**Applied Thermodynamics**
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**Module - 04**
**Gas Turbine Engines**
**Lecture - 31**
# Gas Turbine Engine-Components and Thermal Circuit

Dear learners, greetings from IIT Guwahati. Now, we are in another module of this MOOCs course Applied Thermodynamics. The name of the module is Gas Turbine Engines.

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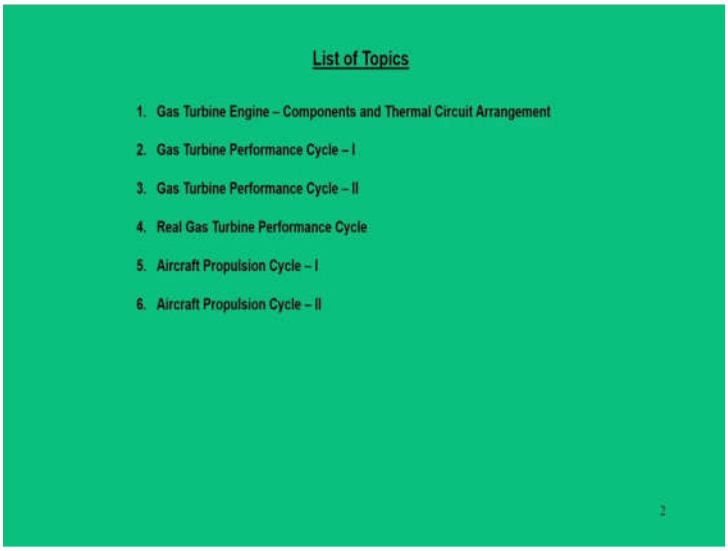


So, this particular module contains the following topics. In the first lecture, that is today, we will discuss about gas turbine engines, components, its thermal circuits. In fact, this particular lecture is mainly on introductory remarks of gas turbine engines. Then, we will go to mathematical and thermodynamic analysis, that is gas turbine performance cycle for module I and also gas turbine performance cycle II that is the 2nd lecture on this gas turbine performance cycle.

And these two lectures will be devoted to mainly the thermodynamic analysis of air standard gas turbine cycles and subsequent enhancement of their performance. Moving further in the lecture number 4, we will have a real gas turbine performance cycle where we will introduce the concept of component efficiency, and other irreversibility factors that affects the gas turbine cycle. And the last two lectures, that is 5 and 6, will be devoted to aircraft propulsion cycle.

Just to give a background that when you deal with the gas turbine engines, they are used in two motives. First motive is that we want to get the power. Other motive is we want to get the thrust. So, depending on the requirement, the components are specified. And in aircraft propulsion cycle our main intention would be to get thrust and in the other category that is gas turbine performance cycle, our main motive would be to get power output from a gas turbine engine.

So, this is all about the broad spectrum of list of topics to be covered in the module 4 that is gas turbine engines.

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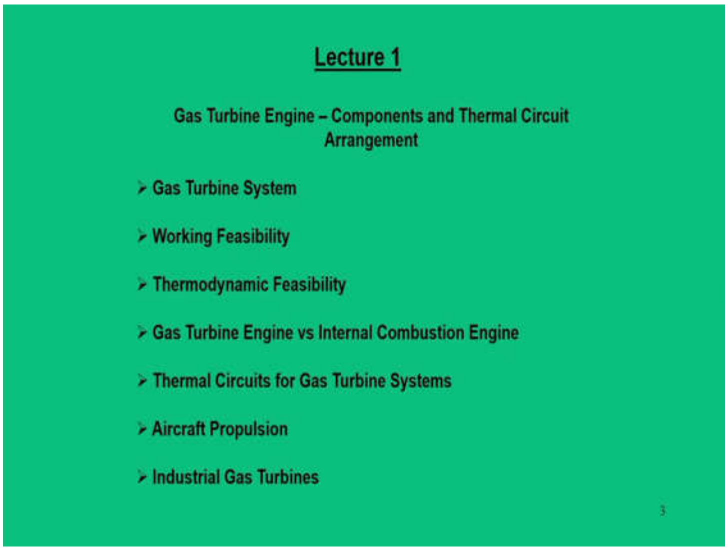


Now, let me start with the 1st lecture that is gas turbine engines. And in this, we will discuss about the components, different thermal circuit arrangements. And other subsection in this lecture would be the working feasibility, thermodynamic feasibility, and we will try to see that how a gas turbine engine is different from an internal combustion engine.

Then, we will move on to different thermal circuits, by thermal circuit I mean different components of a gas turbine engine are arranged in a particular fashion to have the complete cycle. So, this is known as the thermal circuits for gas turbine systems. And now we will give some introductory remarks to aircraft propulsion, how a gas turbine engines can be useful to generate thrust.

Then, we will have industrial gas turbines. So, industrial gas turbines are mainly intended for a rigorous power generation. If you want to use the gas turbine engines for a longer run, how the concept should look like. But, however, our main intention would be simple gas turbine systems that are used for power generation and thrust generation.

For power generation, we are mainly interested to find the work output. For thrust generation, we are mainly interested to get the thrust out from the exhaust of the turbine. So, let me start the background of this gas turbine systems.

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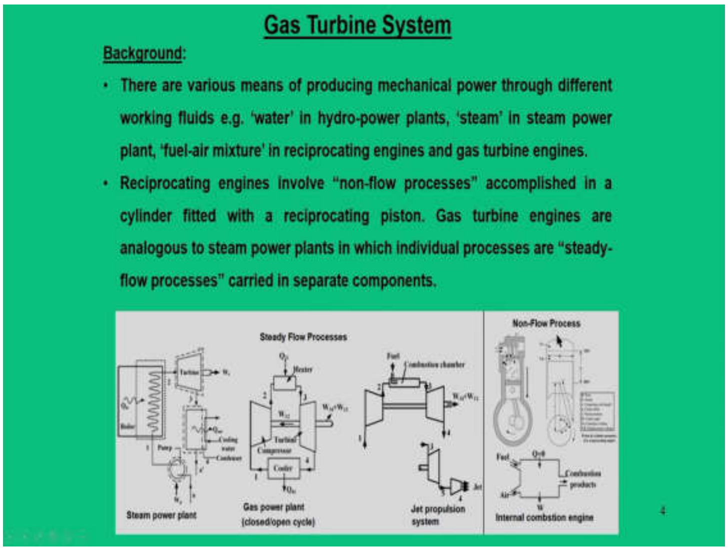


So, the concept of gas turbine systems comes into existence after the Second World War, when people think that the aircrafts propulsion systems can be modified, so that we can generate the power. But originally their entire idea was to generate thrust in a gas turbine engine components.

So, many books refer this as a aero derivatives. That means, initially the concept came from the gas turbine engines that are used for thrust generation in the aircraft, and those concepts are later on utilized to generate power in the ground based systems. So, those are called as gas turbine systems.

