Introduction to Aerospace Propulsion

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Module No. # 01

Lecture No. # 23

Piston-prop engines: Otto cycles;

Ideal and Real cycles

Today, we shall begin to look at various kinds of engines that actually power the aircraft to flight. You had good exposure to various kinds of laws of physics. We began with the laws of motion, the Newton's laws of motion then, you had a full exposure to various kinds of laws of thermodynamics.

These are the laws of physics, which we shall refer to quite often when we look at the various engines because many of these engines or all of these engines are actually have to conform to these laws. If they do not conform to these laws, they cannot perform. This is the fundamental issue on the basis of which the engines are built and operated.

It is necessary for you to understand that all the engines we have today that are powering the aircraft are based on what is also known as heat engines. All these heat engines basically have to conform to all the laws of thermodynamics that you have been exposed to. Since they create motion of the aircraft, they have to conform to the laws of motion, the Newton's laws of motion. So, we have to implicitly and quite often explicitly, refer to those laws of physics all the time that we are talking about the engines.

To begin with, today we shall start off with looking at the most fundamental and the most probably the ancient form of aircraft engine, the piston prop engine. The kind of engine that actually power the first flight by the Wright brothers and almost 50 years thereafter all the aircraft flew with piston prop engines. Even today, most of the aircraft that are flying around the small aircraft and they are actually more in number, most of them are flown with piston prop engines. So even today, 1000 of aircraft are flying around with piston prop engines and hence it is probably a good idea for us to take a good look at how the piston prop engines work.

Basically, the piston prop engines have two components: one which is the piston engine which can also be called some form of internal combustion or IC engine. We will have a good look this kind of engine basis fundamental, basis today and later on in this lecture series, we will take a look at the propellers which are thrusters which make the thrust. So piston engine or the IC engines create the power and the propellers convert that power to useful thrust for flying the aircraft. So we need two components and we will look at them separately.

Today we shall look at how the piston engines or the IC engine actually is fundamentally created, what is the basis? We will have to go back to the thermodynamics that you have exposed to we have to bring back the concept of energy, the concept of work and how the energy is finally converted to useful work or power which can finally fly an aircraft.

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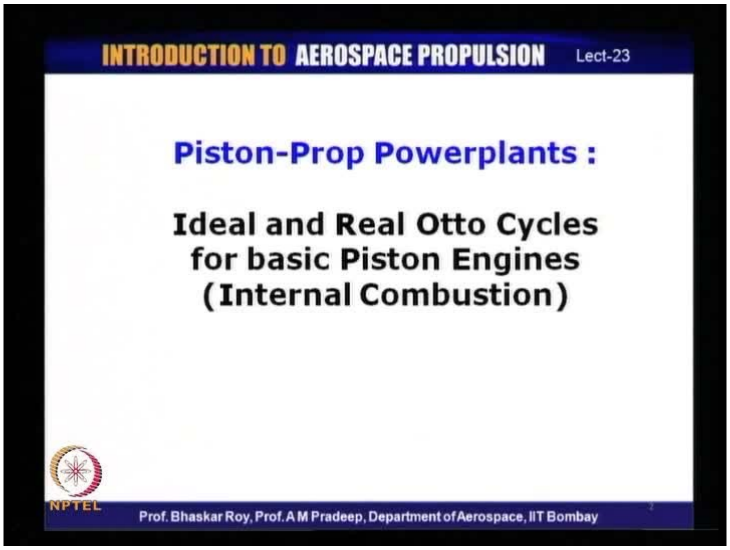

The piston engines that we will be looking at are based on what is known as Otto cycles. Now Otto cycles are the thermodynamic basis on which the piston engines are created. Otto cycle is one of the cycles on which various heat engines are made, almost all heat engines that we know would be based on one of the cycles that you have been exposed to; the piston engine that we are looking at is based on what is popularly known as Otto cycle.

Today, we will look at the ideal form of the Otto cycle as was originally proposed by the thermodynamicist and then we will look at the real form of the Otto cycle which is how the piston engines actually work. What are the difference between ideal cycle and the real cycle; this is what we will have a close look at today.

As I mentioned, these cycles based on which the engines are made are also called internal combustion engines. Now one of the reasons they are called internal combustion engines is because combustion is the method by which the energy is supplied into the system which we call engine. That is the input from outside the system into the system and then the system converts that energy to useful work. So conversion of energy to useful work is something, you may have studied in your thermodynamics and this is what we will now explicitly make use of in actually creating the engines.

So we would be continuously making use of the concept of putting in the energy from outside. In our case for example, by burning fuel through the process of combustion and then we will have to find a way to convert this energy which is released by burning the fuel into useful work and the mechanism by which it is done.

Finally, converted to what we can call mechanical work is what the whole engine fundamentals is all about. So, we will take a look at the thermodynamics of how the engine functions, the cycles and in the process we will try to understand how the thermodynamic concepts are finally used to make an engine that actually perform work which is useful to us finally, for the process of creating thrust which makes an aircraft fly.

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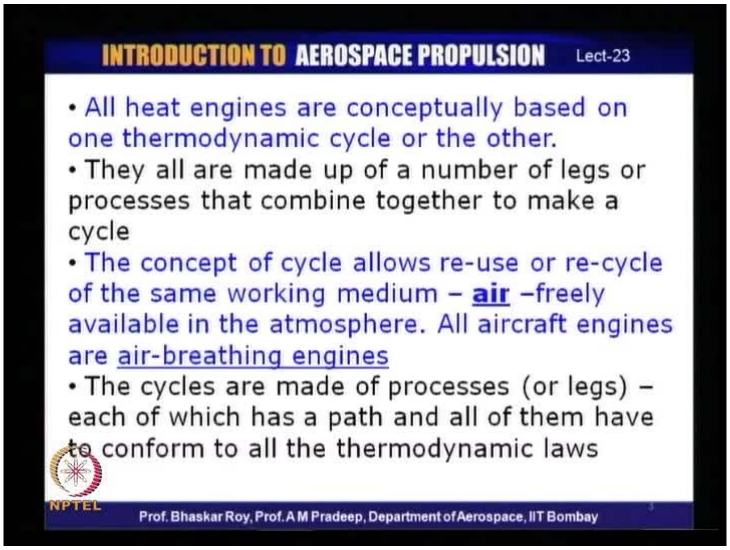

As I mentioned, all heat engines are conceptually based on one thermodynamic cycle or the other. It is necessary that heat engines conformed to one cycle or the other, so that you always have a continuous process of control over what is happening in various legs of the performance of the engine. More importantly with the use of the thermodynamic principles, thermodynamic laws and the mathematics that goes with it, you can actually predict pretty closely how the engine is going to perform, this is very important.

It is necessary for a creator of engines to know very closely how the engine is going to finally perform and this knowledge is very important. So, it is necessary that they conform to one of the known kinds of thermodynamic cycle or the other, so that their final performances could be very closely predicted and later on closely monitored.

As you know, a cycle is made up of number of legs which are actually thermodynamic processes and they combine together to make a cycle. Now each of this process could be different processes; one could be constant volume process, one could be constant pressure process, one could be isentropic process so on and so forth. So, they all made up together to make a cycle and we got to have continuous control over each of these legs or each of these processes when they are occurring. We got to have a priori knowledge of these processes, so that we can predict what is happening in each of these legs which makeup the engine together.

The other important thing is these cycles which we are using for making up the engines they use or recycle the same working medium, now this is very important. The working medium we have in abundance around us is air and that is freely available in the atmosphere to us. So, all these cycles and all these engines have been created with the purpose of using freely available air as a working medium. So that the bulk of the working medium that is used for creating work and in our case, creating finally thrust is available in air and as a result of which all aircraft engines are essentially air breathing engines.

