Introduction to Airbreathing Propulsion
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Lecture – 18
Piston Engines and Propellers

Okay. So now what we have looked at is that the basic performance parameter, thrust coefficients or the other important factors that affect those performance parameters. Now we will go into the details of individual engines that we have talked about in the introductory lecture like there are different kinds of engines. So the first one to start with is the piston engine and the propeller engine and we have already talked where they are applicable.

These are for low speed applications, they are very good, and how those system actually works. Now we will look at in terms of Aerothermodynamics principles. And now onwards all this discussion would be more focused on the individual engines like we start with piston and propeller then we will move to the scramjet kind of engine and then turbojet and turbofan. So this is how the plan is ahead before we move to the turbo machinery.

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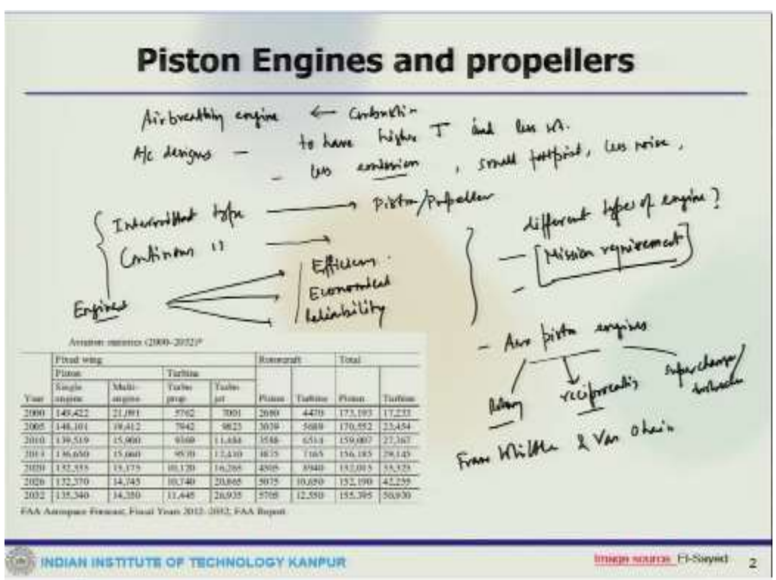

So let us start with the piston engine and propeller engine. So now just to reemphasis that any airbreathing engines, so any airbreathing engine it require some sort of an combustion system or combustion unit, okay. So; and while carrying the appropriate fuels, so the combustion chamber the fuel is burned, so what is the aircraft designer they want, they want to have higher thrust, higher T and less weight, so that means more and more lighter materials in that sense.

Also, they want high thrust to weight ratio, so the other goal is to less emission also, so this typically connected with the combustion system that you want less emission. Small footprint that is the size, less noise and better cooling, lower fuel consumption I mean such those properties which are very much important and that is; what already we have shown that different kind of engines and this particular engine there could be; I mean they depending on that combustion unit; it could be intermittent type or it could be continuous combustion type.

So this is the combustion engine where this could be two different kinds. Now here when we talk about the piston and propeller engine they are intermittent type, and when we talk about the continuous combustion system then we go to the Jet engine discussions of like Turbojet, Turbofan kind of engines. Okay. So, now all these engines whatever it is these engines, they need to basically fulfill certain basic norms, one is the efficiency that means the engine must operate at the high efficiency under a wide range of atmospheric condition, then it should be economical like the; it should be must be economic to produce, run and maintenance the engine manufacturing this is what.

Then the reliability, so the; so these are three major factors which are very, very important for any design and manufacturing of an engine when we talk about the high efficiency, we talk about the less cost in fabrication and production then finally it is a reliable that the engine must be able to in your long period of operations and power settings without failure. Now that brings to a simple questions why are there different types of engines?

So, why there different types of engines? So one simple answer to that is that the engine is designed to fulfill the mission requirement, so that means there are different mission requirements like for example of you look at the cargo plane they operate at the cruising condition mostly, so for this kind of planes thrust is not an important as high engine efficiency or low consumption is important.

Then again if you go to like fighter planes or high speed aircraft they require high excess thrust for their maneuverable, quick accelerations. And for this fighter planes the engine efficiency is not as important like the thrust. Now the modern military aircraft if you talk about then the engine efficiency is not; they deploy afterburners and low-bypass turbofan engines so that the more and more so these are the thing what are different, so that means the different kind of engines come from the mission that is the simple answer to that, the mission requirement.

