NOC: Introduction to Airplane Performance
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Lecture - 20
Range and Endurance

Yes.

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So far, we were discussing about aerodynamic efficiency, that is, CL, CL by CD – a drag in particular separately. And, we were looking for how much lift the airplane can generate to balance the weight. But, we have seen that, we need to have an engine, which should produce thrust to counter the drag; and, the thrust is provided by the engine. And, this I am demonstrating an engine, which is piston driven IC engine. You could see here; this is a 4-cylinder engine; two cylinders here, two cylinders at the back. And, think of a scooter engine; there will be a cylinder; there will be intake; there will be exhaust. If there are two cylinders here, you could see there is one intake here, one intake here, and the common exhaust goes from here. And, there is a muffler here which also we have in a scooter. But, this is typically an IC engine, which is nothing new for us. We have seen in motorcycle, in car; only the difference between car, motorcycle and aircraft engine is a number of cylinders maybe different; maybe it is 4, maybe 6, maybe 8, because we need more power.

But, let us not forget about it. The fuel is burnt in the cylinder, which drives the piston; and, the piston then rotates the crankshaft.

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And, the crankshaft is somewhere here. You see here the shaft is here and there is a propeller, which is mounted on the crankshaft. Whatever energy is burnt in the fuel in the cylinder that delivers power at the crankshaft. And, from crankshaft, when I attach a propeller, the propeller draws that power, but propeller has its own efficiency; it will have some losses. So, you will find whatever power available at the crankshaft or the brake horsepower what you call or the power being made used by the airplane is less; that is, there is a propeller efficiency. This efficiency could be 90 percent, 95 percent. So, 95 percent of the power available at the break or the shaft is utilized by the propeller to drive this airplane.

Now, we will go to the classroom and we will try to see if I want to fly for a larger distance how should I fly; how the engine plays an important role. If you want to loiter in the air for longer time, how engine plays a role, and what configuration I should fly? All these questions we will be addressing. Now, when we are talking about fuel being burnt in the cylinder, the next question comes – how much fuel and where do I accommodate this fuel?

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If you come for most of the aircraft, we will find the fuel tank is in the wing. Here is the fuel tank; you could see here; one fuel tank here, one fuel tank that side. For a larger aircraft, there could be larger number of fuel tank. The most important part is please understand that, fuel has to go through the engine and the engine has got a driving pump, and that pump is used to pull a fuel and put inside the engine. So, all the engines will have its own driving pump; we call driving fuel pump. And, since this is the high wing, the fuel from here to engine comes by simple gravity drop.

Now, the question is – whether we draw fuel all the time from both the tanks; or, we can selectively take fuel from one tank and once one tank is over, I can take this other tank. So, that options are available. Generally, we prefer that, fuel should come from the both the tanks, so that it does not affect the centre of gravity. But, you can always select one fuel tank and fly for some small hours maybe half an hour or one hour and then switch over to the other tank. Or, you also may have options where you can use fuel from both the tanks. If the wing has got a high wing, the wing is somewhere here; then, I need to pull this fuel to the engine. So, there will be additional pump – fuel pump here which will primarily push the fuel from here to the engine. Then, the engine driving fuel pump will take over and it put the fuel inside the engine. So, most important thing we should understand that, we need to cater some space for fuel. The moment I put a fuel tank, not only the weight of the fuel is important, but also important that fuel tank is leak-proof and its weight is not very high; otherwise, it will change the wing loading. And also, we need to know that which fuel pump I will be using. And, the reliability of the fuel pump is extremely important for a good performance of an airplane.

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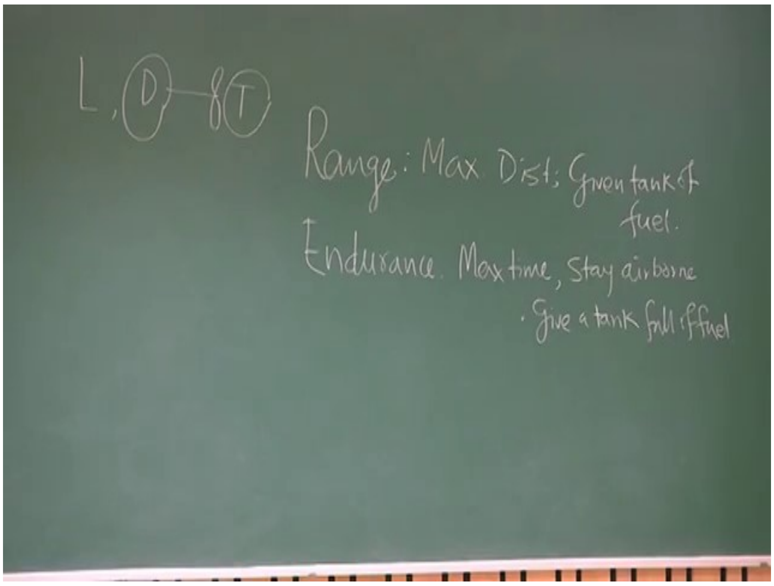

