Introduction to Aerospace Propulsion

Prof. Bhaskar Roy

Prof. A. M. Pradeep

Department of Aerospace Engineering

Indian Institute of Technology, Bombay

Module No. # 01

Lecture No. # 26

Supercharging of aircraft IC engines

In this lecture, we will be talking about IC engine operations, with specific reference to the aircraft engines. IC engines, as you know, are used in all kinds of vehicles and many other operations, but when it comes to their application, aircraft engines have basic power plant and power supply unit. There are certain things that need to be done to satisfy the needs of aircraft engine and for the needs of flying the aircraft.

Now, as you know, an aircraft typically flies or cruises at a high altitude, quite often at 5 kilometers or even higher than that. As a result of which, at that altitude, the air density is very low, hence, the air which is the working medium of this kind of engines is very thin. So, the air supply into the engine is actually much lower in terms of mass flow. Hence, we need to do something about the fact that the air supply in mass flow is rather low.

Now, as we have seen in the earlier lectures, when the air mass flow supply is less or charge as we call is less, the power production also goes down. So, if the power production goes down, in aircraft engine, if it falls short of the power, the propeller which produces thrust would not be able to produce the thrust that is required for the aircraft to fly, in such a case, aircraft would not be able to fly at all. In fact, the problem starts much earlier, when the aircraft starts climbing from takeoff, from let us say sea level altitude to a higher altitude, as the air becomes thinner and thinner, the power supply goes down, because of the fall in the mass flow.

Now, this is something which is typical of aircraft engine; this is not a problem with any other land based application. Hence, the aircraft engineers had to do something to ensure that this problem does not create a problem, when the aircraft is flying. So, aircraft engine - IC engines used in aircraft do have slightly different configuration than the IC engines used in many or various land based operations.

Let us take a look at some of these things that are typically done in aircraft engines. We will also look at how the aircraft engine or IC engine is operated under part load conditions. You do not use an IC engine all the time. At its full throttle or full load conditions quite often you do not need so much of power, so you can operate it under off design or what is also known as part load condition. Under these conditions, how do they operate? How do they produce power and what are their characteristics? These are also few things that we will be looking at today. Along with, as I said, certain augmentation that is required for making this kind of IC engine useful as an aircraft power plant, let us take a look at some of these issues in today's lecture.

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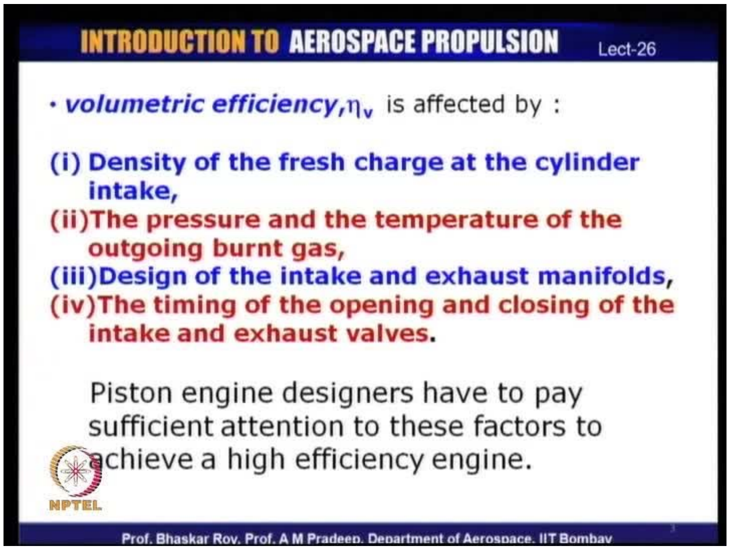

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- *volumetric efficiency*, η_v is affected by :

(i) Density of the fresh charge at the cylinder intake,
(ii) The pressure and the temperature of the outgoing burnt gas,
(iii) Design of the intake and exhaust manifolds,
(iv) The timing of the opening and closing of the intake and exhaust valves.

Piston engine designers have to pay sufficient attention to these factors to achieve a high efficiency engine.

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Now, one of the things that we have seen is the density of the fresh charge, which is going into the cylinder. It is an important issue that determines the amount of mass flow that is going in. At the end of it, the mass flow actually determines the amount of power that is being produced by the engine.

The other important parameter that affects the volumetric efficiency, which we have defined earlier, is the pressure and temperature of the outgoing burnt gas. Then, of course, there are engineering issues, which are the design of the intake and the exhaust valves of the manifolds, and the timing of the opening and closing of the intake and exhaust valves. These are the issues, which have been engineered into the engine. These are engineering issues, they need to be done properly to ensure that you have a good volumetric efficiency, which means, it should be as close to 100 percent as possible, so that you are getting the best out of the engine shape and size that you have.

So, volumetric efficiency essentially tells you how good you are making use of the engine, given - its shape and size already available with you. So, these are the things that the designers, in terms of engineering product, has to be a very careful about, before the engine is made operational to achieve high efficiency during its actual operations.

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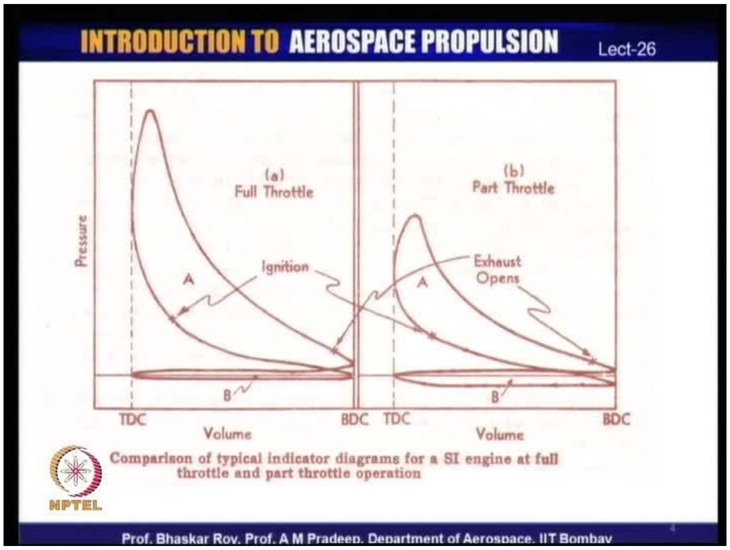

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Comparison of typical indicator diagrams for a SI engine at full throttle and part throttle operation

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Now, let us take a look at some of the things that we need to bother about. For example, when the full throttle operation is going on, as you can see in this diagram, the air is now being compressed along this. As we have seen earlier, quite often, the process of ignition or burning of the fuel can be initiated - may be initiated a little earlier. If it is initiated much earlier, this is how the graph would go. The operation of combustion would be shown in the p-v diagram, which means, it has been started a quite a lot earlier before that TDC. Hence, the graph would go in a curved manner like that instead of a straight line, as we normally see in ideal cycle.

On the other hand, the exhaust for example, if it opens a little earlier, the exhaust may have opened a little earlier some were over here, out of which you could have this exhaust operation initiated earlier. This would take a curved path; hence, the exhaust would be occurring at a substantially higher pressure than the intake operation. This, as we know, results in a certain amount of area that shows up over here and that area would actually be lost as far as the power production is concerned.

So, the opening and closing of the throttle is an important issue. Now, under the part load condition or part throttle condition, similar things would be happening. The work done over here in part throttle, is actually much less now, than compared to the full throttle operation. In this situation, if the opening or closing of the intake or the exhaust occurs much before the actual time of their opening and closing, then a good amount of work would actually be lost in the process of the differential between the exhaust operation and the intake operation.