So as per your requirement the different engines are designed and they are in use. Now intermittent combustion engine we can take look at how this could be like this is an chart from early 2002 to 2032 the projection. So these are sort of the can be identified as aero piston engines and it is like aero piston engines and they are different from the automotive piston engines. So they are classified into three different categories, one is the rotary type engine, reciprocating engine and supercharge or; so there will be rotary type then reciprocating and other could be supercharge or turbocharge reciprocating engine, okay.

So we have already talked about when 1903 the first flight actually came up that time it was only in piston engine which was used. Now we can see the developments since then. So the development has gone really far and we can see the things here like what you can see there, so the essential milestone in 1903 is that Jet engine which was invented by Frank Whittle and the Van Ohain, the piston engine where the only prime over further flight vehicles, later jet engines and all these took over. Now as I said this could be three types rotary, reciprocating and supercharge or turbocharger reciprocating engines.

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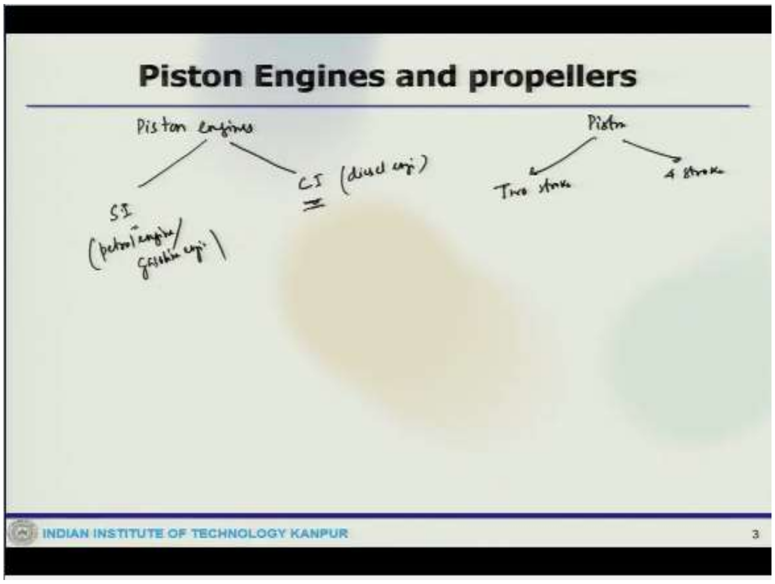

So now also this piston engines or can be classified based on the number of cylinders or method of cooling or cylinder arrangements. So for example two principle types of engines one can see, one could be the SI engine or the spark ignition engine which is pretty much the petrol engine or gasoline engine, the other one is the compression ignition type which is the diesel engine, okay. And other options could be; this could be classified also like two-stroke engine or four-stroke engine, okay.

So in a spark ignition engine here the fuel air is mixed and they are ignited by spark plug and these mostly the petrol engines which are used and the previous thing was you formerly done in the carburetor. So now it is done electronically control fuel injection excepting small engines. And this SI engines are advantageous for applications requiring up to 200 to 225 kilowatt of power or something.

Now in the other hand in this CI engines this is compression ignition kind of engines where actually the fuel air mixture is injected to the system or the piston or insert the cylinder where then the due to the compression process they gets compressed and finally the; so these engines serve more reliable and normally preferred for applications where fuel economy and relatively large amounts of power are required.

Now, the new trend of diesel engine is they bring more fuel efficiency and it also free emission to small aircraft representing the biggest change in the light aircraft engine in the decades. Also the CI engines or the diesel engine has the highest thermal efficiency of any regular internal or external combustion engines due to its compression ratio.