We are looking at various kinds of engines from now onwards, all of them almost invariably would be air breathing engines. We shall see later on towards the end of this course, when we look at the rocket engines those are non-air breathing engines; so till we come to the rockets as long as we are talking about the aircraft engines. Remember we will be talking about air breathing engine that use air as the basic working medium.

The cycles as I mentioned are made up of number of processes and all of them have to conform to the thermodynamic laws that we have done. Each of this process is a thermodynamic process and they have to conform to the thermodynamic laws that you have studied over the number of lectures till now and remember that we will be using those thermodynamic laws quite explicitly and sometimes implicitly in understanding these processes which make up the entire cycle.

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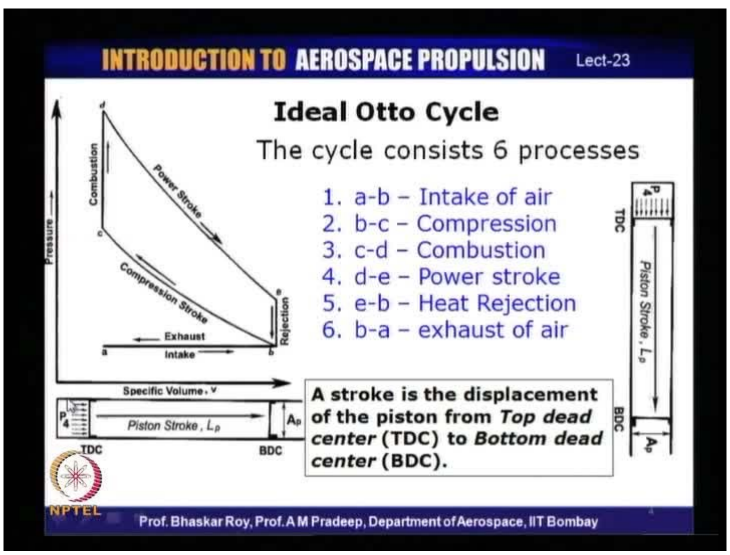

Let us look at what is known as the ideal Otto cycle. The cycles essentially consist of 6 processes and let us start from the beginning. It starts from a point which may call a, from which we have what presently let us call intake of air and it starts from a goes to b, so the process a to b is called the intake of air.

The air is in taken into the system and from b to c, this air is now compressed, this is called compression process (Refer Slide Time: 11:30). It goes to higher pressure over here, as you can see in this p-v diagram. Then from c you have a burning of fuel this is combustion process. So, in the process of burning of fuel, this compressed air now raised in temperature to higher level as per laws of thermodynamics, when you raise the temperature, the pressure also goes up so, it goes to higher pressure at d.

Now at this high pressure and temperature the cycle now does the process of expansion. So from d, the process is expanded which is in engine terms is called power stroke. It expanded from d all the way down to e and that is the end of the process of expansion which is also called power stroke. In the ideal cycle conceptually over here between a and b, you can say that there is a certain amount of heat rejection which occurs from the system, just like there was a heat intake into the system through fuel burning, there is heat rejection through various kinds heat transfer.

Then the process reaches b and from b the air that is been inhaled is now exhaled and the exhaust of the air goes out of the system and then fresh air is brought in to the system. So this is the cycle, the air comes in gets compressed, the fuel gets burnt, then it is expanded the high temperature, pressure air is expanded. Then there is bit of rejection of heat into the out of the system and then the exhalation the air is exhausted from the system and this is a cycle which continuously occurs in this process which we call Otto cycle.

Now, if you look at a schematic of an engine which occurs which operates as per Otto cycle, so just below the p-v diagram you will see this diagram here of a schematic of a piston engine (Refer Slide Time: 13:45). Now what happens is when this is the piston stroke as it is often called and this is what we were calling as stroke, the L p is length of the stroke.

Now what happens is over here, the end of the piston stroke one end is called BDC over here if you look at, if you take the piston in a upright position the lower one is referred to as the bottom dead center and the top one is called the top dead center (Refer Slide Time:

14:11). So, the idea that is how the names were given that this is the bottom dead center and this is the top dead center, the names not necessarily the pistons are always in upright position quite often they are in horizontal position like this but, the names TDC and BDC have remains for almost 100 years and people continue to use those terminologies.

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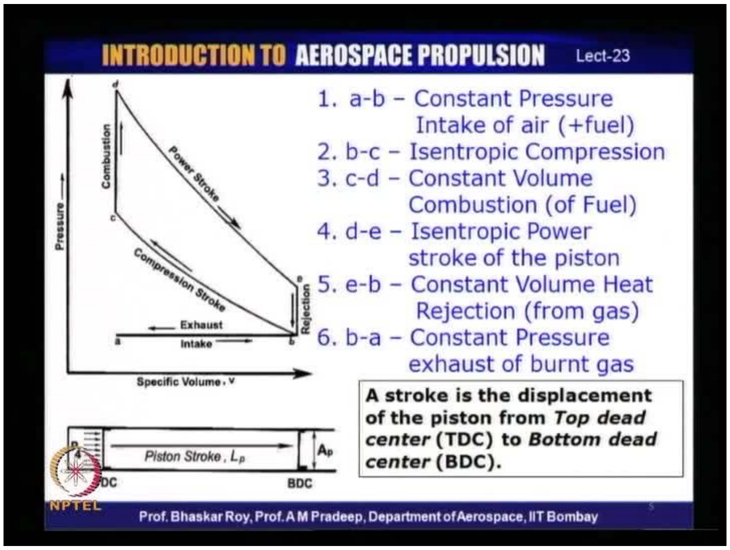

Now what happens is when the air is inhaled, that is the process from a to b the piston actually moves downwards over here (Refer Slide Time: 14:57) and this entire space is opened up. So, air from one of the ports over here comes in and fills up this entire space. Then the process of compression starts from b all the way to c, then the piston here piston head as it is called moves from BDC towards TDC as it moves the air, which had come in and had got captured inside this volume of the piston gets compressed to a much smaller space.

As a result of which the piston now creates a very small space within which the air is now entrapped and is compressed. Now this compressed air is then subjected to burning of the fuel; now this burning of the fuel then in this small space creates even higher pressure and of course, the high temperature.

So this small highly compressed air, when subjected to high temperature and pressure then exerts huge pressure backwards on the piston head, as a result of which the piston is forced to move forward and that undergoes the process of expansion all the way from d to e. During that process, the piston head is now moving backwards back from TDC all the way back to BDC. So, once it comes over here, we have this process of heat rejection out of the system and then the process of exhaust starts. That means the piston again starts moving now what we have inside here is a burnt fuel and air mixed up, so what we may call burnt gas.

So this exhaust of the burnt gas now starts happening as the piston head starts moving and this burned gas is exhaled out of a port here. The port is timed to move to open up at this point of time and this burnt gas now goes out through this port in to the outside the system. Then the fresh charge or the fresh air is coming into the body of the cylinder. So this is how the cycle occurs, the fresh air comes in; it is time to open exactly when it is air is supposed to come in.

Once it has come in, this port is closed down and then the process of compression starts and then again the combustion and then again the power stroke and then exhaustion or exhaust of burnt gas out of the system. So this is how the entire cycle actually operates that we have a continuous process by which the whole cycle does the same job again and again.

Now if you look at some of these processes thermodynamically for example, the process a-b can be referred to as a constant pressure process because during this process there is no change of pressure. So this is what we call a constant pressure process thermodynamically. Now the process b to c, is refer to as isentropic compression in the ideal cycle because this process is now occurring under a thermodynamic process in which the entropy of the system is said to be conserved. So during this process, there is no change of entropy as envisaged in the ideal cycle and the process of compression occurs along that.

