Introduction to Aerospace Propulsion

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Module No. # 01

Lecture No. # 24

IC Engines for aircraft application

In today's lecture, we will look at the development of aircraft engines using the piston cylinder concept of IC engines, using various considerations of thermodynamics and various other mechanical engineering issues that needed to be all put together to make aircraft power plants.

First, we will deal with various issues that are related to basic IC engines starting with thermodynamics, which we did in the last class. We shall see, how all these fundamental sciences and certain amount of mechanical engineering is put together in to the making of engines that finally go on to fly the aircraft.

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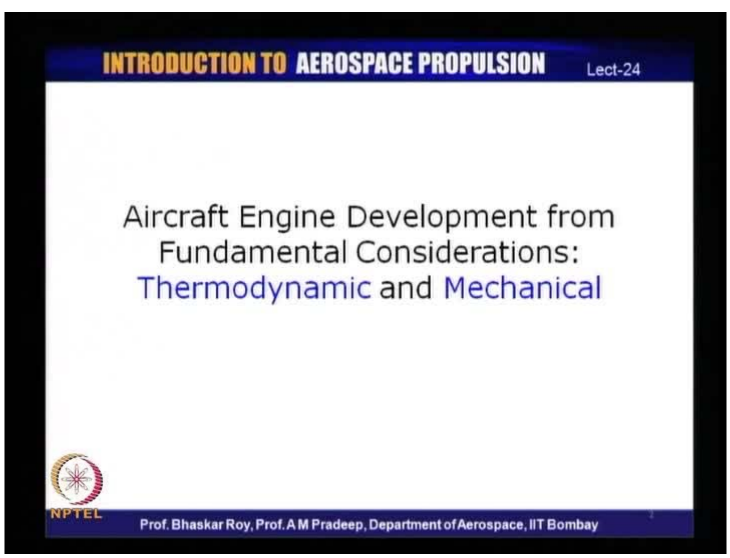

The various thermodynamic issues that need to be considered, much of it has been dealt with in the earlier lectures. The cycle consideration is needed to be looked in to. As we have discussed, all engines - the engines that we are talking about are the heat engines, need to be based on thermodynamic cycles. We will look at some of these thermodynamic cycle issues once again. Then, we will look in to the various mechanical engineering issues that need to be put together along with the thermodynamic issues to create aircraft engines.

The IC engines or the piston engines, as they are more popularly called - are quite often the main source of power plant in aircraft, literally for 1000s of aircraft over the last 100 years. Even today, literally 100 - probably 1000s of aircraft are still flying around with engines or aircraft power plant based on piston engines. These are the small aircraft, which are flown by small engines. We shall have a look at some of these engines today, how these engines are actually put together - created and put together to fly aircraft.

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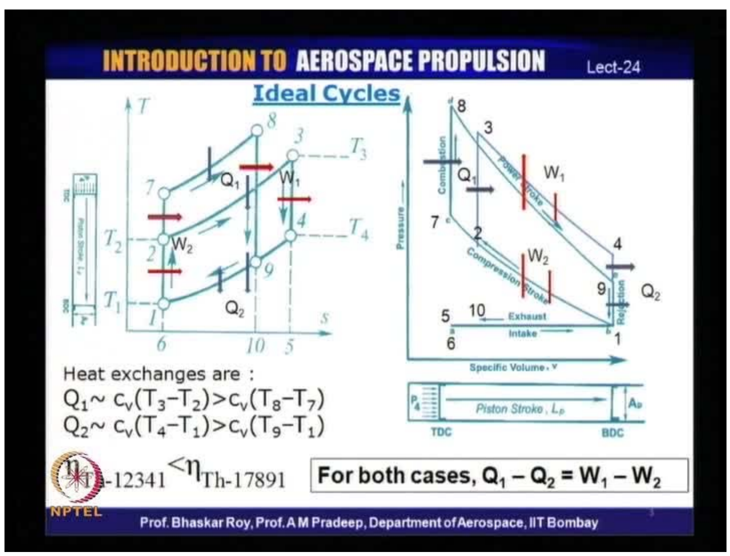

We started with talking about cycles. Now, we look at the cycles all over again to see - that is where we start again from to build up our engines.

Now, we had a look at the concept of a cycle, both in PV diagram, as well as in TS diagram. Let us have a quick look at that all over again. We have seen that if you have, let us say, two different ideal cycles at this moment, let us just considered simple ideal cycles.

If you have two different cycles given by, let us say 1234 or 12341 and then the other one, which is 17891. If the two cycles are doing same amount of work, from both the cycle considerations, we can write down that the work done by both of them may be same, but the work input requirement in case of one cycle is more than the other, as a result the work output is also different from the two cycles. The result is that the cycle 1234 actually has more work heat input and more heat output. However, when you consider the efficiency, the efficiency of the cycle 12341 is actually less than the efficacy of the cycle 17891. Now, this comes from the efficiency definition, which we have done in the last class.

If you look at the PV diagram or again if we look at the work done, now we had seen, there are two legs of the cycle, where the work is done; one, is of course what we call the power stroke, during which the work is extracted from the engine; the other is a compression stroke, in which the work is actually put inside the engine. In this, we can see here that the work is being put in and work is being taken out from both the cycles. In terms of the basic consideration that we have seen, the two cycles are supposed to do same work. So, for both the cases, Q 1 minus Q 2 is actually equal to W 1 minus W 2 so that the net work done is equal to the net heat that is gone in to the system and that is same for both the cycles.

However, as we have just seen that the efficiency of one of the cycles that is 17891, is actually more than the efficiency of the cycle 12341. Now, this brings us to the point that if I have two cycles with same work output, but the efficiency of one could be better than the other one; that means the efficiency translated to fuel efficiency. It would mean that one cycle would actually consume less fuel than the other one doing same amount of work. Now, that is obviously very attractive thing for any engine maker.

Now, if we look at the schematic of the piston that we have here, we have discussed this in the last class, let us look at it again quickly. We have this piston stroke, during which you would need to perform the work, so when the piston is moving in, it is actually doing the compression work and when it is forced out, it is the power stroke.

Now, what happens is, if you want to do more work out of this piston, you would need to change the volume of this, this will come to the actual formulae in a few minutes. The point is that if you want to create more efficiency of one cycle, you would need to create more compression ratio, as we have seen in the last lecture.

The thermal efficiency is directly dependent on the compression ratio, which means that one of them has a higher compression ratio than the other. Which means, a process 1 7 actually is executing a higher compression ratio than the process 1 2 and that is the source of the higher efficiency.

Now, to create higher compression ratio, this piston has to move more; that means the length of the stroke would have to be more. This would require the piston to be of a larger size, so if you want more compression ratio, more efficiency, which translates to more fuel efficiency and fuel conservation, you would need to probably have a piston, which has a longer stroke length. Now, this is something which comes out of the basic consideration of thermodynamics as seen from simple ideal cycle analysis.