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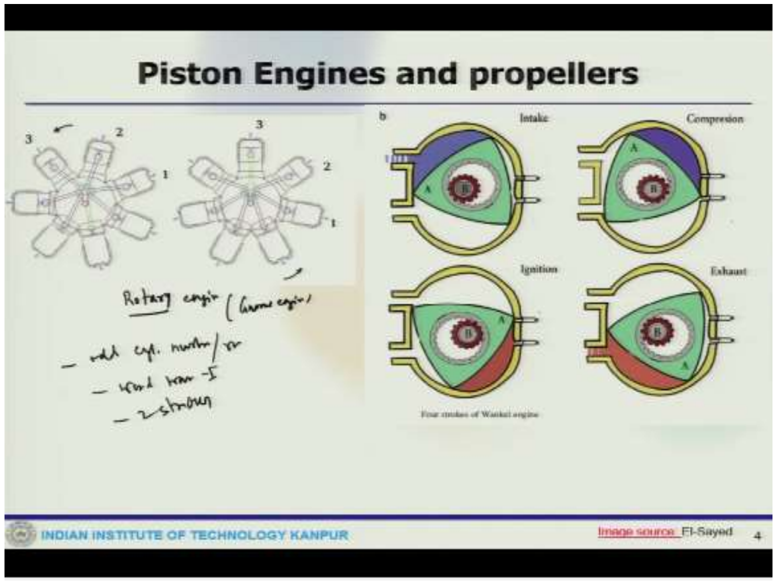

So now we will look at this; let us go to the one which we look as the rotary type engine, okay. So this is a rotary engine, so this is a conventional type. So in the rotary engine this was basically one type of internal combustion engine, so which is used with the odd cylinder numbers and per row in a radial configurations, also the crankshaft remain stationary remain stationary and the entire cylinder block rotated around it, so this was widely used during World War I and the air is immediately preceding the conflict.

These are described as very efficient in power output, weight, cost, manufacturing and reliability. So this is one of the sort of an genome engine. So this engines are also sort of an two-stroke design giving them high specific power and power to weight ratio, but there are certain problem like the sever gyroscopic effects from the heavy rotating engine make the aircraft very difficult to fly, okay. So that was the sort of an awareness that was there during that time.

Now there is another one which is called the Wankel engine which is of four-stroke type. So this is a four-stroke Wankel engine, so this having odd cylinder numbers per row, World War I, 2-

strokes and this is another type which his called the four-stroke of Wankel engine. So Wankel engine is also considered for optimum power plant for lighter aircraft and it is light compact almost vibration less and you can see this is how the stroke, so one stroke the intake comes in, then the compression then ignition and then finally the exhaust.

So this engine include rotors cannot see since rotors casing expand more than rotors, not susceptible to; so cooling during descent does not require any enriched mixture for cooling and such like that. So this was also popular in experimental aircraft in early days. And now since the Wankel engine are also becoming popular in experimental aircraft.

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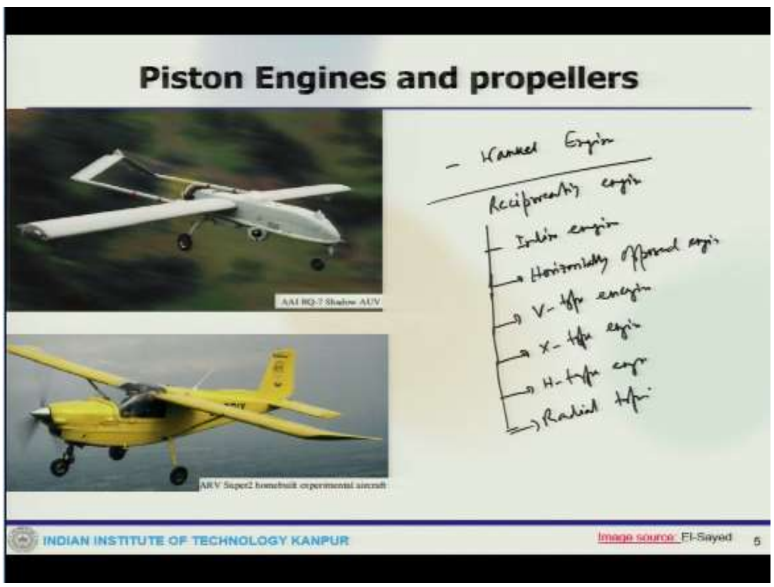

Like some lightweight aircraft like this ARV and some aircraft for this kind of medius twin rotor engine, so these are the some of the design which are recently using this kind of engine. So the pattern it need also developed Diesel Wankel engine for using prototype beetle flying called the transformer the engine based called IR UAV diesel Wankel concept called So these are the some of the developmental work that Wankel engine is in use.

