Introduction to Aerospace Propulsion

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Module No. # 01

Lecture No. # 27

Tutorial: IC Engines

In today's lecture we will be covering some of the problems related to IC engines with specific reference to their usage in aircraft power plants. We have covered the introductory ground of the IC engines, how they operate, how their performances are measured, and the cycle on which they are based on and how to get the basic parameters calculated through certain fundamental formulae.

Today, we shall use some of that knowledge to solve a couple of problems and then I will pose a few problems to you for your own homework and I will also pose a few questions in the form of quiz questions for you to ponder over. Those will be based on things that we have discussed in the course of our lecture here over the last three four lectures. You may refer to those lectures or you may refer to any of the books that you have at your hand and try to find out simple answers to some of those quiz type questions. So that it will clear up some of the fundamental notions and possibly similar questions may be occurring in you as you have gone through these lectures.

The problems we are looking at today are based on the otto cycle that we have done for IC engines. We will be looking at two problems to which I will bring the solutions. The first problem is an IC engine based on otto cycle. The second problem is actually futuristic engine which I mentioned in passing during the course of our lecture that it will be a diesel cycle.

Now I mentioned, some are in the course of our lecture, there is a new kind of diesel cycle which is being designed for aircraft power plants. Over last 100 years that aircrafts have been flying with various kinds of piston engines, the diesel engine was never considered. One of the reasons is that the diesel engine tends to be quite heavy since it is based on high pressure and a compression ignition engine. But in the recent years, attempts have been made to develop diesel engines for aircraft power plants also and one of the reasons is that the diesel engine is intrinsically more efficient heat engine.

You have done a little bit of this in your basic thermodynamics. So, we will bring that together and try to solve a problem. In the course of solving the problem, hopefully, you will get the notion that how the diesel engine actually works, quite similar to the way otto cycle works; except that otto cycle is slightly different cycle. The basic steps of calculations are of the same order.

So, in the course of solving the problem, some of those small differences would be introduced. You would get firsthand experience of how the diesel cycle which is likely to be good future candidate for aircraft engines actually operate and how do they finally, calculate the performances of a typically diesel engine which may be used in aircraft engines.

Then of course, I will be posing a few problems to you with specific reference to the aircraft engines. Those are very simple problems making use of the theories that we have done earlier, simple things that we have done. It should allow you to make use of those simple ideas in solving those problems. The answers of those problems will be given, so you would be able to check out whether your solution is correct or not.

So this is what we will be doing in the course of today’s lecture. First, I will be solving couple of problems and then I will be posing a few problems to you for your own homework. Let us start with the problems that we would like to do today.

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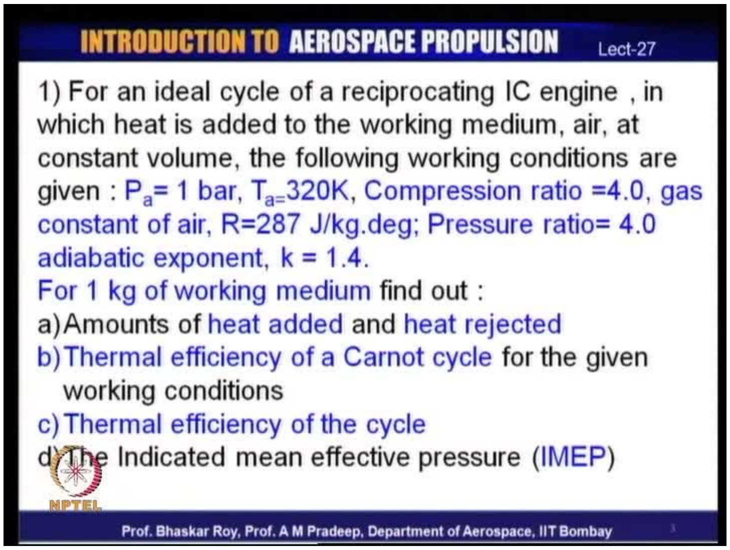

The first problem that we would like to pose is that you have an ideal cycle of reciprocating IC engine, in which heat is added in the working medium, which is air at constant volume. This is what you remember is basically an otto cycle and the following working conditions are prescribed.

The pressure at the inlet is 1 bar, temperature is 320K, the compression ratio is 4 and the gas constant given is 287 joules per kg. The pressure ratio that is prescribed normally operating through the combustion chamber would be 4 and adiabatic exponent of air as working medium continuous to be 1.4, which is a standard value.

The problem asked for solution for 1 kg that means all solutions per unit kilo gram of mass of an air charge. The parameters required to be found in the solution are the amounts of heat added and heat rejected.

Thermal efficiency of a Carnot cycle for the given working condition, Carnot cycle if you remember from thermodynamics is the fundamental cycle on which heat engines were conceived. This cycle of course, gives the ideal best cycle possible given those conditions; the efficiency of the Carnot cycle is the ideal maximum efficiency of any heat engine.

Any heat engine given can quickly also find the equivalent heat engines Carnot cycle efficiency which of course, gives the maximum possible efficiency that particular condition can achieve by any means.

Having found that we would also like to know actually, what is a thermal efficiency of this cycle; that is the otto cycle that we are looking at and the Indicated Mean Effective Pressure-IMEP, which we have defined earlier. These are some of the parameters that we would like to find out. We will see that in the process of finding these parameters, he would require to complete the cycle. The temperatures, pressures at all these radius cyclic loads will have to be found to actually calculate these required parameters. Let us go and do that and solve the problem as posed and find the various parameters at the various nodes of the cycle.

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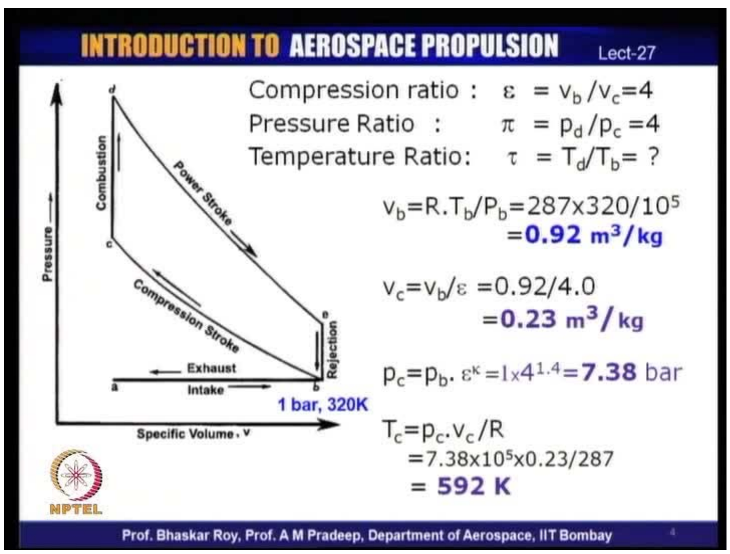

This is the cycle which we had looked at earlier. What is prescribed here is the compression ratio which is 4. The pressure ratio is also given as 4, that temperature ratio is not described, so that is one of the thing we will probably have to find out before we complete all the calculations. As a result of the prescribed values, the specific volume given in small v at intake to the cylinder v subscript b can be now found from the equation of state using the basic thermodynamics. If you use that you would get a value of 0.92 meter cube per kg.

Now that is a specific volume at the intake to the cylinder and then the process goes through a process of compression, which is normally the compression stroke, which goes from b to c. When it goes from b to c it goes through a compression ratio of 4. As a result of which the v c; small v c, would give you specific volume of the order of one fourth of the earlier one and that would be 0.23 meter cube per kg. So that is a specific volume at the end of the compression stroke.