So, this loop, you see over here, is a something which is not available for, as a power output of the engine. This is the area that goes into the operation of exhaust and intake, as a result that it could not be available in terms of BHP. This is one of the issues that come up, when the operation of the exhaust, the ignition and the intake do not quite happen exactly, ideally as we have seen, in the ideal diagram.

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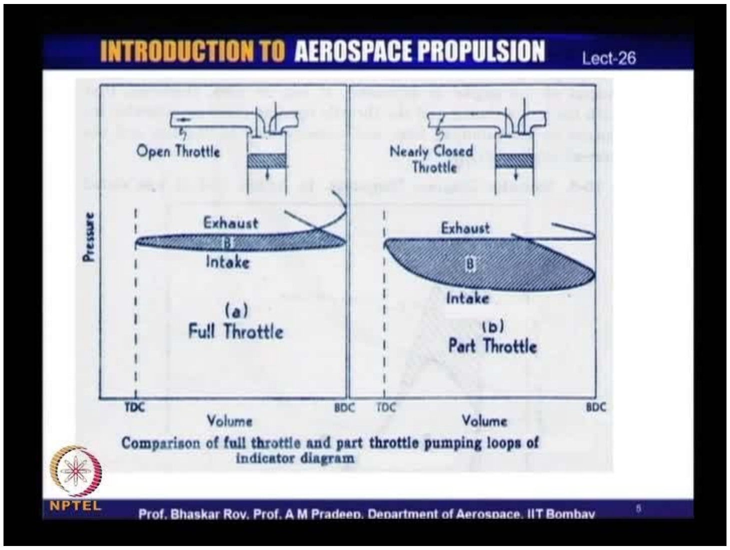
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Comparison of full throttle and part throttle pumping loops of indicator diagram

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This actually shows the loop which I was just taking about. In this, as you can see here, in the full throttle condition, if it happens nearly ideally, you have a very small loop over here. As a result of which, you can see that the power lost in the process of intake exhaust is a rather small. On the other hand, what can happen is under part throttle condition, this loop could become very big.

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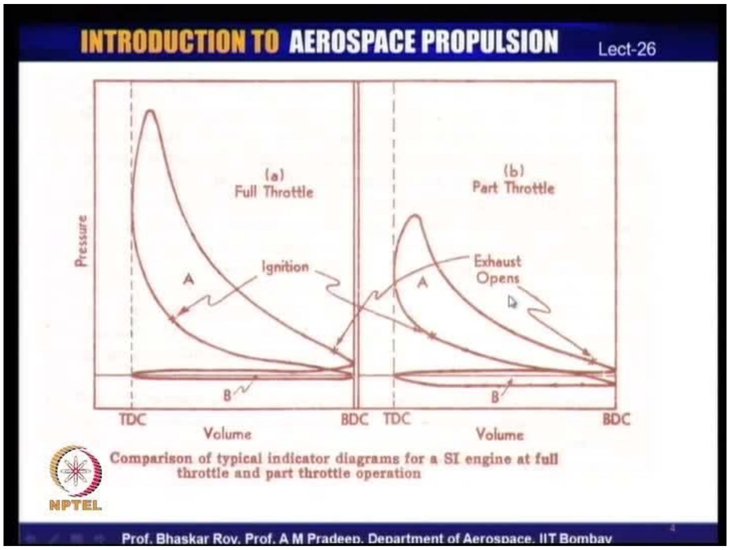

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Comparison of typical indicator diagrams for a SI engine at full throttle and part throttle operation

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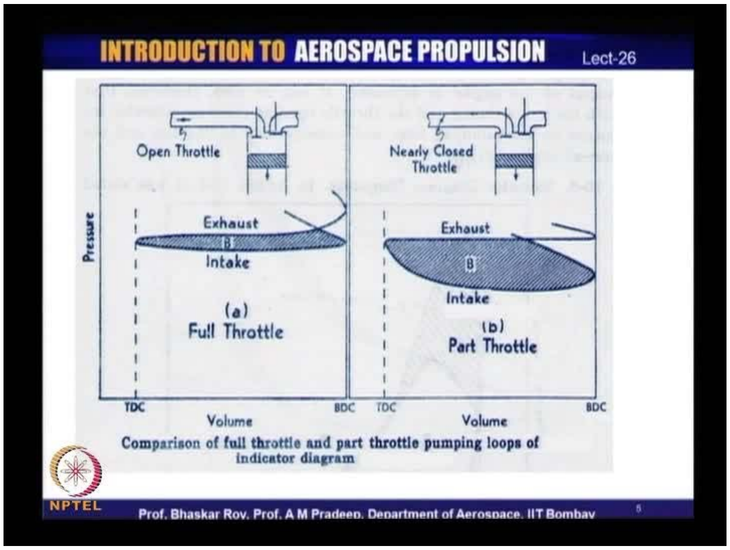

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Comparison of full throttle and part throttle pumping loops of indicator diagram

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Now, as it is, as we have seen in the earlier diagram, the part throttle condition, the actual operational power available is actually on the lower side. Then, if the power lost in the process of intake exhaust is of much higher order, this could happen due to the fact that the opening of the intake valve could be earlier or closing of the exhaust valve could be earlier.

Now, some of these issues then affect the loop or the area of the loop that is shown over here. If the area of the loop is higher that means more and more energy is being wasted, by the fact that the operation of the intake and exhaust valves are not happening properly. So, some of those issues need to be taken care of by the engineering aspects of the engine design. Hence, it shows up in the thermodynamic diagrams and as a result of which, the engine power suffers.

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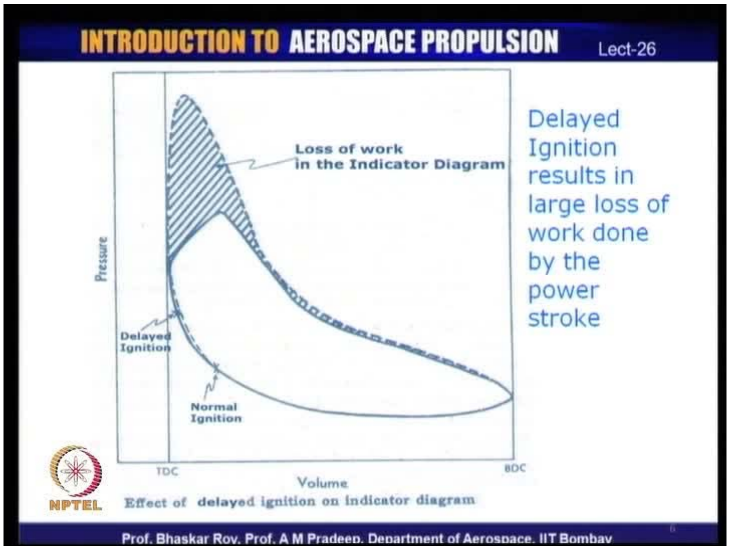

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Delayed Ignition results in large loss of work done by the power stroke

Effect of delayed ignition on indicator diagram

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This is one of the issues that again we were just taking about that the delayed ignition - what happens when you have a delayed ignition? We just saw what happens when you have early ignition. Supposing, you know this is what we would call normal ignition a little early, so that even when the compression process is being completed, the ignition is initiated. As we have seen, this goes along this path, now supposing the ignition is delayed, as a result of delayed ignition the ignition process is much later. Then, the path that it takes, it does not take along this; it quickly goes into this path. As a result of which, this huge area that you see here - shaded area is in loss of work with relation to the indicated diagram of the ideal process that one would have accepted.