Now the other thing what could be, so we can have the reciprocating engine in a different varieties like you could have reciprocating engine, you can have Inline engine. So this is based on the cylinder arrangement, you could have horizontally opposed engine, you could have V-type engine, you could have X-type engine, you could have H-type engine and then also radial type. So these are based on the cylinder. Now Inline engines, you could have horizontally opposed, V-type there are different kind of engines which are possible.

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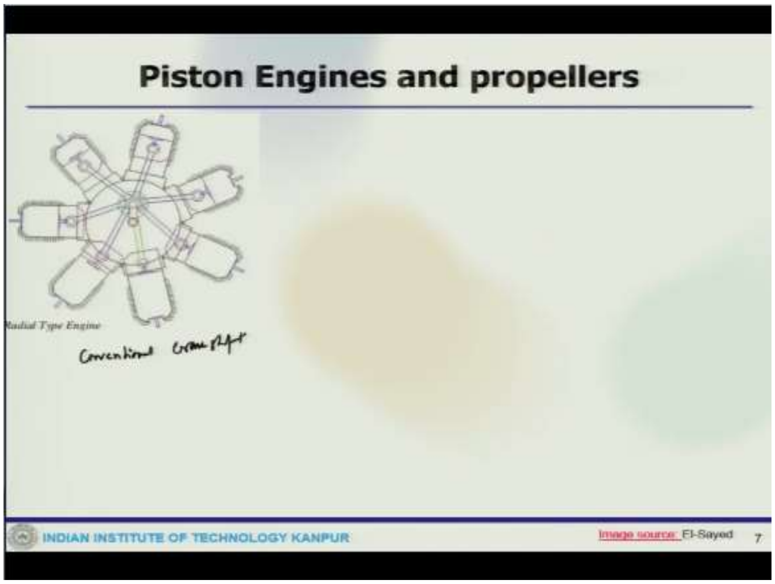

And some examples we can see like this is one of the radial type of engine where you can see this picture, there has one or two rows of cylinder and arrange in a circle around centrally located crankshaft. Each row must have an odd number of cylinders in order to product smooth operation. Rotary and radial engine look distinctly similar when they are not running but can easily be confused, since both have cylinder arranged radially like this direction, around a central crankshaft. Unlike the rotary engines, radial engines use a conventional rotating crankshaft. So this uses conventional crankshaft, so that is important.

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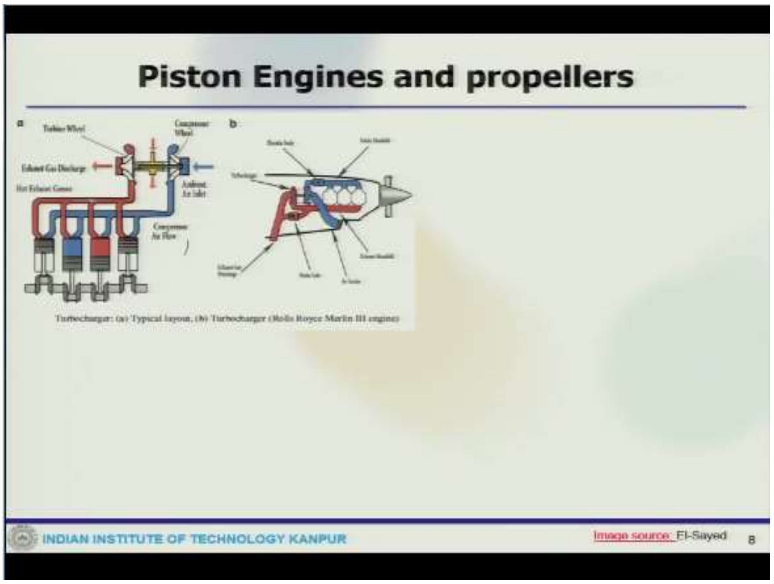

Now another type could be this turbocharger or supercharge kind of this is a Rolls Royce engines where you can see, you have a compressor then turbine wheel and how this cylinders arrangement is done and when they are; so this is a typical layout and this is a; so these are also another category of engines or this kind of intermittent combustion engines which are available for this things.