Then process from c to d, now this is combustion occurs under constant volume process during which as you can see in the p-v diagram, there is no change of volume envisaged in the ideal cycle. As a result the combustion is expected to occur in constant volume combustion process. At the end of the combustion, we have the power stroke or expansion thermodynamically. This is again an isentropic process which means during which the process undergoes no change in the entropy, which essentially means the process is essentially adiabatic and no losses are occurring during this process.

Same was true for the compression that means these two processes are isentropic process during which there is the processes are adiabatic and there no losses are envisaged in the system. That means the two processes are reversible processes, so they are reversible adiabatic processes which in short or in other words we call isentropic process.

We have work done or power stroke which is isentropic, work input or compression which is isentropic and then at the end of the process e at e, we have a constant volume heat rejection from the burnt gas a mixture of fuel and air. Then at the end of this rejection process, we again have this exhaust of the fuel of the burnt gas from the system which is again a constant pressure process; it is ideally envisaged to occur in constant pressure.

All the legs that we have seen now, can be now cast in the form of one thermodynamic process or the other that you have already done. Hence all these processes are now conforming to various thermodynamic laws. So we can now apply the thermodynamic laws to these processes and to the cycle as a whole to find how this entire cycle is actually going to work because finally, we want work out of this whole system.

So the entire process that entire cycle consisting of all these processes, that we have now talked about have to now conform to various thermodynamic laws and all of them put together finally, will tell us how the entire cycle which means the entire engine is expected to work in this ideal process as envisaged.

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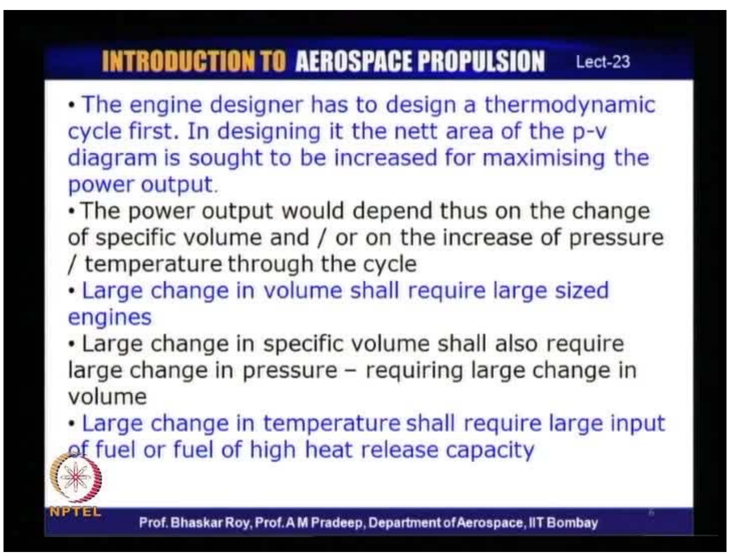

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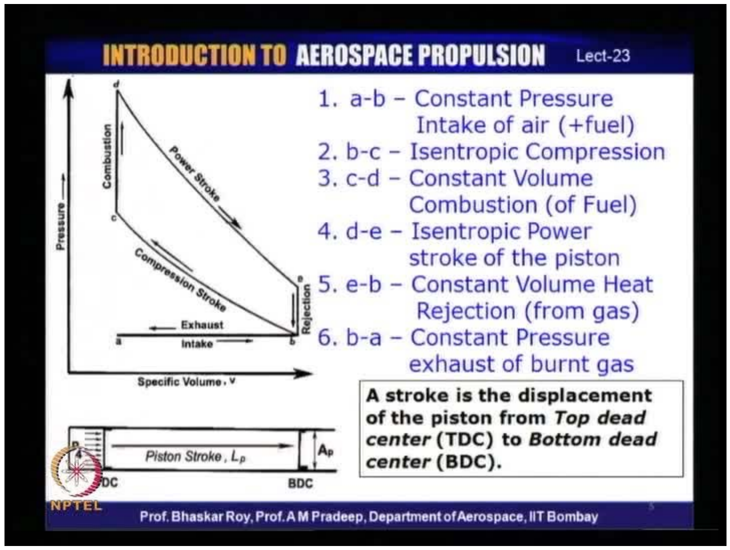

The net area of the p-v diagram in this thermodynamic cycle diagram is sought to be increased for maximizing the power output. Now what we can see here, this was the power stroke and this is the input stroke; so this is the so called output stroke, this is the so called input stroke (Refer Slide Time: 22:05). Typically it is envisaged or it is understood that the area subtended under this is essentially the output work. So, the entire area under the curve d-e is the output work; on the other hand, the entire area under the curve b-c is the input work.

So out of the output work, certain amount of work goes inside the system back again in the form of compression and hence the difference between these two areas that is the area subtended between b c d and e essentially, now represent the work that is available for doing some useful work. That is in our case, it will be used for creating let us say thrust or making the engine work.

So that is the useful work that would be available or often thermodynamically or in simple terms referred to as the net work. So the gross work done by the power stroke minus the work input of the compression stroke is the net work that is available.

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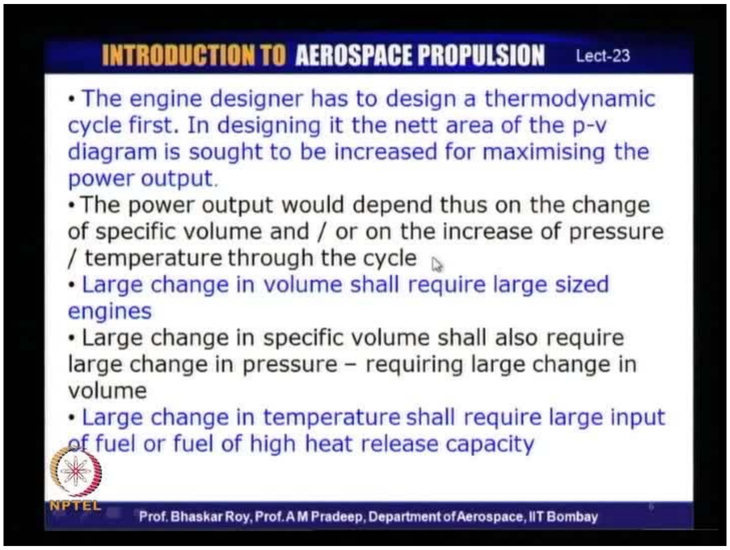

Now it is stands to reason that every engine designer would try to create a thermodynamic cycle in which the power output if it is to be increased, the net area that is available in this p-v diagram is to be maximized. How to do that? That is another story but, the designer of the engine he has to design a cycle first. The engine designer needs to design a cycle first and that cycle design needs to concentrate on the concept of increasing the p-v diagram, the net area of the p-v diagram, so that the work output expected can be maximized. Now, how do you do that? So, the idea is so if you want power output maximized you got to have a change of specific volume or the increase of pressure or temperature through the cycle.