So, this loss of work is now due to the fact that the ignition is delayed and not initiated at an appropriate time. So, there is an exact time at which the ignition needs to be initiated and if it is delayed, is going to incur a lot of a loss of work from the engine. So that is another issue that the ignition needs to be timed exactly, otherwise a large loss of work by the power stroke is most likely to happen.

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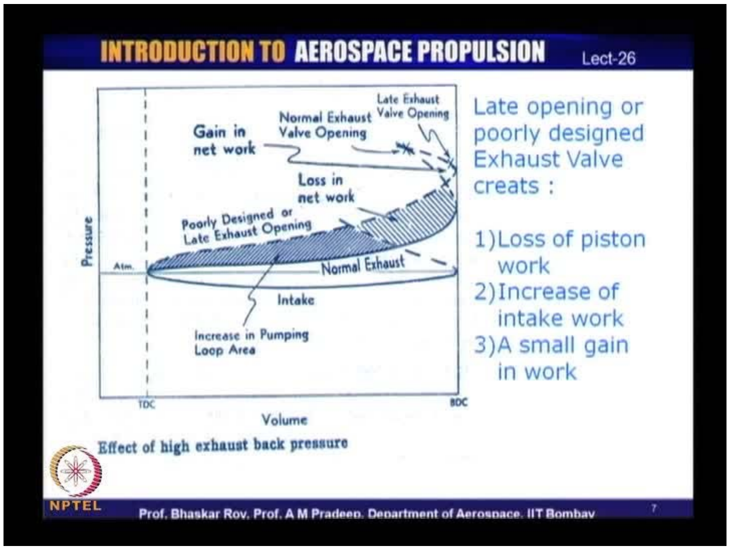
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Effect of high exhaust back pressure

Late opening or poorly designed Exhaust Valve creats :

1) Loss of piston work
2) Increase of intake work
3) A small gain in work

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Let us look at some of the issues. Again due to the late opening or poor designed exhaust valve, this happens when - for example, this is your normal exhaust. Now, suppose your late exhaust valve opening shows that it is occurring around this, as a result of which, this is the now the exhaust path. Now, this exhaust path is, as you can see, well up of the exhaust over here, this is situation; that mean, this much of extra work needs to be done during the exhaust operation. This extra work would now not be available as an output of the engine, this could be due to either late opening or poorly designed exhaust valve.

There is a one small issue here; due to the late exhaust the path that it takes actually creates a slight bit of gain in work, which is shown here. Rest of the work is actually due to the loss of work, so there is a very small gain in work, which is shown here. But, the loss of work is of a much higher order, as a result which, there is large amount of loss of piston work, a very small amount of increase of intake work and a very small amount of gain in exhaust work. So, the total loss is of a much higher order, as result of which total output of the engine could go down substantially, this is due to the fact that you have a late opening or poorly designed exhaust valve operating within the engine. This may happened due to various reasons; some of those reasons need to be looked into, either by the designer or by the operator during its functioning.

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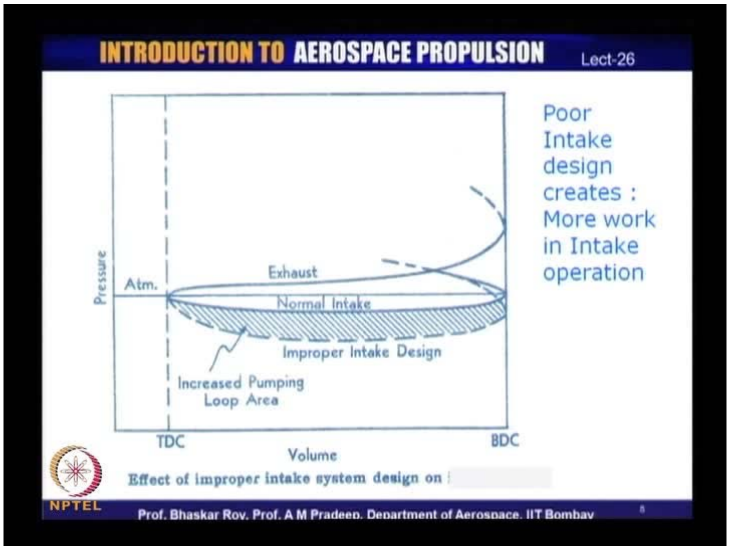

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Poor Intake design creates : More work in Intake operation

Effect of improper intake system design on

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The other issue is the poor intake design. We need to look at the fact that the intake operates ideally at a constant pressure. If the intake operates at a pressure much lower than what it is scheduled to, we get inlet intake loop that is now much bigger than what it should have been ideally. This intake loop now takes away work from the main engine in the process of pumping as it shown here, this extra intake pumping work now, is not available as an engine output.

So, the poor intake design often also leads to a poor operation of the intake valve, often leads to a loss of work, which would not be available to the engine BHP or engine output. This is another issue, which needs to be looked into, by the engineers who designed the engine.

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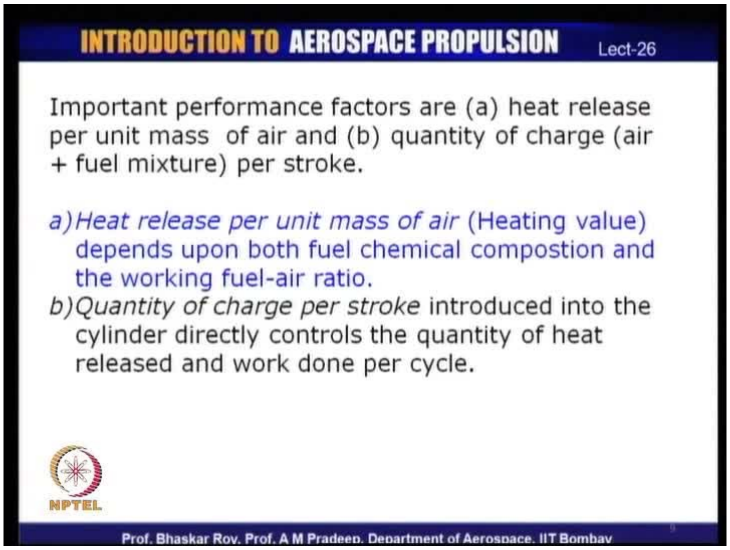

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Important performance factors are (a) heat release per unit mass of air and (b) quantity of charge (air + fuel mixture) per stroke.

a) *Heat release per unit mass of air* (Heating value) depends upon both fuel chemical compostion and the working fuel-air ratio.
b) *Quantity of charge per stroke* introduced into the cylinder directly controls the quantity of heat released and work done per cycle.

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The important performances parameters that we need look into are; the heat release per unit mass of air. This is the quality of the fuel that you are putting into the engine, so the choice of the fuel needs to be taken care of by the heat release capacity of this fuel. The other is the quantity of charge, which is a mixture of air and fuel mixed in the carburetor per stroke of the engine.

Now, heat release per unit mass of air, it is decided by the chemical composition and the working fuel-air ratio. Chemical composition is something which one needs to analyze, before one makes a choice of the fuel. We have talked about the kind of fuel or aviation fuel that is normally used these days - high octane fuel that was chosen because of their chemical properties.

The other is the working fuel-air ratio. As we have seen, the working fuel-air ratio actually can change from one operating point to another. This is something which the engine operator has some control over. The normal or the ideal fuel-air ratio is what we call normally the stoichiometric ratio, but quite often the operation happens at a ratio which is slightly different from the ideal stoichiometric ratio; it could be slightly higher or it could be slightly lower. As long as it is within a certain zone of operation, a safe zone of operation of a fuel air ratio, as long as it operates in that ratio, the engine and the ignition process would continue to happen in a normal fashion.