But previously before the gas turbine systems there are many other methods that were in existence for power generations. For example, the mechanical power was produced by using working fluid that is water in hydropower plants, steam in steam power plants, fuel air mixture in reciprocating engines.

Now, when you put the reciprocating engines and gas turbine systems, thermodynamically they qualify as a steady flow processes. All power generating systems they qualify as a steady flow processes involving different components.

Such as in a steam power plant, we have boiler, we have pump, we have a condenser, we have turbine, and all these things entire components constitute a thermodynamic cycle. But, however, each component has its own efficiency and each components are organized in a fashion that it takes input from one ends and its output goes to other components.

So, logically they are arranged in a particular fashion to have net effect to produce power output. And in fact, even same concept happens in the gas turbine power plant here. But instead of we will talk about what are the different components of gas turbine systems, but very bottom philosophy is that they come under the category of steady flow processes. And the analysis of these processes can be done through component analysis as well as the global analysis.

So, in the component analysis for example, in steam power plant the component analysis could be only concentrated for boiler or it could be concentrated for turbine or it could be concentrated for condenser or pump. But similarly in a gas turbine system, we are dealing with the compressor, or a heat exchanger, or a turbine system. So, that way we call this as a steady flow processes. And all these components runs steadily and continuously.

So, they are categorized thermodynamically steady processes. But in contrast, when you look at IC engines what we discussed in the last module; there, some fuel comes in and air comes in. So, fuel layer mixture gives necessary energy to the system and as long as the gas is within the cylinder, there is no output.

So, in that process, in one particular cycle, the entire system we can view is as a piston cylinder system. There is no non-flow processes as long as the gas comes and goes out.

So, gas turbine system or power generation system are called as steady flow processes and these are non-flow processes.

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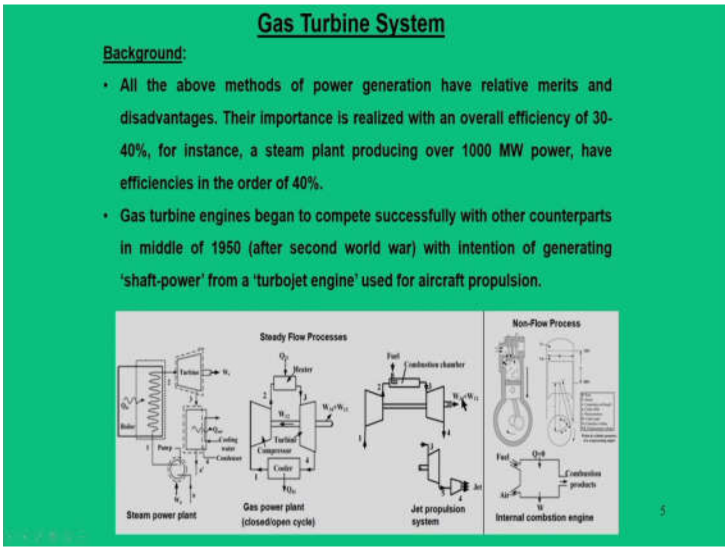


The other important aspects of power generation system is that whatever method whether a steam power plant or IC engine, but the maximum efficiency that is realized is about 40 percent. So, this has been proven thermodynamically that we cannot go beyond 40 percent efficiency.

So, a steam power plant for a for instance producing a power of 1000 MW has efficiency of about 40 percent. So, this was the essentially background when the power was generated before the Second World War. So, but after the Second World War, the concept of aircraft propulsion used in a turbo jet engine, this turbojet engine was initially used to generate thrust in the aircraft.

People thought of using instead of thrust, we want to get the shaft power. That means you have to couple it with a turbine system, so that instead of thrust which was supposed to be in aircraft jet propulsion system, we used to get power output. So, here it is a jet or thrust, here it is a work output or power. So, that was the essential idea.

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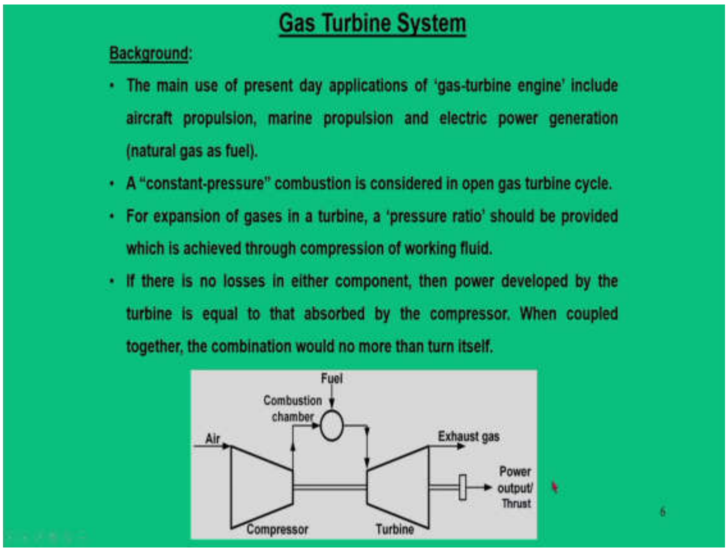


In fact, that was a huge success, and after that it finds tremendous applications. Apart from aircraft propulsion it also finds the marine applications, electrical power generations as well. But here also, we use the similar concept what we use in the IC engines. In IC engine we use air plus fuel, but in a jet propulsion system or aircraft population system, the fuel was typically aviation fuels or high grade kerosene, but here this gas turbine system, the fuel could be natural gas, it could be a conventional diesel, like what you do in a marine propulsion. So, that variety or variation is possible in a gas turbine engine systems.

Now, apart from that, if you look at a gas turbine system typically what happens? It consists of two major components that is compressor and turbine, and they are coupled together, and side by side we have a combustion chamber where fuel is input. So, basically, if you cut this particular part combustion chamber from the compressor and turbine then the gas turbine system would operate.

So, what you do is that, here compressed air is used and it is fed to turbine, when it expands in the turbine we get power output. However, we also require the power output for the compressors. So, in an ideal scenario, the turbine would develop a power that will run the compressors. That is the very basic or limiting stage to have a successful operation of a gas turbine engine. But that does not solve our purpose. We require more power.

To have more power, what you have to do? You have to use the extra power from the fuel. So, the total power that comes out from the turbine, some power getting utilized to run the compressor and rest of the power you can take it as a shaft power, that is for our electric power. So, this is the basic philosophy of a gas turbine operations.

And in fact, thermodynamically this heat addition process through a fuel is a constant pressure combustion. And for expansion of the gases in the turbine, a pressure ratio is provided through the compression of the working fluid, and typically our working fluid is always air.

