Introduction to Airbreathing Propulsion

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Lecture – 21
Piston Engines and Propellers (Contd.,)

Let us continue the discussion on the reciprocating engine and we are looking at different cycles, so primarily we are going to talk about Otto cycle and diesel cycle, so we have looked at Otto cycle and how to calculate thermal efficiency and other parameters.

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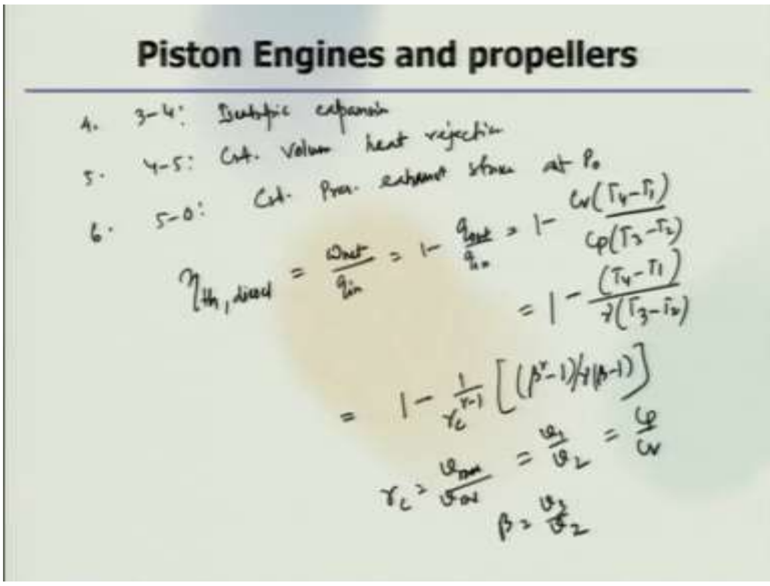

And then we started off the diesel cycle and this is what we looked at the diesel cycle thermal efficiency that we have derived, this is where we stopped.

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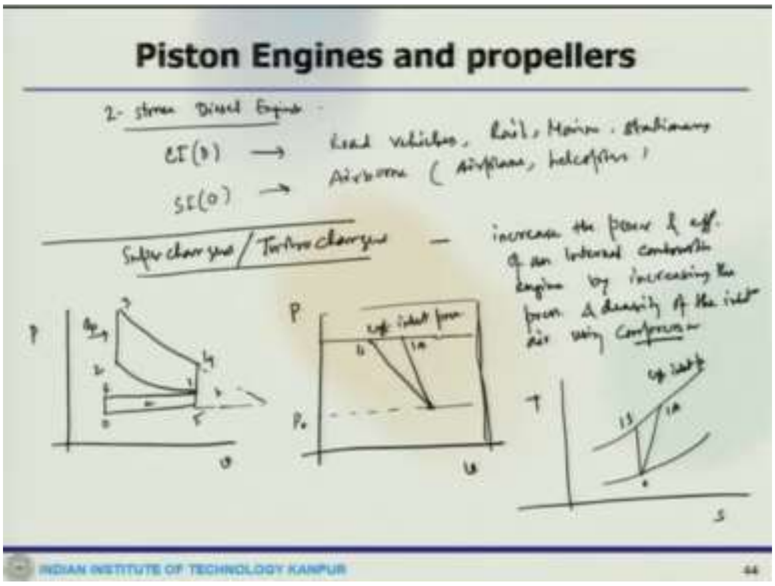

And now from here, we can take it further where we can now take it to; there could be also 2 stroke diesel engine, so when you look at that in a 2 stroke cycle, all the operations are exactly same as the SI cycle, so there is; but only thing that one can note here also it is possible to have 2 stroke cycle and this could be now, just to give you an idea about different these things that applications area, the road vehicles there are both predominant type is the diesel and railroad locomotive that is also predominantly used the diesel cycle.

