IC Engines and Gas Turbines
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Lecture – 41
Aircraft Engines

So, welcome the class. In the last class, what we have seen was about the performance parameters which are new for the case, if we are not having Gas Turbine as a power plant for electricity generation, but if it would be used for preparation or transportation applications then obvious extension of that was the aircraft engines. So, today's class we will deal with Aircraft Engines.

In the last class if you remember we have talked about the fact that there is a propulsive efficiency and then propulsive efficiency was the thrust based power divided by the change in kinetic energy and it turned out that it is equal to 2 upon 1 plus c g m upon c and then we defined that ok. So, there are engines which have higher propulsive efficiency, but they have to go with lower altitude and there are engines which are having lower propulsive efficiency, but they with high higher altitude.

That time we defined that there are engines like turbojet, turbo prop, turbofan, but then we are seen the aircraft engine in broader aspect in this in class.

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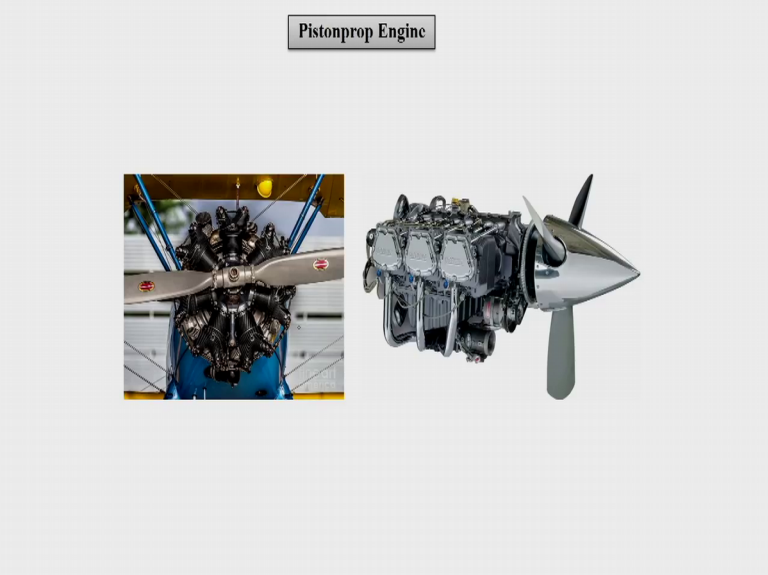

And then among that we will start with first as the turboprop engine. So, first is Pistonprop Engine. So, pistonprop engine is a basically not part of exactly this course where this part of the course basically where we are studying the gas turbine cycle, but; obviously, this is part of the present course where we are studying IC engine and gas turbines.

So, here the internal combustion engines which are run using the piston arrangement and cylinder piston and cylinder arrangement, those engines are used to drive the propeller. So, basically as the aircraft engine requirement says that we need different entities for the thrust and different entity for the lift. So, an aircraft to cruise we need 2 different entities are unlike birds. In case of birds they have winds which do 2 kind of things; one is they also get lifted and they also go forward, so, they also get propelled.

So, lift and propelled lift and other thrust both are obtained using the winds in case of birds, but in case of aircraft we need different arrangement. Conventional aircrafts, civil aircraft we have winds for the lived generation and we have the engine for the thrust generation. So, among that the engine if we are talking here is the internal combustion engine of cylinder and piston arrangement then such engines are called as pistonprop engines.

So, here as we see that there are multiple cylinders and all these multiple cylinders are connected with their pistons and those pistons with the connecting rods and then they are having all the connections to one shaft and that shaft has a 2 blade propeller has that we can see in this figure. In the right hand side figure what we can see that there is an engine which is coupled to a 3 shaft propeller or rather 3 blade propeller.

So, the engine which is basically our conventional piston cylinder engine which would be running upon its own fuel like petrol or diesel would be running and then it is driving the propeller. So, such aircrafts which use such engines are called as pistonprop engines and then pistonprop propelled in aircrafts. So, those aircrafts would normally have the propeller on their knows and in that propeller would be driven by these engines or it can be also for a small helicopter where the shaft of the propeller can be driven by the IC engine Internal Combustion engine of piston cylinder arrangement. So, this is pistonprop.