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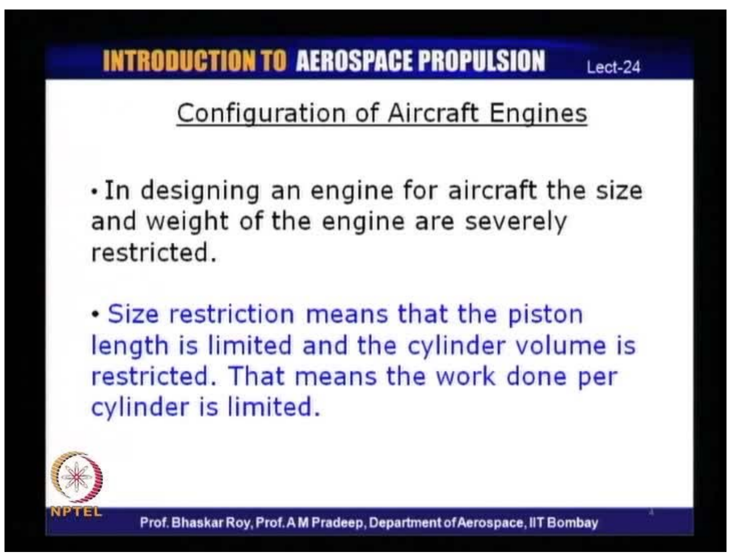

Now, this means that you would require a piston, which is of larger size or longer in length to obtain higher efficiency. Now, this a bit of a problem that in an aircraft, if you are looking at anything that has to go on a flying aircraft, the size and weight are restrained, they are premium. Because, anything that you carry in an aircraft would have to be compensated for, by creating more thrust.

So, larger size and higher weight are something that severely restricted, whenever an engine is being considered for aircraft. This is one of the reasons, why - for example - aircraft do not use diesel engine; which as you know are higher in weight, because of the fact that they operate under higher compression ratio; those compression ratios do give the diesel engine higher efficiency.

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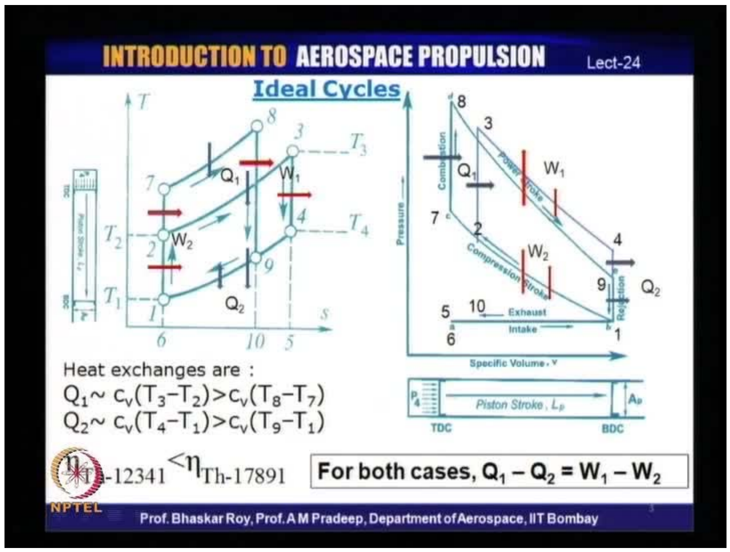

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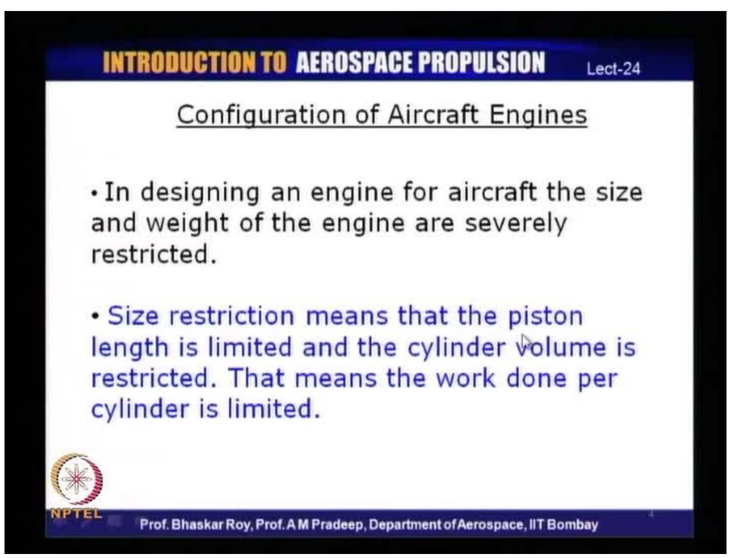

So, conclusion from the earlier slide is that you can go for higher compression ratio. If we move towards the diesel engine, it could become unacceptable to the aircraft designer, because diesel engines are typically heavier, would not be carried in an aircraft in efficient manner - taken the aircraft as a whole.

So, even the engine is more efficient, the aircraft as a whole would become inefficient device; so that is one of the considerations. The other is of course that the size limitation, if you have larger piston sizes, the size of the whole engine would tend to go up. As we have seen before, we shall see again today that the total size of all the cylinders put together, make up the whole engine. That means there is restriction on the total number of cylinders that you can put, the total sizes of each cylinder that can go on an aircraft, because finally whatever goes on an aircraft has to meet the aircraft shape.

The shape of the aircraft is very important to make it air over - as a result of which, there is a restriction in the size of the piston length and the cylinder volume that can go on an aircraft. Such limitations, of course normally are not there in land based vehicles, so land based vehicle quite often can go on for higher efficiency using a heavier or larger engines.

So, as a result of these restrictions, the work done per cylinder in a piston engine that goes on an aircraft tends to get somewhat limited. This limitation is what aircraft designers have to live with.

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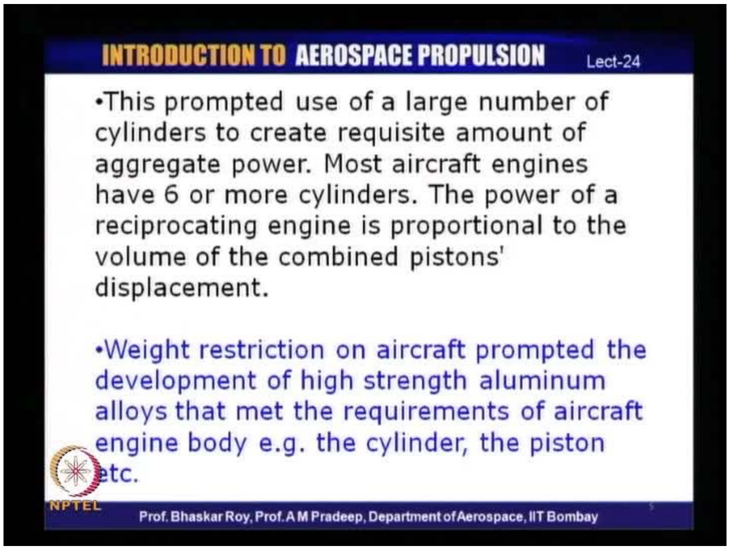

Now, as a result of the fact, to make an aircraft fly, you need certain aggregate amount of power. To use this aggregate amount of power, you need to then put together a number of cylinders, so that the aggregate amount of power is quite sufficient to meet the requirements of aircraft thrust requirement.

So, the power of reciprocating engine, as we know, is proportional to the volume of the combined pistons, quite often to many of the IC engines or piston engines. You may have heard often is referred to as or sited as so much of volume, because the volume does represent the work capacity of that particular engine.

The other thing that is required in an aircraft is a light weight; anything that goes on an aircraft, it has to be as light as possible. As a result of which, many of the piston engines very quickly started getting made of aluminum alloys, which were developed specifically for the aircraft grade.

So, the aircraft grade aluminum alloys were developed, of which the aircraft engines were made, which are quite often not used in the land based vehicles. So, both terms of the way the engines are designed and created, then the way they are made, needed to be developed differently for aircraft engines. This is something which happened probably more than 40 or 50 or 60 years back, as a result of which, most of the aircraft engines today are much lighter than corresponding, and much smaller than corresponding engines used in land based vehicles.