If there is no loss in either component, the power developed by the turbine is exactly equal to the power absorbed by the compressors. So, when they coupled together, the combination would be no more than turn itself. That means, simply turbine will drive the compressors. But here there is no output. To get higher output, we require fuel.

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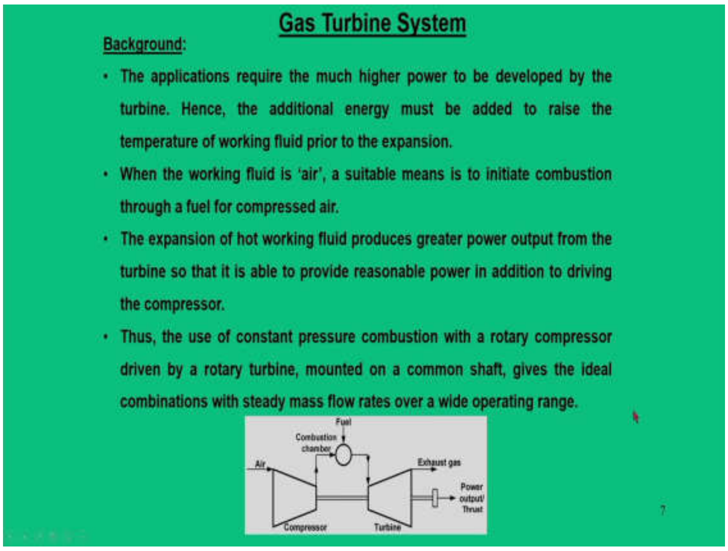


So, that is what we need now. The application requires higher power to be developed by the turbine. So, hence, additional energy must be added to raise the temperature of the working fluid prior to the expansion. Now, to do that, we require fuel. So, since the working fluid is air. So, using the concept of IC engine, to initiate the combustion, we require a constant pressure mode combustion as used in a CI engine.

Now, once you have this, then expansion of this hot working fluid that goes from the combustion chamber to the turbine expands and gives a reasonable power to the compressor side by side it gives extra power output. And thus, the use of a constant pressure combustion with a rotary compressor driven by the rotary turbine mounted on a common shaft gives the ideal combination of steady mass flow rate over wide operating range.

So, this is the complete statement that says that how a gas turbine engine operates. A constant pressure combustion with a rotary compressor driven by the rotary turbine, mounted on a common shaft gives the ideal combination for a steady flow operations over wide range of gas turbine applications.

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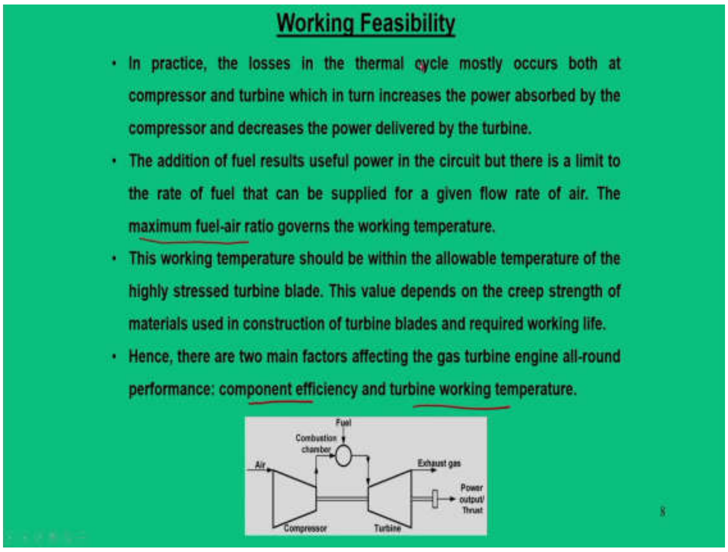


Now, let us talk something about working feasibility. That means, what are the limiting situations that a gas turbine system can work. There are two main concerns here is that, when we are giving the energy from the fuel, that means, the compressed air from the compressor goes to the combustion chamber, so fuel is added. Then, that fuel air mixer goes into the turbine.

So, here the turbine inlet temperature, when the fuel air mixture enters and expands, is typically very high. In fact, at different location of the turbine, we will have very high temperatures. And since, it is a continuous operations, high temperature material requirement becomes a necessity, because the thermal endurance that material is going to sustain over a continuous operation as well as the thermal fatigue becomes important concern.

And typically, this temperature could be as high about 1500 K. So, it is a continuous operation and gives thermal fatigue. So, that means, the material that are going to use in the turbines they should be able to sustain that thermal endurance.

And in fact, that is one limiting case that decides the working life of the turbine blades. That means, this fixes the upper limiting case of operation. That means, if your material is available for 2000 K and then we can go for that similar turbine materials.

And other limiting case is that how much compression we can achieve through a compressor. In a realistic says, although it is very easy to say you can achieve a pressure ratio of 30, 40, 50, 100 or so, but handling those high-pressure ratio becomes a critical factor.

So, at the same time when you say the components turbine or compressor as far as we talk about pressure and temperature, all these components should run at its best possible efficiency. So, that is what we call as a component efficiency.

And in a gas turbine system the compressor should operate at 85 to 90 percent efficiently, and turbines should operate of course in similar range, then only it becomes a viable options for power regenerations. So, this is what we call as a working feasibility.

So, main important factor that could be component efficiency, the turbine working temperatures, and maximum air fuel ratio. So, all these three things becomes a deciding factor for working feasibility of a gas turbine engines.

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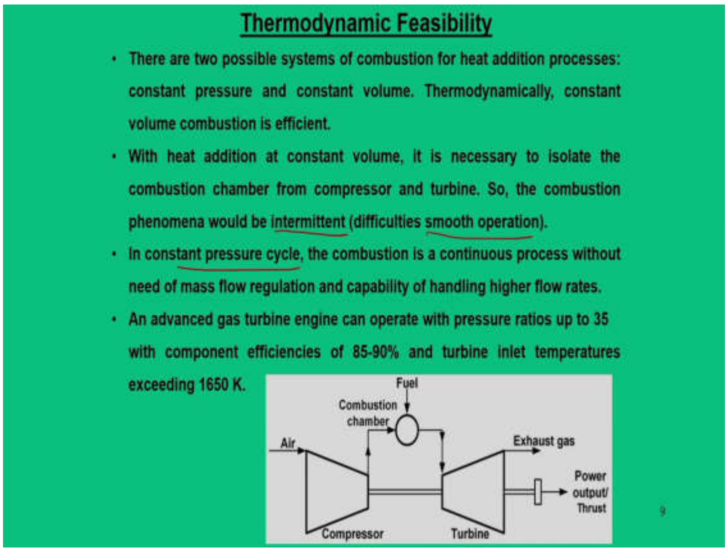


Then, we will move to thermodynamic feasibility. Why we look for the thermodynamic feasibility, that if you look at this thermal circuit, we have a compressor turbine and we have a combustion chamber where heat is added through fuel.