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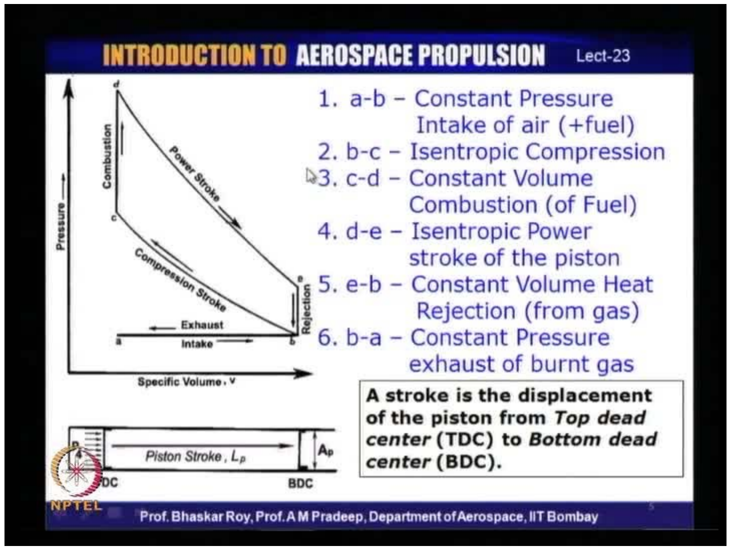

If you look at the cycle diagram, you are trying to increase this volume. Now if you want to increase this volume, there are 2 or 3 simple ways one can do it. The length of this stroke can be increased by which you can increase the volume or the difference between compression stroke and power stroke; this vertically can be increased which requires that the point d is to be raised to higher level and the power stroke occurs at higher pressure and compression stroke occurs at a much lower pressure. So those are the ideas by which the cycle can designed to maximize the power output from this system.

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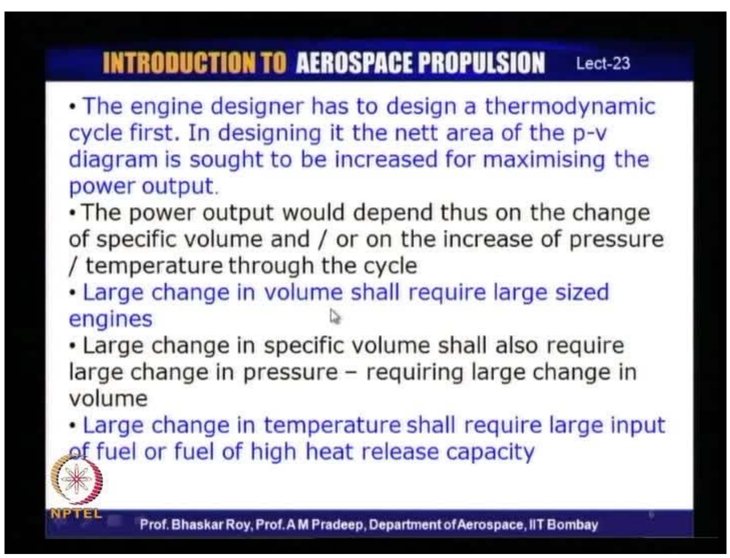

What it requires then is you have a large change in volume which shall require then a large size engine. The large change in specific volume shall also require large change in pressure and which requires again a large change in volume. Large change in temperature shall require large input of fuel or fuel of high heat release capacity.

So these are the means by which you can try to increase the work done of the system. Some of the troubles that we have is if you want to increase the volume, you want to increase the size of the engine; it may have some limitation when it comes to the use in aircraft.

Those are the limitations which we will again look into later on but, if a cycle is being designed to create an engine these are the issues that the cycle designer, the engine designer will have to look into will have to contend with for designing engines that create certain amount of power or a maximum amount of power under given operating condition.

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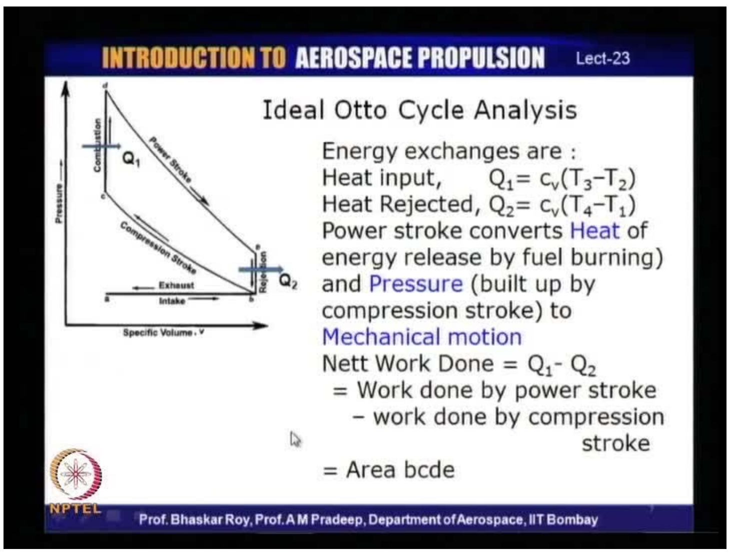

Let us try to understand how the Otto cycle analysis can be done to quantify some of our needs. We need to quantify some of the parameters that we are talking about. Now this is the cycle, you have just had a look into and this is where the heat is coming in, the fuel is being burnt and the heat is coming in and this is where we assume that certain amount of heat is being given out of the system which could be called Q 2, so Q 1 is the heat that is coming in.

Now understand that, not withstanding this long compression stroke and power stroke the input to the system is through here and output through the system is from here. So the heat input Q 1 is in a constant volume process, it is given over here. It depends on the temperature level from here to here and the heat rejection is from here which is the temperature differential between this point and this point. We may call these points 1 2 3 4 and we shall be doing that again, so this gives the heat input and the heat output of the system.

What the power stroke does is converts the heat of the energy released by the fuel burning and the pressure that is built up by the compression stroke to mechanical work or mechanical motion; so the net work that could be available from this cycle is Q 1 minus Q 2.

This is the work done by the power stroke minus the work done by the compression stroke. What we call the net area that is available in this cycle between b c d e and that is the area that we are looking at in terms of the work done or work available from this cycle.

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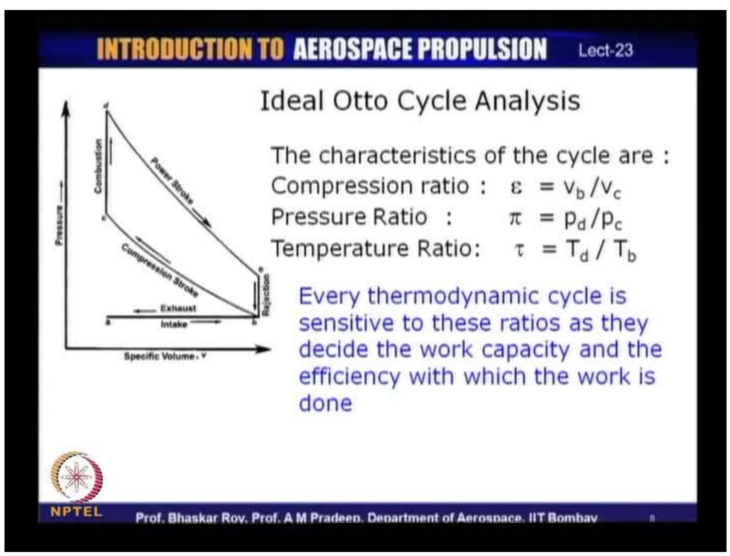

If you look at the cycle, you would probably see there are number of parameters that one can create to characterize this cycle. These are often called the characteristic parameters of the cycle. The first one is the compression ratio, which is the volume ratio between V b and V c. That is the compression ratio under which this cycle operates and this volume ratio is simply called compression ratio.

The other is the pressure ratio that is between the pressure that is occurring between this line and this line and this is referred to as a pressure ratio (Refer Slide Time: 29:12). We shall see later on that this pressure ratio has greater importance in other kinds of cycle. In this particular cycle, the compression ratio it is a more important item and then the temperature ratio that is the maximum temperature which the cycle experiences starting from the starting temperature, this is often called the cycle compression ratio. So, this is the cycle compression ratio and this is the cycle temperature ratio.

So, every thermodynamic cycle is actually very sensitive to these ratios because these ratios, we shall see as we go along actually decide the work capacity and the efficiency with which this work is accomplished. These ratios are extremely important as I mentioned, they characterize the cycles, they are the characteristics of the cycle and the cycles are often mentioned in terms of compression ratio, temperature ratio.