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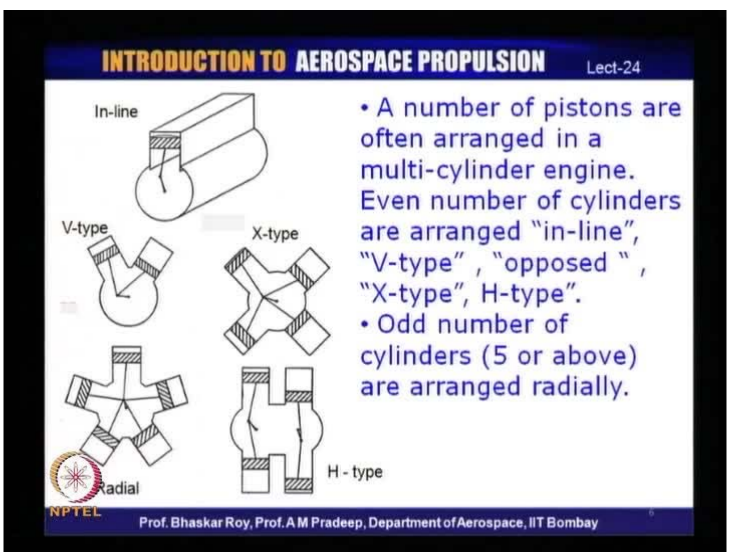

Let us take a quick look again at some of the arrangements that are quite often done in various kinds of aircraft engines, which often tend to be multi cylinder engines. As we seen, the multi cylinder is often arrived at by putting together the total amount of work that is necessary to drive the propeller, which of course creates a thrust that flies the aircraft.

Now, as we have seen, the number of cylinder arrangements, let us quickly look at it again. You can have cylinders lined upon one after another, what is known as the inline version, where they are one after another. The other version is where you can put two cylinders in a V formation and then you can have a V inline; so, you can have 2 by 2 cylinders lined up. Or you could have X type, where four cylinders are around one central main shaft or crank shaft. Then, you can have a four inline, which means you can have multiples of 4 or 8. Just like, you can have multiples of two, which means 2, 4, 6, and 8, etcetera.

However, there are options where you can have four cylinders in this fashion, which is often refer to as H type, so that four cylinders are arranged in an opposed fashion and not in X type. The other possibilities is that if you have odd number of cylinders depending on the - as I mentioned earlier, the aggregate amount of power that is required finally to drive the propeller - if you land up with a number that is 5 or for example 7 or 9, if the aircraft shape accommodates it, quite often one of the arrangements is refer to as the radial arrangement, where you have 5 or 7 or even up to 9 cylinders arranged radially around the central crank shaft.

So, all these pistons supply power to a central crank shaft. Except, in this case, as you can see here, you would need a large diameter to accommodate all these engines, so the point here is that each of these as you have has different kind of final shape.

This would have one kind of shape, this would need another kind of shape, this has a different kind of shape and this of course has a different kind of shape. The outer shape - I am talking about right now, the outer shape within which all these cylinders are arranged, because this outer shape has to conform to the aircraft body, inside which this engine is going to be housed.

So, the final arrangement is quite often decided by two considerations. One is the aggregate amount of power that is required to drive the propeller, which finally flies the aircraft. The other consideration is the shape of the aircraft, in which, this arrangement is going to - go inside, whether it can accommodate this arrangement, is the other consideration. So, these two put together finally create the aircraft engine, which goes inside an aircraft.

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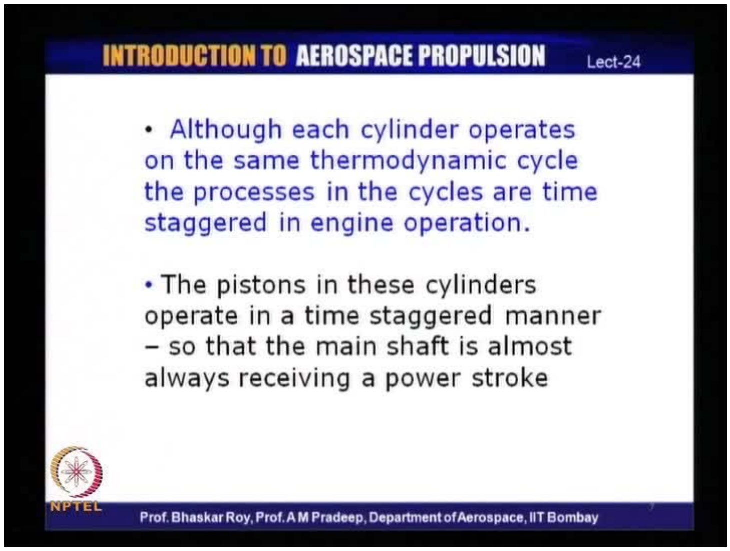

As we have seen, in the earlier one, each of these pistons actually operates under a particular thermodynamic cycle. Thermodynamic cycle is the basis on which each of these pistons is actually working.

However, what happens is that since they are all supplying power to the same central crank shaft, it becomes necessary to supply power to the crank shaft almost on a continuous basis. To do that the mechanical engineering requires the power supplies stroke or what we call the power stroke needs to be time staggered. So, each of these cylinders are now operated in such a manner that the power stroke of those cylinders do not occur simultaneously, they are time staggered.

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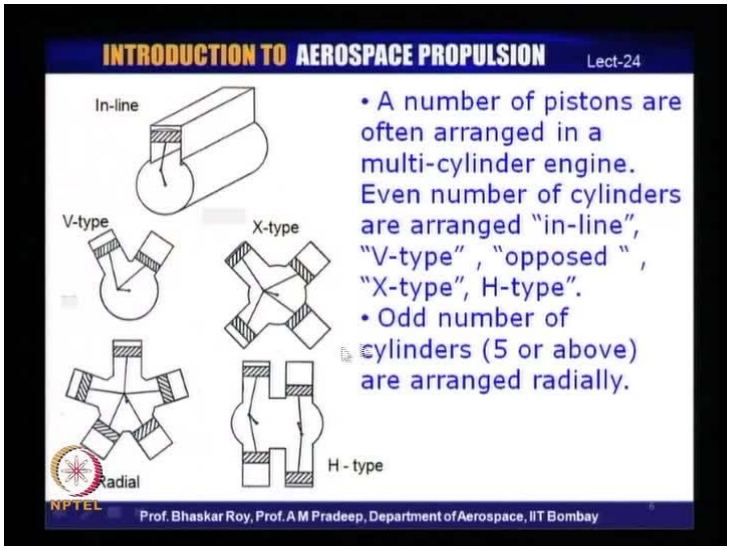

Let us quickly go back to the earlier one. If you can see here, for example, this diagram, the cylinders, as you can see here, are at different positions. These two are more or less at same position; whereas these two are at same position. So, the power stroke of these two are probably time together, whereas the power stroke of these two cylinders are probably time together.

Whereas in X type, you can see each of them has a different stroking arrangements, so the strokes are essentially staggered in time so that the supply to the central crank shaft occurs in a time staggered manner. So, almost at every split second there is a time stroke being supplied to the main crank shaft. Now, this is the mechanical arrangement, which needs to be created when you have a multi cylinder arrangement.