The pressure rise through this process can now be found, because the process is assumed to be an isentropic process in this particular cycle. We are considering an ideal cycle at this moment, so if you use the ideal cycle expressions and the isentropic expression, the pressure rise from b to c could be found using the isentropic relations. Hence, p c would be 7.38 bar using the isentropic relations that we have done earlier and we have also done that in basic thermodynamics.

At station c the pressure now is 7.38 bar and now we have to find the temperature. The temperature again can be at that particular point can be found by using the equation of state. At any point when there is no process you can always use the equation of state to find the temperature or pressure or volume whichever is yet to be found whereas, through a process you have to use the process relationship to find the change in temperature, pressure or volume. At station c end of the compression stroke, the temperature is now found by using the equation of state and that is found to be 592 K. We have the volume - specific volume, the pressure and the temperature at station c calculated using the thermodynamic laws that we have done earlier.

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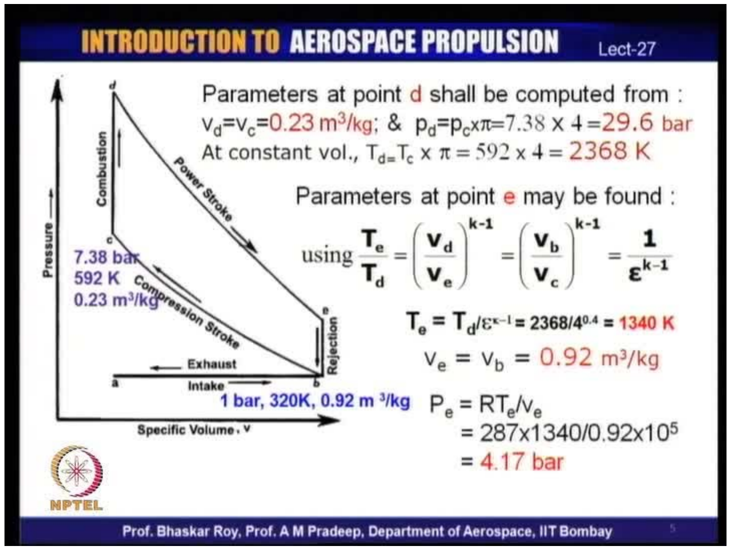

The next thing would be of course, to find what is happening through the combustion process. Now, the pressure, temperature and specific volume are shown here at the stations b and c. From c we have to now progress towards d, which is through the combustion process during which of course, as you can see the specific volume remains constant. So, the specific volume at d remains same as specific volume at c and that would be 0.23 meter cube per kg whereas, the pressure goes through a rise in pressure and that pressure ratio was prescribed to be 4. Now, we have p d 29.6 bar 4 times more than what it was at c.

As a result of which the constant volume now comes out to be - at constant volume, the temperature can be found. Now, this is a constant volume combustion process, fuel has been burnt, the pressure and temperature are raised at constant volume. As a result of which the pressure has gone up to 29.6. Now, the temperature will go up by the same ratio and it comes out to be 2368 K. This is a value which is the highest temperature in the cycle, so the cycle maximum temperature is reached at point d.

Now, from there starts the power stroke. Of course, we are considering the ideal cycle, so the power stroke goes from d to e in a ideal manner. Hence, we can again use the isentropic relationship, so the power stroke of the expansion process occurs in isentropic process. Hence, it goes from d to e and as a result using the isentropic process, we can find the values of T e; the temperature at point e at the end of the power stroke using isentropic relationship. If we do that the temperature at point e comes out to be 1340 K. The cycle that we are using at a point e at the end of the power stroke it comes back to the same specific volume as it started with at b. Essentially, the specific volume at e would be same as the specific volume at b and that would be 0.92 meter cube per kg, which we have calculated already earlier.

So that is a known parameter given the kind of cycle; ideal cycle we are looking at. Hence, from equation of state we can find the value of the pressure at point e and that comes out to be 4.17 bar. So, these are the values that you get through the cycle calculation. As a result now we have a temperature pressure and specific volume at b, c, d and e.

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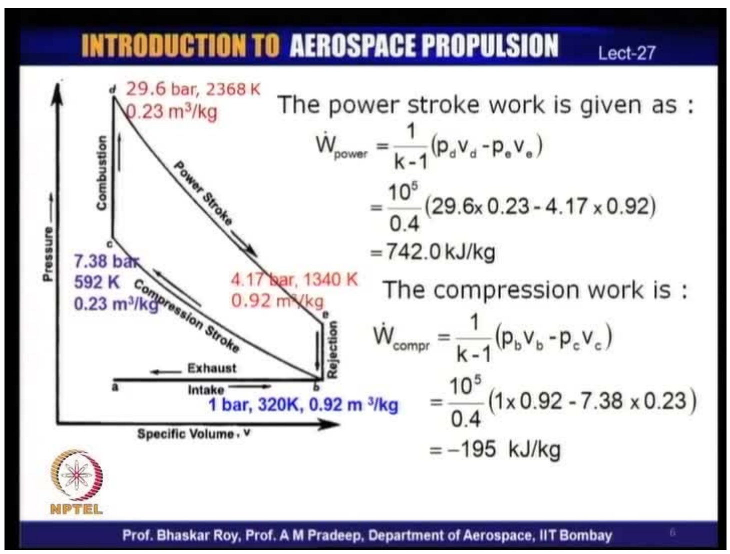

What we can do now? We can show all those temperature, pressure and specific volume at various points b c d e and then go on to calculate the parameters which is been asked in the question statement. First is the work that is being created or what that is taken out and that can be found by using the work done relationship and this is the power stroke work. This comes out to be using the work done relationship that is change of pressure volume from d to e and that gives us the work of the order of 742 kilo joules per kg. Now this calculation, this thermodynamics has been done earlier and this is the work done or work output from the power stroke (Refer Slide Time: 15:40).

On the other hand, the compression work that needs to be done to compress the flow is calculated again from change of pressure and volume from b to c. If you do that you get work that needs to be put in of the order of 195 kilojoules per kg. Now, it is shown here is minus because that is the work you need to put in to do the compression stroke. So, the work done during the compression is put into the system and the work done during the expansion process or power stroke is taken out of the system. These are the two works that was needed to be found out to calculate the net power or net work that can be found from the cycle or the engine that we are at the moment concerned with.

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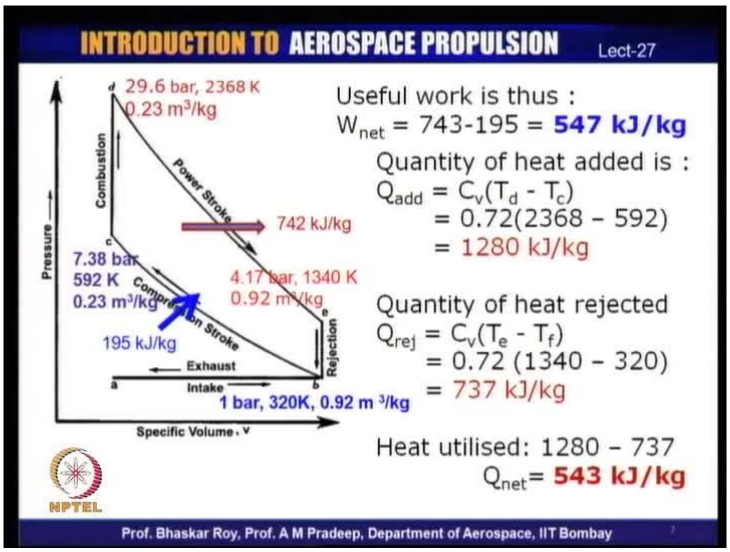

Now, if you use the two works, the useful work or the net work that you can take out of this engine is 547 kilojoules per kg. So that is a kind of work you can expect to get out of this cycle that has been prescribed. On the other hand, the heat is added to the system through the process of combustion and a certain amount of heat is rejected from the system in the exhaust process and those values now can be calculated.