Now, this is with reference to the heat release, then all these will decide the heat release rate or unit mass of air, as it is inducted into the cylinder. The other thing that we will decide is the amount of power that is coming out is the quantity of charge. The thermodynamics always gives us values in terms of power produced per unit mass flow. However, the total power produced is always dependent on the mass flow that is going inside the cylinder or inside the engine, as a whole. Hence, the quantity of charge that is going in decides the amount of power that we would actually get.

Now, this is one of the issues that we would need to look into with specific reference to aircraft engines. Because, in aircraft engines, the quantity of charge that is going in goes down with the increase of altitude, as you go to higher and higher altitude, you may be using the same fuel - you would be using the same fuel. So, its heat release rate probably would remain of the same order, but the mass of air is going down and the quantity of charge is going down. So, we need to look into this issue with specific reference to aircraft engines.

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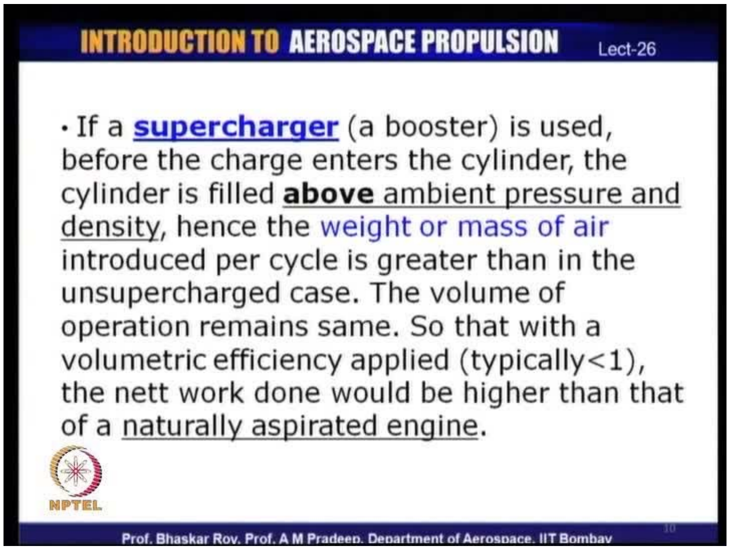

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- If a supercharger (a booster) is used, before the charge enters the cylinder, the cylinder is filled **above** ambient pressure and density, hence the weight or mass of air introduced per cycle is greater than in the unsupercharged case. The volume of operation remains same. So that with a volumetric efficiency applied (typically<1), the nett work done would be higher than that of a naturally aspirated engine.

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In aircraft engine, this issue of charge or mass of charge is taken care of or compensated for with the change of altitude by an additional unit called supercharger. This is basically a booster, which is used before the charge or the air fuel mixture enters a cylinder. This cylinder is filled above the ambient pressure with the help of the supercharger. Hence, the density of the air is now higher than the ambient density; hence, the weight or mass of air that is introduced inside the cylinder per cycle is greater than in the un supercharged case.

So, if you do not have super charging, this mass of air that is going in would continuously go down when you reach higher altitude. It would continue to go down when you increase the altitude, so you need a supercharger to compensate for the decrease of ambient pressure and ambient density. This is where the supercharger for an aircraft engine comes into the picture.

Now, as you know, the volume of the operation would remain same for the same engine. So, when you apply the volumetric efficiency, the net work done would be higher than that of a naturally aspirated engine, which means un supercharged engine. So, you need a supercharger to get more and more work done for the same engine as it goes to higher and higher altitude.

Let us see, how that actually happens. If you have supercharged engine, typically you would be using some kind of a centrifugal blower to boost the density or the pressure that is going inside the cylinder. This boosting is done after the air and charge has been mixed, before of course it enters the main cylinder, before it is supplied to the main cylinder. Now, this is a separate unit, the supercharger is separate unit from the basic IC engine. As I said, it is used specifically for aircraft engine.

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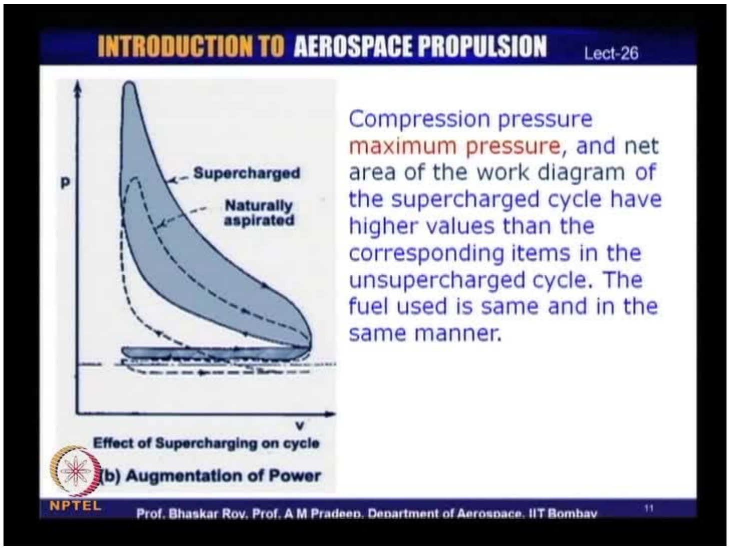

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Compression pressure maximum pressure, and net area of the work diagram of the supercharged cycle have higher values than the corresponding items in the unsupercharged cycle. The fuel used is same and in the same manner.

Effect of Supercharging on cycle

(b) Augmentation of Power

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Now, let us look at this diagram. We will see that when you have un supercharge or what is often called naturally aspirated engine, your basic indicated diagram would actually go along the dotted line. But, as soon as you apply supercharging, your basic intake now has gone to a higher pressure and then your compression would take it to a much higher pressure. Hence, your power stroke would be actually occurring at a higher pressure.

So, the mean effective pressure, which we have talked about, would now be occurring at a much higher pressure - the value of MEP, would be in much higher for this cycle compared to this dotted cycle, which is a un supercharged engine. As a result of which, you can well imagine now that the power produced by the supercharge engine would be of a much higher order. This is exactly shown in this thermodynamic p-v diagram that supercharger actually boosts the performance to a much higher level. How high it can be depends on the amount of supercharging that is available with the engine.

In all these time, the fuel used is same, is introduced or injected into the cylinder in the same manner. So, there is no change in the way the fuel is used or the kind of fuel is used, it is only that the air charge that is being used as a working medium is supercharged or boosted in its pressure and density to a higher value. That allows us to produce more power that may be available to the aircraft power plant.

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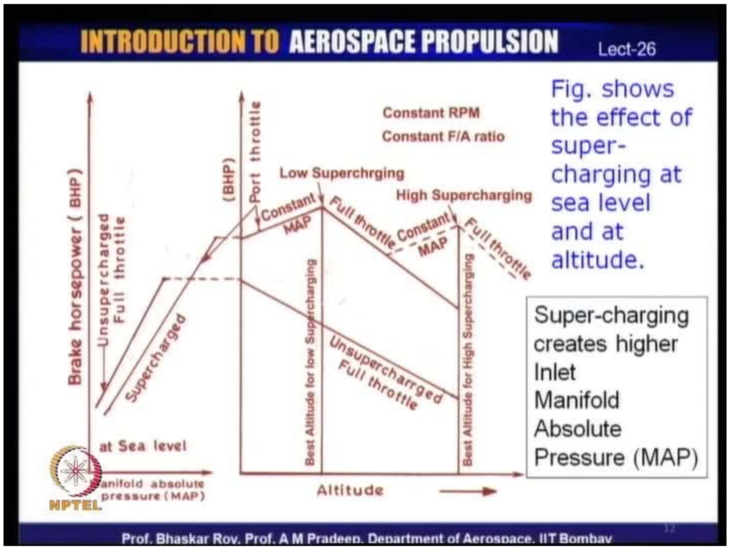

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Fig. shows the effect of super-charging at sea level and at altitude.