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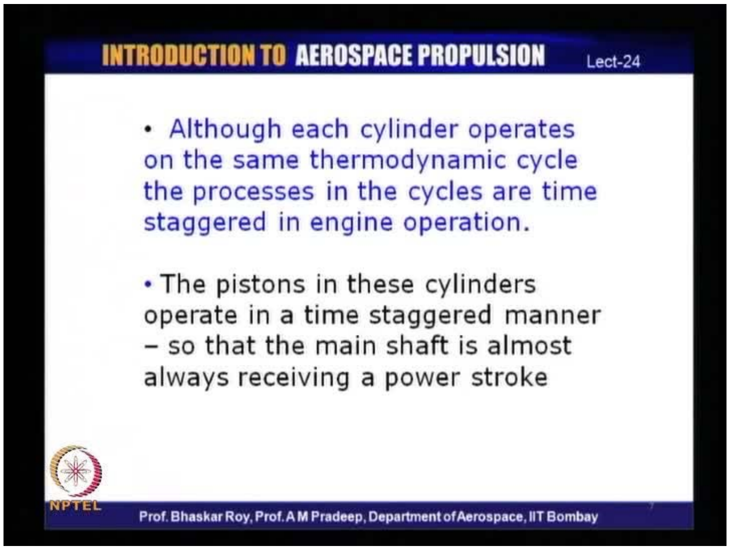

Especially, most of the aircraft do have multi cylinder arrangement, even though each and every of these cylinders is actually operating under same thermodynamic cycle.

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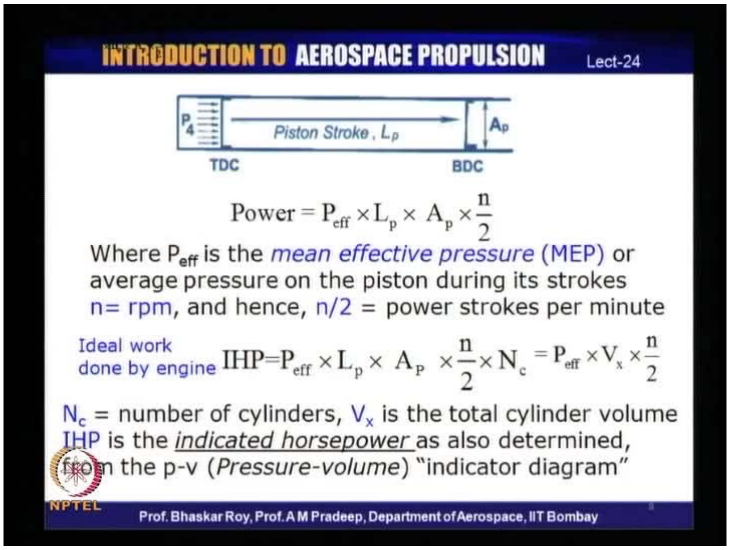

Let us take a look at how the piston engines actually create power in terms of actual operation. We had seen how they can be put together in terms of thermodynamic considerations, now we can look at it from pure mechanical considerations.

The power created or as we said the power stroke, is directly proportional to the average pressure that is applied on this piston, by this length of the piston stroke and the area. That into n by 2 n is of course the rpm; n by 2 is the power stroke per minute.

So, these parameters put together L p into A that of course is the volume though which the piston is displaced, so that is the displacement volume of the piston. As I mentioned earlier, is often refer to as one of the specifications of an every engine that is multiplied by the piston, so that of course gives you the force in to the rotation, gives you the power per unit time.

Now, this of course tells you that if you have longer piston stroke, you get more power, if you have a bigger area of the piston, you get more power, if you have a higher mean effective pressure, you can get more power, or if you run the - if you can offered to - if you are in a position to run the engine at a higher rpm, you can get more power.

Now, let us look at these parameters quickly again. We have just seen that in an aircraft engine, you cannot - there are size restrictions, there are weight restrictions, so you cannot have a large piston stroke, you cannot have a large piston, you cannot have a large piston area, because of the size restriction. So, those two get automatically restricted by their requirement of the aircraft, they have to be restricted.

The pressure gets a little restricted, because of the fact that if you have a very high pressure - very very high pressure, this piston would have to be built with very heavy material that is what is normally done. For example, in a diesel engine is made of very thick material to with stand the very high pressure; that is normally created in a diesel engine.

So, the pressure has some restriction, otherwise this have to be - the whole piston cylinder would have to build like pressure vessel. So, all this restrictions put together the aircraft engine need to be designed or created.

The fourth possibility which we have here is the rpm. So, most of the aircraft engines do operate at somewhat high rpm, so that the power created is of a reasonable amount and it is sufficient to drive the propeller that creates the thrust. As a result, the power stroke that is created would have to be very fast.

So, this is the aircraft engine requirement, you cannot have high length of the piston stroke, you cannot have large area, those are restricted. You cannot have very high pressures, because of the limitation on the weight, but you can go for a somewhat higher rpm. As a result, most of aircraft engines do operate at a somewhat higher rpm than many of the land based engines.

Hence, we can say that the ideal work that is done by an engine. This IHP is something we can be also configured from the PV diagram or which is often sometimes referred in many books as indicated diagram, which comes from the thermodynamic cycle diagram of a pressure volume diagram. You can get the amount of work from that diagram that would have to be equal to the work done, as we have written down above. This is now expressed in terms of the volume; this is a volume of the cylinder. As I mentioned, quite often cylinder volume is mentioned in the specification of the engine as indicator of its work done.

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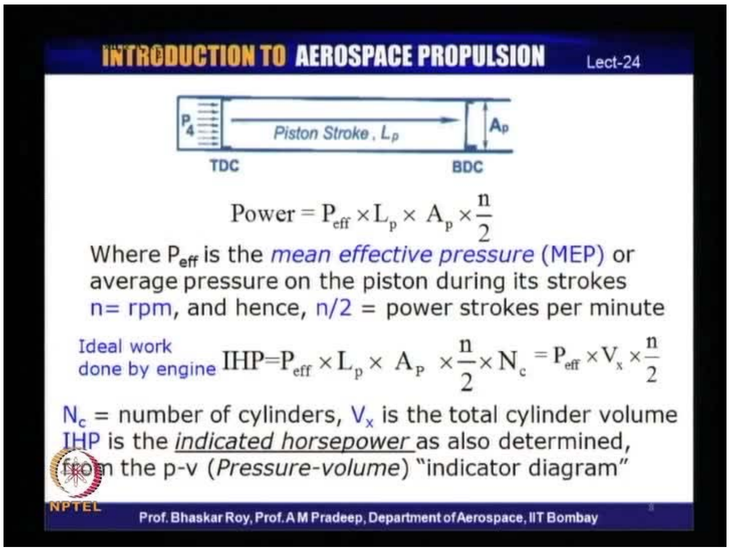

Capital N c is the number of cylinders, now that tells you what is the total amount of work that would be required to be done for a whole aircraft, not by one cylinder, but for the whole aircraft. So, when you put all of them together, you get the total work requirement for the whole aircraft to drive, let us say a propeller.

Now, the question here is, let us go back to this pressure, which I have written here as mean effective pressure or MEP. Now, this mean effective pressure is quite often - you know is average pressure, which is operative on this piston during its piston stroke. As a result of which, we have what is called - the pressure is actually changing from TDC to BDC as the piston is moving.

So, mean effective pressure is defined; it is not one single pressure, it is a mean effective pressure between this point and this point during the traverse of the piston. This is often defined as mean effective pressure or MEP to facilitate certain amount of computation of the power or the prediction of the power that can be made from various prior calculations.

Now, we shall define the mean effective pressure later on in the next lecture, in various ways, which can be connected to either IHP or what we call BHP. As a result, you could have two mean effective pressures, indicated mean effective pressure or break mean effective pressure. So, there are two slight different variants of mean effective pressure, we shall define them appropriately in the next class.