So, essentially the CI or the diesel cycle are predominantly used in road vehicle, then rail, then marine and stationary, in gas turbine unit also but in SI or Otto cycle that is or gasoline cycle also airborne application where basically is small airplanes, helicopter this is where there is an use. Now, with that we will go to the other one which is the supercharger or turbocharger.

So, this will actually increase the; so when you use the supercharger or turbocharger, it increase the power and efficiency of an internal combustion engine through increasing the pressure and density of the inlet engine by increasing the pressure and density of the inlet here using some compressor. So, 2 types of compressors are used; one is the positive displacement, another is the dynamic.

And there are 3 types of positive displacement compressor are also extensively used like compressor like that. Now, when you talk about the PV diagram of a supercharger or turbocharger this is what it states, then it goes like that, it goes like this then finally comes like that, it comes and then, so this is 0, this is 1, 2, 3, 4, 5, 6 and if we put that thing and the TS diagram, so like pressure and specific volume, so this is P_0, this is state 0, this is 1S, this is 1A.

So, this is where the cylinder inlet pressure and TS diagram, so this is 0, this goes to 1S, this is 1A, this is cylinder inlet pressure and this is the; so now here we have; so here the boost pressure P_1 is greater than the ambient, so the ends to get the net power.

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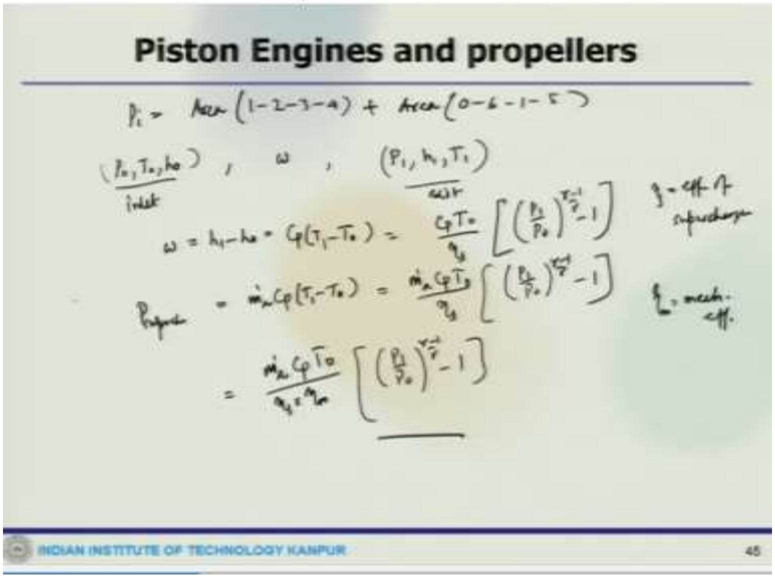

We will get P_i is that area under the curve 1, 2, 3, 4 plus area under the curve 0, 6, 1, 5, so the power required for driving the supercharger can be calculated considering the flow to be adiabatic steady. Now, the air when it enters the compressor at a pressure temperature like P_0, T_0, h_0 and the works supplied to the supercharger is W and the when it leaves the supercharger that temperature pressure is P_1, h_1, T_1.

So, this is at the inlet, this is at the exit, now from the PV diagram or the previous TS diagram what we can write, this is

$$w = h_1 - h_0 = C_p(T_1 - T_0) = \frac{C_p T_0}{\eta_s}\left[\left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

where η_s is the efficiency of supercharger. So, the power required to drive the supercharger then is equivalent to is

$$P_{supercharger} = \dot{m}_a C_p(T_1 - T_0) = \frac{\dot{m}_a C_p T_0}{\eta_s}\left[\left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

Assuming a mechanical efficiency of the supercharger and the piston is eta m, so that is the mechanical efficiency, then what we get, this one is

$$= \frac{\dot{m}_a C_p T_0}{\eta_m \cdot \eta_s}\left[\left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

so this is how you get the supercharger calculation, so that is talk about this piston base engine or rather reciprocating engine. Now, we will go to the aircraft propeller or the discussion on the aircraft propeller.