Super-charging creates higher Inlet Manifold Absolute Pressure (MAP)

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Let us take a look at some of the issues that are related to the effect of supercharging at sea level and at altitude. Now, as I have mentioned, you can use an engine both at full throttle or at path throttle, depending on the amount or power you actually need to make use of or you need to fly the aircraft, in case of an aircraft engine.

Now, what happens is, when you are at sea level, if you have un supercharged full throttle, your characteristic would move along this line. Then, it will kind plateau of when you go to high altitude. The un supercharged full throttle characteristics would continue to go down along this line, with the increase of altitude. As a result of which, you break horse power, would be continuously coming down.

So, when you are at sea level, at full throttle un supercharge, as you are manifold absolute pressure goes up, your power production goes up. Then, as soon as you move to high altitude, the aircraft starts climbing, altitude is gained and the power production continuously starts going down. Let us say at cruise, your power production some are over here, one has to very quickly figure out whether this power production is sufficient for flying the aircraft. In most cases, this power production would probably be found insufficient for flying of an aircraft that is where the supercharger now comes in.

If you have a supercharger, the supercharged power production would go along this line; it would go to higher values. Then, as you move to the altitude, you could have a high supercharging or low supercharging, it could move along this line, along which you have constant manifold absolute pressure MAP. Then, this is - you are still working at part throttle, you can open up the throttle and go to full throttle, because you need to conserve power, you need get more power to make the aircraft fly.

With change of altitude your air is thinning down, so even with supercharging air will continue to thin down. As a result, their mass flow going into the engine will continue to go down, but it will go down at a much higher value than what we had seen in the un supercharged case. As a result of which, this full throttle now allows you to produce more power - far more power, than you can get for un supercharged engine.

If you are able to create a high supercharging, you can boost the power some over here, to even higher value, at full throttle. So, you can apply higher supercharging, this was with low supercharging, you can go to even - that means, the second booster for example, you can have two superchargers. Then, you can even go to even higher power production and take the power production some were over here, at a very high altitude, if the need arises.

So, the combination of supercharging, use of a low supercharging or a high supercharging, which means you can have two superchargers, allows you to create more power during the aircraft operation at high altitudes. In all this, what we have considered? Were the engine is operating at constant RPM; they are operating at constant fuel air ratio. Those also can be varied, but we have not considered those variations in this particular diagram. As a result of which, as you can see now, the supercharger gives immense amount of power boosting to the aircraft engine, starting at sea level, going to higher altitudes. You can produce more power either through single supercharger or through a double supercharging operation, to get a lot of power during its high altitude operation.

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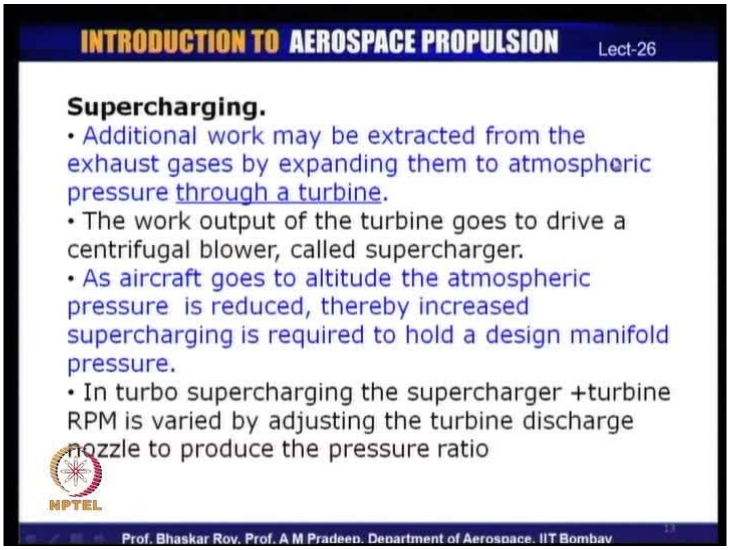

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Supercharging.

- Additional work may be extracted from the exhaust gases by expanding them to atmospheric pressure through a turbine.
- The work output of the turbine goes to drive a centrifugal blower, called supercharger.
- As aircraft goes to altitude the atmospheric pressure is reduced, thereby increased supercharging is required to hold a design manifold pressure.
- In turbo supercharging the supercharger +turbine RPM is varied by adjusting the turbine discharge nozzle to produce the pressure ratio

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So, the supercharging produces additional work that may be extracted from the exhaust gases by expanding them to the atmosphere through a turbine. So, the question now is how do you run the supercharger, which produces this boosting of intake density and pressure? It is done by a running it with the help of a turbine; the question is how do you run the turbine?

The turbine is run by the exhaust gas that is coming out of the engines that is fed into the turbine. Remember, the exhaust gas that is coming out of the engine is still at reasonably high temperature and at a reasonably high pressure. So, if you allow it to run through a turbine, it will produce certain amount of power and this power then can be used to run supercharger or the booster, which as I mentioned earlier, is basically a centrifugal compressor. Hence, the powers supplied to this supercharger can be done with the help of the turbine, which is running with the help of the exhaust gas that is coming out.

The aircraft, then when it goes to high altitude, increases the pressure. This allows the manifold pressure to be either held to a design value - close to the design value for which the engine was designed for or something very nearby that value. As a result of which, you continue to get a good amount of power that the engine is originally designed for.

So, many of the superchargers are often called turbo superchargers. This supercharger plus turbine configuration - the RPM of this can be varied by adjusting the turbine discharge nozzle to produce pressure ratio of the turbine, so that the turbine power production can be varied to run the supercharger. So, the whole supercharger turbine combination can also be controlled separately by controlling the turbine discharge nozzle. So that the pressure ratio produced by this supercharger can also be varied depending on the need of the engine at that particular altitude.

So, the turbo supercharger has a control system of its own, independent of the engine control. As a result of which, the amount of supercharging that you can do to boost the engine can also be varied depending on the need of the aircraft when it is flying.

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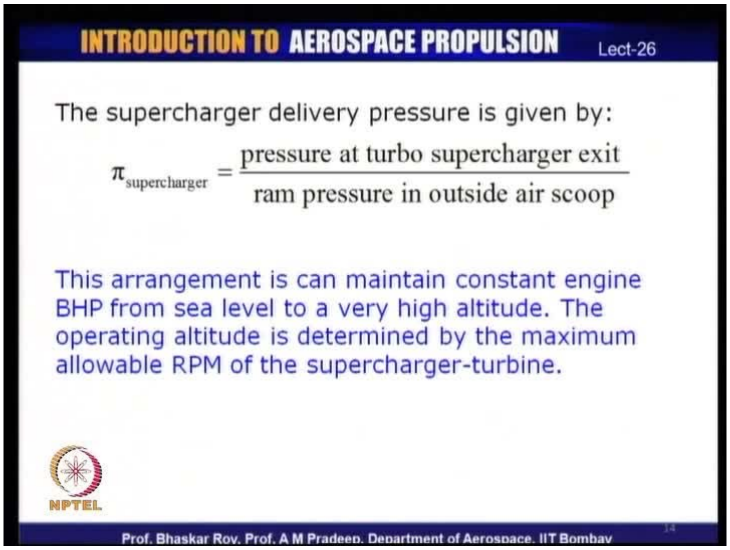

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The supercharger delivery pressure is given by:

$$\pi_{\text{supercharger}} = \frac{\text{pressure at turbo supercharger exit}}{\text{ram pressure in outside air scoop}}$$

This arrangement is can maintain constant engine BHP from sea level to a very high altitude. The operating altitude is determined by the maximum allowable RPM of the supercharger-turbine.