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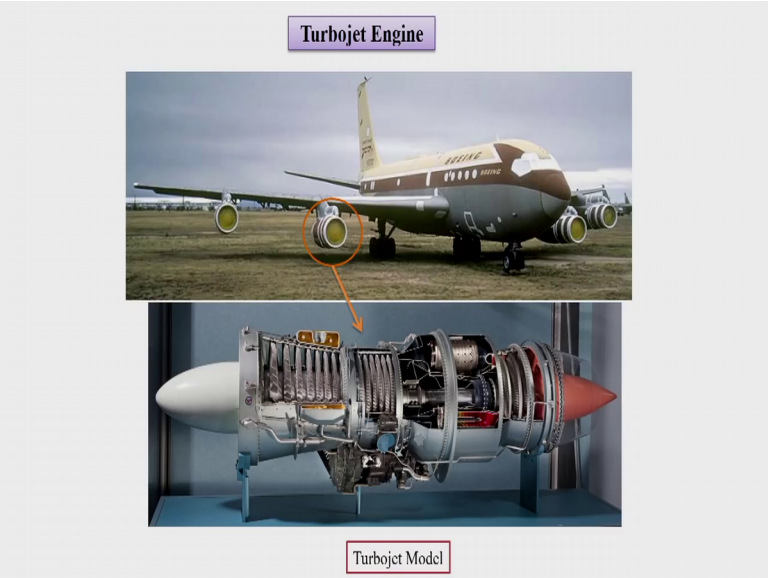

Then what we have is the next engine as Turbojet Engine. Purposely we are taking a lift, we are taking a jump and we are going directly to turbojet engine since it is simple to understand. In case of turbojet engines we have suppose we have a turbojet engine and in that engine we have 2 kinds of we have multiple components among those components we have compressor first then we have turbine then we have a basically combustion chamber and then we would have nozzle.

Basically in the case of turbojet engine these are our components compressor, turbine, we have combustion chamber and we have nozzle.

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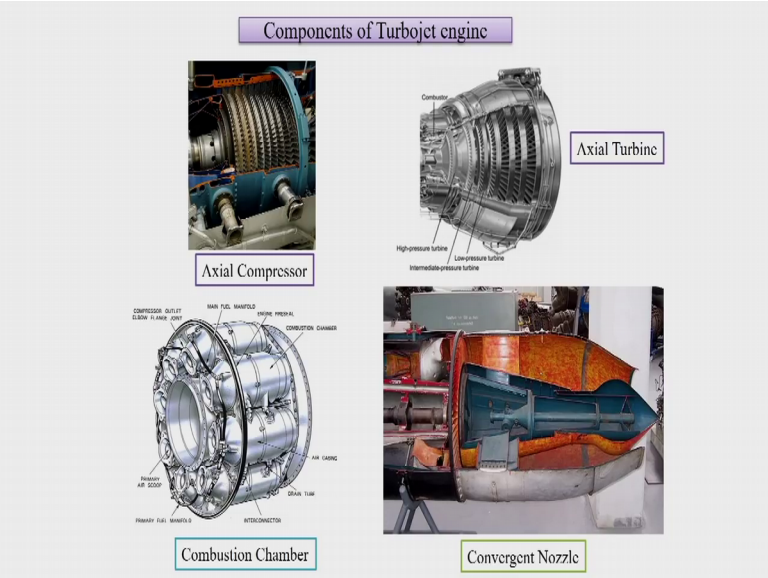

As what we have said earlier that Turbojet engine is the engine or aircraft engines which are turbo based engines. We do not need blue net there. So, what is our requirement over there is that we want that enthalpy to be remained in the nozzle inlet such that upon the enthalpy release upon the enthalpy decrement that energy can be converted into kinetic energy and that kinetic energy will be used to the propulsion. So, in that case we have a nozzle.

So, a conventional arrangement in a turbojet engine would initially be compressor then multiple stages of compressors then we will have combustion chamber, then we will have turbine and then we will have nozzle. So, multiple stages of compressor combustion chamber, multiple stages of turbine and nozzle and then this turbine would be running the compressor and then what we have seen was there are multi spool arrangements. So, there can be high pressure compressor and by high pressure turbine, low pressure run compressor run by low pressure turbine or what we can have a singles spool arrangement.

So, this is what we have seen in one of the early classes. Now basically the types of compressors which are required for a Turbojet engine is the axial compressor or centrifugal compressor. We can have this kind of compressors as suitable for the turbojet engine. As the name suggests for this engine here complete thrust is obtained from the jet. This power plant is same or similar to the power plant what we consider for

electricity generation since accept the nozzle most of the components are same then we have in the electricity based power plant, also we have compressor, we have combustion chamber and we have turbine.

And turbine drives to the compressor, but rest of the power which is w net is used for electricity generation and here rest of the power is given to the nozzle and then that nozzle runs and expands the gas which is present that is inlet which is high pressure high temperature gas and then expansion of that gas leads to the expansion of that gas leads to the thrust for.

So, axial compressor or centrifugal compressor can be used as components for the turbojet engine then we have axial turbine as one of the components, we can have then combustion chamber then these are can type of combustion chamber, they are multiple in number and then we have nozzle. So, here before the every component there can be also intake of the engine what we can see that intake is before the compressor.