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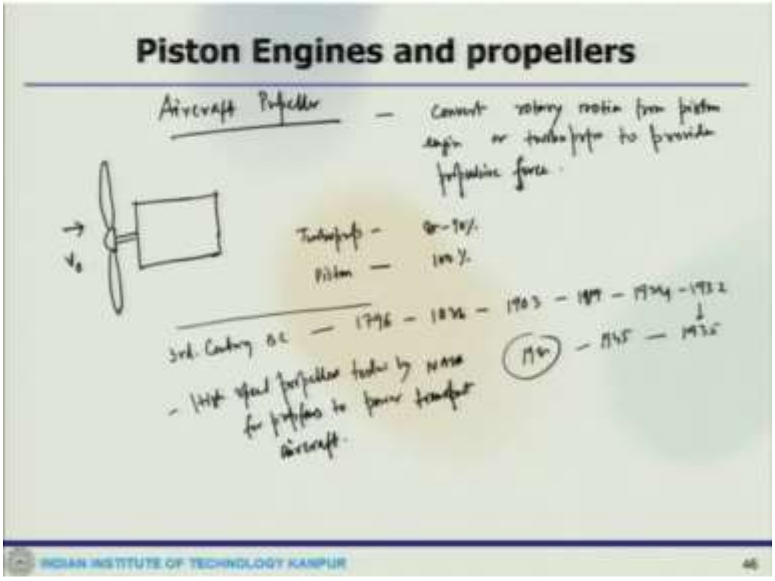

So, what aircraft propeller does or what it does is that it is actually convert rotary motion from piston engine or turboprops to provide propulsive force okay, so it may possible that so typical impeller kind of things one can think about the propeller kind of things that here it could be connected like that. So, this is a typical diagram of a propeller but this is the inlet velocity of V0.

So, there are different kind of propeller just this is just an schematic, it may be fixed or variable pitch but whatever be the case the propeller actually accelerates a large quantity of air through a small velocity change, so turboprop engine, so the 80 to 90 percent of the thrust is produced by a turbine driven by the propeller and whether the rest 10 to 20 percent by the jet.

And in the piston engine, the propeller produced almost 100 percent of the thrust force, so it has several definitions, one can think about it is a device having a central revolving hub with rotating blades for propelling an airplane or one can think about it is a device consisting of a set of 2 or more twisted airfoil shapes blades mounted around the shaft and span to provide propulsion of a vehicle through air or water or alternatively.

So, these are actually drags the air and pushes it back to produce a lot of thrust, so now there are; I mean there is a brief history of these propellers where it was when since its invention like it started in third century BC, when the Greek scientist Archimedes figure out how to enclose a long spiral screw inside these things and then so it started with third century BC, then moved to, then later development around 1796, 1836, 1903, 1919 fixed pitch propellers and others in the service.

So that is what the different kind of advancement; 1932, 35, 45, and finally 1980 for around that time, we have high speed propellers tested by NASA for propeller fans to power transport aircraft. So, all along the way there are different things which are kind of tested.

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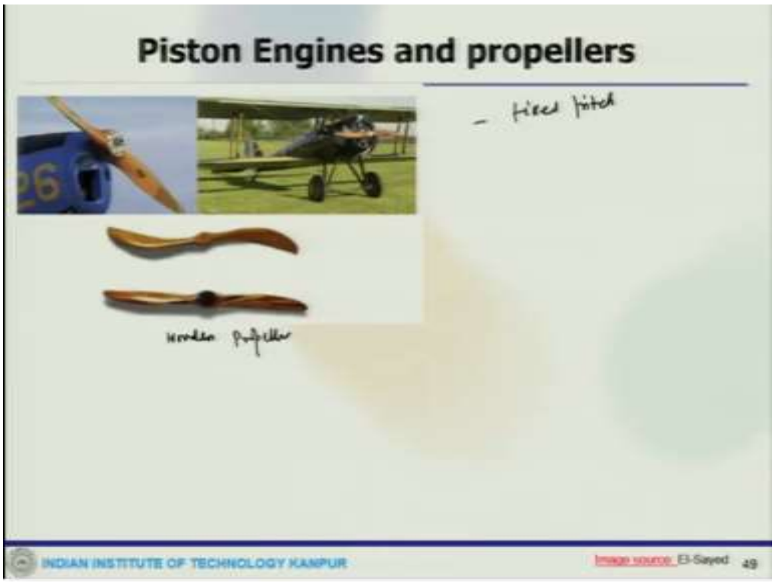