Now, heat added to the system which is done during the process of combustion that is between c and d and that is given by the temperature differential between the two states. Since, the process was in constant volume we use C v to find out the heat that is added and if you do that you get the heat addition of the order of 1280 kilojoules per kg. So that is the heat added to the system by the combustion process.

The heat rejection of the system can be found again from the constant volume heat rejection process typically that would be the exhaust process ideally. That is also at constant volume, so the temperature differential into C v gives us the heat that is to be rejected that comes out to be 737 kilojoules per kg. Hence, the differential of the two between heat added and heat rejected is the net heat that is available for utilization or net heat to be utilize by this engine and that comes out to be 543 kilojoules per kg.

Now, if you compare the value at the bottom in red and value at the top in blue, the two are very close to each other the work done is 547 and the heat available or utilized is 543. These two need to be very close to each other they cannot be greatly different, because the work done is to be accomplished out of the heat that is been made available by the system. So, these two would have to be very close to each other if not exactly same.

Since, two computations of work done or heat added or done in a slightly different manner quite often, a very small difference comes up but, that difference has to be extremely small, ideally or very rigorously or very accurately they should be exactly same as each other. But, in actual calculation quite often a very small difference always comes up. The work done and the heat utilized that is needed by the question statement have now been found. We can now move forward to find the efficiency of the system.

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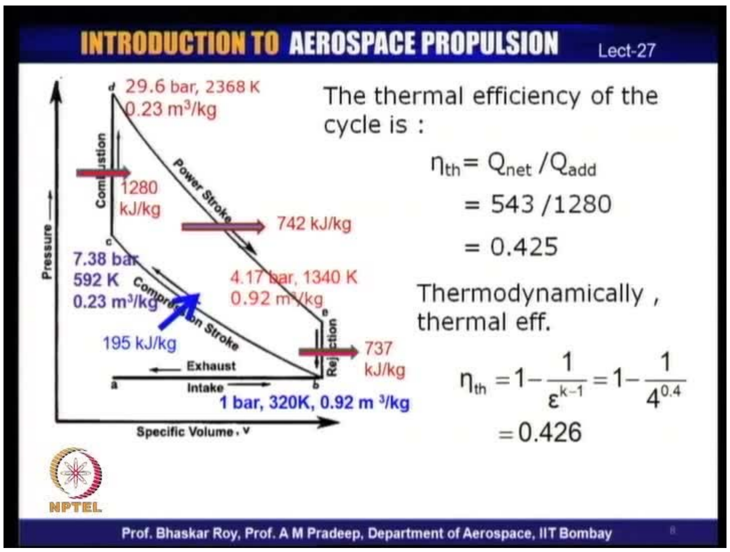

Now, given the work done and given the efficiency of the system, we have found the work done and the heat added and rejected. If we use those two parameters we can find that the thermal efficiency of the cycle is typically given by the heat that is utilized by the heat that is actually put in the system. That comes out to be 0.425 that is 42.5 percent would be the thermal efficiency of this cycle, which is as we have mentioned earlier is an ideal cycle.

On the other hand, thermodynamically the thermal efficiency can be simply calculated from the compression ratio that is been prescribed right in the beginning. That prescription gives us ideal thermodynamic cycle efficiency of the order of 0.426, which is 42.6 percent. We see that an ideal thermodynamic thermal efficiency calculation comes pretty close to the thermal efficiency calculation from the heat transaction in the cycle, which was calculated earlier.

So, they also need to be very close to each other if not exactly same well they are pretty close to each other; it means that answers that you are getting for various steps are generally more or less correct. Those small differences often are acceptable differences because they are calculated in different ways, in the two methods by which the two efficiencies are computed. So that is very small differences normally accepted.

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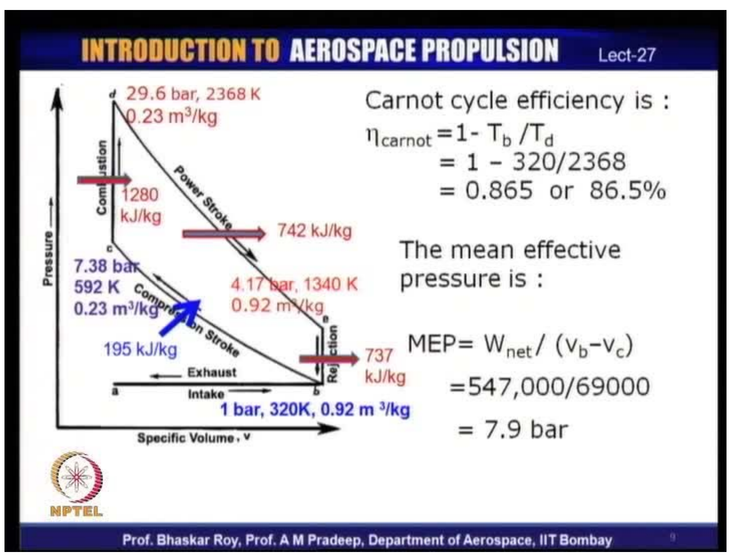

The other thing that was asked in the Carnot cycle definition is the Carnot cycle definition, which efficiency of the Carnot cycle was done in your thermodynamic course in some detail. If you will just refer back to that the Carnot cycle definition was very simple, it is 1 minus the cycle temperature ratio. This is something which quite often is used to find out, what can you maximum expect out of a cycle. Once, the cycle temperature ratio is found, you remember this ratio was not given to us, so we had to find it in the process of calculating the various parameters. Now that we have found the cycle temperature ratio 1 minus inverse of that actually gives us the efficiency of the idealized Carnot cycle and this comes out to be 0.865 or 86.5 percent.

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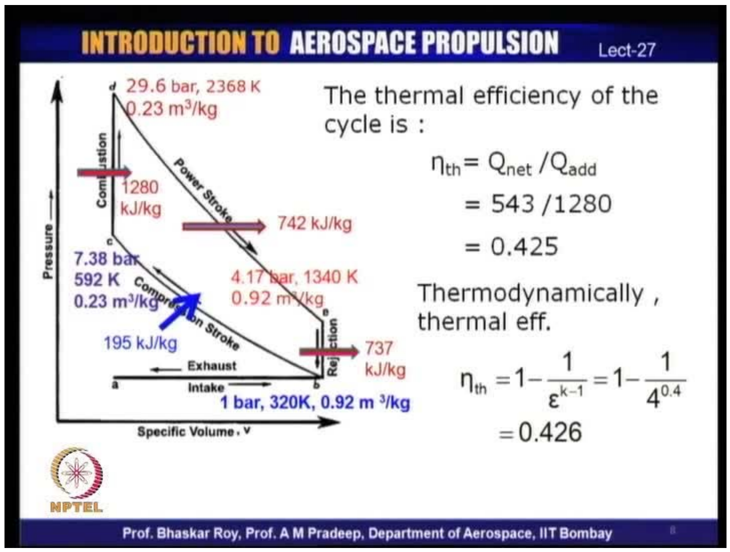