So, what practically we will have is intake and then we will have compressor then we will have combustion chamber then we will have turbine and then we will have nozzle. Every component has its own job. Compressor job is to compressors objective is to compress the air to the desired pressure, but we know that we need power input to run a compressor. So, to reduce the job of a compressor we can actually take the help of the inlet momentum of the air and then that inlet momentum can be used to raise the pressure in the form of a diffuser and that diffuser section which is present before the compressor is called as intake.

So, intake would also compress the air and then that compressed air would go to turn compressor and then we would have combustion chamber where we will have fuel injected, fuel present for the combustion with high pressure higher temperature air. Upon combustion pressure and temperature pressure expected to be remain constant, but temperature would increase and then our nozzle would expected to increase the kinetic energy. So, as we see that here we are having nozzle; nozzle is an additional entity, it is only for propulsion, but there is one thing what especially written over here is a convergent nozzle.

So, nozzles can be of different types and then those types of nozzle depend upon what is the exit condition which we are going to create. So, convergent nozzle will have a

limitation that at the entry we are having very low velocity subsonic flow at the entry to the nozzle, but it has very high pressure and high temperature. Due to the pressure difference between intake and outlet inlet and outlet of the nozzle what we would have is an expansion and in that expansion pressure decreases, temperature also decreases and then velocity increases, but this increment in velocity increases the nock number in the axial direction of the nozzle.

So, the limit what we can get at the exit is Mach number one which is called as sonic. So, convergent nozzle would have sonic in outlet, but then if we want some other nozzle then that other nozzle would lead to the supersonic outlet where we would have convergent divergent nozzle, but then these are the types of nozzle what generally used for the turbojet engine is the convergent nozzle.

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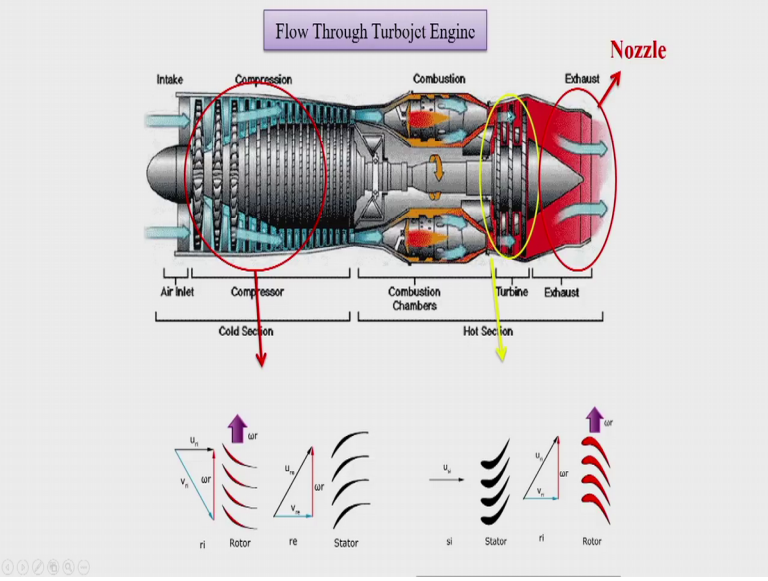

Then this is the flow through the different components of the Turbojet engine. So, as we have seen that first we are having air getting passed over the low pressure compressor then high pressure compressor and then we will have air which is going through the combustion chamber and then it will go to the high pressure turbine and low pressure turbine and then we have nozzle, so, this is the nozzle. So, then what we will be seeing in long run in the course next chapters that the components of aircraft engine where we are going to see how velocities going to change its direction and magnitude maybe in the compressor and maybe in the turbine. So, this is what depicted here in.

Since we know that in the compressor also there are 2 parts where one is called as a rotor and other is called as stator and in the turbine there are again 2 parts; one is called as stator and other is called as rotor. So, these are the parts clearly shown over here.

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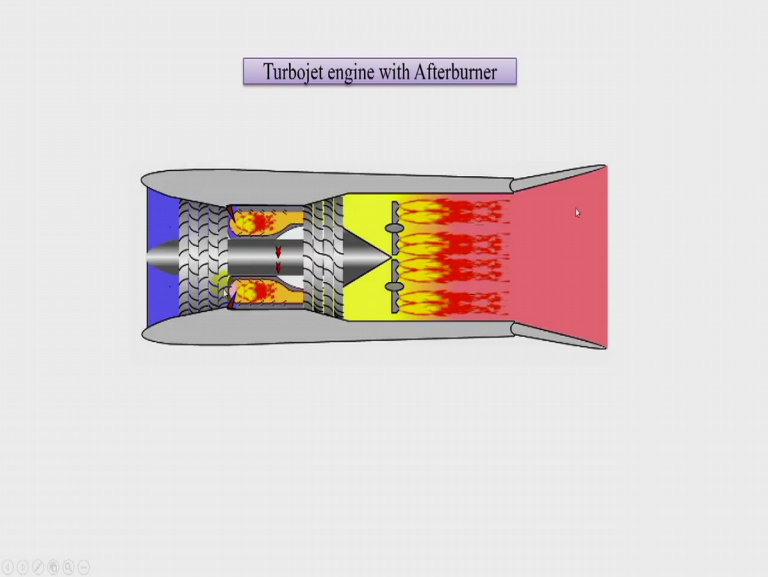

Then in case of turbojet engine there is one more entity, which is called as after burner once the flow passes from the compressor combustion chamber and turbine it is expected to expand, but there is some amount of oxygen which is unburnt here since most of the time this combustion whatever it would take place it would take place in the lean range. So, fuel is a lean less and then a oxidizer is more.