And now you can see a, this is an typical wooden propeller, so this is a; this is fixed pitched one piece wooden propeller, so this is used for the lighter aircraft, then the cross section would look like slightly different and the cross section of this blade, so this was used for these things.

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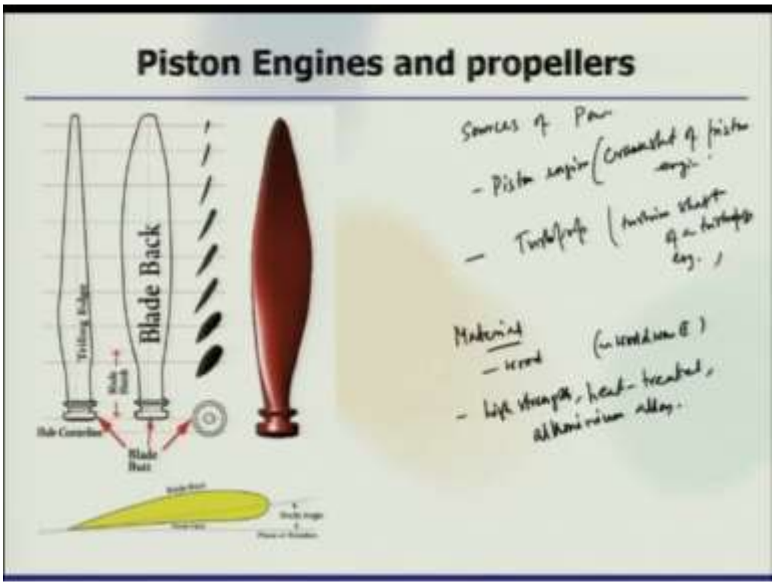

And if you want to this is a fixed, the cross section looks like this, so this is an interesting cross section, so that shows the hub centreline, trailling edge, the blade, how the airfoil shape looks like, so there are typically thick and if you see there to provide strength, so it is cylindrical where it fits the hub barrel but the cylindrical portion of the shank contributes little or nothing to trust.

The some propeller blades are also designed, so that the air foil section is carried all along to the hub by means of cut off, so these are different kind of things. Now, if we go to the classification and then we can see the; this propeller what is the sources of power, so one is the piston engine, so this could be either driven by piston engine like crankshaft of a piston engine or it could be turboprop for the turbine shaft of a turboprop engine.

So, to run this kind of propeller blades we need power and the power comes from the either the piston engines or turboprop engines and like this. Now, another thing could be the material which is important typically, wooden was or wood was used early days probably around World War II or something like that but then later on the metal which are used and after 1940, propellers are made of steel.

But recent propellers are fabricated for high strength, so high strength, heat treated aluminium alloy, so metal propeller is similar to the wood propeller except that sections are generally thinner, okay.