Now, we have seen from IC engines, the heat addition from the fuel can be done through two different modes, one is in SI engine we say it is a constant volume combustion, in CI engine we call this as a constant pressure combustion.

And ideally, both means can be possible for gas turbine engines, but in reality, only constant pressure mode has a physical advantage or many advantage. First thing, that when you go for the constant volume combustions, combustion of the fuel has to take in a constant volume that means, heat has to be generated from a separate entity and that has to be transferred again back to the air. So, this becomes a intermittent options and it will not give you a smooth operations.

And it is very difficult to integrate the air that goes out of the compressor and heat that is coming from a combustor which operates through constant volume, synchronization of both these things is a very difficult task. So, it leads to difficulties in smooth operations.

So, ideally speaking the constant pressure cycle is a better options because it gives a continuous process of combustions, it gives the advantage of high mass flow regulations and handling higher flow rate. So, because of this reason, the constant pressure combustion is a reality for a gas turbine power generation system.

So a gas turbine engines can operate with pressure ratio up to 35, component efficiency is about 85 to 90 percent, and turbine inlet temperatures could be about 1650K. So, this gives some realistic number or maybe design parameters, only then the importance of power generation through gas turbine engines can be realized.

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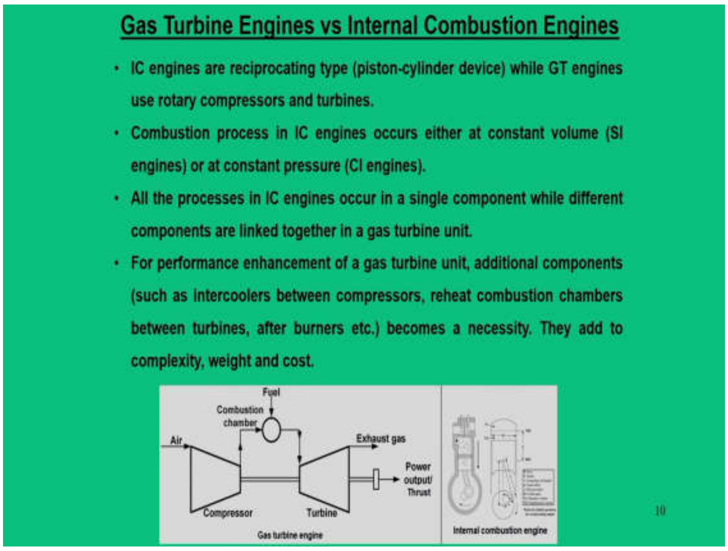


Then let us move to some basic differences between a gas turbine engine and internal engine systems. So, this is just a repetition just what I have told or explained so far. So, IC engines are reciprocating type, so they are piston cylinder device while gas turbine engines involved rotary compressor and turbines.

Combustion in IC engine occurs either at a constant volume based combustion that is in SI engines or constant pressure based combustion in CI engine. Whereas, in gas turbine it is only realized in constant pressure mode.

All the processes of IC engine occur in a single component while different components are linked together in a gas turbine unit. So, whatever things that happens in IC engine that is enclosed, where fuel charge continuously compressed and expanded within this piston cylinder.

But whereas, different operations are performed in a gas turbine engine because compressor has to compress, the combustion chamber has to add heat through fuel, in turbine the gas has to expand. So, each component has its own role. And they are linked together to give a consolidated unit that is called gas turbine unit.

The performance enhancement of gas turbine unit also involves additional components. So, additional components are involved in a gas turbine unit for performance enhancement. We will see them in the subsequent class. They are known as intercoolers which is used between the compressors, that is mainly used when we are going for high compression, compression may be 10 or 20, then single compressor will not solve a purpose.

So, we need a multiple compressor means 2 or 3 compressors. But when you use 2 or 3 compressors together, in a synchronized manner, then there must be an intercooler because without which you will not get a best performance efficiency. So, that is the reason that we need to have intercooler when you have multiple compressors involved.

Similarly, when you go for high power, we want to go for very high expansion in a very wide range of pressure, then we have to use reheat options. So, we need to have reheat combustion chambers between turbines and after burners. So, they becomes a necessity. So, when you add this in the name of performance enhancement, they add to complexity, weight, and cost. And all these things will be only realized when they make a viable option in a commercial mode of power generation.

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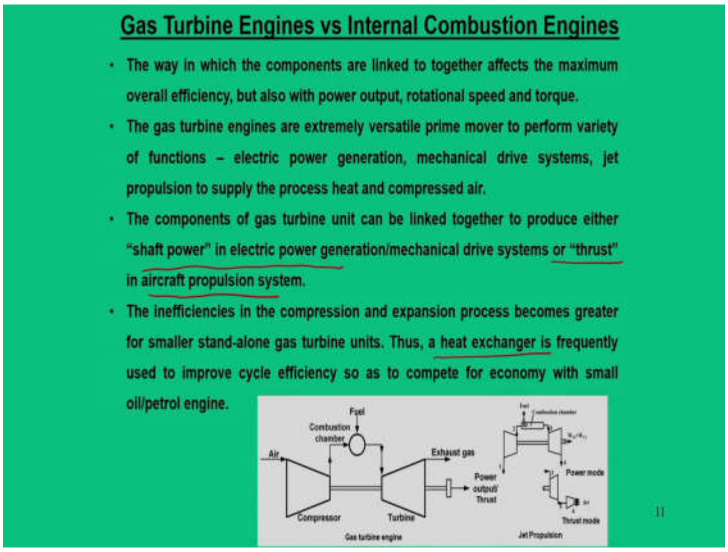


Some other differences are the way the components are linked together in IC engines. Normally, they deal with the maximum efficiency, power output, rotational speed, and torque. In fact, in a gas turbine unit, they have a versatile prime mover to perform variety functions that is electric power generation, mechanical drive systems, jet propulsion supply system to process the heat and the compressed air.

The components of a gas turbine units are linked together to produce either shaft power for electric power generation or you call this as a shaft power. Other way we look at this is thrust which is mainly used in aircraft propulsion system. And in fact, this particular module we will give emphasize how these two things are achieved thermodynamically in a gas turbine systems.

The inefficiencies in the compression and expansion process becomes a higher for a standalone gas turbine unit. And many a times what happens, we go for a heat exchanger in a gas turbine unit because this heat exchanger gives us the fuel efficiency. And when you say talk about fuel efficiency, it will be at par with the conventional IC engines.