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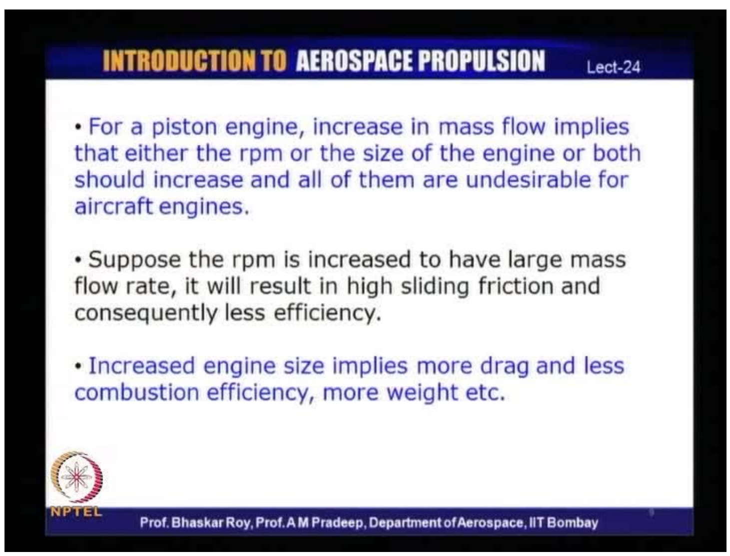

So, for a piston engine, the increase in mass flow, either you have more number of cylinders or you have higher rpm, so that the mass flow per unit time is very fast. So, cylinder is filled up and exhausted very quickly - in very quick succession, as a result of which, you get more power or you do both. That means, you have higher rpm, then you have higher size; now size is restricted. So, some of these things would have to be optimized for every engine that you need to configure. Now, suppose you have an increased rpm to create large mass per unit time, this will being the piston, will be moving up and down the length of the cylinder more frequently, as a result of which, it will actually encounter more of sliding friction.

As a result of which, there will be friction losses, which we shall be talking about a little. As a result of which, there will be a loss of efficiency that is a mechanical loss not a thermodynamic itemreally, but all that has to be considered.

Once you consider how the aircraft engine works, there are thermodynamic issues, there are mechanical engineering issues and all of them put together make an aircraft engine. We shall look in to them one by one, as we go along.

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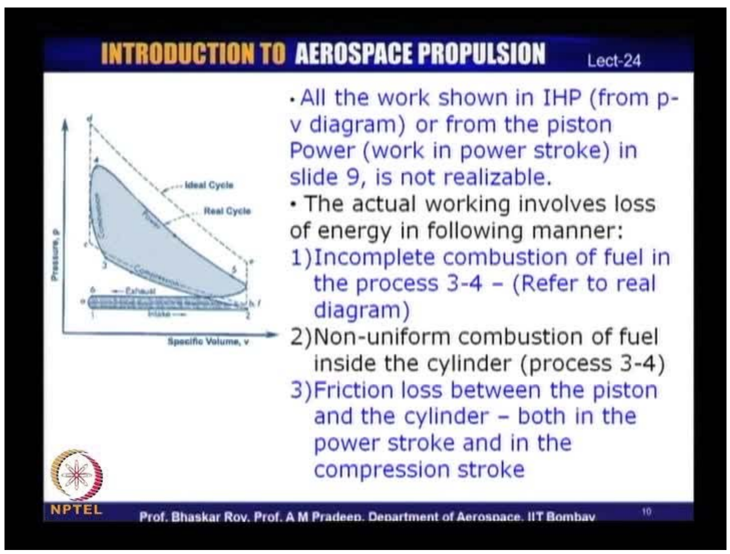

Let us quickly look at some of the thermodynamic issues all over again. We have the real cycle, which we had a look at in the last class. We see here that the actual work involves the number of things; we have the heat input here and then the work output here.

Now, what happens during the heat input is, it is entirely possible that the processor combustion that we are looking at is not a complete combustion. As a result of which, during the process 3 to 4, the combustion of fuel is actually incomplete. As a result of which, it does not reach the top value, this is what we had seen happens in a real cycle.

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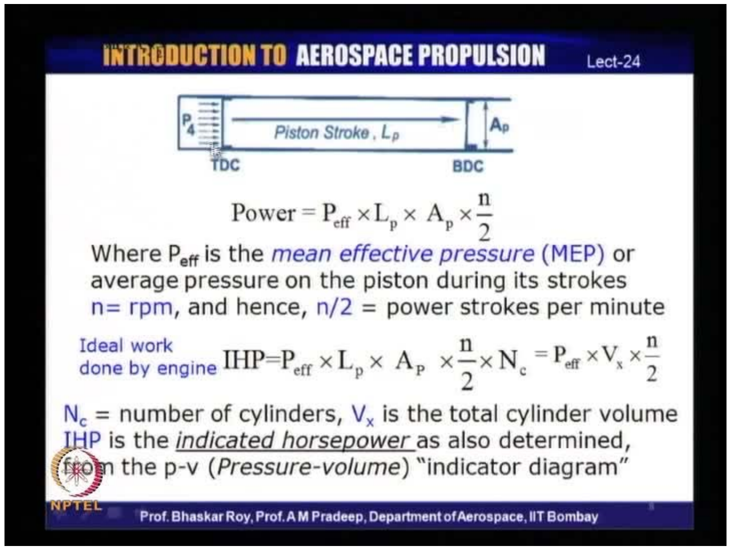

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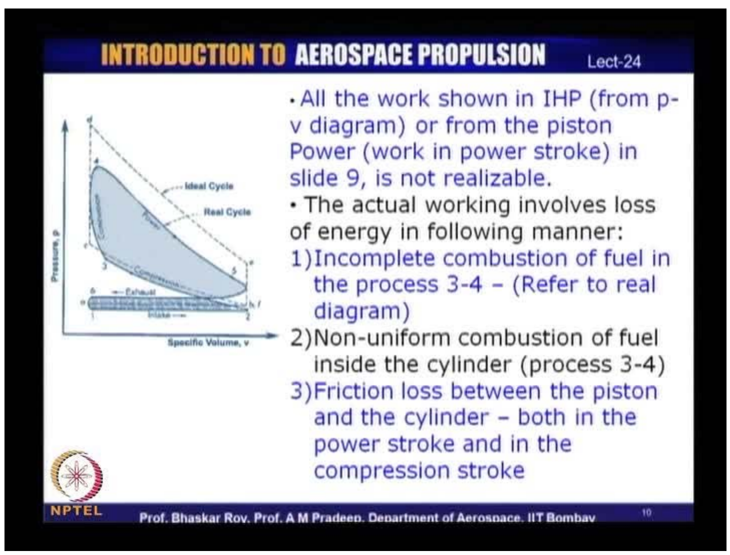

Apart from the incomplete combustion, the combustion within the piston engine, if you have a quick look at the volume that is created here, at the end of TDC, this is the volume in which the combustion is to be performed - combustion is to be done. It is entirely possible that when the combustion is initiated, it is not uniform along this volume or it is not uniform around the cross section of the piston head, this known uniformity also again leads to certain amount of work done, which is less than the ideal amount of work considered.

Then, we look at the fact that the piston is moving. Now, the movement of the piston, as I said, the mechanical friction loss between the piston and the cylinder body, as a result of which it happens twice, once during the power stroke and once during the compression stroke. So, the friction losses would have to be brought in to the reckoning while considering the real efficiency of the engine.

Then larger the engine size that is length and diameter, more is the surface of the friction loss, as a result the higher are the losses. Larger the cylinder size, more are the heat losses through its cylinder surfaces. So, those are the other losses that start coming into the picture now.

Now, the cycle efficiency, as we have seen, is directly influenced by the compression ratio, the pressure ratio and the temperature ratio. More the compression ratio or pressure ratio, we have seen the cylinder would need to be built heavier; these things as I have mentioned are prohibited. So, if you want to overcome some of the incomplete combustion by building a heavier engine; you really cannot do that because, aircraft requirements puts prohibition on such increases.