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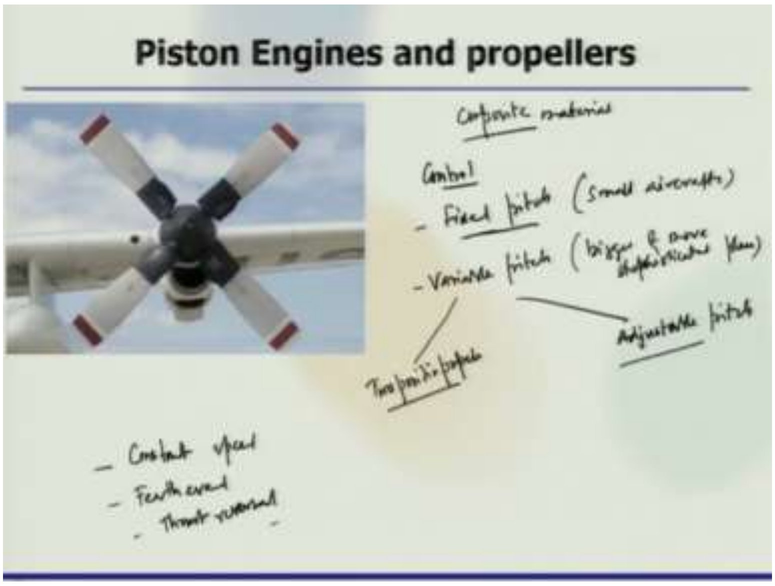

So, now also there are some other designs, now this is another picture which can show you the cowling of these things essentially, the air foil shape of the propeller and how it is attached with the main aircraft wing, then there are thin sheets and metal and other material which function like cowling as shown here. So, this will give you an idea, now recently, these guys I mean, the material could be also composite kind of material which are also used for fabricating this kind of blades, okay.

So, coupling to the outer shaft, so that could be another issue, now then we can think about control, so there could be fixed pitch okay, so which are used for sort of small aircraft and blades are fixed at a certain fixed angle to the hub usually never changes but it can be altered on the ground only not during flight. So, Wright brothers was the first successful developer of such kind of propellers which are fixed pitch type.

Then it could be variable pitch, where these are bigger and more sophisticated planes that means the blades maybe rotated about its long axis and this could be also again divided into 2 sub categories; one is the 2 position propeller and another one is the adjustable pitch. Now, when you talk about 2 position propeller that the blades are limited to 2 angles, so one for take-off, another and climb, low speed operation and the other one for cruising, which is high speed operation.

Whether when you go to adjustable pitch, so where the one whose pitch can be altered by the pilot, these are controllable pitch has automatic mechanism to adjust its own pitch to match the flying requirement, okay. So, then we can have now constant pitch propeller, so this is fixed pitch, variable pitch, then constant speed type propeller, these are designed to change the pitch automatically allowing the engine always to turn over the same constant speed.

So, this is another one, then we could have feathered, so again the turning the propeller blades, so that they are edge on making a very shallow angle to the one coming here, minimize the air resistance and allowing the plane either to keep on flying on its remaining engine or glide to crash landing, then could be thrust reversal. So, here the pitch of the blades can be reversed, so a propeller makes a forward draft of the air instead of one moving backward, so this is handy for extra breaking or something.

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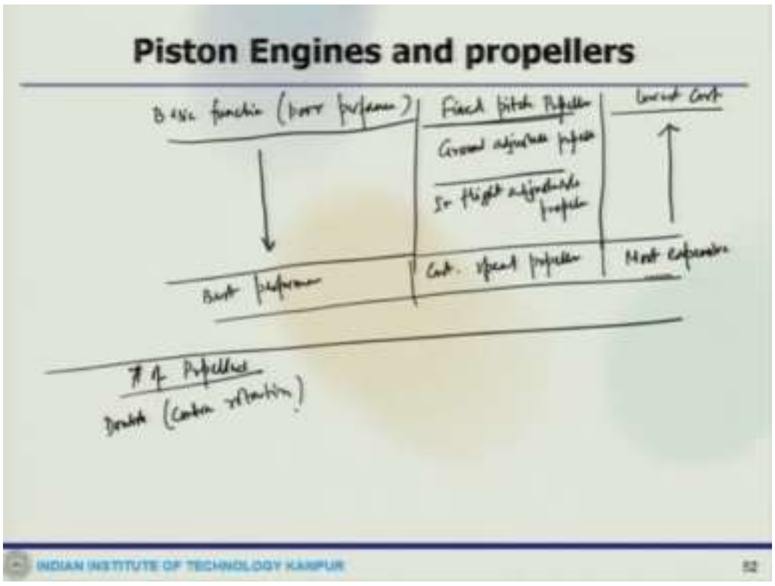