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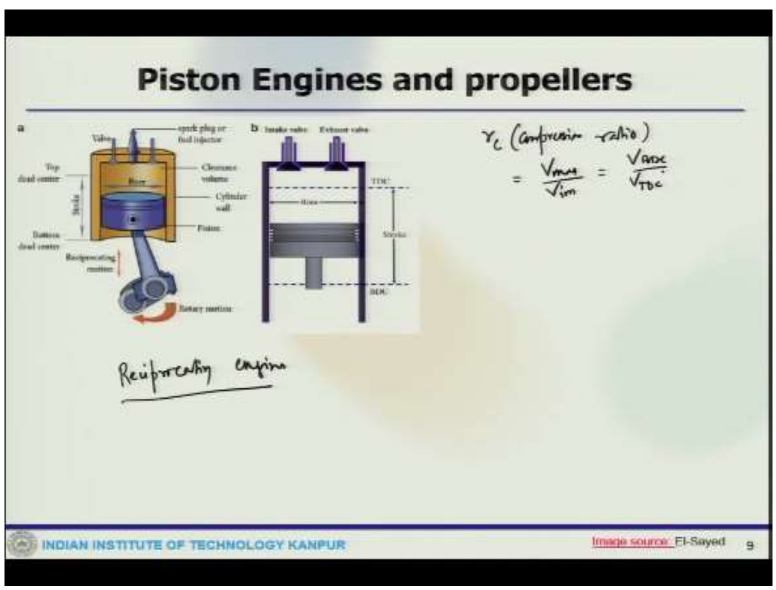

Now when you go to the Aerothermodynamics of the; let us say we start with the; so this is a typical nomenclature of any reciprocating engine. So what you have, you have cylinder which is connected with the crankshaft here and the crankshaft which rotate so this cylinder with the piston head, a cylinder with this piston actually moves up and down which creates this reciprocating motion and then there are spark plug, there are valve which is use for the intake and exhaust.

Then these are the nomenclature like stroke, bore, bottom dead centre, top dead centre, so this is a bore, this is the bottom dead centre that means the cylinder goes below up to that, top dead centre so there is a clearance volume, intake, exhaust valve. So there is the compression ratio or r c so the compression ratio which is defined as Vmax/Vmin which is V bottom dead centre by V top dead centre, so that is the ratio of that. So any four-stroke internal combustion engine, so what happens that when the; I mean so that is an; these are some of the nomenclature.

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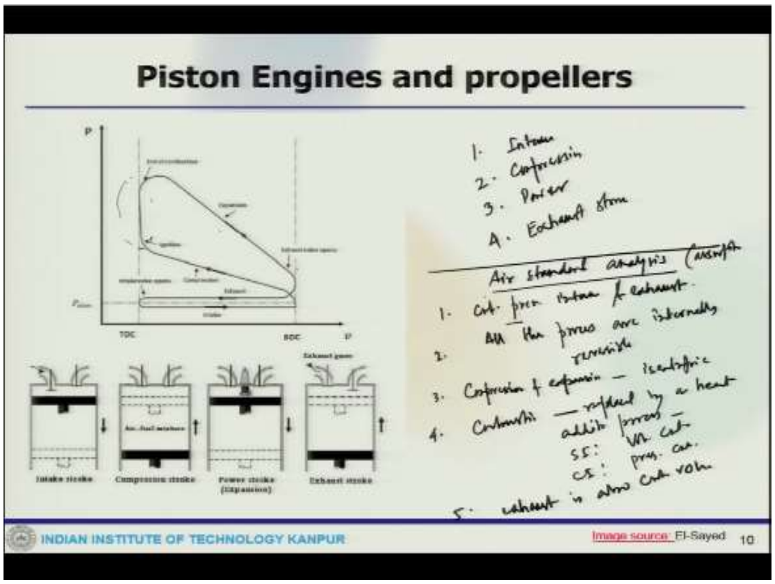

And then you can see how this happens and this is the pressure verses velocity plot. You having intake stroke where actually the valve is open; intake valve is open and the piston actually moves downward to get the fresh air inside the cylinder. For spark ignition engine this charge is combustible mixture of fuel and air and compression engine ignition engine it would be the air only.