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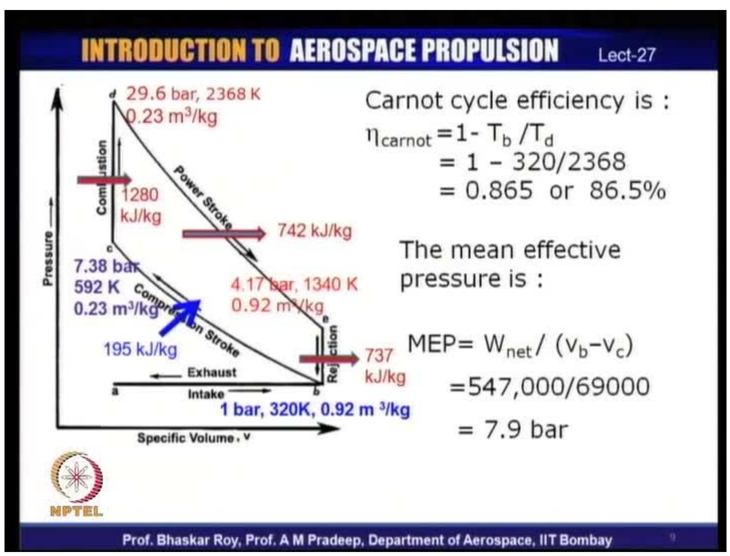

That would be the maximum possible efficiency any heat engine can get out of this temperature ratio that we have got at hand. There is no heat engine possible which can give you efficiency more than 86.5 percent. Compared to this Carnot cycle efficiency our efficiency if you look at, was of the order of 42.5 percent. So, the otto cycle efficiency that we are getting is almost half of that of the Carnot cycle efficiency that typically one would get from ideal Carnot cycle theory.

The last thing that was needed for this cycle was the mean effective pressure, which we had defined earlier as some kind of theoretical average pressure acting over the cycle and this is normally found theoretically by using the work done that is been calculated. The compression difference between the specific volumes at the two ends of the stroke and that gives us mean effective pressure of 7.9 bar. So, this if you remember was averaged theoretical pressure definition over the entire cycle. Now, you know what the mean effective pressure would be for this cycle.

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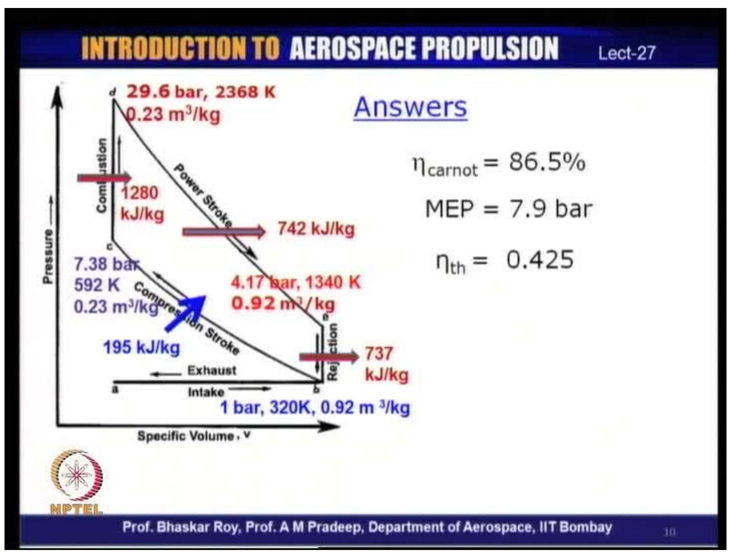

These are the parameters that we are wanted out of the cycle, as we have seen before once you have these values, you can now easily go on to find out, how this engine can be utilized for some practical purposes. If we put all this parameters together, we get the final picture; the cycle is shown here (Refer Slide Time: 25:01). At these points b c d e the various pressure, temperature and specific volume are shown. What input into the system for compression is 195 kilojoules per kg and the work output of the system is 742 kilojoules per kg.

The heat input into the system is 280 kilojoules per kg and the heat rejected is 737 kilojoules per kg, so that is the whole cycle of the engine that we have at hand and this has an ideal Carnot cycle efficiency of 86.5 percent whereas, the thermal efficiency would be 42.5 percent. Mean effective pressure or theoretically computed pressure is 7.9 bar; so that gives us the answer to all the questions that have been posed in this particular question.

The next question that we will be looking at is question that deals with diesel engine. Now, I have brought this problem to discuss the diesel engine, which is being considered as a future candidate for aircraft propulsion and one of the reasons is that diesel engine can operate at high, much higher, pressure ratio. This much higher pressure ratio actually gives the diesel engines prospectively a better efficiency.

Now, this better efficiency of course, translates to better fuel efficiency and as a result of which we have an engine a heat engine that is fundamentally a better engine. Now, this is what some of the people are now working on to create a new diesel engine, which could probably be put on an aircraft and fly with an aircraft. Through the process of solving this problem, we would like to take a look at how the diesel engine actually works.

The basic thermodynamic cycle you have done in your thermodynamic course, the cycle is slightly different from the otto cycle, which we have done but, through the process of solving this problem, you would probably get the notion of how the diesel cycle or diesel engine would be expected to operate. Find out the various parameters, very similar to the parameters that we have found in the first problem. As a result of which the diesel cycle operation would hopefully become clear to you.

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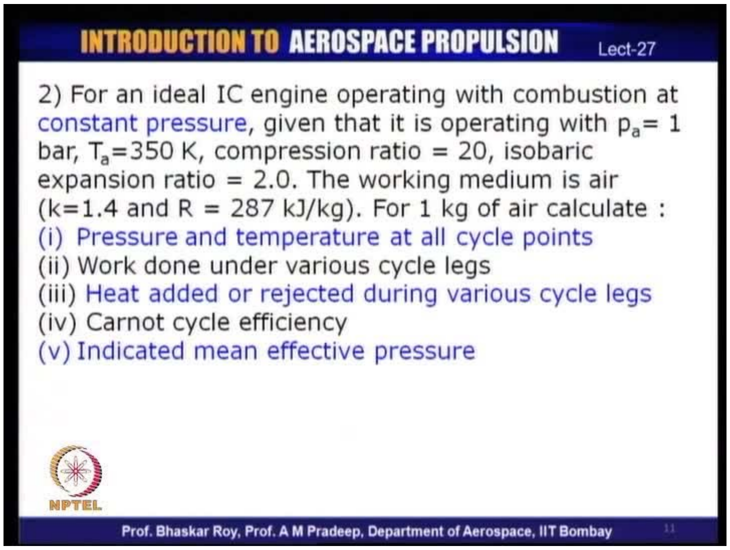

The problem that is being posed is for an ideal IC engine operating with combustion at constant pressure and that is the cycle that we are now looking at differently, earlier cycle was at constant volume combustion. Now, this cycle at constant pressure combustion is operating again with a pressure of 1 bar, temperature at 350 K. The compression ratio is now given as 20 and the isobaric expansion during which the combustion would be actually done; expansion ratio is given as 2.

The working medium is again air with a specific ratio k equal to 1.4 and the gas constant 287 kilojoules per kg. For 1 kg of air the problem asks for pressure and temperature at all cycle point, this is the same thing that we have done for the first problem. The work done under various cycle processes various legs of the cycle the heat added or rejected during various cycle processes. Again, the Carnot cycle efficiency and we will also find the thermal efficiency and the indicated mean effective pressure as before.