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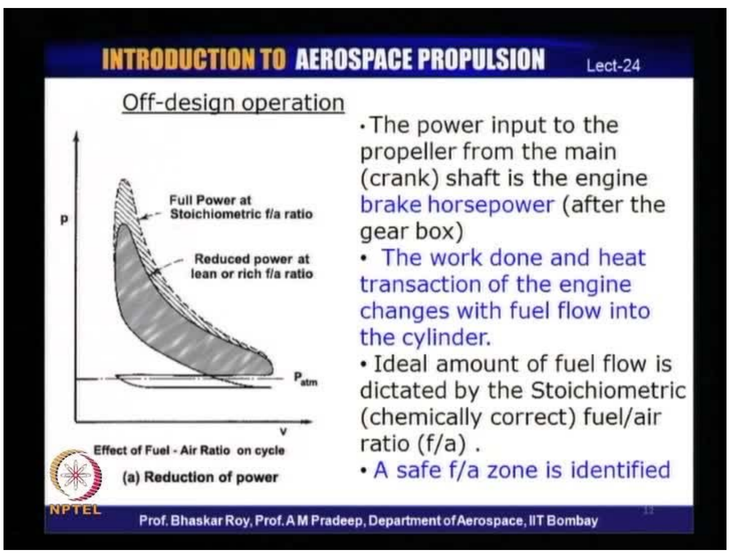

Now, the another issue that often occurs in aircraft is that quite often an aircraft, as you know, it has to fly; which means that it has to take off, it has to climb, it goes through a cruise operation, then it as to come back and land.

Now, dealing these entire processes of operation, the engine has to continuously operate at various operating condition, as a result of which, it has to create more power or less power during all these operations.

Now, as a result of which, the power input to the propeller from the main shaft is finally the consideration that is referred to as the brake horsepower; that is a power finally supplied to the propeller. Now, this work done and heat transaction of the engine, it has to be controlled, it has to be changed with the operation of the aircraft. It can be changed with the fuel flow in to the cylinder that is the primary control of the engine - the fuel flow and the fuel control provides the engine control primarily.

Now, what we can see here, from a thermodynamic diagram version of the real cycle that we have seen before in the PV diagram that if you have fuel supply that is reduced, the work done will be reduced. So that is the reduced work done, quite often aircraft could do with reduced power, especially when it is cruising. On the other hand, you may need to have more power, when the aircraft is climbing. So, it has to climb from low altitude to high, you would have to pump in more fuel in to the cylinder and you would need to get more power.

So, as a result of which, the piston has to operate with differential or different kinds of fuel flow. Now, the fuel flow that is considered depending on the property of the fuel, most correct is often referred to as a stoichiometric ratio. This is the chemically correct fuel-air ratio that needs to be supplied to the engine, it depends on the fuel. Every fuel depending on it is chemical composition has identified stoichiometric fuel-air ratio.

Quite often around this ratio there is safe fuel-air ratio zone that can be identified and the aircraft has to operate within this safe fuel-air ratio zone. That means the reduction of fuel-air ratio and the increase of fuel-air ratio has to stay within his safe zone, so that the engine continues to operate. If you go outside the zone, the engine could actually get blown out; that means, the combustion process could get blown off and the engine would stop operating.

Hence, it is necessary that you stay within this fuel-air ratio all the time during its entire operation. Now, when we talk about entire operation, we just said that the entire operation means it has to aid the aircraft to fly, it has to take off, it has to climb, it has to cruise. During the World War 1 and 2, many of the aircraft were actually used for military purposes, which mean they have to do all kinds of maneuvers. During this entire - all these maneuvers, finally landing of course, the engine has to be supplied with fuel in a controlled manner within the stoichiometric ratio defined by the chemical property of the fuel.

If you can do that then the engine is in a position to continuously supply power to the aircraft during its entire flight spectrum.

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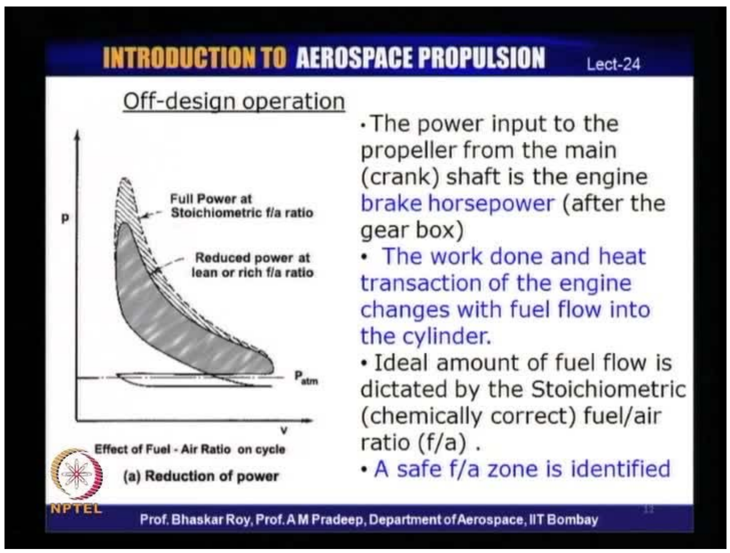

Now, to do that it is necessary that you supply power within the stoichiometric ratio, which means, the engine could be operating under lean fuel-air ratio or a rich fuel-air ratio. If it is too lean, it could have a lean blow out; if it is too rich, it could have a rich blow out. So that is the danger which I was talking about, you will have no work done out of this cycle.

Now, quite often, the way the engine is design and put on an aircraft during its entire cruise, it actually operates at the lean fuel-air ratio. During which, as you can see, the fuel consumption would be less, which is good that the amount of fuel carried in an aircraft would be carried further.

So, engine has to be designed such that during the cruise it will always operate under lean fuel-air ratio. Now, this means that the actual working cycle changes with a fuel-air ratio, each fuel-air ratio then actually produces one real cycle, as a result of which, one can say that every engine during its entire flight spectrum is operating essentially in a variable cycle manner. That means, the cycle of the engine is actually changing depending on the fuel-air ratio and the work done capability, hence it effectively becomes a variable cycle engine.

So effectively, all engines that are operating on an aircraft go through the entire spectrum of flight, operate on an essentially variable cycle mode. Of course, there are terms like variable cycle engines which now many people are trying to develop; that means, something quite different from what we are talking about.

What we are talking about is a normal engine put on an aircraft. During its entire process of flying it actually undergoes a variable cycle operation, so this is what we mean at this moment that every engine operates on a variable cycle mode.

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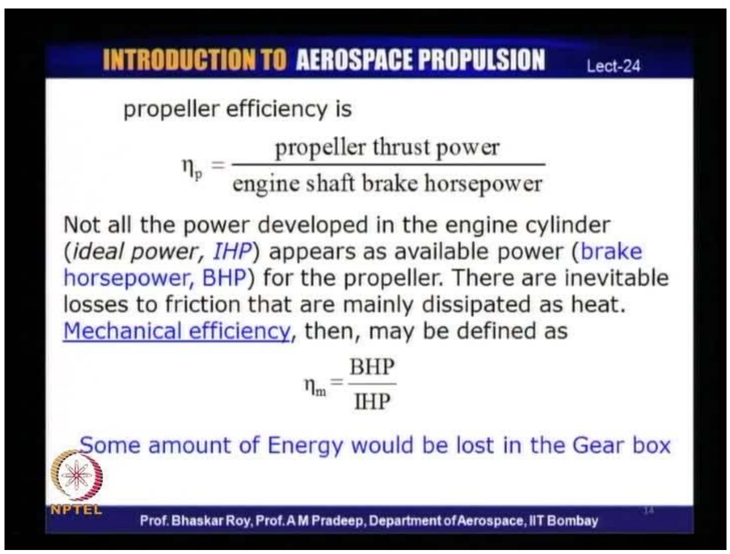

Let us look at the efficiency that we have talked about. Finally, engine has to fly the aircraft; it has to actually power a propeller. The power developed - supplied to the propeller creates a propeller thrust power, this thrust power is what is required by the aircraft. What the engine supplies is the engine shaft brake horsepower, this is referred to as BHP and this is available at the end of the shaft. Quite often the shaft operates through a gear box, so there is certain amount of loss of power in the gear box. What is supplied to the propeller is BHP, what is created by the engine is the IHP, so the ratio of those two essentially refer to as the mechanical efficiency of the engine. As you can see, which is different from what we had earlier considered the thermal efficiency of the engine, which is burn out of the thermodynamic considerations.