The supercharger delivery pressure is given by supercharger pressure ratio. This is the pressure at the turbo supercharger exit divided by the ram pressure outside of the air scoop. This arrangement can maintain a constant engine BHP or almost constant engine BHP from sea level, to a very high altitude, so that the engine, it continues to give its - nearly its design power produced a power production. This operating altitude is determined by the maximum allowable RPM of the supercharger.

So, which means, the aircraft engine can now operate at a higher and higher altitude, because of the supercharging available. The final altitude at which it can operate - an aircraft can fly is now determined by the supercharging capacity and the maximum allowable RPM of the supercharger turbine combine.

So, not only the power is boosted, now you can fly the aircraft at an even higher altitude, which has the advantage. As we all know that higher the altitude at which you fly the aircraft, lesser is the drag experienced by the aircraft and hence lesser is the power actually required to fly the aircraft. If you require less power to fly the aircraft, your continuous fuel consumption is also going to be low.

So, all those gains can be actually facted into the aircraft mission or aircraft flight schedule if you have a supercharger. So, the supercharged aircraft engine can actually fly at a higher altitude to affect the net gains that come from flying at a high altitude. This is something which is typical of aircraft engine, normally not necessary in most of the land based operation.

So, aircraft engines typically have a supercharger, which is designed to operate at high altitude, it is normally not necessary when it is cruising at low altitude or when it is taking of, it is necessary when it is flying at high altitude. As I mentioned, to what altitude aircraft can fly, would actually be determined then by the availability of the supercharger and the capacity of the supercharger. Supercharger is designed separately to a fit into an aircraft engine, fit into the need of the aircraft; take the aircraft to high altitudes.

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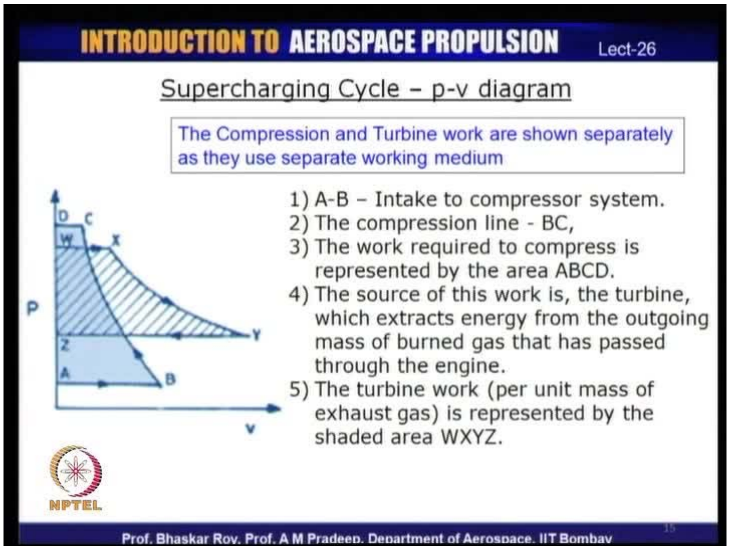

INTRODUCTION TO AEROSPACE PROPULSION Lect-26

Supercharging Cycle – p-v diagram

The Compression and Turbine work are shown separately as they use separate working medium

1) A-B – Intake to compressor system.
2) The compression line - BC,
3) The work required to compress is represented by the area ABCD.
4) The source of this work is, the turbine, which extracts energy from the outgoing mass of burned gas that has passed through the engine.
5) The turbine work (per unit mass of exhaust gas) is represented by the shaded area WXYZ.

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Let us look at what happens if you have a supercharger and what happens to the p-v diagram of the cycle. You have a supercharger, which again is some kind of aero thermodynamic unit; hence, it needs to have certain amount of thermodynamic basis of its own, for it to be included in the overall engine configuration. So, if you look at this, we will find that the basic engine which operates. Let us say at AB, which is the intake to the compression system. The compression line is BC, as we have seen normally, in most of the cycles that we have looked at. The work required to do this compression process is then given by ABCD that is the area were the compression work that needs to be done, in the compression process of the engine.

Now, the source of this work is the turbine. Now, this turbine is supplying power to this compression process that is being supercharged; now the turbine work, is it extracts energy from the outgoing mass of burnt gas that is being exhausted from the main engine. The turbine work can also be represented in the same p-v diagram. Let us say that the turbine work is now represented by ZYXW or this particular area. As we can see, now that this works done by the turbine, then needs to be equal to this work that is needed for the intake. So, as long as this work done by the turbine, as represented in the p-v diagram here, is equal to this work shown by ABCD. We have a combination of turbine and compressor that can do the supercharging job and aid the engine in operating at high altitude.

So, this is the supercharging p-v diagram separate from the engine p-v diagram that we have seen before. This needs to have comply to the loss of thermodynamics that you have done in detail earlier. So, a supercharging operation by itself has to conform to the basic laws of thermodynamics that you have done before in the earlier lectures.

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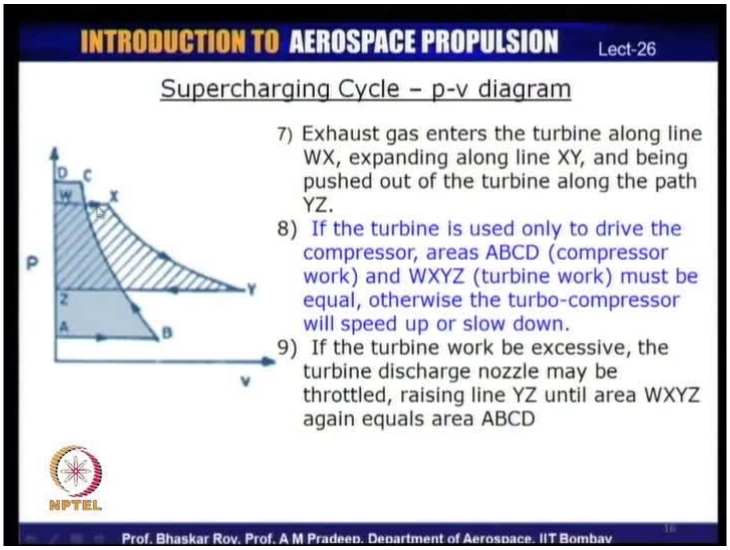

INTRODUCTION TO AEROSPACE PROPULSION Lect-26

Supercharging Cycle – p-v diagram

7) Exhaust gas enters the turbine along line WX, expanding along line XY, and being pushed out of the turbine along the path YZ.
8) If the turbine is used only to drive the compressor, areas ABCD (compressor work) and WXYZ (turbine work) must be equal, otherwise the turbo-compressor will speed up or slow down.
9) If the turbine work be excessive, the turbine discharge nozzle may be throttled, raising line YZ until area WXYZ again equals area ABCD

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The exhaust gas which enters the turbine, along the line, let us say W X and then expands along the X Y line, this is how the turbine operates. So, the intake starts from A B and then goes up to C and D. The exhaust starts form W, then it enters through W X. It expands along the line X Y and does the work that is the working of the turbine. The working of the compression is from B to C; working of the turbine in this p-v diagram is from X to Y and then pushes out the work of the gas along the Y Z line.

If the turbine is used only to drive the compressor, the areas as I mentioned - the areas A B C D and the areas W X Y Z must be equal. If the turbine work falls short, then the turbo compressor combination would slow down, if the turbine produces more work, then the turbo compressor combination will speed up to higher speeds, whether that is required or whether that is warranted or allowed is to be decided by the engine operator.