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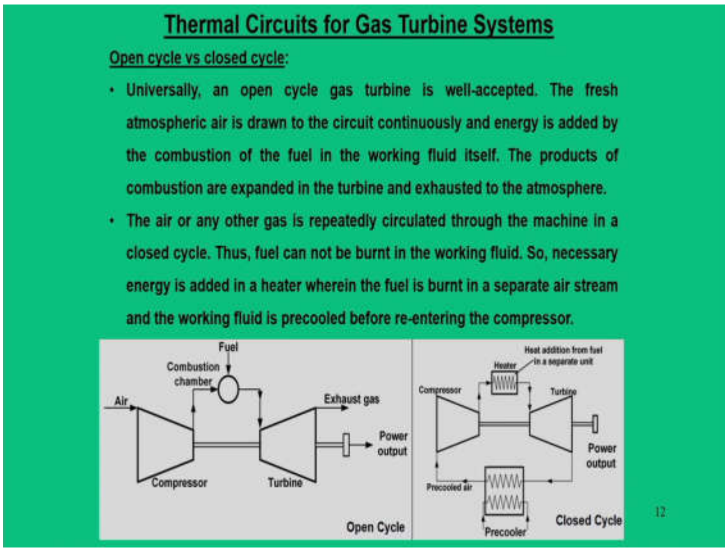


So, having said very broad spectrum or generic differences between an IC engine and gas turbine, let us move to different thermal circuits that are conventionally used that we should know. So, first thing is that open cycle and close cycle. So, the thermal circuits for open cycle and closed cycles are different. So, ideally, as the name implies, that open cycle means in one end the working fluid comes into the systems and in other end the exhaust gas goes out of the systems.

So, here in a open cycle system air is drawn simply from atmosphere and it is compressed in a compressor, then it is fed to a combustion chamber, that means, compressed air, where fuel is added. So, both fuel and air mixer comes out from the combustion chamber and they enter into the turbine, and finally, after expansion exhaust gas goes out and we get the power output from the turbine. So, again the next cycle happens, fresh air comes again from the compressors.

So, every time we fresh air always enters into the circuit. So, we call this as a open cycle. And in fact, this open cycle are more visible or more useful as far as a gas turbine system is used because air is available in plenty, so normally we go for the open cycle mode. And similar thing that we use in a steam power plant where the fresh water is taken into the system.

But in some situations we require closed cycle, normally this closed cycle are preferred if the working fluids become scarcity and they need to be circulated continuously in the circuit.

So, in that case, this they operate in a closed cycle mode where the compressor and turbine and there is a heater which takes heat output from the fuel from a separate unit, and there is also a pre-cooler because the exhaust from the turbine should give out the heat to some other fluid.

So, this means same working fluid continuously flows in the circuit. So, this we call as a closed circuit operation.

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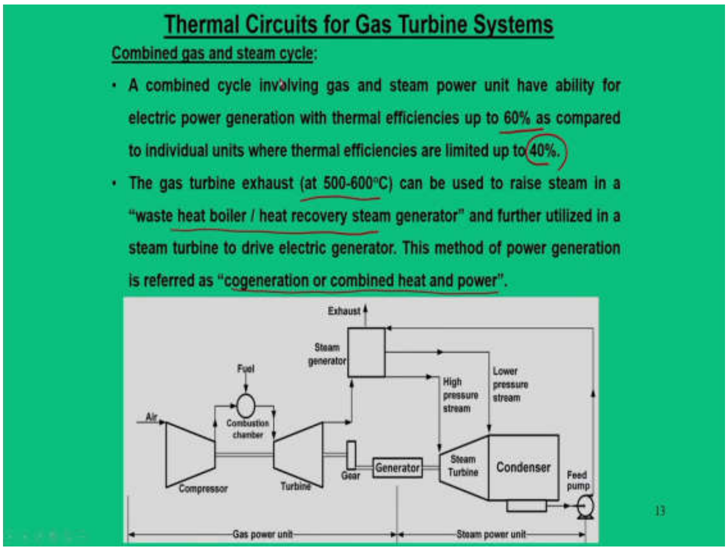


The other mode that we call as a combined steam and gas cycle. Ideally, speaking that the gas turbine systems in a large power production unit, it becomes a feasible options if at all they are integrated with a steam power system.

And such things we call this as a co-generation mode of power generation. That means, combined heat and power through steam and gas. Because it is very difficult to generate megawatt power range specifically only using a gas turbine system because you need a huge compressor and huge turbines. And that too we have to play with very wide range of pressure ratio.

So, instead of that people think of combining a steam system with a gas power unit. So, they have a common generator unit that are common power producing unit. In one side, steam power unit operates, other side gas power unit is operated.

And both steam and gas power units are combined together. How they are linked together? Because power production from both steam turbines and gas turbines goes to the common entity that is electric generator.

Second thing, the exhaust from the gas turbine has typically very high temperature, that energy is utilized to produce steam. So, we call it a steam generator. So, basically, this energy is used to generate the steam. And except that the gas turbine units and steam turbine units, they operate in a independent manner. And why it is very significant way? Because, the exhaust from the gas turbine is typically at a temperature 500 to 600°C; so, if you do that, it has been found that the combined role of steam and gas turbine unit as ideal way of improving the efficiency that is as high as 60 percent. But had this gas turbine unit and steam turbine units, operate independently, their independent efficiency would have been 40 percent, whereas, when we combine them their thermal efficiency could be as high as 60 percent.

And in fact, in addition to that, other infrastructure gets reduced and other requirement like for steam power plant, the requirement of fuel in terms of coal gets reduced. And in fact, it is pollution free if you take the heat from the gas turbine exhaust systems. So, in such case instead of conventional boiler, we can use a waste heat boiler or heat recovery steam generator. So, this kind of words that are used in a combined mode of power generation in a combined gas and steam cycle.

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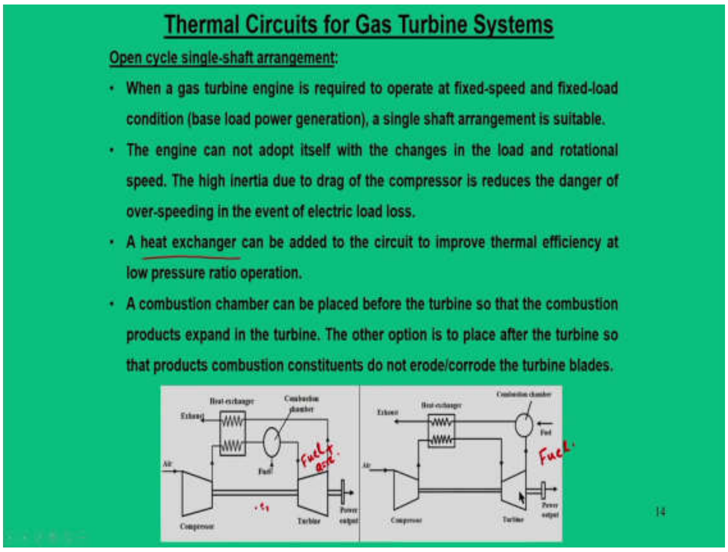


The next arrangement could be open cycle single shaft arrangement. First thing we have emphasized that out of open cycle and closed cycle, open cycle is a best option. So, you will have to go for the open cycle arrangement. And single shaft, so the single shaft means the entire idea is that we have a compressor, turbine and shaft power. There are 3 rotating units and they are put in a common shaft. So, its a single shaft.