Later on we will see in case of open cycles, other kinds of cycles, the pressure ratio; some of these ratios would be coming back to us as important parameters. As you can see, they are non-dimensional parameters and they are very important in terms of trying to prima facie find out what could be the efficiency of some of these working cycles.

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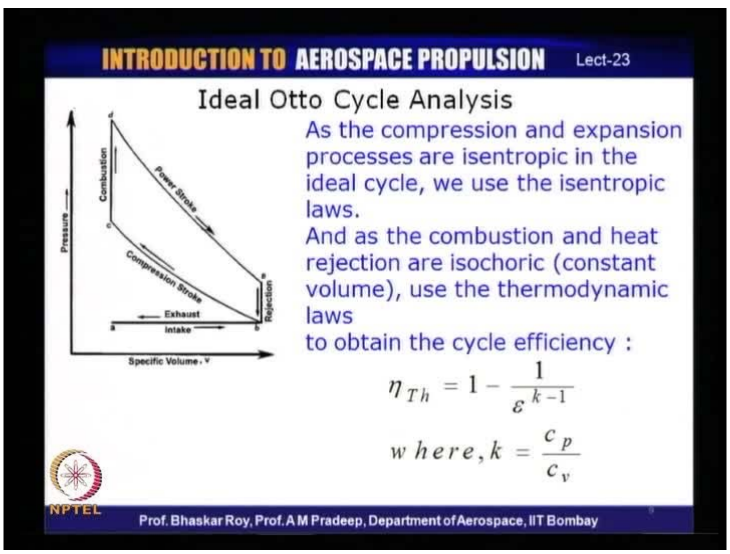

Let us look at the ideal Otto cycle that we are at the moment trying to understand. That is a cycle that we have looked at and as the compression and the expansion processes as we have seen are isentropic, we can use the isentropic laws that you have studied. Then we have the combustion and the heat rejection processes, which are a constant volume processes and we can use the thermodynamic laws that you have used for those kinds of processes.

If we use all of them and we can sit down and do a simple derivation what you can find is the cycle efficiency can be written down, this is the thermal efficiency of the cycle. It can be written down in terms of the compression ratio or the volume ratio and the specific heat ratio that is of the working medium that we are using in our case that is air.

If we have just these two values available with us, that is the compression ratio and the specific heat ratio of the working medium, we can quickly find out what the cycle efficiency would be. So you see its quite simple that if you prima facie have the compression ratio available with the working medium that you are using, you can quickly find out what the cycle efficiency is likely to be and as we shall see this allows the cycle designer, the engine designer to indeed configure a cycle or configure engine even before it is actually built.

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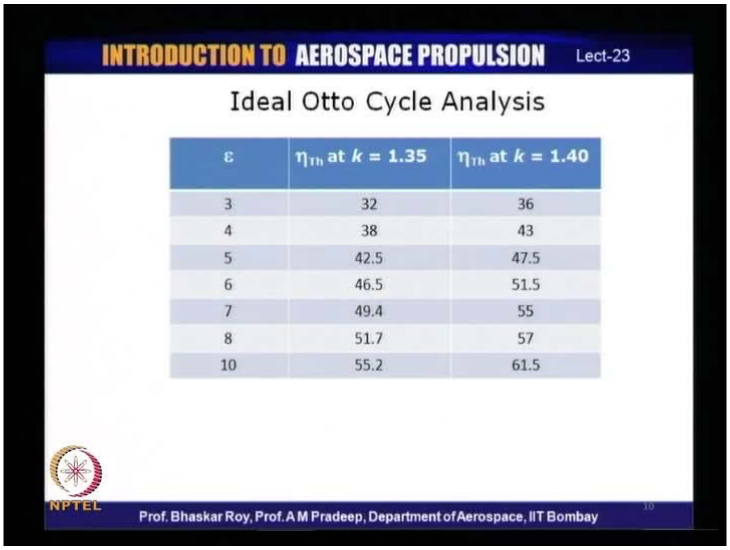

ε	η_{Th} at $k = 1.35$	η_{Th} at $k = 1.40$
3	32	36
4	38	43
5	42.5	47.5
6	46.5	51.5
7	49.4	55
8	51.7	57
10	55.2	61.5

Using this for example, we can put down some numbers. This is the compression ratio (Refer Slide Time: 32:37) for example, the cycle designer or the engine designer is trying to build and if you have these kinds of values, these are the thermal efficiencies with which the engines will work. Now I have used here, two different specific heat ratios 1.35 is what is quite often used for hot gases or when the fuel has been burnt quite often that is a kind of value used; 1.4 as you might know already is normally used for simple air.

So if you use those specific heat ratios, you get various values of efficiencies and as you can see here, as the compression ratio increases, the efficiency of the cycle and that of the engine actually increases. If you have a pure air of course, the efficiency's little higher but, as you know we have to burn fuel to put in the energy into the system and hence this is the kind of value that we are normally likely to encounter in actual engines.

That gives an idea to what extent you can have high compression ratios to get higher and higher energy efficiency of the engine. What the compression ratio can be depends on number of parameters or number of practical considerations. We shall be talking about some of that as we go along in this lecture and in the next lecture.

So the cycle designer has an idea now, if he chooses certain compression ratio and given the working medium, he would be able to attain certain kind of cycle efficiency which he hopes to come pretty close to in an actual working engine.

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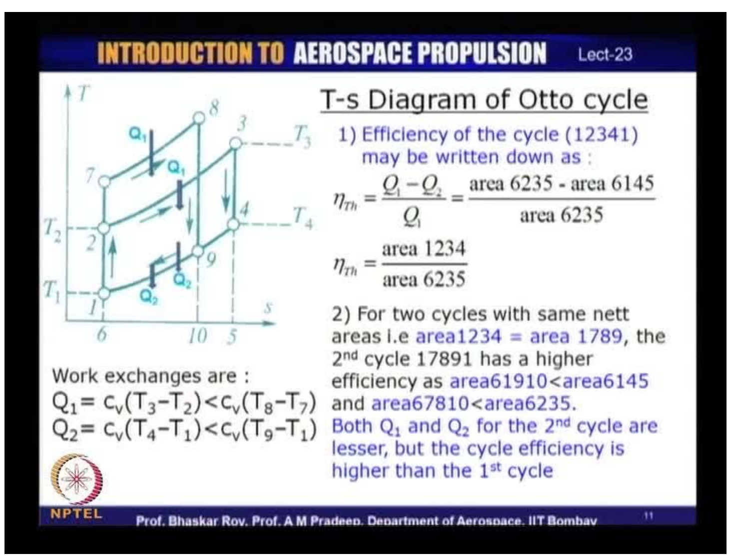

Now the p-v diagram that we have looked at can also be recast in the form of what can be called what is often called the T-s diagram which is of course, as you know the other way of diagrammatically representing a cycle. So cycle is often represented either in p-v diagram or in T-s diagram. In this case if we cast the Otto cycle in the form of T-s diagram to begin with for example, we have written down the thermal efficiency all over again.

In the T-s diagram, we can now see that the work done. For example, if we take the first cycle here 6 3 2 and 5 and that is the work done of the system or the heat input in to the system. Heat output Q 2 is in terms of 6 1 4 5 now, T-s diagram directly tells us the work the heat input and the heat output of the system and as a result of which the thermal efficiency can be quickly found and it tells us again that the net area that is 1 2 3 4 actually gives us the net work output or net energy available for work divided by the net work input or net heat input and that is thermal efficiency of the system.