So, if the turbine work is excessive, the turbine discharge nozzle may be throttle, raising the line YZ, until the area W X Y Z is again equal to - that is one way of reducing the turbine work, if it comes out to be doing more work. As I mentioned earlier, you have the discharge nozzle to control the amount of work that is being done by the turbine, which runs the compressor, which is the supercharger. So that the turbine and the supercharger work are equal to each other, no more and no less. This how the supercharger actually functions and that is what is shown here thermodynamically in this p-v diagram.

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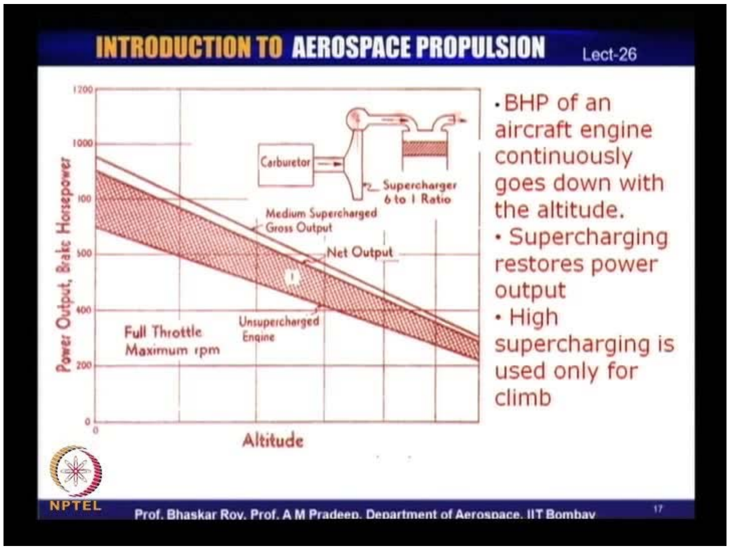

INTRODUCTION TO AEROSPACE PROPULSION Lect-26

- BHP of an aircraft engine continuously goes down with the altitude.
- Supercharging restores power output
- High supercharging is used only for climb

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If we look at the way it is shown, you have a supercharger over here, before the flow actually gets into the cylinder. As I mentioned, it is normally done after the carburetor, where the air and fuel are mixed in the correct proportion or the required or the wanted proportion for that particular operation. Then, the fuel air mixture, which we call charge is supercharged, one of the possible or more used supercharging is of the order of 6 is to 1 ratio at high altitude; that is a kind of supercharging you probably would need. Then, boost the density before it is fed into the cylinder.

Now, what happens is, the power output of the break horse power, as we call it, it can be now shown with the altitude, it is expected that it will all time go down, but the un supercharged power goes down along this line. The supercharged power goes along the upper line; in between there is a line, which is actually used for the purpose of supercharging itself. As a result of which, one can say that the net output is given along this line.

So, supercharger nearly restores the power output of the engine. Typically, a double supercharging or what is often known as high supercharging is used essentially only for the climb operation of the aircraft, it may not be necessary actually during the cruise operation of the aircraft. It is necessary for the climb operation, where you have to take the aircraft from low altitude to high altitude along with it is passenger or cargo. You need excess power over and above the drag of the aircraft. The differential between the thrust produced by the engine of power plant and the drag experienced by the aircraft takes the aircraft to higher altitude through the climb operation. So, during the climb, the thrust produced by the engine of the power plant has to be more than the drag experienced by the aircraft. This differential produces the climb operation.

So, during the climb, you need that excess power to produce excess thrust and hence during the climb operation, one may use double supercharger or high supercharging. Once you reach the cruise operation, you do not need the high operation - high supercharging anymore. You need only as much power as the aircraft is experiencing as thrust, because during cruise, as you know, the thrust is equal to the drag for straight and level flight.

So, during the cruise operation, you need to produce only as much thrust as is experienced by the aircraft as drag and extra thrust is not required anymore. Hence, during that operation that second supercharger can be switched off, aircraft can operate only with a single supercharger or what we can call may be a low supercharger.

So that is how the supercharger is used for various aircraft operations during climb, then later on during the cruise flight of the aircraft.

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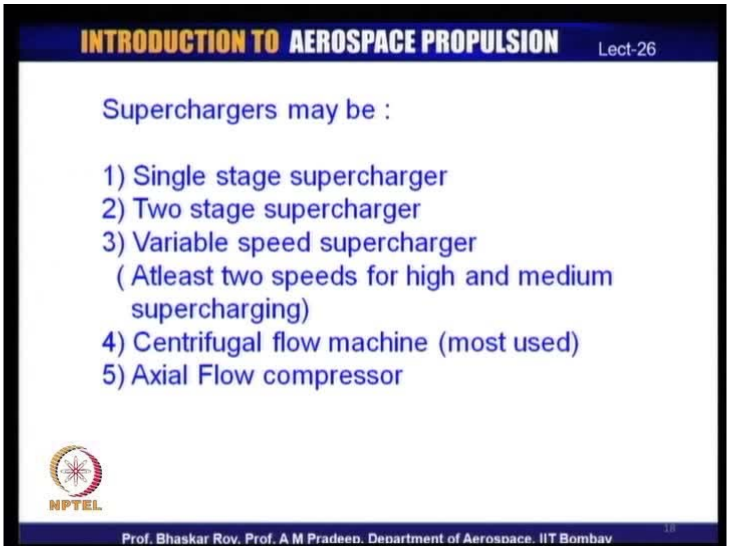

INTRODUCTION TO AEROSPACE PROPULSION Lect-26

Superchargers may be :

1) Single stage supercharger
2) Two stage supercharger
3) Variable speed supercharger
(Atleast two speeds for high and medium supercharging)
4) Centrifugal flow machine (most used)
5) Axial Flow compressor

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So, let us sum up and say that you can have a single stage supercharger, which is good enough for the aircraft to fly at high altitude. You may have two stage superchargers, which allows additional boosting during the climb operation. Or you can have variable speed supercharger, where the supercharger speed can be varied to a high or medium. As we were discussing just now that you may need to do at high speed supercharging, to get high supercharging during climb and then settle down to medium supercharging for medium to low supercharging during its cruise operation of the aircraft.

Most of the superchargers are centrifugal flow machines or centrifugal flow blowers or compressors. Often compression ratio as we mentioned of the order of 3, 4, 5 or 6 and this kind of machine is being used for superchargers right from the beginning. However, it is possible that if you need low supercharging, you can probably use actual flow compressor which in 2 or 3 stages, can produce a sufficient pressure rise inside the supercharging facility, to boost the performance of the aircraft. So, you can have a number of choices; in your choice of supercharger, depending on the size of the engine, depending on the kind of aircraft power, scheduling that you need to do. Of course, depending on the altitude at which finally you expect the engine to be used for aircraft thrust making device. So, these are the choices that engine designer has in choice of his supercharger. As you can see, he has a number of choices for making a choice, for supercharging of the aircraft engine.