So, power generation shaft and the compressor and turbine has to be integrated. So, there are two important aspects, the turbine and compressor should be integrated through a common shaft. At the same time power also comes out from another shaft. And if it is common to all of them, then we call as a single shaft.

Now, why we require single shaft? Because in many situations we require to operate the system at a fixed speed or fixed load power generation or fixed load conditions, so the single shaft becomes a suitable. Now, if we have a multiple shaft system then synchronization of all these things will be different.

So, once you set that synchronization things for all this in a common shaft, then it becomes easy to run that turbine unit. So, when they are in the single shaft, the high inertia drag due to the compressor reduces the danger of over speeding in the event of electric load loss.

Now, apart from this when you want to have a single shaft, there is a requirement of heat exchanger. We will talk about why it is a must when you deal with the thermal analysis later. So, this circuit must be added to improve the thermal efficiency.

And also, another issue could be a location of this combustion chamber. Many a times what happens, when the fuel is added into the combustion chamber, the entire fuel air mass expands in the turbine. So, there the issue would be that the turbine blades are always get exposed to the combustion products in this continuous operations.

But the other way of looking at that, instead of expanding that gas in the turbine we only tap their heat. So, what happens? In that case, what the circuit could be? There will be a separate combustion chamber where fuel is added and when that heat get tap through an heat exchanger, that means, when the compressed air from the compressor enters to the heat exchanger, heat from this heat exchanger gets tapped by the air and high pressure and high temperature air enters.

That means, only air expands in the turbine whereas, in another mode air and fuel mixture expands in the turbine. So, this is the very basic differences. So, basic drawback is when the fuel and air expands in the turbine, they erode the turbine blades. There is high chances of erosion of turbine blades and that is not true when only air expands in the turbine.

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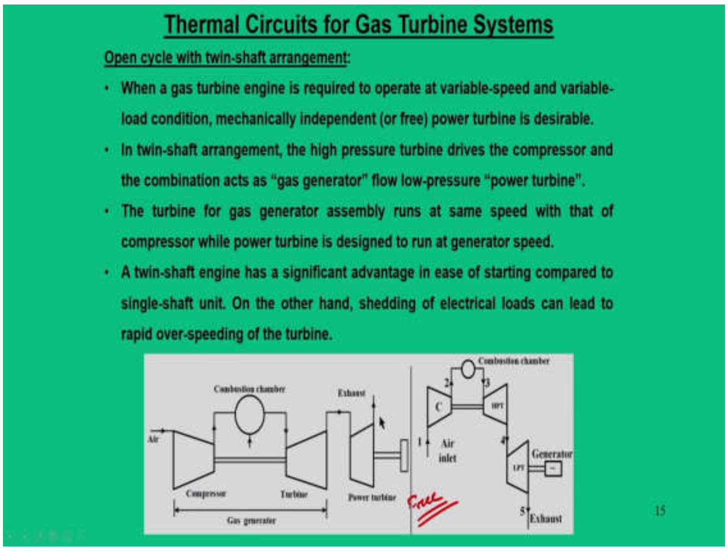

Then, there is also some situation when we require twin shaft arrangement. There are some situations, where it is required to operate variable speed and variable load conditions. That means, gas turbine unit should be operated in a variable load and variable speed conditions, because your requirement is such.

So, that case we can divide it to into two shaft. One shaft, that means, compressor and turbine, they are joined together, and they are synchronized. Other is power turbine or normally we call this as a free turbine. So, that means, this power turbine is a free turbine, it can produce power freely. It has nothing to do with the integrated shaft requirement for the compressor and turbine assembly.

So, in such cases, we may have options like the power required to drive the compressor is provided by the turbine. And after expansion, it again goes to another turbine where necessary power is produced, and this power turbine is actually coupled to the shaft and both the shafts are different. So, in that way we can play with the variable speed and variable load conditions.

So, there are certain advantage like the turbine and gas end runs at the same speed, whereas, power turbine can be designed to run at generator speed. So, power turbine can run at generator speed, and this can run at a separate speed and compression and turbine can run in synchronization mode.

A twin shaft turbine has a significant advantage that is easy of starting compared to the single shaft unit. On the other hand, shedding of electrical loads can lead to rapid over speeding of the turbines. See, if at all there is a rapid speeding only power turbine would be affected.

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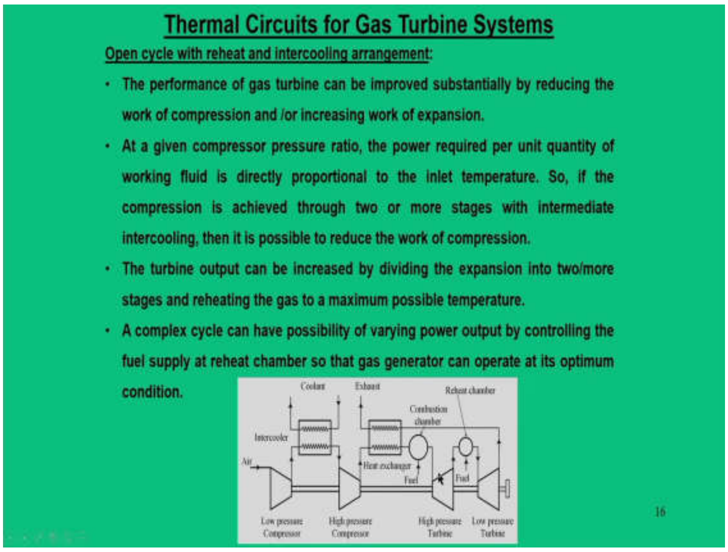


Another thermal circuit arrangement could be open cycle mode, reheat and intercooling arrangement. So, thermodynamically, we have seen that you have to deal with the steam power plant. We use the concept of reheat regeneration etcetera.

So, similar concept are used here that is reheat and intercooling concept. So, reheating, means, thermodynamically it is proven that if you are going for a expansion from wide pressure range, so instead of going in a single mode, you can go for multiple stages, then your efficiency will go up.

So, also power output will be higher. So, stage efficiency or stage power is more efficient than a single expansion. So, that is the concept that is used here, that we use multiple turbines and multiple compressors. The concept of reheat is used. So, single combustion chamber we will have multiple combustion chamber, and one in one case we call it as a primary combustion chamber, other case we call as a reheat combustion chamber.