Now let us consider in this T-s diagram, another cycle which has a same net area as the first one that is area 1 2 3 4 is same as the area let us say 1 7 8 and 9 so, these two areas are exactly same. So, two different people let us say have configured two different cycles and the net area of both of them are actually same. Let us say, designers have created these two different cycle what happens is in this second cycle which is 1 7 8 9 1 this actually would have a higher efficiency and this higher efficiency is because this area 6 1 9 0 is actually less than the area 6 1 4 5. That means the heat rejection in the second cycle is actually much lower and a result of which the area 6 7 8 1 0 that is 6 7 8 10 is actually higher than it is also the area 6 7 8 10 is lower than the area 6 2 3 5.

As a result of which the efficiency which is now given in terms of the net area and the heat input into the system the because of the fact that the net area of 6 1 4 5 is actually higher than the 6 1 9 0. The efficiency of the second cycle comes out to be much higher which means, if you can do the heat input at a higher pressure, now this is the higher pressure line in the T-s diagram, 7 8 is a pressure line constant volume line; that constant if you can do that the heat input at a constant volume line you can get a higher efficiency of the system, even if the net area is same. It means the cycle design or the cycle designer who looks into creating the cycle has a very important role to play in finally, creating the engine that finally, is out of various kinds of materials.

So the conceptual cycle that the Otto cycle is designed on creates the engine and a lot of thought needs to be given to creating the Otto cycle which finally, creates the piston engine that works and that supplies power for creation of thrust.

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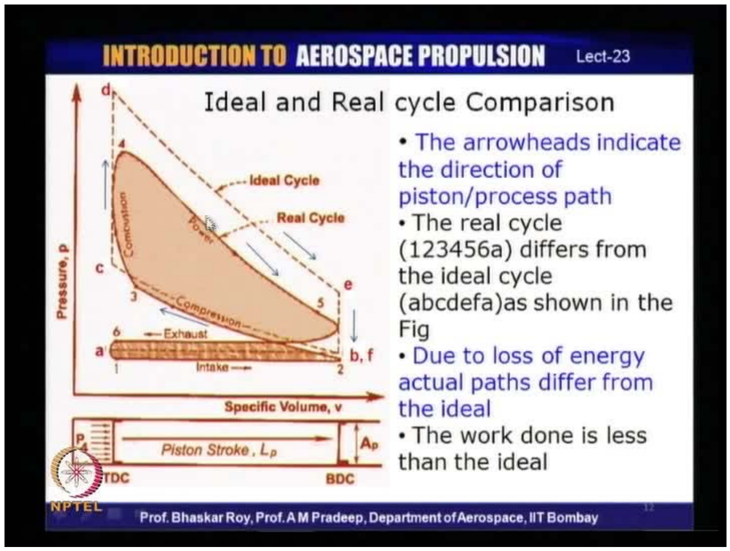

Let us now take a turn our attention to what could be called the real engine or the actual piston engine, according to which the actual engine would work. Now some of these things are born out of the understanding of how the piston engine actually works and as a result of which we shall see here that what we can call now a real cycle. Let us say conforming to some piston engine differs quite a lot from the ideal cycle.

The difference is for example, you see the net area that is created by the real cycle seems to be substantially less than the net area that was being created by the ideal conceptual cycle. This is due to the fact that the work which is being done during the expansion compression process quite often is not isentropic. You remember, we had assumed that the processes are isentropic and as we shall see as we move along more and more that these processes cannot be isentropic quite often they can indeed be adiabatic; they can be pretty closely adiabatic but, quite often they are unlikely to be reversible processes.

So we are going to have processes which are mostly irreversible processes which means they undergoes certain amount of loss; this loss in the form of loss of energy and as a result of which the net work that is available outside of the system, out of the system is going to be much less than what is conceived in the ideal cycle. As we shall see here, the intake and exhaust processes are not on the same pressure line; these are the reasons because of which the real cycle differs quite a lot from the ideal cycle.

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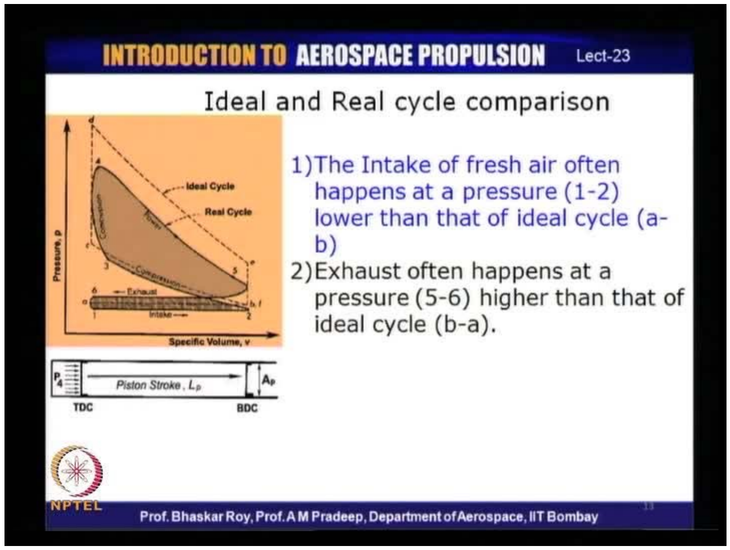

Let us get into them a little more in detail the intake of the fresh air. Let us start from the intake often happens at a pressure which is 1 to 2 and which is often a little lower than the ideal cycle. As we shall see later on that the exhaust often happens at a pressure higher than that of the ideal cycle, it starts from here and it goes around here (Refer Slide Time: 41:41) then this is how the intake occurs.

Now this is how the air is driven out to the piston and this is how the piston actually takes in the air, as a result of which there is a slight different between exhaust stroke pressure line and the intake stroke pressure line. It creates a certain amount of work that goes away in the process of exhaust and intake that would not be available to the external agency which requires that work for creating thrust through the propellers. So, the intake and exhaust do not conform to the ideal cycle concept.

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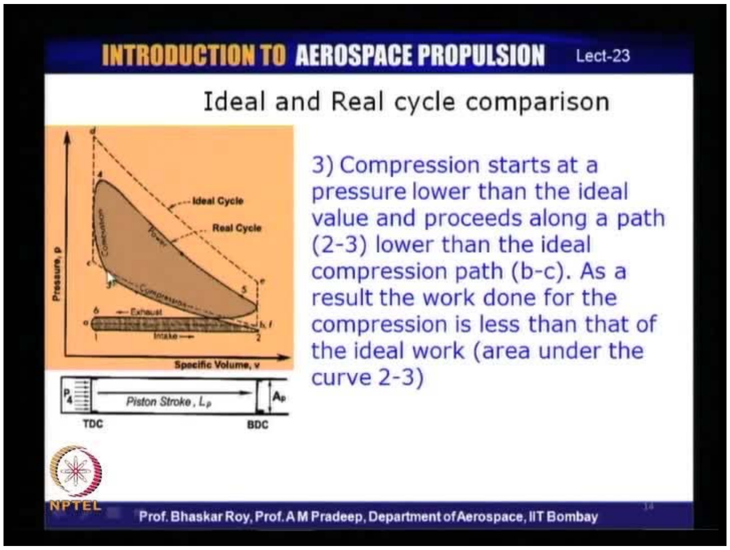

Now, let us look at the compression process. The compression that process quite often since the intake process finishes its intake line at 2 which is as you can see a little lower than b, compression process starts at a pressure which is lower and quite often proceeds along a isentropic line which is a little lower. As a result of which it quite often and as a result of the fact that it does not conform to the reversibility and it encounters certain amount of losses due to the motion of the piston inside the cylinder; it does not quite reach the point c, the compression process often goes up to 3 and then at 3 the combustion is initiated.