So, we have more oxygen present in the air. So, in order to burn that oxygen and also to get extra thrust some amount of fuel will be burnt in the nozzle and that would be used to the getting extra thrust from the engine. So, after burner is necessarily used to get extra thrust and obviously, since we are putting extra fuel and at the that fuel cost we are getting extra thrust. So, that here we need fuel also to burn in the case of after burner. So, this after burner as it is said that it is used for the getting extra thrust, but it uses fuel for that all aspect. So, this is the example of afterburner put in a turbojet engine.

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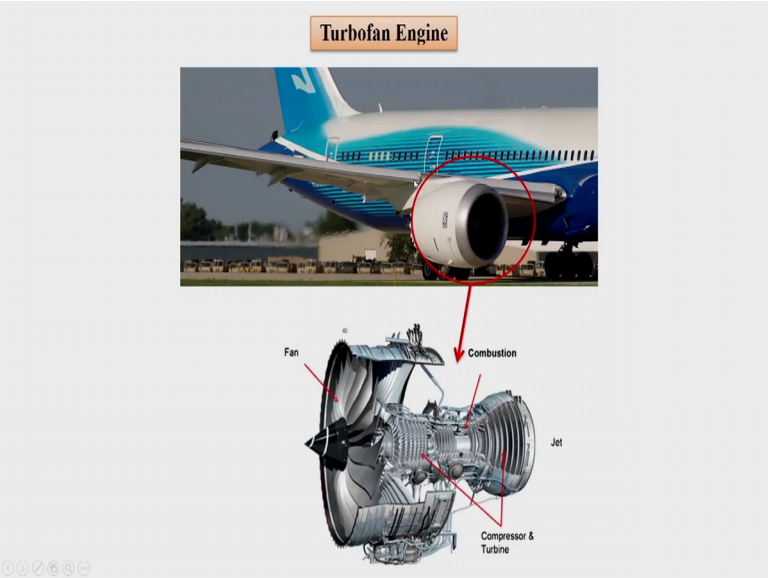

Say then now next engine is Turbofan Engine. Turbojet engine as it was suggested that whole thrust was obtained from the jet. So, j c j is very high and across that c j we are having extra thrust. So, now, we have an engine which is called as turbofan engine where not all thrust is obtained from the jet there is some thrust which is obtained from the other part of the engine where air is not combusted.

So, that part is called as fan. There fan as what we would remember in one of our classes we have said distinguish between fan, compressor, diffuser ok. So, fan is also an entity, it also a turbo machine which is used to compress, but it would compressed very small amount of pressure. So, this is a typical turbofan engine where addition to the components of the turbojet engine we have also fan.

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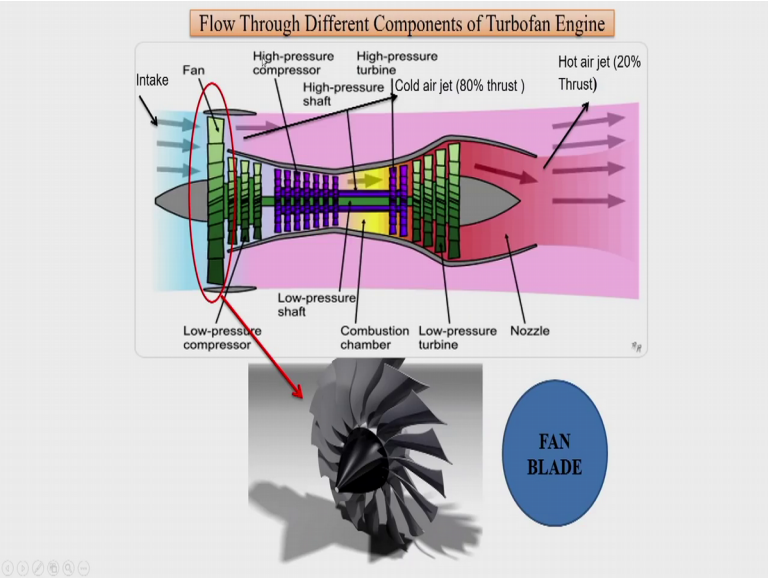

These are the components and flow through different components of a Turbojet in Turbofan engine. Additionally initially we will have a fan and that fan will compress the air. Upon compression some part of the air would go into the compressor, but some part would go externally outside and that will go through the nozzle and create some thrust which is called as cold thrust. But some part of the air which would go from the compressor would get compressed then it will be burnt in the combustion chamber, it would then pass through the turbine and then through the nozzle where it will be expanded and then that part which creates hot air, which creates the thrust is called as hot thrust.