After the fuel air mixture expands in the first turbine, they are allowed to expand in the next turbine, but before they are allowed, further heat is added. That means, instead of adding heat at a single unit, this heat addition takes place at multiple places and fuel air mixture has expanded in multiple turbines. And this concept we call this as a reheat concept.

Other way of looking in the compressor side, instead of going from a very high-pressure ratio compressions, we use multiple compressors. So, the requirement of multiple-compressor always leads to a fact that intercooler is a must.

From the first stage compressor the pressure goes up, temperature also goes up. But we have to bring this temperature back to the atmospheric or ambient conditions. So, this intercooler does not do anything on the pressure, rather it brings down the temperature back to the normal conditions.

So, again this high-pressure but low temperature gas goes into the second compressors. So, we call this as a high-pressure compressors. So, in this way, the compressors are integrated through intercooling arrangement. Intercooling requires less compression power, reheating gives higher net-work output. See in both the cases, your efficiency will go high.

But one important thing to be noted is that the justification of intercooling and reheating is possible when we are looking for expansion or compression over wide range of pressures. Pressure ratio could be more than 35-40, above that range the justification of reheating and intercooling is felt.

The performance of a gas turbine can be improved substantially by reducing the work of compression or increasing the work of expansion. So, at a given compression pressure the required per unit quantity of working fluid is directly proportional to the inlet temperature. So, if the compression is achieved through two or more stages with intermediate intercooling, then it is possible to reduce the work of compression.

Similarly, the turbine output can be increased by dividing the expansion into two or more stages, so reheating the gas to a maximum possible temperatures. The complex cycle can have a possibility of varying power output by controlling the fuel supply at the reheat chamber, so that gas generator can operate at optimum conditions. However, the reheater and intercooling cooling components gives complexity to the system.

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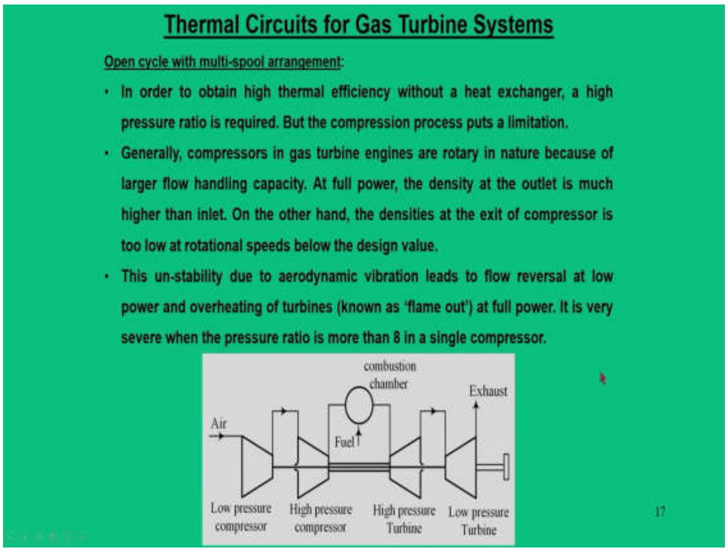


There is another concept called as a multi-spool arrangement. Now, in some situation what you require is that we do not want other ancillary components like intercooler, reheater or something like that, but still we require high compression ratio. So, that situation we call this as a multi-spool arrangement. That means, same high-pressure compressor and turbine are there, but there is a single combustion chamber.

But what you do is that instead of going for a complex thermal circuit, if you want to go for a simple thermal circuit, then you decouple the low-pressure compressor and low-pressure turbine and try to synchronize and they are linked in one shaft.

And high-pressure turbine and high-pressure compressor are synchronized at their speed and they call this as a multi-spool. That means, high-pressure turbine drives high-pressure compressor, low-pressure turbine drives low-pressure compressors. So, this concept we call as a multi-spool arrangement.

So, in order to obtain high thermal efficiency without a heat exchanger, high-pressure is required then compression process puts a limitation. So, generally, the compressor in the gas turbines are rotary in nature because they have large have fuel handling capacity, and in those cases at full power the density of outlet is very much higher than the inlet.

On the other hand, the densities of compressor is too low at rotational speeds below the design value. So, this limitation put a unstable situations because of handling different densities. And this becomes unstable due to aerodynamic vibrations because all these are the rotary nature. And in some cases, it leads to overheating of turbines.

So, such cases we go for a multi-spool arrangement where the low-pressure turbine and compressor are integrated separately, and high-pressure compression and high-pressure turbines are integrated separately.

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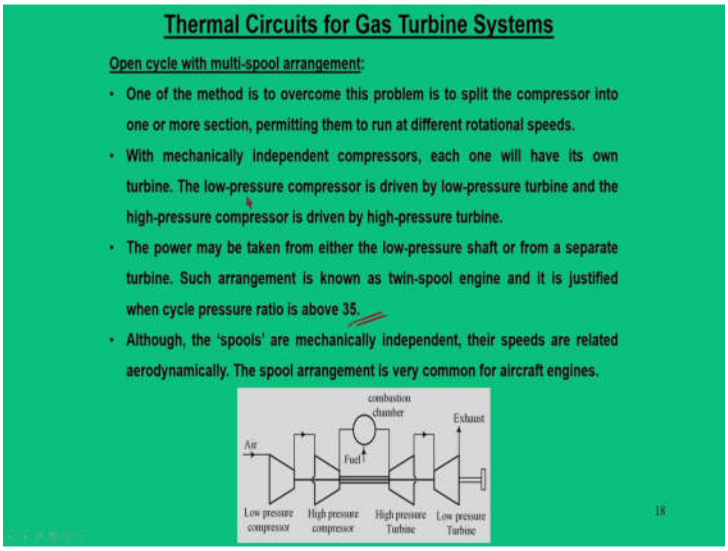


And when you have twin spool gas turbine engines, its role is felt when the pressure ratio is above 35. Otherwise, you do not go for the multi-spool arrangements.

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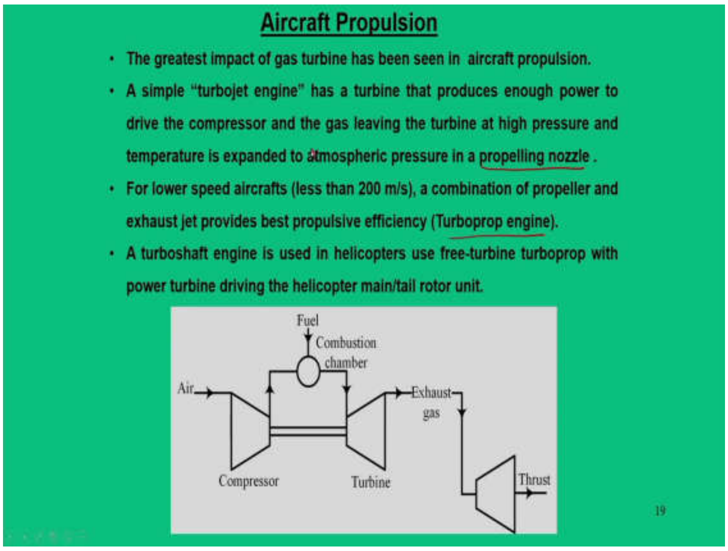

Now, next part is to give some introduction about aircraft propulsion. As I mentioned, here when you only deal with aircraft propulsion, there we simply do not think about power developed from the turbine. What this turbine does? It does two things one is it drives the compressor, that means, it gives a reasonable or sufficient power to run the compressor.