The parameters that are required to be computed in this cycle is more or less same as the parameters that we had done for the earlier cycle, except that this one is now a constant pressure combustion process. Hence, the steps would be slightly different and in the process of solving this problem those slight different steps would be made known to you.

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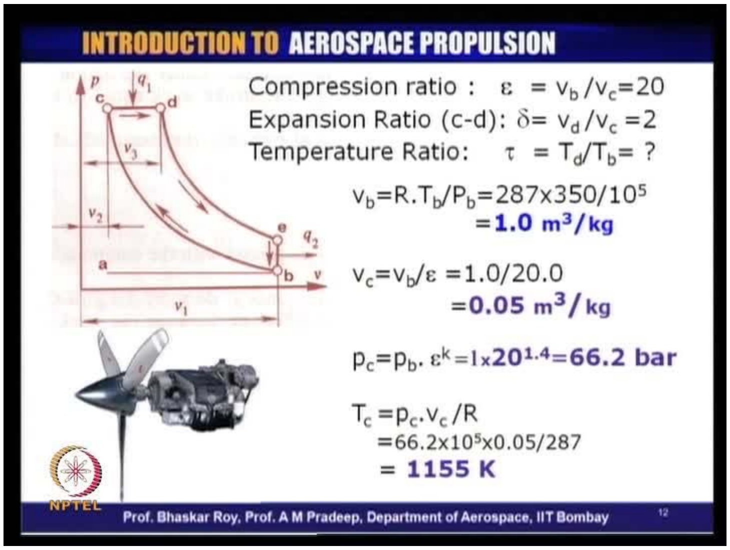

Now, let us look at the cycle. This cycle shows that process which is occurring from b to c is an isentropic process again, but the combustion is from c to d is now at constant pressure, earlier we had at constant volume that was otto cycle. Now, this cycle gives the combustion at constant pressure from c to d during which heat is added. So that is the only difference between the earlier cycle and this cycle.

As a result of this, the process of expansion effectively has started from c and it goes to d during which actually combustion is done and then of course, you have the power stroke from d to e. So, the process is slightly different from what we have done. This is typically the picture if you remember, we had seen this one before, typical diesel engine that is been develop to power an aircraft propeller, which would hopefully be flying with aircraft very soon. So, this diesel engine would be made of lighter material however, strong enough to withstand very high pressures. So that it can operate and we can get some benefit of prospective high efficiency that normally the diesel engines promise.

Let us see whether we get that kind of efficiency from this particular cycle that has been prescribed to us. What is given in this cycle definition is the compression ratio is 20, which as you now see is much higher from b to c compare to the earlier otto cycle. We have an expansion ratio which is of the order of as given here and the temperature ratios again not prescribed, which we will have to find actually.

As a result of which the specific volume at station b we can start finding. Given the parameters using the equation of state, we can find the specific volume at station b to be 1 meter cube per kg. Now, it is compressed from b to c and the compression ratio prescribed is 20. As a result of which the specific volume at point c of the cycle would be 0.5 meter cube per kg.

The pressure can be computed by using the isentropic laws. As the process is from b to c is an isentropic process and of an ideal cycle. Hence, using the isentropic laws we can find the pressure at c to be 66.2 bar and then again using the equation of state, we can find that the temperature at station c would be 1155 K. At station c we have the pressure, temperature and of course, the specific volume.

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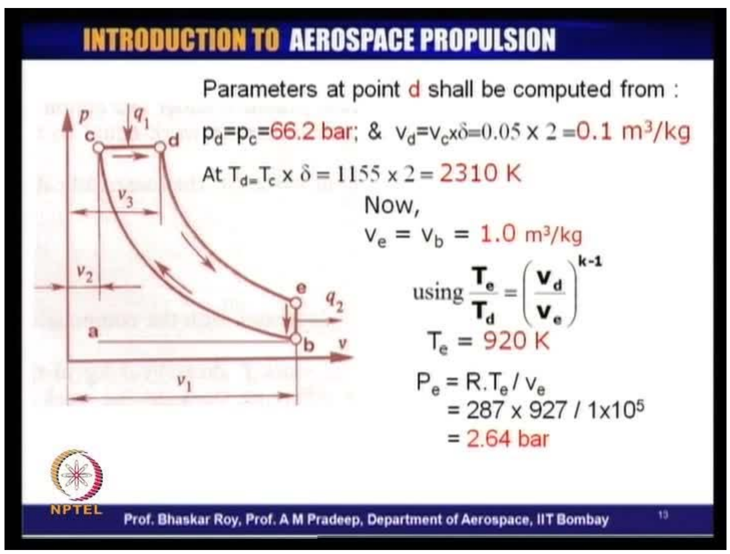

Then we can compute the values that are needed to find in pressure at point d, which is the process from c to d is the combustion process. At d we have pressure which is conserved or remain same as c. So, p d would be same as p c and that would be 66.2 bar. The specific volume now under goes an expansion process and that expansion ratio was prescribed and as a result of which we now get specific volume of 0.1 meter cube per kg.

Now, using the expansion ratio that is been prescribed to us, we can find the temperature at point d to be 2310 kelvin. Now, this is again the highest temperature of the cycle, because now combustion has been done even though pressure is same as c, the temperature at d would be much higher because of the combustion process that has been accomplished and that now is the highest temperature of the cycle.

Across from d to e of course, again you have the power stroke. At e the specific volume again comes back to 1 meter cube per kg with which it started from b and hence that is a known value. The temperature change from d to e can now be found using the isentropic laws.

Now, isentropic laws because the process from d to e is an ideal isentropic process and hence, the isentropic laws can be used to find the temperature variation between d and e; that is the power stroke, so the temperature at e now is 920 K. Using the values of temperature and specific volume, we can now find the pressure at a point e and this is now 2.64 bar. As a result of which we now have the pressure, temperature and specific volume all the three parameters at point e.

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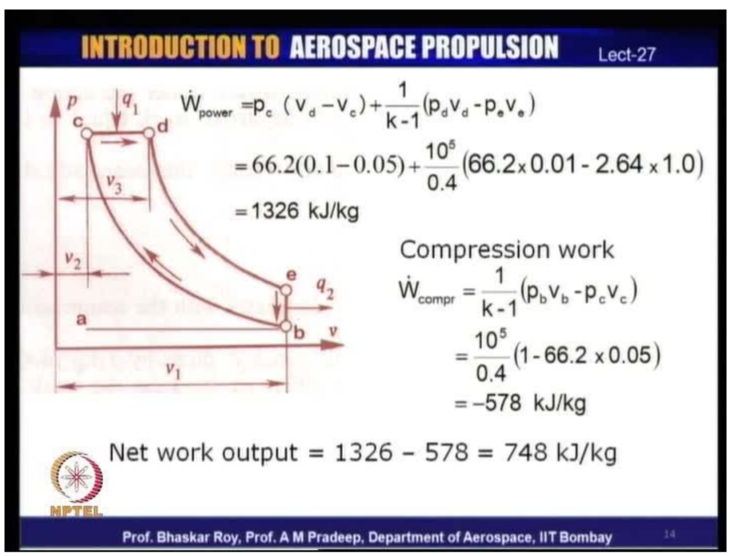

At various parameters; at various point of the cycle we have all the parameters that are needed to find the cycle performance. Now, we can calculate the cycle performance, now the relationship shown here for the power stroke is slightly different from what we have done for the otto cycle.

So that is one of the differences between the weight is calculated for constant pressure combustion and the weight is calculated earlier in the earlier problem in constant volume combustion. This work done now comes out to be 1326 kilo joules per kg.

