operating envelope, ok.

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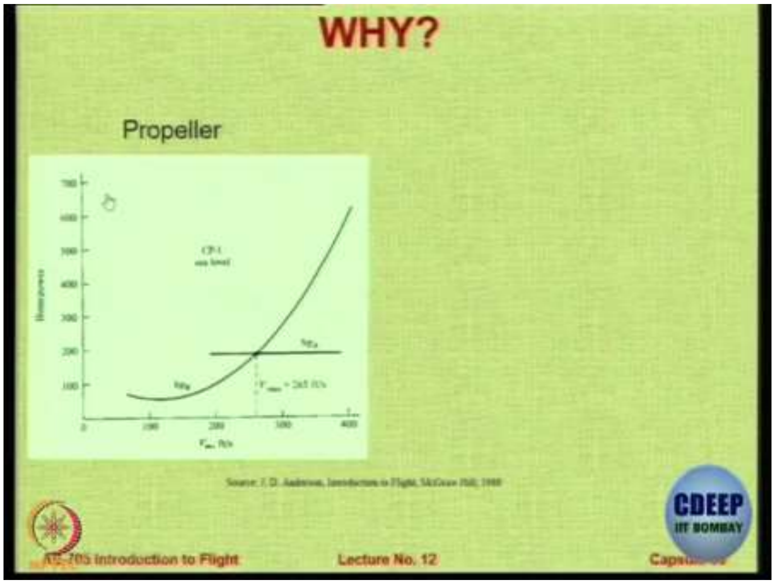

So, I have borrowed some material now from the standard textbook that we use for this course, the book by Anderson, ok. In Anderson’s textbook, he has taken two examples, one of them is called as the Cp1 which is a propeller driven aircraft and then there is another one which is a jet engine aircraft and he has derived the entire performance formulae for these two aircraft. So, we were also expected to go through that and self study. This is important because you have to go beyond the classroom, the classroom is not the complete story; the classroom is only a curtain raiser. So, I am going to assume that you are going to read the performance portion from the book by Anderson for this and the next two capsules because, in the next three capsules we are going to cover aircraft performance.

So, here is the data for an actual piston engine aircraft, we have one horizontal line which is approximation for the power available of this aircraft as the velocity changes. So, here the assumption is that for a piston engine aircraft at a given altitude, the horse power available remains constant as velocity changes. It does not remain constant; it changes slightly but assuming it as a straight line is easier for classroom discussion ok. And the required horse power to fly at a particular speed, it is increasing in the way that is shown. So the intersection of these two lines will give you the speed at which you can fly maximum. because, beyond that speed the power available will be less than power required so the intersection on the right hand side. Now there is also typically an intersection on the left hand side ok, but it is not shown here.

So, you can see that there would be some value of minimum speed which is the stalling speed actually, and there is some value of maximum speed which is the speed at which power available is equal to power required. So, that determines the operating range or the possible operating range of the aircraft.

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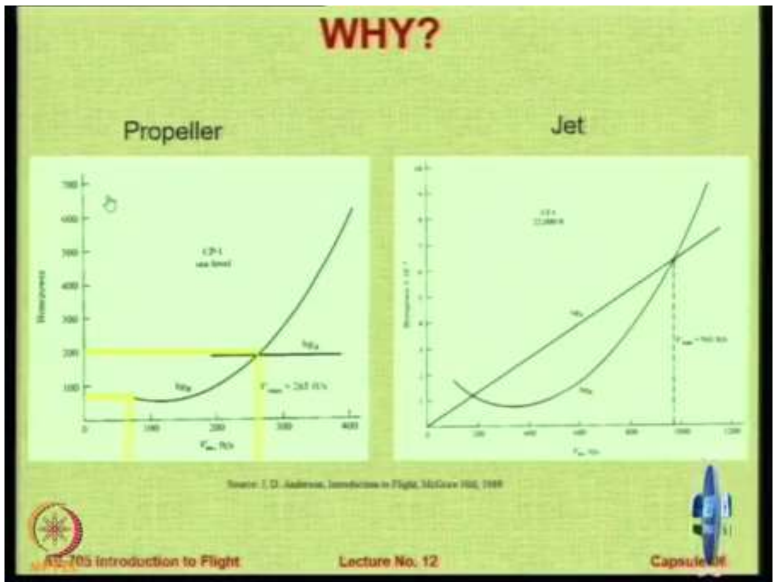

There is a similar graph available for a jet engine aircraft. The difference is that in the case of jet engine aircraft is the thrust that remains almost constant with the speed at a given altitude not power. So, if the thrust remains constant, power is thrust into velocity so if T remains constant and V is increasing then the line that is plotted between power and velocity is going to be basically something like a constant into velocity so it will be a straight line.

So, this is the line for and the inclination of this line is a function of the power plant characteristics. So, you will have a line starting from origin linearly increasing as the power required with velocity and you have a similar curve sorry for power available and this is the power required curve. Here they have shown two intersections; the one on the left is the intersection that shows that there is a low speed also at which power available equal to power required. Now if this speed is lower than the stalling speed, it is meaningless because, you cannot fly below stalling speed. In fact from safety point of view, you actually cannot fly at may be 1.1 times below the stalling speed, ok.

So but however if the stalling speed is much lower than this speed then this intersection has any meaning, so again we see that there is a range, now the range of operation here appears to be larger for the jet engine aircraft, ok.