So far, we were discussing about lift and drag – lift and drag. And, we realized that, lift is required to hold the weight; and drag – for drag, we realize that, we need to put an engine and generate sufficient thrust. Now, we are coming one step closer to investigate some parameters of engine, which will finally affect the overall performance of the airplane. For example, if I am talking about range – range of an airplane; what do you mean by range of an airplane? It is the maximum distance it can travel for a given tank full of fuel; that is, range if I try to understand, it is maximum distance for a given tank of fuel. Similarly, I also may be interested to stay for larger time in air, which we call loiter. There we define a term called endurance. Endurance – here it is maximum time or hours I can stay airborne given a tank full of fuel. One can ask a question – why to increase the endurance or range? You go on adding tank, you go on adding fuel; the problem will be solved. The answer is not so straightforward, because as I add fuel, it adds to the weight; and, the weight means it changes wing loading; it makes the cost. And so, for a good designer, one needs to optimize its aerodynamic characteristics, so that for a given tank of fuel, I can get maximum range or maximum endurance.

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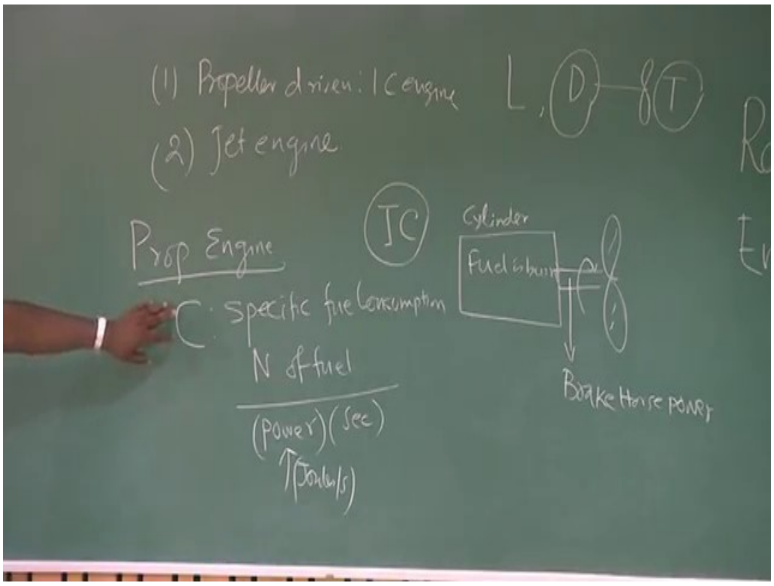

So, let us see; we have been discussing about two types of airplane: one was – it is propeller-driven – typically IC engine; another – second one we are considering is jet engine. So, we will be first talking about propeller engine, that is, if an aircraft is fitted with an IC engine-propeller combination; then, what is the maximum range I can get; that is, what is the maximum distance I get for a given tank of fuel. The secondary question, which is the most important question is – how should I fly, so that this distance is maximum for a given tank of fuel? We will now develop some foundation towards this understanding.

See for an IC engine, the principle is simple that, there is a cylinder, which I have shown you this just now. And, we will be seeing that again. The cylinders of fuel is burnt; fuel is burnt and there is a shaft; power is transferred to the shaft. And then, there is a propeller, which rotates – which generates the thrust or generate the power, because we have understood for a propeller-driven IC engine combination, these engines are rated in terms of power. So, we will be saying – the fuel is burnt and power is available at the brake. This is the brake or the shaft. So, you call it brake horsepower available. Then, we attach here propeller depending about propeller efficiency. Around 90 to 95 or 96 percent of this power is taken out by the propeller, which is used to drive the machine. If this is the understanding, then we need to understand something about fuel consumption. We are representing it by C, which we call specific fuel consumption. Typically, this is defined as Newton of fuel consumed per unit power per unit second; that is, for power, I will write joules per second. So, if I try to see dimensionally, what is a specific fuel consumption; it is the Newton of fuel consumed per unit power, which is joules per second per unit time second.