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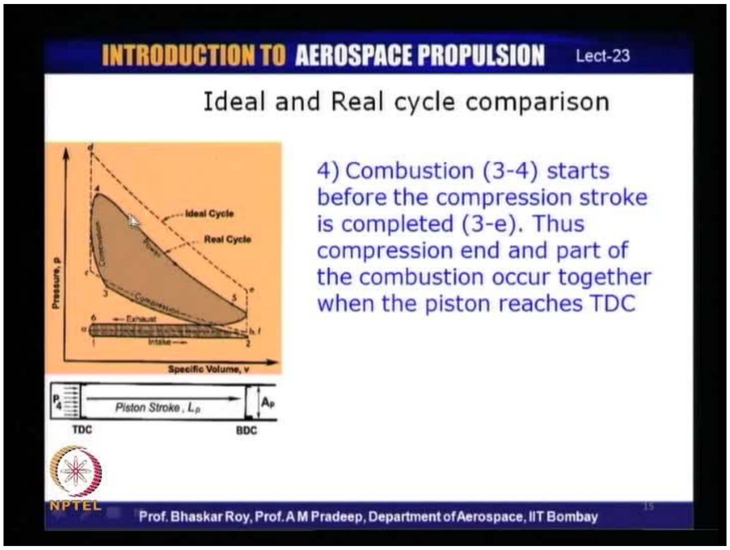

So the compression process, the only compression process as we know goes from 2 to 3 and at 3 the combustion is initiated. This combustion starts at 3 the compression actually continuous a little it goes to what we had called TDC in the piston and then the combustion process continuous up to 4 so, the pressure and temperature keeps on rising. Then over here, the expansion process starts; so the process of combustion you can see quite often due to the process of either incomplete combustion or due to the fact that the movement of piston has somehow come in the way it never quite finally, reaches the point d somehow or other. It finishes off at somewhere around 4 and then the process of expansion or the power stroke starts.

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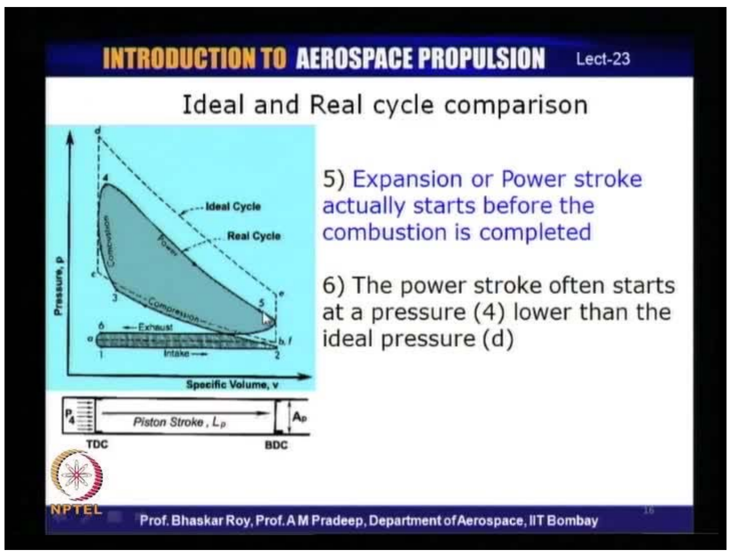

This expansion process now starts as you can see quite often somewhere over here (Refer Slide Time: 44:27) which means, the expansion in some manner has started even before the combustion process is actually completed. From here, we can officially say that the expansion has started now, by now the fuel has been burnt and we have a mixture of fuel and air and then the power stroke starts at pressure 4 and this high pressure now moves the piston down to 5.

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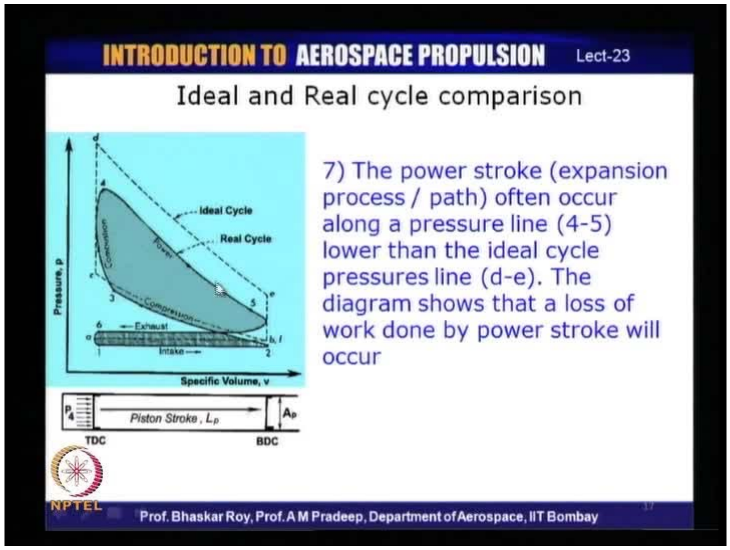

As we can see slowly that finally, it starts at a pressure lower than d it finishes off at pressure eventually which is lower than e and over here as we shall see that the power stroke actually takes around over here quite often you do not have much of a time really for the heat rejection process which is ideally conceived or envisaged. As a result the exhaust process starts right away here and the heat rejection process which is shown from e to b or e to f is quite often very quickly almost instantaneously rounded out over here.

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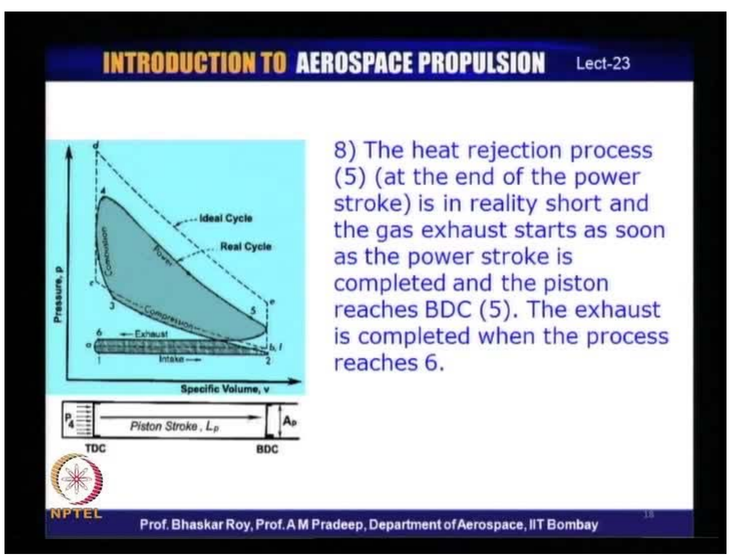

In fact, the exhaust gas that is going out carries away the heat, so the heat rejection often happens with the exhaustion process and the exhaust gas or the burnt gas that is going out actually carries away a lot of heat. So, the ideal process and the real process as you can see, happen quite differently because the motion of the piston, the burning of the fuel.

This as a result of which the exhaust process is completed when it reaches 6; this often occurs, now you can see at a pressure which is at a higher pressure its start off actually as I mention over here, little after 5 and then as a result of which it settles down at a pressure which is exhaust pressure which is at a higher pressure than the ideal pressure envisaged and it ends up at 6. Then the intake process starts all over again, so the whole cycle of the engine starts all over again. This is how the real cycle operates and this is how the real cycle is quite often different from the ideal cycle.