This is the mechanical efficiency of the engine, but BHP is what the propeller gets. Then, propeller creates thrust, so that thrust if you consider into thrust power, the ratio of the two actually gives you the propeller efficiency. So, we have three efficiencies now; one, which we refer to as thermodynamic thermal efficiency; now there is mechanical efficiency of transmission of power from the engine to the propeller; finally, the propeller efficiency by which the propeller creates thrust.

So, at the end of whole thrust creation, it has to negotiate through three different efficiencies. It is necessary for the aircraft power plant designer to keep in mind that all the three efficiencies need to be as high as possible to get maximum utilization of the power that is being created by the engine.

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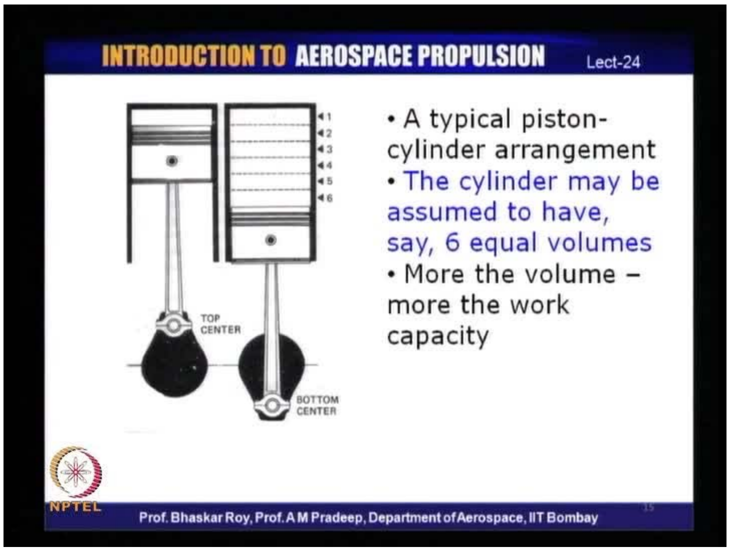

Now, if we look at all over again a typical piston cylinder arrangement, as we have seen here, quickly the cylinder you can have; this is the volume of the cylinder which we are talking about; the cylinder is often typified or specified by it is volume.

Let us say six different equal volumes of the cylinder, you could have the cylinders made of any of these number of volumes put together. So, more the volume more is the work capacity of the cylinder as we have seen before; this is what the initial engine.

Mechanical designer will have decided what should be the volume of the cylinder which creates a work, as a result of which - within which, the moment of the piston have to be restricted, so movement of the piston is restricted within this. The volume of the cylinder or more specifically the volume of the displacement of the piston is what is to be considered in creating the engine.

So, one could have the volume that is most appropriate or most optimized for a particular kind of aircraft, on which those cylinders would have to be arranged and put together to create an a aggregate amount of power.

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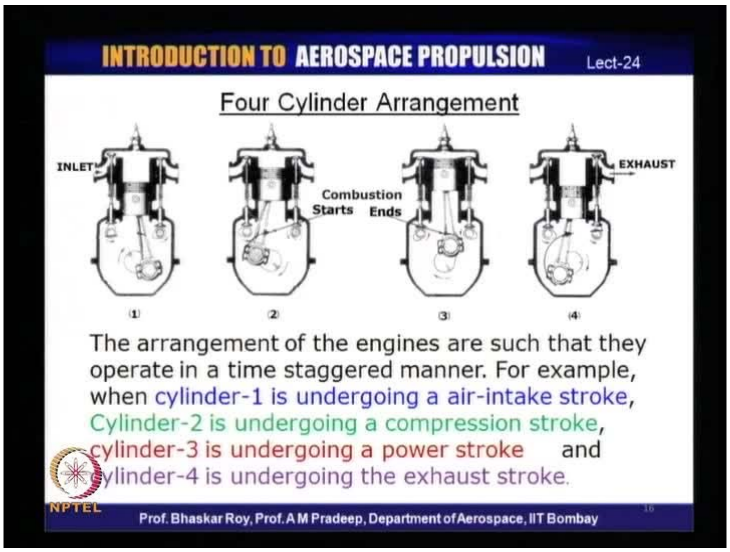

Now, let us look at an arrangement of cylinders, let us take say four cylinders - the kind of thermodynamic arrangement that we have. We have four stroke engines, so let us say that we have four cylinders, let us look at the four strokes that it has to undergo.

Now, it is entirely possible that if you have four cylinder arrangements, each of these cylinders could be operating in a time staggered manner that I mentioned earlier. Let us say, the first cylinder could be undergoing an air intake stroke, the second cylinder at the same instant could be undergoing compression stroke, the third cylinder could be undergoing a power stroke and the fourth cylinder would be undergoing the exhaust stroke.

So, the time stagger that I was talking about is shown here in this diagram. If you have cylinder arrangement in line, opposed, x type or whatever, you could have them staggered in a manner in such a way that the four strokes that the engines typically undergo can be operated simultaneously through these four cylinders. Each of them would be supplying power to the central crankshaft.

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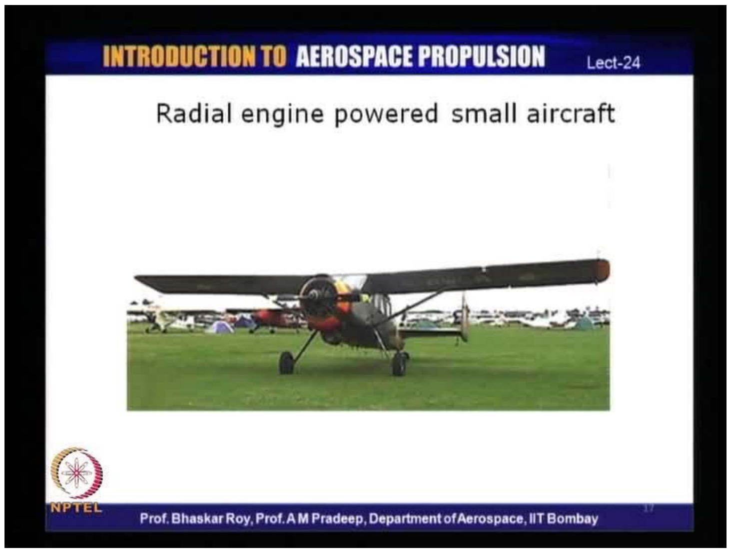

This is the kind of radial engine that often powers a small aircraft. Now, this is the kind of shape that typically a radial engine would have to be housed inside. You would have circular front body of the aircraft within which the radial engine would be housed inside, it would of course drive the propeller.

So, the shape of the aircraft then comes into the picture, we need to understand or need to know what would be the shape of the front part of the aircraft within which the engine would go. The other consideration as we have mentioned is the aggregate power that is required by the aircraft for flying, it is passengers or whatever the other material that it wants to fly. So, the shape of the front body of the aircraft is what accommodates this radial kind of engine.

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This is an engine, which is nowadays being considered; all over again, I mentioned earlier that diesel engine was completely ruled out for aircraft usage.