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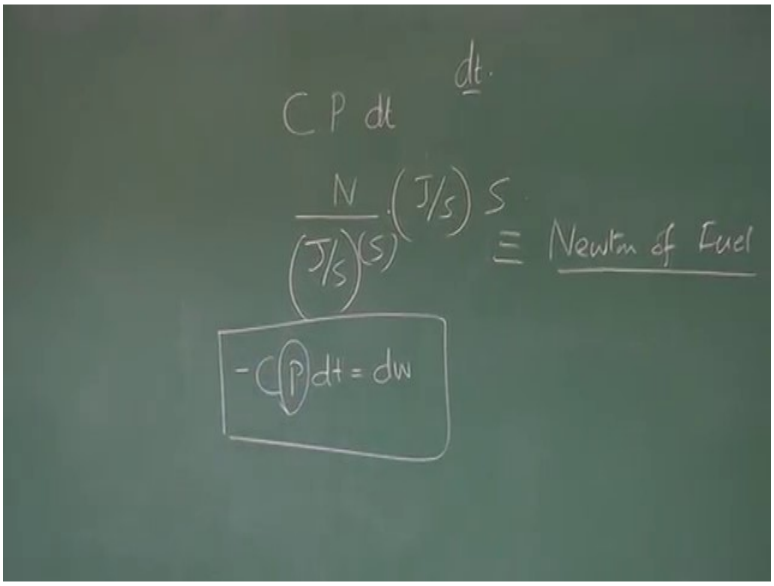

Now, let us try to understand what is C P dt. dt is the small incremental time during which the fuel is burnt, that is, during which the fuel is burnt and some power is developed at the shaft. So, what is C P dt? Dimensionally, if you see, C is Newton; this is joules per second second power again joules per second and time is second. So, you get dimensional; this is Newton of fuel. So, I know now if I multiply C into power into dt, then I get Newton of fuel, which is consumed. So, I can understand one thing; if everything is same, nothing is changing for an airplane when it is flying from one point to another; then, the change in the weight is primarily and only due to change in the fuel, because the fuel is consumed to develop this power. So, I will write C P dt as dw – change in weight of the airplane; I will put a minus sign to make it consistent that, this is a reduction in the weight. Before we go into next step to utilize this; before we go to the next step, let us have a closer look on this term – C P dt. I would like to know, I would like to understand better what is this P.

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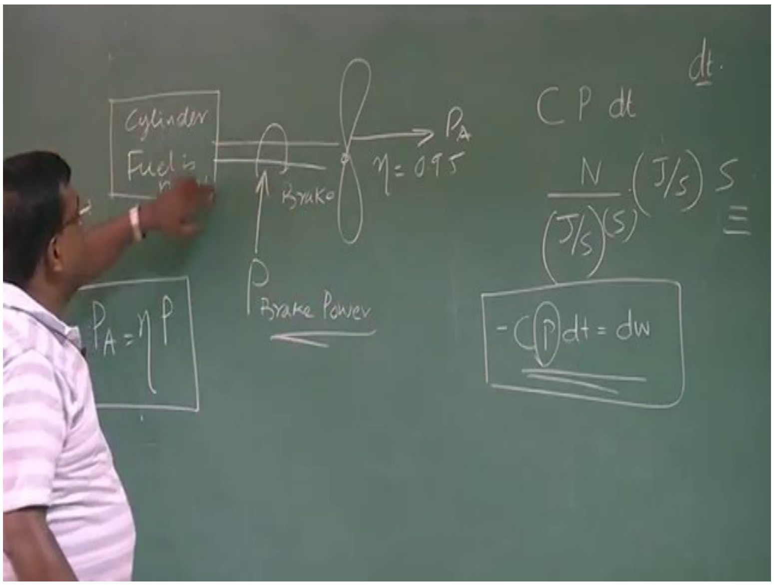

So, let us come back to the basic mechanism. You know there is a cylinder; and, here the fuel is burnt and then this power is generated at the brake; and, here we put a propeller. And, depending upon how efficient is the propeller; the power is extracted from the brake. If the propeller is very efficient, it takes the largest power; if it is inefficient, even if there is a power available at the brake, but the extraction by the propeller may not be that good. So, it is important that, you need to have a highly efficient propeller. And typically, propeller efficiency one; in practical sense, you can get up to 0.9 – 0.95; that is good enough and practically it is acceptable.

Now, let us see. So, please understand – since this is related to the fuel consumption and this power is coming because fuel is consumed; so, this is the power. This P is the power available at the brake, that is, brake horsepower or brake power; horsepower is a unit. So, because fuel is consumed and this power is available at the brake, this P is directly linked to the fuel burnt here. This P is not the power being available for the machine. For the machine, power available will be eta into power at the brake. This is extremely important.

$$P_A = \eta P$$

So, when you are talking about dw, I am concentrating on the power here. So, I am linking myself. So, this… That is why C – the specific fuel consumption, which is gain here a property here as well as some property with the environment, I am stressing this that, this power is not the power available; this power is the power at the brake. Why? Because we want to relate range or endurance via the fuel consumption. So, we are concentrating here.