So, this is typical fan which is at the entry to the turbofan engine. Then what would happen is we are having cold air and hot air based thrust or gas based thrust. So, here what would happen is the amount velocity object would reduce and then since velocity object is reduced lesser amount of thrust is generated from the hot gas and small amount of thrust is also generated from the cold gas and then the total thrust is mixture of or addition of hot thrust and cold thrust, but then here since velocity object is reduced noise gets reduced ok. So, turbofan engines are lesser noise engines than the turbojet engines.

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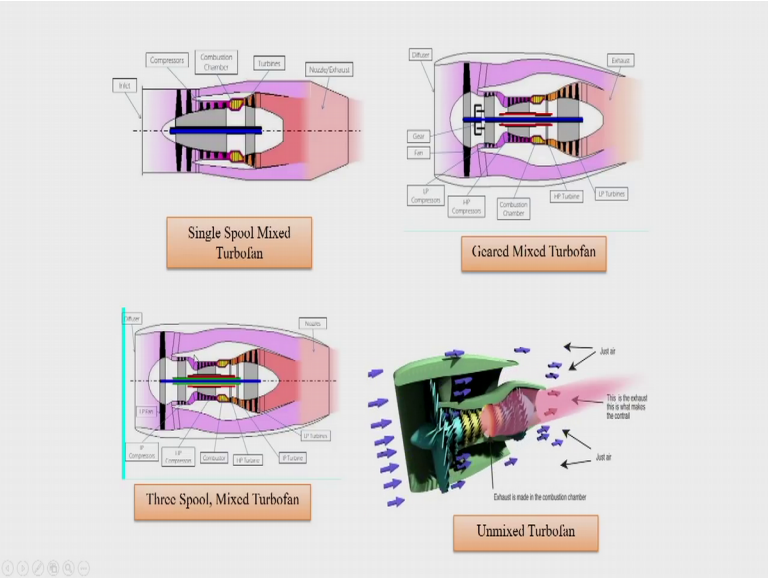

Then there are different arrangements of turbo fan engine we have seen some arrangements of this kind earlier also. So, we have single spool arrangement then in an arrangement we can have a fan which is connected in a spool with a gearbox to the turbine such that you will have a geared operation for the fan. And in other case this is a 2 spool arrangement for gear, this is a 3 spool arrangement where one of the turbines rotates the fan directly and then what we would have is the gas which is passing over the fan would get compressed initially and then it would expand and creates its own thrust and then there would be gas which is going from inside getting combusted and creating its own thrust.

But if you remember then there are 3 figures in this slide we say that mix turbofan, mix turbofan and mix turbofan. Actually here what is going to happen if you see properly then the hot air and cold air mix together and then that mixer expands and creates the thrust. So, this is that is why this is called as mixed type of turbofan engine, but if you see this diagram on the right hand side bottom then you can see that the fan is compressing the air, but that air is not mixing before expansion with the hot air.

So, this is unmixed kind of turbofan. So, there are 4 basically types what are shown over here, but mainly what intention of this slide was to depict that there is an arrangement which is called as mixed turbofan and which is called as unmixed turbofan we have earlier seen that there is a multi spool kind of arrangement. So, in case of unmixed the 2

thrusts are separate cold air thrust and hot air gas thrust are separate in mixed kind both the gases mixed together and then the create the thrust.

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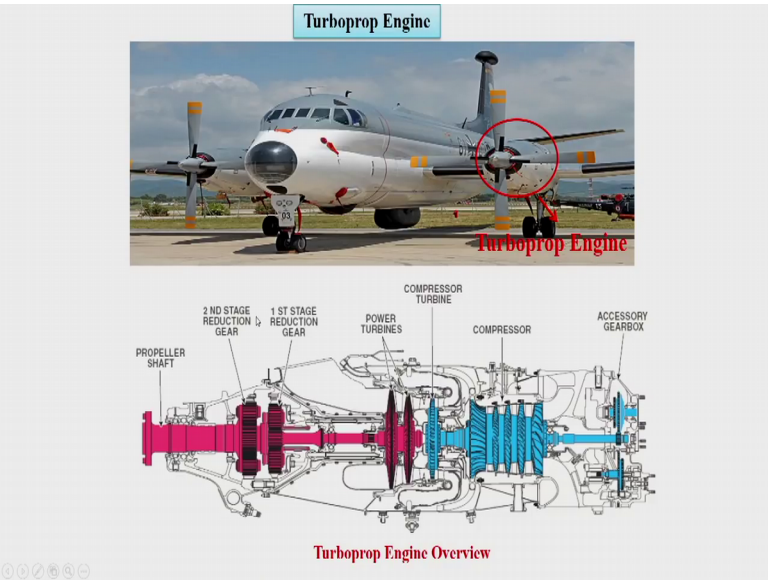