This is the work output from the power stroke. On the other hand, the works needs to be done to create the compression and this work can be calculated as before. This procedure is very similar to that we had done in the earlier problem. Using the values that we have got in this problem the work of the compression comes out to be 578 kilo joules per kg. Again, it is shown here as minus because that is a work that is put into the system whereas, the power stroke produces work out of the system.

The net work output of the system would be the differential of the two and that comes out to be 748 kilo joules per kg. So that is the work that you can expect out of this particular engine given the parameters that have been prescribed to us.

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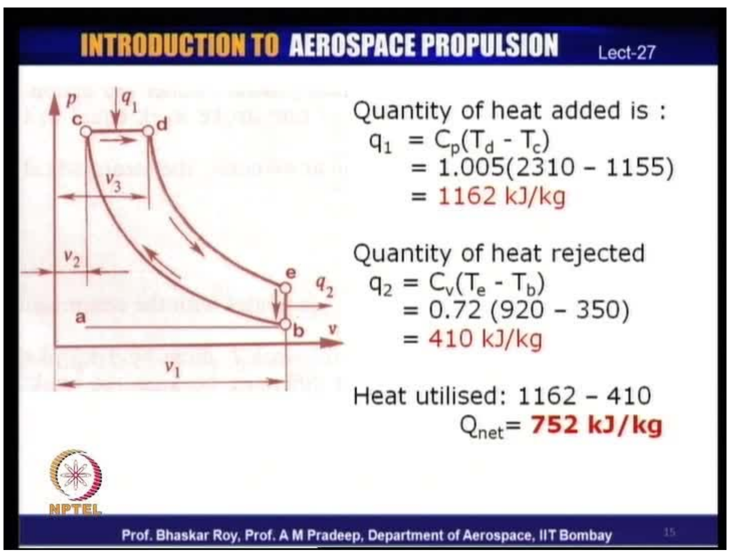

We can now also calculate the heat addition and heat rejection using the thermodynamics that you have done in great detail earlier. That gives us the heat added in the constant pressure process, so we use a value C p and not C v that we have done earlier, because that was a constant volume process and this is a constant pressure process. As a result of which we now get heat added of the order of 1162 kilo joules per kg.

Correspondingly the heat rejected between the points e and b and that is again a constant volume process. As a result of which we again use C v and using that we get a heat rejected of the order of 410 kilojoules per kg, so the heat that is utilizable of this cycle would be the differential of the two and that is 752 kilo joules per kg.

As we had seen earlier the net work output was 748 as calculated and the heat that is can be utilized as 752. Again, they are very close to each other and that shows that the calculations are probably more or less correct. As I had explained earlier, the two would give slightly different answers but, they need to be very close to each other to ensure that your calculations are correct through the cycle processes.

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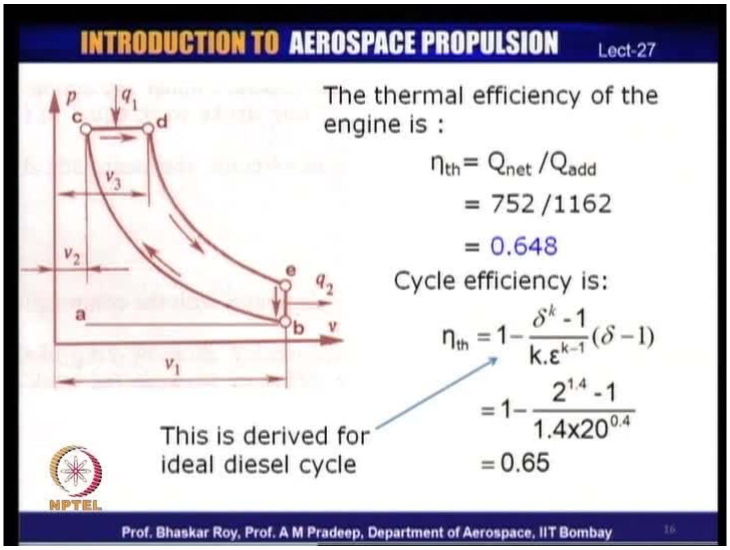

Now, we can calculate the thermal efficiency of the engine as was asked for and that can be found to begin within a simple fashion that we have the net heat that is utilizable. Of course, the heat that was added and the ratio of the two, straight away gives us the thermal efficiency and that is 0.648 or 64.8 percent thermal efficiency as calculated of this cycle.

Now, if you use the basic thermodynamics again to calculate the cycle efficiency and the efficiency definition of this kind of cycle is given to you here. We had not done this in the theory coverage, so I am giving the formula here which is a derived formula and using that the thermal efficiency comes out to be 0.65 or 65 percent.

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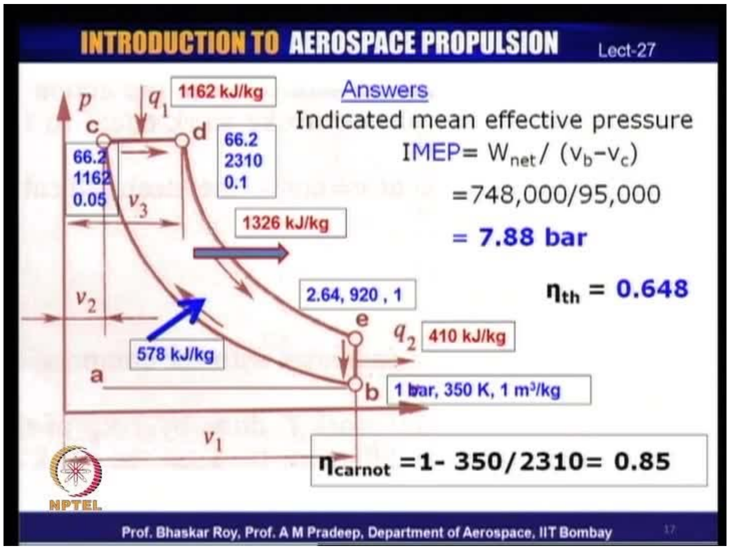

The thermal efficiency is calculated by two different means again come out to be pretty close to each other, which is the indication that the efficiency of the order of 65 percent is likely to be achieved from this cycle that is been prescribed to us.

If we put all of it together in this diagram, we can find then last parameter that is needed for solution of this problem. That is the indicated mean effective pressure, which is found the same way that we did in the last problem and that comes out to be 7.88 bar. Hence, we have all the parameters now shown here on the cycle diagram that pressure, temperatures, specific volume, the work input for the compression, the work output for the power stroke, the heat input through the combustion chamber and the heat output from the heat rejection process. The Carnot cycle efficiency which was asked for given the cycle parameters and the cycle temperature ratio that are available comes out to be of the order of 85 percent or 0.85 percent.

Now, we can see here in this particular engine that is been prescribed to us. That a typical diesel engine can actually give efficiency of the order of 64 to 65 percent whereas, a typical otto cycle would give efficiencies of the order of 42 43 44 percent and anything more than that is quite difficult to get out of an otto cycle.

So, intrinsically a diesel cycle promises to give substantially higher efficiency during the course of its operation substantially more than that of otto cycle. This is the promise, this is attraction based on which people are now trying to create new diesel engines made of lighter material that would take this theoretical promise to a practical engine design and we shall wait for that kind of engine to fly with an aircraft.

Next, I shall be giving you a few questions in the form of quiz. Now, these questions are posed to you on the basis of the various things that we have discussed in the process of this lecture on IC engines. Many of which you would probably remember and you might get the answer to most of these questions in some of those things that we have discussed earlier.