However, very recently some people have started looking at the diesel engine simply because of the thermodynamic consideration that we have talked about. A diesel engine has intrinsically more thermal efficiency that is something which has triggered recent research. In which, people have tried to design diesel engine that is light - made of light alloys and uses normal aircraft variety of gasoline; it can be used to power a propeller.

This is the kind of engine people are now trying to develop to make use of the fundamental thermodynamic consideration. The diesel engine is more efficient because of their high compression ratio.

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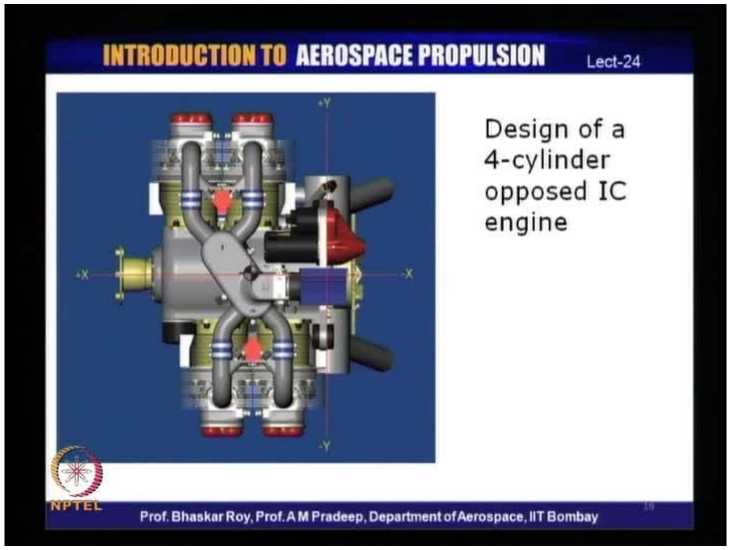

This is a design of a four cylinder opposed IC engine, which shows the internal parts of the four cylinder IC engine. It powers one single crank shaft and powers propeller, so this shows all the details of cut out of typical four cylinder opposed IC engine.

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This is a 4-bladed propeller - piston propeller, you can see here that the shape of the aircraft again has dictated the kind of engine it should use. One can make a guess that the engine used here is the opposed type - multi cylinder opposed type, probably 3 in to 3 that is 6 cylinder in opposed formation housed inside; this fore body of the aircraft powering for 4-bladed propeller.

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This is a very famous spitfire military aircraft used during the Second World War. It is a 4-bladed propeller, it had engine here, which is big engine probably 8 or 12 cylinders. This particular spitfire military aircraft use the piston-prop. As I mentioned, military aircraft need to have all kinds of maneuvering capability, as a result of which, many of these were configure to have very good combination of aircraft and engine to aid the aircraft maneuvers. Some of these need to be considered during the choice of the engine or the design of the engine itself, so that they provide the continuous power during various maneuvers of the aircraft. This is extremely important for aircraft operations.

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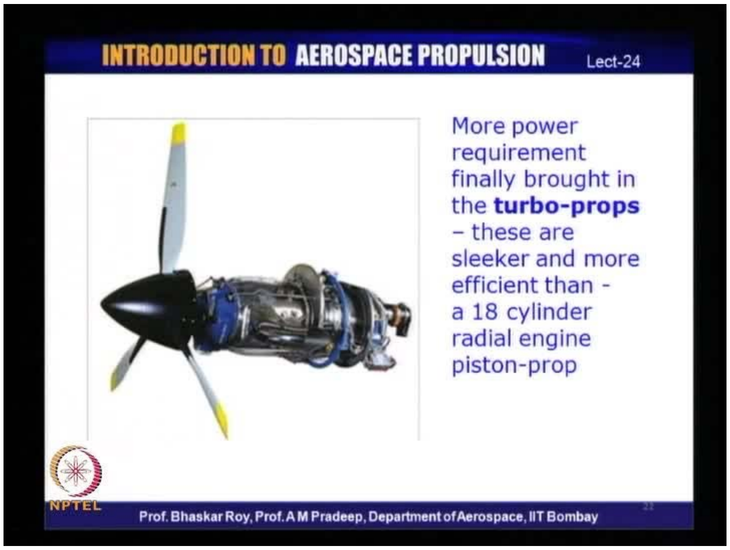

Once the amount of engine power required goes up, we have seen that you could have 6 cylinders, you could have 8 cylinders, you could have 10 cylinders, you could have 12 cylinders, you could have 9 cylinders and you have 9 in to 2, so18 cylinders. So, there are engines - piston-prop engines, where up to 18 cylinders have been put together to power an aircraft.

However, if the aggregate power becomes more, it becomes more and more difficult to put together more of these cylinders. In which case, one has to look for some other solution which is not probably piston based, you need more power, you need to have engine that supplies that power. Aircraft engine may not be the piston engine, may not be the best aircraft engine in such circumstances. These are the situations in which you then start looking for other alternatives; that is why the jet engines came in after the second world war when the requirement of power for the aircraft to fly faster, for the aircraft to fly higher and the aircraft to become bigger; to carry more passengers, more material or more cargo required more power, the bigger engines had to be, not in the form of piston engines, they had to be in the form of gas turbine engines.

These gas turbine based engines are what finally created today what we call the turbo-props; that means, the propeller remain as the thrust making device, but the engine that finally came in to being were not the propellers, not the piston engines, but the gas turbine engines. So, the amount of aggregate power of an aircraft needs to decide to what extend or to what level you can arrange the piston engines, how many cylinders you can put together. At the end of the day, if the amount of aggregate power required is more, then you have to go outside the piston engine requirement, you have to look for other kind. So, what is shown here is a turbo-prop engine, in which supplier is a gas turbine engine, but the thrust is still the propeller.

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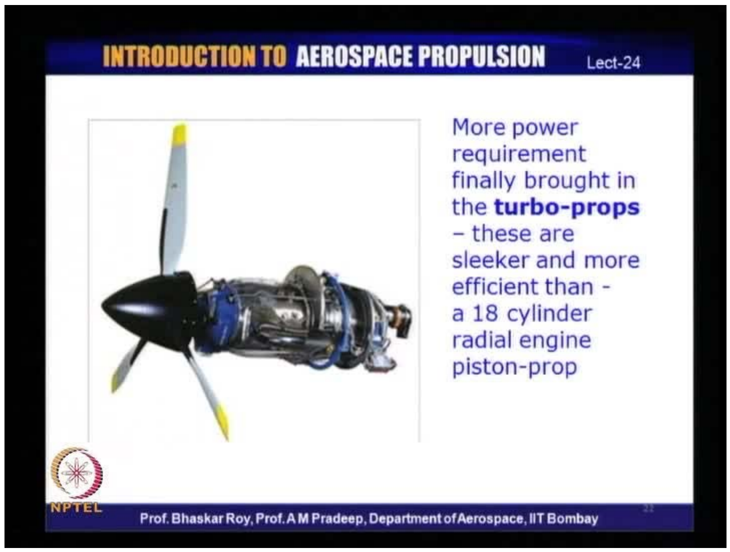

However, we will continue to look at various kinds of piston engines and the performances of piston engines in the next class. We shall see how the piston engine performance can be estimated; we shall see the various kinds of ways by which the aircraft engineers have devised method, by which the piston based engines can continue to give good efficiency and good power supply during its flight; much of the flight often happens at high altitude. We shall see how aircraft engines are configured to create power at high altitude, where the air is thin - the density of the air is thin, but the piston engine continues to give good efficiency and good power supply. We shall look in to some of these aspects of engine design in the next class, in which, we shall consider the performance of the piston engines as used in aircraft.