Then we have a Turboprop engine. So, in case of turboprop engine what we have is a propeller. Piston prop and turbo prop are same kind engines, but in case of piston prop what we will have is a IC engine of piston and cylinder kind here in case of turbo prop engine what we would have a gas turbine power plant to rotate the propeller. The rest of the mechanism of thrust generation is similar. In case of propeller change the large mass of air and then it takes mass of air at CA velocity and then sends it at backside of it and then as a virtue of this it will get thrust for the air since it is pushing back the air.

So, we have seen this in case of the formula for thrust calculation. So, in case of turboprop engine as said earlier we will have propeller, but that would be run by the gas turbine power plant.

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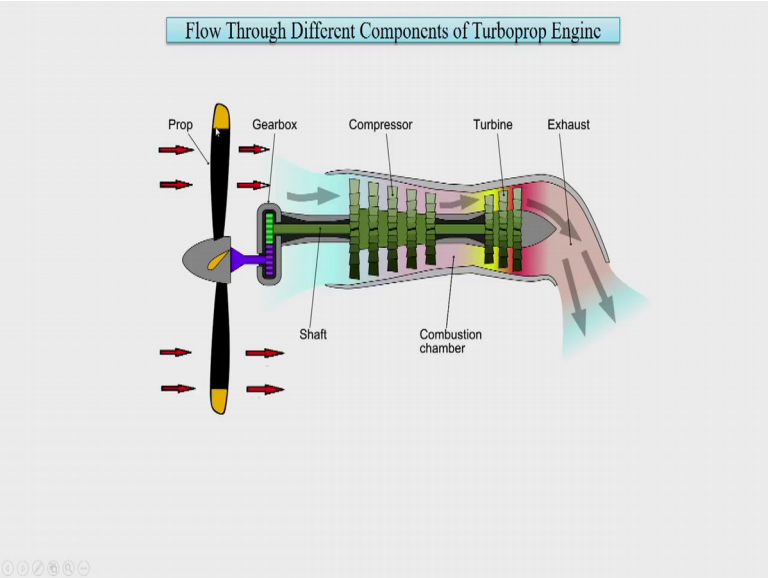

So, practically what would happen in case of turbofan engine is there would be turboprop engine, is there would be a propeller which is basically the driving mechanism, propulsion mechanism for the getting thrust. So, these needs to be rotated. So, since this is needing to be rotated first air would pass over it.

Then it would get compressed then it would get burnt and then it would get through the turbine and rotate the turbine. Once the turbine rotates then this propeller would run automatically, but propeller speed is less. So, we need a gear box to connect from the turbine to the propeller. So, that is how we will have a turboprop engine, which has the turbine compressor arrangement or gas turbine based power plant arrangement to drive the propeller. Here small amount of thrust would also be generated from this nozzle, but that is much lesser in comparison with the thrust which is generated from the propeller.

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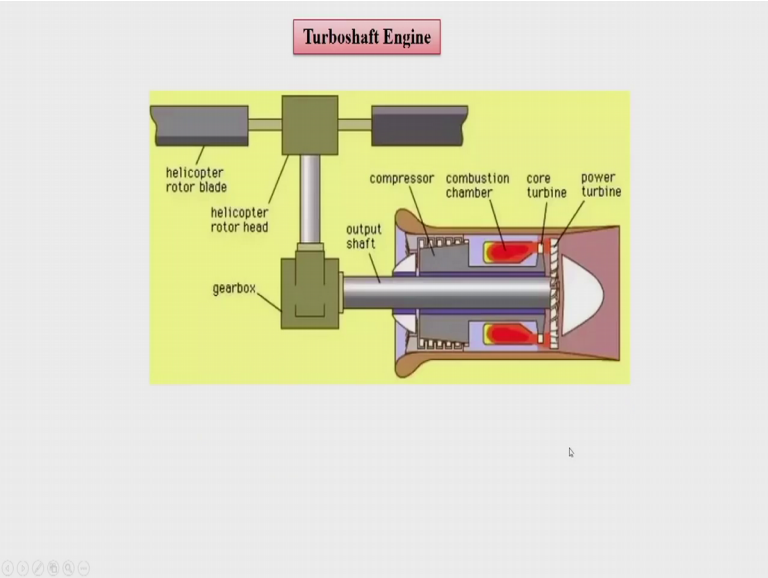

Then what we have is a Turboshaft arrangement. Turboshaft arrangement is what we can have it in the helicopter. Turboshaft arrangement is not different from the arrangement what we generally have in case of the electricity based gas turbine power plant where shaft is connected to a gearbox, shaft is connected to a generator, but in this case the gas turbine power plant is connected to a shaft and that shaft is going to rotate the blades of the helicopter.