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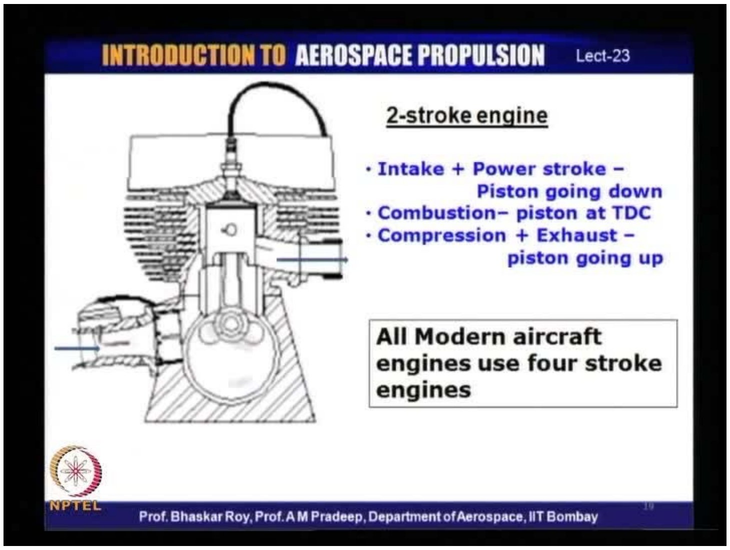

This particular cycle was initially used for creating what is known as 2-stroke engines. Various kinds of 2-strokes engines are operational even today; however the 2-strokes engines are not used in the aircraft power plant anymore. All the modern aircraft engines used what is known as 4-stroke engine, now very quickly the 2-stroke engine what it used to do are wherever they are used even today they kind of combine the intake and power stroke, then they combine the compression and exhaust stroke and somewhere in between the combustion is expected to occur in a very short time when the piston is at TDC.

So this is a kind of hand drawn sketch of a 2-stroke engine, so when this reaches the top over here, the combustion is expected to occur and then the power stroke could occur and when the power stroke occurs, the intake also starts coming from this side (Refer Slide Time: 48:20). This is the side from which the intake comes and when the compression stroke occurs, the burnt gases simultaneously exhaled out of the system.

This is called 2-stroke because the 2 legs of the cycle are combined together into 1 stroke and as a result this engine operates on 2-stroke principle whereas, as I mentioned most of the engines today are 4-stroke. So from now onwards, the cycles and other forms of engines that we look at would be 4-stroke engines.

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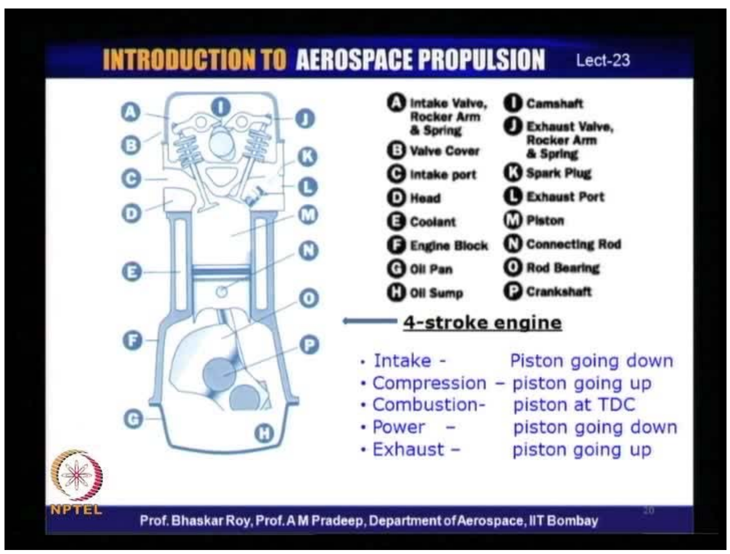

This is a kind of 4 stroke engines that is used in the modern aircraft engines, all kinds of modern aircraft engines. Let us quickly understand how the thermodynamic processes are converted to what we call now strokes. The familiarity of the engine very quickly we have an intake valve over here, which opens this intake port through which the fresh air comes in and there is a timing given. So, this has to be timed properly and air comes in through this and comes in and fills it; so when this is at the bottom what we call BDC and the piston is going down in the intake process. This entire space is now filled up by the air coming in from here and this valve is open (Refer Slide Time: 49:44).

Once the air is filled up over here and once the compression process start that means, the piston starts going up this valve closes. So this air cannot go out from anywhere anymore and it is entrapped within this space of the cylinder and now the piston is moving up, so this is entrapped air is compressed in this enclosed volume. Once this moves right to the top and it reaches the top dead center, the fuel is burnt and we have a spark plug over here, which initiates the ignition process and as a result of which the combustion occurs over here.

This combustion creates a high pressure, high temperature and the high internal energy level of the air and the burnt gas which then pushes the piston backwards and what we call then have the power stroke. So, then the piston again starts moving backwards pushed backwards by the pressure or high internal energy and it creates the power stroke.

Once the power stroke is completed that means, the piston reaches the bottom dead center, the piston then starts moving upwards again in the form of inertia of the system. Then this outlet valve is opened its time to open when the piston starts moving up wards after the power stroke. Then the burnt gas - now this is closed (Refer Slide Time: 51:30) so - this is burnt gas the work has been taken out through the power stroke and then this burnt gas goes out of the cylinder altogether. This reaches top dead center and almost the entire amount of burnt gas is now moved out of the system.

What does happen is a very small amount of burnt gas actually stays back. So, when the fresh air is coming in, it mixes with the burnt gas and as a result of which you do not actually have fresh air from the second cycle onwards; you always have a residual burnt gas mixing with the fresh air. As a result of which as we have seen, the real cycle operates slightly different from the ideal cycle.

This is another reason why the real cycle differs from the ideal cycle. So this is the mechanism, this is the mechanical mechanism by which the cycle is converted to an engine. Now what we are looking at is a picture or a diagrammatic sketch of an engine by the virtue of which you can create work or mechanical work and this engine then moves the crankshaft over here (Refer Slide Time: 52:50). This is the crankshaft which creates the motion rotary motion and through the shaft power is taken out on a continuous basis for running any working body, in our case that would be the propeller which creates thrust.

So these are the details of a working engine and some of these are what we will be looking into in the next lecture as to how an engine of this kind is finally converted to an aircraft power plant.

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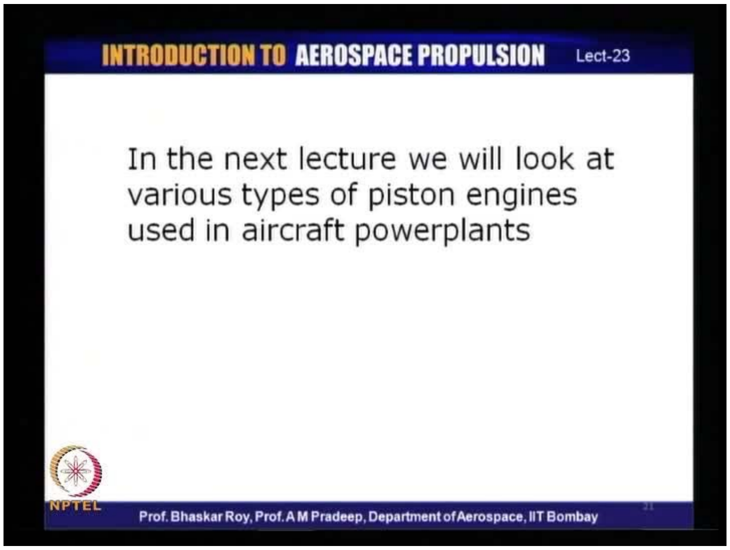

So our next lecture will be on converting or arranging some of these engines into various kinds of useful power plants that can be used on an aircraft which finally, will create thrust. Our business is finally, creating thrust engine is the method by which we create power. We have just looked at the thermodynamics of the engine; in the next class, we will look at the arrangements of these engines in the form of aircraft power plants.