So, this is used when the typically, the hand breaks and such things fails okay, so what we can look at is that some fixed pitch versus variable pitch propeller, we can have like basic function like poor performance that could be one, then we could have fixed pitch propeller, lowest cost, okay. So and this side is the best performance, constant speed propeller and most expensive one.

So, this is how it goes, this is how it goes and we have fixed propeller, then we have ground adjustable propeller, we have In flight adjustable propeller, so like this. So, from here as we move with this constant speed, we can see the performance but at the same time, this is probably the most expensive, so this gives you an idea about this comparison of this propeller and all these.

Now, the other thing would be number of propeller coupled to each engine, so that depends on the how the design is done, so one could be single propeller which is connected, okay. So, the one which we have already seen, this is a single propeller kind of one, this one it is a single propeller or we can have double contra rotating.

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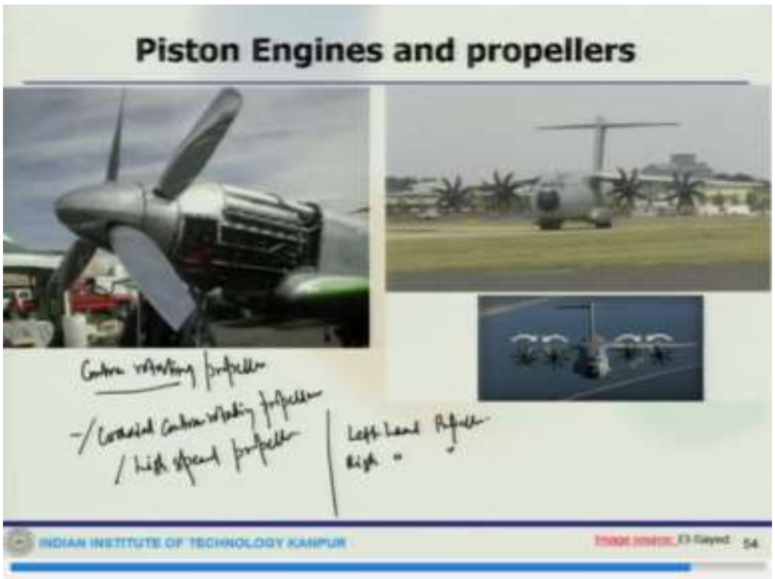

Let us see this is a double contra rotating propeller, this is a contra rotating propeller, so this is Rolls-Royce griffon powered P 55 propeller. Now, this contra rotating propeller are also called, they are also called coaxial contra rotating propeller or high speed propeller, so this apply the maximum power of an engine to drive 2 propeller in contra rotation, this rotation about the same axis in opposite direction.

So, 2 propeller are arranged one behind the other and power is transferred from the engine via planetary gear or a spur gear transmission okay, so that is another one, then we have like direction of rotation, then this could be another example. Now, direction of rotation where we can have left hand propeller, like left hand propeller; a left hand propeller is one which when viewed from the cockpit rotates in the anti-clockwise direction.

And when it viewed from the outside, then they rotate in clockwise direction, so this is what it is, then right hand propeller that means, when it is looked from the cockpit, it would be rotating in the clockwise direction, then it can rotate in the similar directions, it could be in the counter-rotating directions, so these are some of the example like counter-rotating pairs, so this is a counter rotating pair what you can see.

So, this one rotates in this direction, this one rotate in the other direction and now propulsion methods, there could be pusher or puller or something, then number of blades are another important.