So, turboshaft engine would have helicopter blades and it is rotating the difference in helicopter and aircraft propulsion in general is what you will have the lift and thrust both using that rotary blades.

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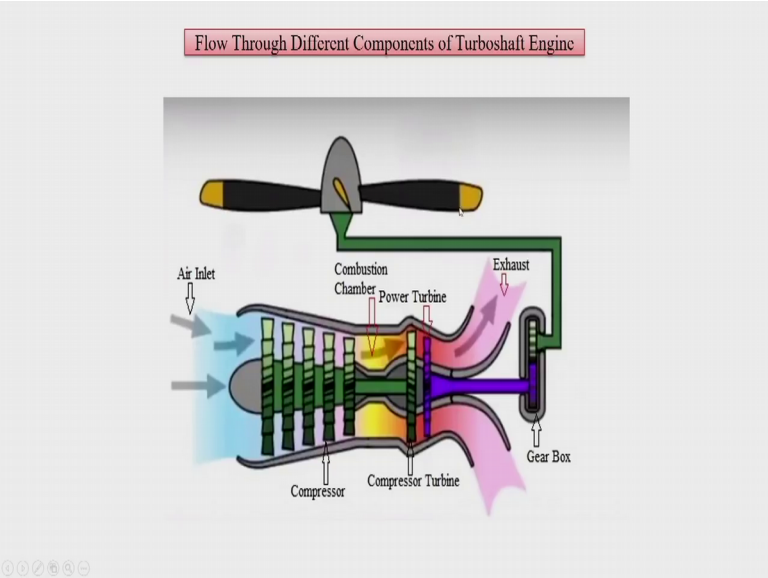

Here the arrangement of turboshaft engine is same way as what we have in a general or conventional turbojet engine except that the shaft which is connected to the turbine is also connected to the gearbox. So, turbine runs the gearbox and hence the propeller. So, practically turbine drives the compressor and propeller both in case of a Turboshaft engine.

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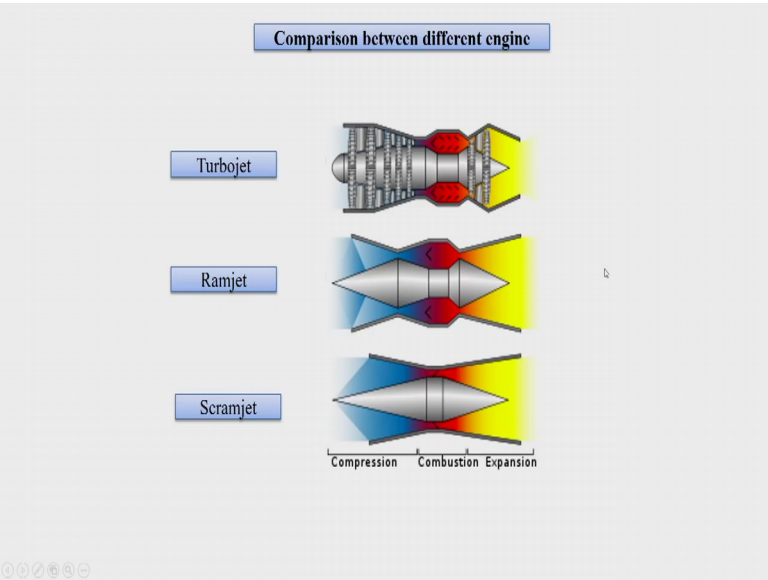

Then there are some more extra engines what we had talked about in the last class. So, we have talked about Scramjet and Ramjet as 2 more engines. So, in case of turbojet

engines we have compressor to compress the air. Here generally the speed with which the propulsion system is supposed to move is subsonic speed. So, Mach number which is defined as velocity upon speed of sound is less than 1. So, if we want to go with higher Mach number then there comes limitation to maximum Mach number what it can go for a turbojet engine.

So, although turbojet engines are available for supersonic Mach number for vary high Mach numbers turbojet engines are not preferable. So, then in that case we have 2 engines which are called as ramjet and scramjet engines. Both the engines are non rotary engines. So, there is no rotary part in this engine. Here the gas which is coming into the engine it is at the supersonic speed. So, in c since it is at supersonic speed this gas would encounter shock system or shock arrangement while passing through the intake which is deliberately designed to have shock.

So, that gas would get compressed while passing through the intake shocks and once it is compressed then it would raise its pressure to the desired value as what the compressor would have raised in case of a turbojet engine. Then that high pressure high temperature air will would go into the combustion chamber. Upon combustion it would expand in a nozzle, but in case of ramjet that compression is going to lead to decrement in velocity and that decrement is to such an extent that the combustion takes place in ramjet engine in subsonic speed, but in case of scramjet engine the compression would take place in intake.