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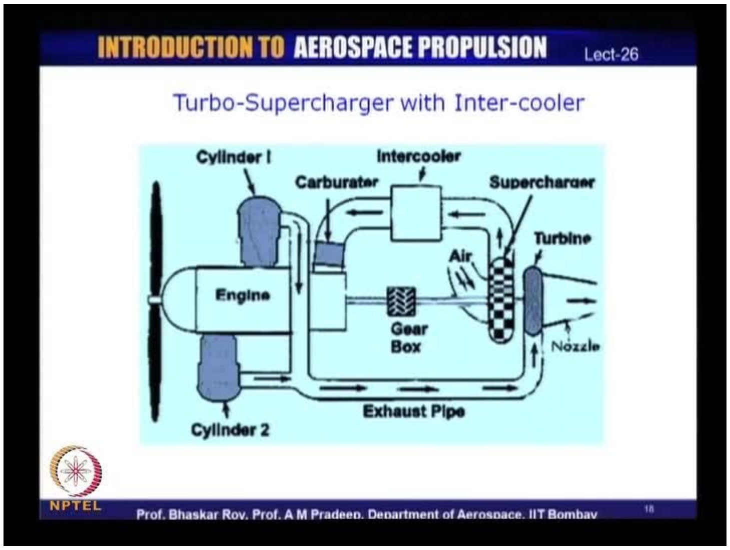
INTRODUCTION TO AEROSPACE PROPULSION Lect-26

Turbo-Supercharger with Inter-cooler

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One of the choices that typically an engine designer would have is a turbo supercharger. One of the possibilities is that he can use a turbo supercharger with what is also known as intercooler.

Now, in this diagram, this arrangement is shown. You have the engine, we are showing, let us say only two cylinders. You have the basic engine that of course runs the propeller, which as we know produces the thrust. Then, this is your carburetor it of course combines the air and the fuel, and produces the charge that goes inside the cylinders. Then, you have normally a gear box that runs the supercharger, which is of course, as we know, has normally a centrifugal compressor.

Now, what can be done is; as supercharge is operating, the supercharger as we have seen is running with the help of a turbine. This turbine run with the help of the gas that is coming out from the exhaust pipe, so instead of the gas going straight away out to the atmosphere, the exhaust pipe takes it to the turbine, runs the turbine and then from the turbine. It goes out through a small nozzle, which as we mentioned can have a variable geometry capacity or variable throttle capacity to control the operation of the turbine. T Through the operation of the turbine control, you can have control over the supercharger operation. So, this is how the turbine supercharger combination is brought to a certain amount of control through the outlet control of the turbine.

Now, what can we done is, you see from this supercharger the air is coming into the supercharger, let us say from the atmosphere. Then, it is being fed into this pipe, through which it goes to the carburetor. Then, through the carburetor it is fed into the cylinder, now on the path of it is going into the carburetor. The air can be further cooled with the help of ambient atmospheric air, which is at high altitude quite cooled.

So, this cool air can now be used to cool the supercharged air. Because, in the process of supercharging, if you have compression, the air actually gets heated up. So, along with the rise in pressure the thermodynamic tells us very clearly that through the supercharging process the pressure has gone up, the temperature also has gone up. Now, from the thermodynamics, we know that if the temperature has gone up, the performance of the engine would actually suffer a little. The higher the temperatures of the intake air, lower would be the performance. As a result of which, in fact, the lower would be the density of the air coming in.

So, one of the ways of further boosting the engine performance is by cooling and this is often called an intercooler. That it is a cooler, which is intermediate between the supercharger and the carburetor. This intermediate cooling is simply called intercooler and this intercooler cools the air.

The air you remember, is still compressed to a high pressure, compensating for the loss of altitude. Now, it is cooled and it is passed through this intercooler. It is just passed through it and it just gets cooled. This now compressed, but cooled air is now fed into the carburetor and then the fuel air mixture is created, which then goes inside the cylinder. As a result of which, we have a kind of double boosting of the engine performance. First, it is boosted by their supercharger and then it is boosted by cooling the air.

All these concepts come from the basic understanding of the thermodynamics of the engine. So, you need to always refer back to the basic thermodynamics to understand why these things have done. Of course, finally, they have to be engineered into the engine configuration so that they operate properly during the actual functioning. So, intercooler is a possibility that has been used some times to boost the engine performance a little more, if the engine is operating at very high altitudes.

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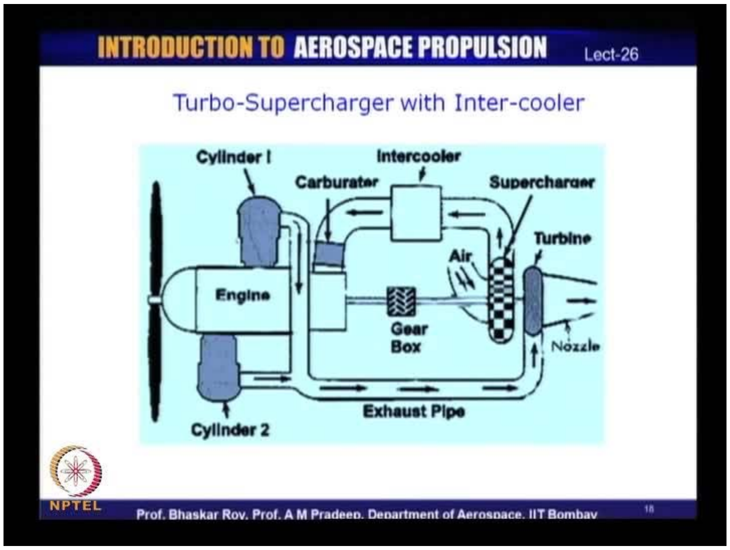

INTRODUCTION TO AEROSPACE PROPULSION Lect-26

Turbo-Supercharger with Inter-cooler

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So, intercooler is an additional method by which a turbo supercharger can be further compensated for its heating that occurs through the turbo supercharger unit. So, these are some of the combinations through which the aircraft engine often gets its operation boosted or augmented in its flight during climb, during high altitude flight. Some of these as I mentioned are typical of aircraft engine, they do not normally happen necessary during the land based operations. So, you probably would not see them in most of the land based engines or land based vehicles. Sometimes you may have heard of that they may be used in the raising engines, where of course for raising purposes, this kind of boosters are used to obtain the power, for the raising engines.

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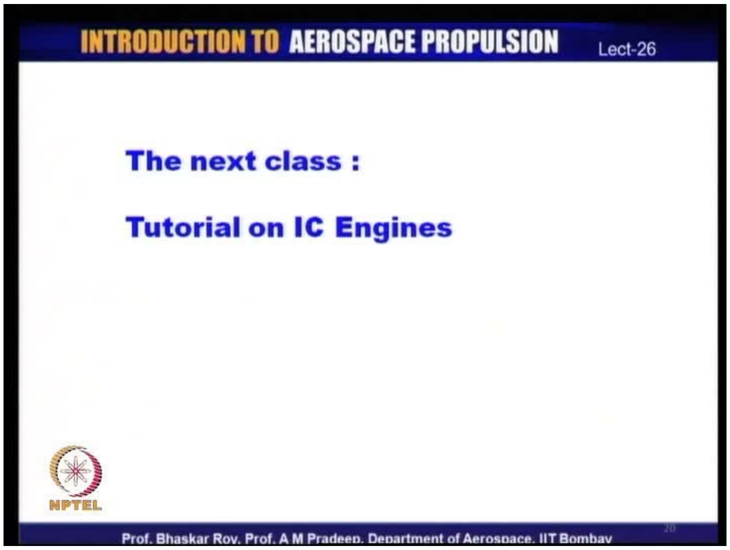

INTRODUCTION TO AEROSPACE PROPULSION Lect-26

The next class :

Tutorial on IC Engines

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In the next class, we will look at all the things that we have done with reference to the various aircraft engines. Try to solve a few problems using the basic thermodynamics and basic engineering parameters that we have defined and see whether those things can be put together in solving of realistic problems. I will also bring in a few problems for you to solve by yourselves. This is what we will do in the next class. So, it will be some kind of a tutorial, where we will indulgent a little bit of problem solving using the basic thermodynamic cycles and the aircraft engine parameters that we have discussed in the earlier classes.