You may also like to look at one or two books that you have at your hand and you would be able to get the answer to all the questions quite easily. You may have pondered over these questions yourself, so you may like to know what the answers would be, so I am posing the questions to you, for you to figure out what are the answers. I am sure it will not be difficult for you to find out the answers for this simple quiz type questions.

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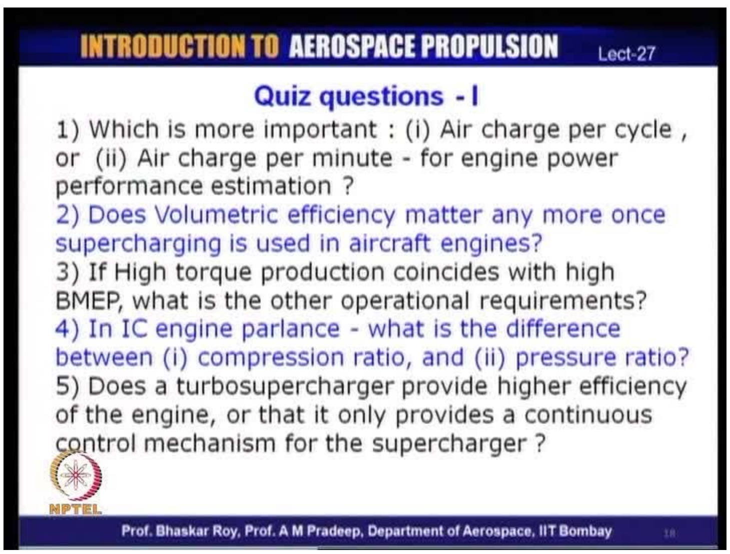

The first question that I would to pose is which is more important? The air charge per cycle or air charge per minute for engine power performance estimation, to find out how much is the engine power or how powerful the engine is, which of the two parameters is the more important parameter. We have seen that there are two definitions air charge per cycle and air charge per minute and you can probably try to find out which of them would be actually more important than the other. Of course, both are important but, one of them probably gives a more direct indication of the power production capability of the engine.

The next question is the volumetric efficiency of the engine that we have prescribed. The question here is does the volumetric efficiency matter anymore once supercharging is used in aircraft engines? That means the supercharger induced engine, do you need to have volumetric efficiency computed at all.

Third question is the high torque production coincides with high BMEP this is a most probably the case, what are the other operational requirements? To achieve high torque it goes probably with high BMEP what would be the other operational requirements to do that.

The fourth question is in IC engine fuel, what is the difference between compression ratio and pressure ratio? Now, compression ratio and pressure ratio both have been prescribed to you and it is necessary that you understand the different between the two.

Fifth question is does a turbo supercharger provide higher efficiency of the engine, or that it provides a continuous control mechanism for the supercharger? Exactly, what is the utility of turbo supercharger? Does it actually give a higher efficiency of the engine? You can think about that and try to find out what the role of turbo supercharger is compare to the other kind of superchargers that we have discussed in the course of our lectures.

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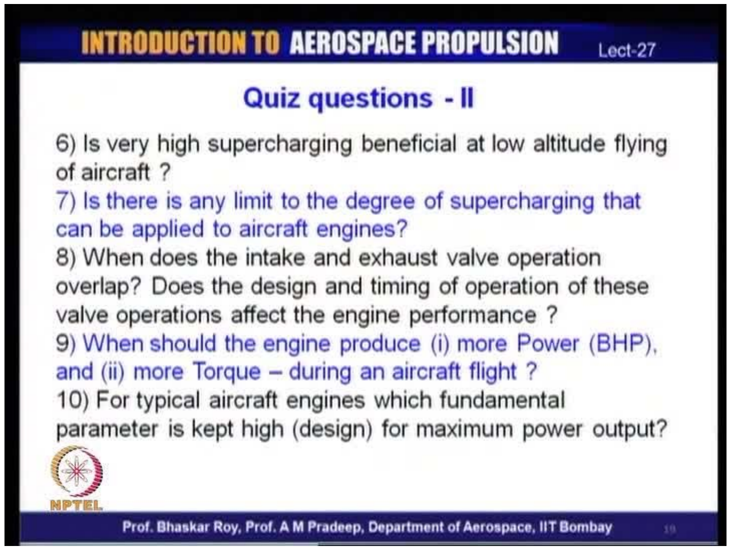

The next question - a quiz type question that I would like to pose to you, is very high supercharging beneficial at low altitude flying of aircraft? We have seen in the course of our lecture that your supercharging can be a low, it can be medium and it can be high. The question is do you always need to deploy high supercharging all the time when you are flying. This is something you need to understand that you have a supercharger for aircraft engines, when do you use low supercharging? When do you use medium supercharging? When do you use high supercharging? So, the sixth question is pointed to that.

Seventh question is, is there a limit to the degree of supercharging that can be applied to the aircraft engines? If you think of the various things that we have discussed you would probably start getting an idea what should be the answer to this.

The eighth question is when does the intake and exhaust valve operation overlap? There is a certain point of time when both of them are operational almost around the same time and when does that happen? The next corollary to that question is does the design and timing of operation of these intake and exhaust valve operations affect the engine performance? We have discussed this in the course of our lecture, so you probably might get an answer to it, if you go back to some of the things we have discussed in the earlier lecture.

Ninth question is when should the engine produce more power and when should it produce more torque during an aircraft flight? Now, this is an important issue with relation to the engine usage in an aircraft, because at a certain point of time of flight of the aircraft the engine actually needs to produce a more power, whereas at certain other point of time of the flight the engine actually needs to produce more torque.

This is true of the engines used in automobiles also, but in aircraft it is extremely vital and the difference between these two operating situations is pretty much known - I can tell you right now for example, that unless you have this differential worked out and the engine operation scheduled accordingly we are going to have problem during the flight.

The tenth and the last question is, for typical aircraft engines which fundamental parameter is kept high by design for maximum power output? Aircraft engines, we have seen there are lot of limitations in terms of size, in terms of weight, keeping in mind all those limitations, what is it that needs to be done to make an aircraft engine so that it continues to produce high amount of power during the course of its operation.

The typical aircraft engines are built and designed slightly different from the land based engines. So, this question is asking, what makes an aircraft engine fundamentally different from the land based engine? One of the main parameters that make it different from the lane based engines.

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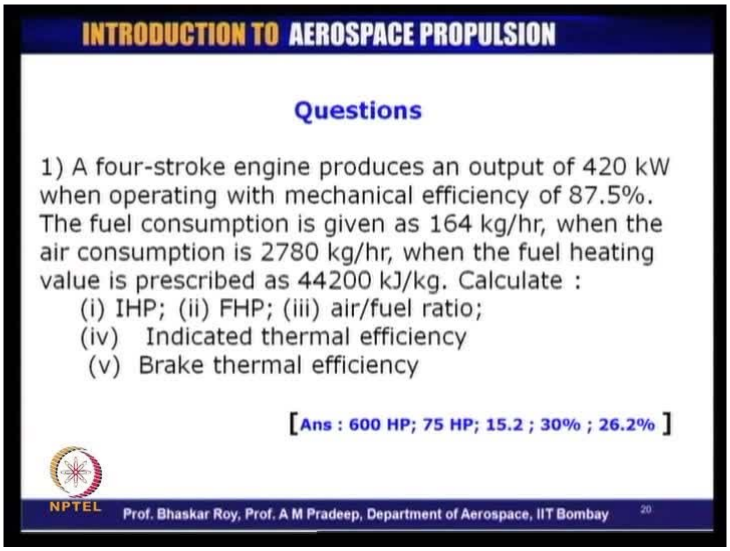

Now, I shall pose to you, some of the numerical problems that you may like to solve on your own based on the theories that we have done. Some of the simple introductory theoretical definition that a parametric definition that we have done in the course of our earlier lecture. Those things can be used in solving these problems to get the answers.