Other is the exhaust gas is fed to a nozzle, and that nozzle gives the thrust. So, there is no concept of shaft, there is only one shaft, turbine drives the compressor, but the exhaust gas expands through a nozzle that is used to give the thrust. And this is the main concept of a simple turbojet engines.

So, the greatest impact of gas turbine engine has been seen in the aircraft propulsion since it has come into existence from the 19th century and where the concept of turbojet engine or aircraft comes into picture. And there, the entire idea is that to generate the thrust using a propelling nozzle, where this propelling nozzle and this nozzle was not a part of gas turbine units when you generate power, but nozzle is a one of the important component, when you in an aircraft propulsion systems.

So, for low-speed aircrafts that is less than 200 m/s, the combination of propeller and exhaust jet provides best propulsive efficiency that is what you call as a turboprop engine. Also, we have another engine what we call as a turboshaft engine that are mainly used in the helicopters, they use free turboprops with power unit driving the helicopter rotor unit.

So, there is a turboshaft engine, turboprop engines, and of course, there is a turbojet engines. And there is another latest variant what we call as a turbofan engines. So, these are the different variants of aircraft propulsion unit in a gas turbine systems. But the very basic bottom line is that they all of them are used for thrust generations.

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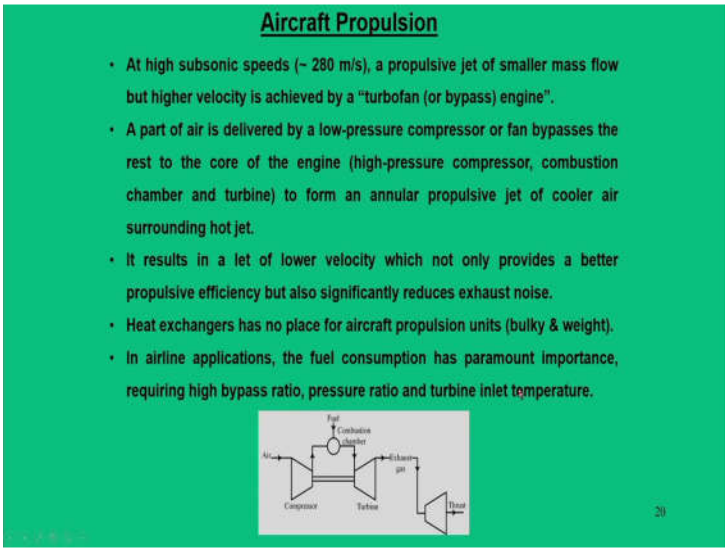


So, this is what I have explained here. So, at high altitude, that means, we require something about 200 m/s where all commercial aircrafts fly that is close to Mach number of may be 0.8. So, in that situation, we use an engine what we call as a turbofan engine and that is the most efficient engine so far.

So, a part of air is delivered by low-pressure compressor or a fan that bypasses rest of the core engine. That means some component goes to this mode, other one goes as a bypass. So, we call as a turbofan engine. So, these are the some of the summary. But another most important thing that heat exchanger has no place in aircraft propulsion system because it makes the system as a bulky. So, only we have a simple combustion chamber.

And another important aspect is that in airline application the fuel consumption is a paramount importance that requires high bypass ratio, pressure ratio, and turbine inlet temperatures. So, these are some critical feature. And we will touch upon some of the important aspects when you deal with the actual thermodynamic analysis.

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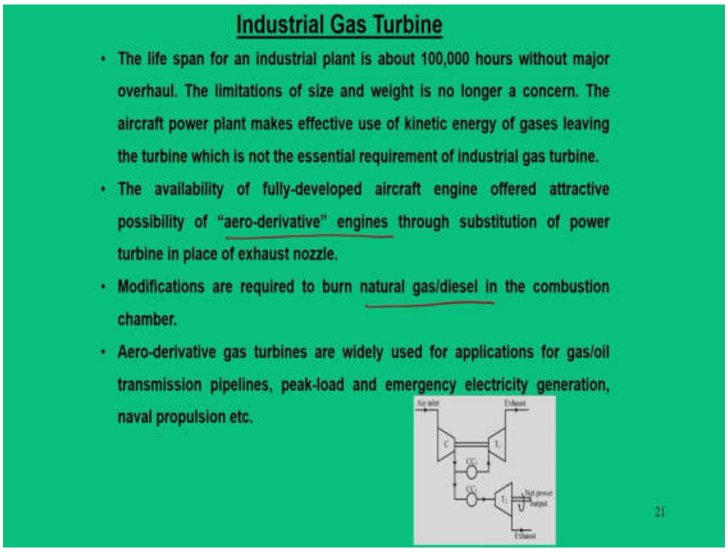


And the last segment I just give you some introduction about industrial gas turbine. So, when you are thinking this gas turbine to run in a industrial mode, that means, it has to run continuously 24-7, 365 days, you require a very rigorous life span. So, the lifespan is failed when we have 1,00,000 hours without major overhaul, that is the requirement that gas turbine engines in industrial mode has an efficient way of operations; but no limitations in the size and weight. So the aircraft power plant makes an efficient use of kinetic energy of the gas leaving the turbine which is not essential requirement for the industrial gas turbine unit. For industrial gas turbine units, first thing is that they should not have major overhaul. Second thing, they should have continuous operation throughout year. Third thing is that, their power production capacity in the megawatt range.

But, however, the concept of gas turbine come into existence only when it was realized that aircraft propulsion concepts can be utilized for power generation mode. So, that is the reason, they are called as aero derivative engines. The industrial gas turbines or gas turbine units when they use for power production, they are aero derivative engines.

But, when you say aero engines fuels are different, they use kerosene, aviation fuels and any other high-grade quality of fuel. But when they operate in a gas turbine mode for power generation we can think of using natural gas, diesel, or any other biogas or any other alternative fuels.

So, finally, with a last remark I say that aero derivative gas turbines are widely used for application of gas, oil power transmission pipelines, peak-load, and emergency heat generation, and mainly this gas turbine for power generation is used in the marine or naval applications.

So, with this, I conclude this lecture for today. So, in the subsequent lectures, we will discuss about the Thermodynamic Analysis of Gas Turbine Systems.

Thank you for your attention.