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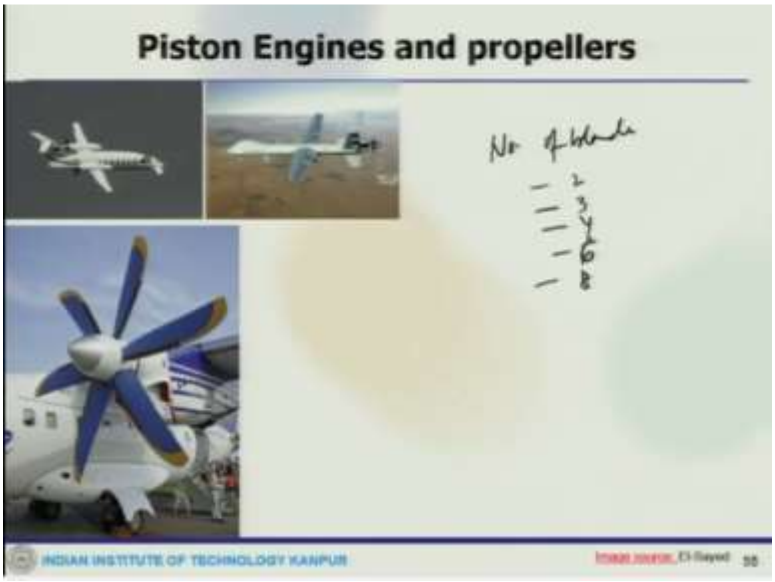

So, these are also pusher and puller, so this is number of blades where it could be; the number of blades could be 2 or 3, so let us say number of blades that could be 2, 3, 4, 5, 4, 6, 8 so multiple greater than 4 as example 8 bladed propeller which is shown here, so and this one is 6 bladed propeller which you see here.

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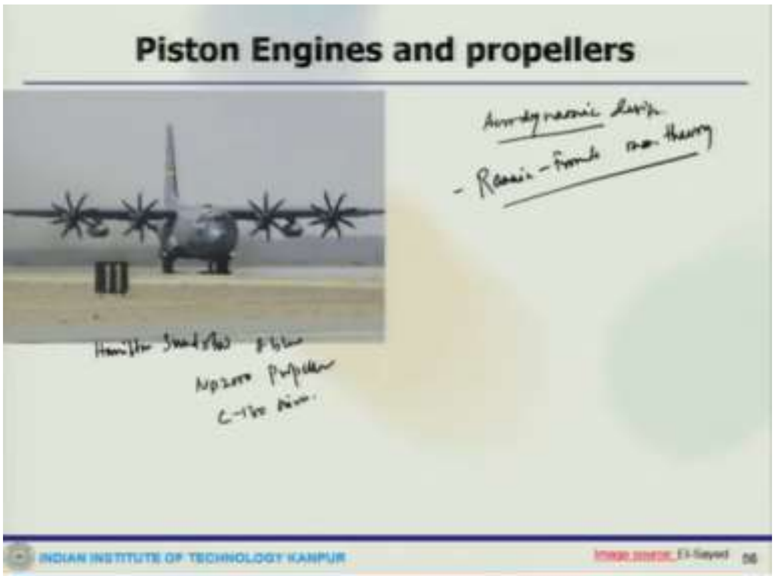

And 8 bladed propeller is here, this is Hamilton Sundstrand 8 blades NP 2000 propeller, this is used in C-130 aircraft, so there are different thing which are there like its blade, its rotation, counter rotation, now also one important factor is that aerodynamic design of the propeller because these are important how to reduce drag and so there are the way it is done is a simple Rankine-Froude momentum theory.

So, this is what we can use to look at the aerodynamic design okay, so we will now look at some of this design, how the design of these different kind of propeller is done like we start with the some of this baseline theory and look at how the design is considered for this propeller, we will continue the discussion in the next class.