The first question is, a four-stroke engine produces an output of 420 kilo watts, when operating with mechanical efficiency of 87.5 percent. The fuel consumption is given as 164 kilo gram per hour, when the air consumption is 2780 kilo gram per hour, when the fuel heating value is prescribed as 44200 kilo joules per kg, for the kind of fuel that is normally used in engines.

It is asked for that you calculate indicated horse power, frictional horse power and the air to fuel ratio that is operative in this given operating condition, indicated thermal efficiency and the break thermal efficiency of this particular engine for the condition that are prescribed over here. The answers are given here, so when you get your answers you can check out whether your coming very close to these answers which are given, you should be coming very close to ensure that you have got the correct answers.

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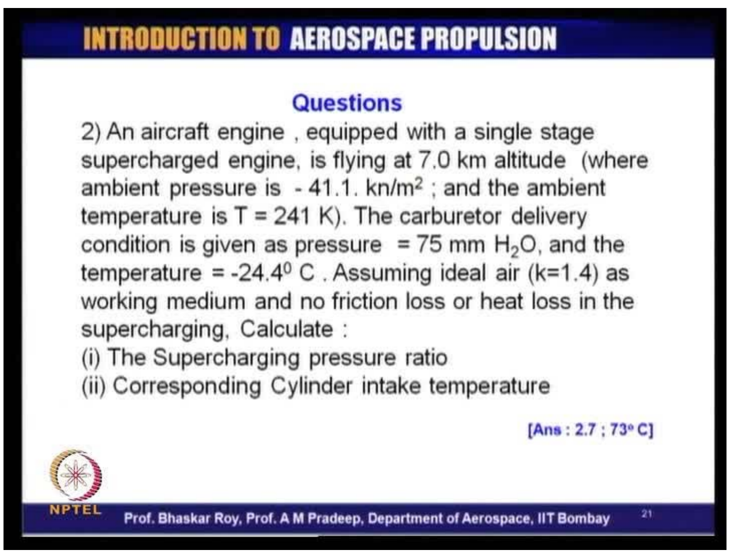

The next question that is posed is for an aircraft engine which is equipped with a single stage, supercharger is flying at 7 kilo meter altitude where ambient pressure is given as minus 41.1 kilo Newton’s per meter square and the ambient temperature is 241 K. So, it is flying at a high altitude.

The carburetor delivery condition after the carburetor where air and fuel are mixed and that condition is given as pressure is 75 millimeters of water and the temperature is minus 24.4 degree centigrade.

Now, if we use those conditions and assuming that you have air as the working medium, for which the specific ratio is 1.4, assuming that there is no loss of inflection or no loss in heat in the process of supercharging, so the entire supercharger is assumed to be ideal. Calculate the supercharging pressure ratio and the corresponding cycle intake temperature, so this is a supercharger based problem for an aircraft engine. The answers are given here and you can check out our answers, when you start getting your calculations done.

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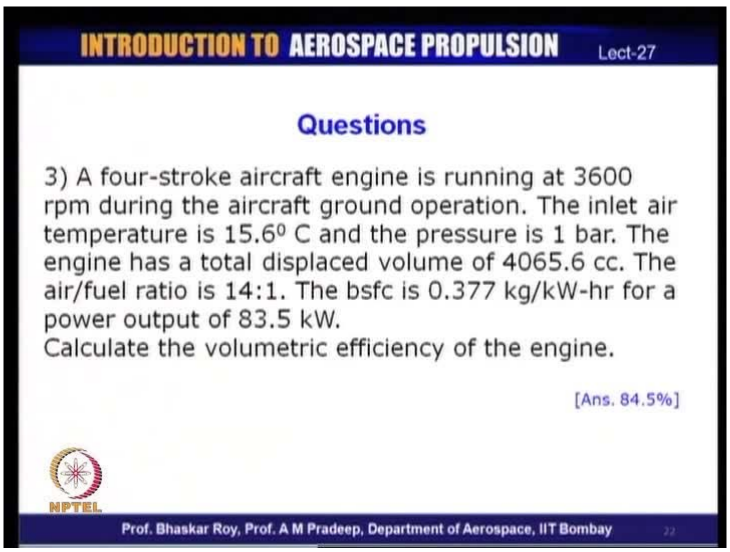

The third question that is prescribed for you is a four-stroke aircraft engine, which is running at 3600 rpm probably during an aircraft ground operation. Most aircraft engines run probably at a higher rpm than that while flying, now given that operating condition the inlet air temperature is 15.6 degree centigrade and the pressure is 1 bar.

The engine has a total displaced volume of 4065.6 cc, which is as you know is quite a good number. The air fuel ratio is prescribed is 14 is to 1 given here are the values of a break specific fuel consumption, which is given here as 0.377 kilojoules per kilo watt hour for a power output of 83.5 kilo watt.

Those are the operating conditions given, bsfc is given, power output is given, what we wanted is the volumetric efficiency of the engine. The answer is given here, you can check out whether your answer is coming quite close to the answer that is been given with this question.

With the help of these questions you should be able to understand some of the issues that we have discussed in the class, some the basic theories and basic parameters that we have been talking about and have been defined. You should be able to get the cycle operation and the engine operation quite well calculated through very simple methods that we have done in the course of last few lectures.

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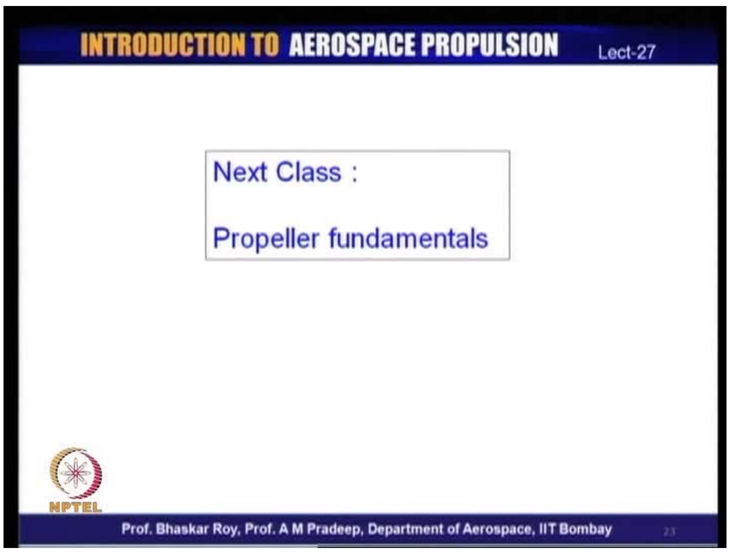

These problems are illustrative of some of the things that we have done in the course of last few lectures. In the next lecture, we will move on to a different topic all together. We will be moving on to the propeller fundamentals; we have been talking about engines and the engines produce power of the shaft power they run the propellers. It is the propellers that finally create the thrust which make the aircraft fly. In the next class, we will be talking about propellers and the propeller fundamentals and over the next two three lectures, we will be looking at various issues and how the propellers actually finally, create thrust.