Now the second, if the both the valve closed the piston undergoes a compression stroke, okay. So this is where the compression takes place and raising the temperature and pressure of the charge. This requires work input from the piston to the cylinder contents and combustion is induced near the end of the compression process that means when the cylinder reaches toward the TDC, top dead centre and this is achieved using a spark plug in the spark ignition engine or in compression ignition engine the combustion is initiated by injecting fuel into the hot compressed air.

So when the fuel is injected there the gas is so compressed and hot, the fuel gets evaporated and the combustion occurs. So that is what it happens. And then, this is the power stroke or expansion stroke, so during which the gas mixture actually expand and the again the cylinder piston moves towards the bottom dead centre and then finally in the exhaust stroke the piston moves back, so there is a one is intake, two is compression, three is power stroke, four is the exhaust stroke.

And this is how the valve operates this is at the intake and then it goes where the ignition, this is where your this region where the combustion takes place and then again in the expansion stroke, so this is the typical pressure velocity diagram. Now when I; we try to do this analysis so we can do air standard analysis and for doing that some of the things for air standard analysis, so there could be simple procedure.

So one it could be a constant pressure intake and exhaust strokes are also assumed to be constant pressure intake and exhaust. So it could be at wide open throttle or fully open throttle valve, the intake stroke is assumed to be at constant pressure which is there and partially closed throttle valve where supercharge the inlet pressure will assume a constant value.

Second, this is for air standard analysis, these are some of the assumption. All the process are internally reversible, so that helps us to; now third the compression and expansion strokes are approximate by isentropic process. So the compression and expansion they are isentropic, that means reversible and adiabatic. So sometime the lubrication minimizes the friction between the piston and cylinder valves and fourth the combustion is replaced by a heat addition process from an external source at process for SI engine, V constant or rather volume constant and compression ignition engine pressure constant and five exhaust blowdown is approximated by constant volume, so exhaust is also constant volume process.

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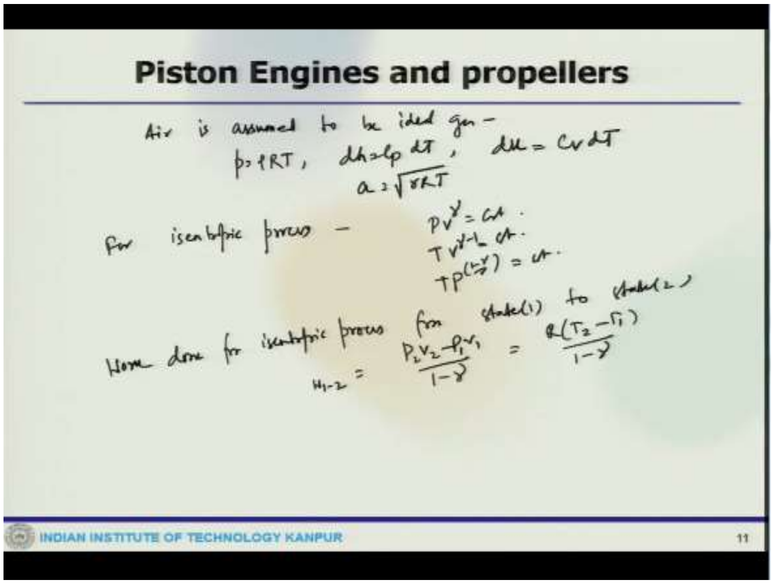

Now in air standard cycle, air is assumed to be ideal gas, so that means we can write

$$p = \rho RT$$

we can write

$$dh = C_p dt$$

we can write

$$du = C_v dt$$

or also

$$a = \sqrt{\gamma RT}$$

And for isentropic process we write

$$pV^{\gamma} = C$$

and what else

$$TV^{\gamma-1} = C$$

and

$$Tp^{\frac{1-\gamma}{\gamma}} = C$$

Now similarly, the work done for isentropic process from state 1 to state 2, this is let us say

$$W_{1-2} = \frac{p_2V_2 - p_1V_1}{1-\gamma} = \frac{R(T_2 - T_1)}{1-\gamma}$$

So these are the some basic assumption for air standard cycle. And now with this assumption, we can actually look at the cycle analysis and we will do that in the next session.