Then we would have combustion, but compression would not take place to an extent where gas would go or air would go from supersonic or hypersonic flow to subsonic flow. So, in the combustion chamber of scramjet we will have supersonic combustion as name suggests scramjet supersonic combustion ramjet engine. So, after combustion the gas will expand. The major difference after the process of combustion is in the nozzle. In the case of ramjet engine nozzle has to be in convergent divergent section such that the entry to the nozzle is subsonic.

So, the convergent portion who lead to sonic exit and then further divergent portion would lead to supersonic exit, but such a requirement is not required in case of scramjet engine since for this scramjet we have only divergent portions since we have supersonic flow based combustion.

So, here we practically are going for higher Mach number. So, here jet velocities are becoming higher and higher in case of ramjet and then further higher in case of scramjet engine. So, this is the difference between different engines. As what we have seen that propulsive efficiency decreases if the ratio if the difference between the ratio of c j by c a or c j minus c a if it is decreasing if c j minus c a is increasing or c j by c a is increasing.

So, propulsive efficiency decrease from turbojet to ramjet and tamjet to scramjet, but these engines become more and more useful if we want to go for faster and faster speed or if we want to go for higher and higher speed.

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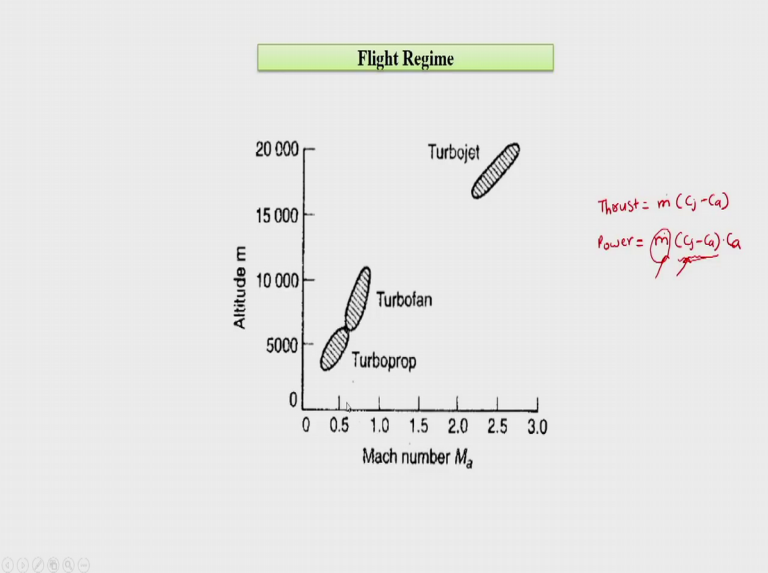

Then we have Flight Regimes. What we have talked till time was about the application and different arrangements of the turbojet or turbo based engines or aircraft engine, but the turbo engines which is turboprop, turbofan and turbojet as what we have seen if we remember there we have said that there is thrust which is m dot c j minus c a and then there is power which is based upon thrust which is m dot c j minus c a into c a.

Then what we discussed was to increase the thrust either we can just keep on increasing c j for given m dot or what we can do is forgiven c j minus c a we can increase m dot. So, the turboprop engine are based upon higher m dots, but they will deal with lesser c j minus c a and then that is why they will have higher propulsive efficiencies in case of turboprop engines. But the problem with turboprop engine is since they deal with higher mass flow rate you can see that they cannot go for higher altitudes and then there is a

limitation on rotational speed of the propeller. So, they cannot go with here Mach numbers, but now we have reduced the constraint of having the propeller we are combusting most of the air.

So, in case of turbofan engine some thrust is obtained from the cold part, but some thrust is actually obtained from the hot part, but that is why it lead to higher Mach number and further we can go for higher altitudes, but then in case of turbojet engine what we will have is further increasing Mach number and what we will have is further increment in altitude. So, turbojet engines prefer to have higher altitudes and they would they can operate at very high there can operate at supersonic Mach numbers also. So, this is how the flight regimes are defined for different aircraft engines ok.

So, having said this what we did till time was more upon to the total cycle or total power plant where we have seen that how a gas turbine power plant is having different component now they are connected and then how thermodynamics cycle is run, what are the different parameters or propels or different efficiencies performance parameters for the electricity based power plant or for the transportation based power plant or propulsion system based power plant, how to increase those efficiencies that is also seen, how to increase the other performance parameters that is also seen.

Now our objective here onwards would be to concentrate upon the each component of the engine. So, we will first concentrate upon turbo compressor then we will concentrate upon turbine. So, this is how the major components, which we will be covering in the remaining part of the course.

Thank you.