Jet Aircraft Propulsion

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Lecture No. # 05

Turbofan, Turbo-prop and Turboshaft Engines

Today is the fifth lecture in this lecture series on jet aircraft propulsion. In the last class, we talked about basic turbojet engines and we talked about a variant which includes a reheat or after burning, at it added to basic turbojet engine. So we were essentially talking about turbojet engines with or without after burning. Today we will talk some other variants of jet engines meant essentially for aircraft line and these are the variants which are often categorized in the form of turbofan engines. And there are so many variants of turbofan engines and we will take a look at as many of them as possible today will also have a look at these variants with reference to the performance parameter that we have talked about in the earlier lecture.

Today, let us take a look at some of these variants which are used in most of the modern aircraft today, specially the transport aircraft and they provide the bulk of the service which refers to aircraft flying all over the world. The various kinds of jet engines that we will be looking at today essentially cater to more efficient flying, they also cater to bigger engines which often are used in big aircraft which carry very large number of passengers or cargo and as a result of which its necessary there. They are very efficient and very useful and very reliable in terms of flight applications. Let us quickly take a look at the list which we had looked at once before all kinds of jet engines.

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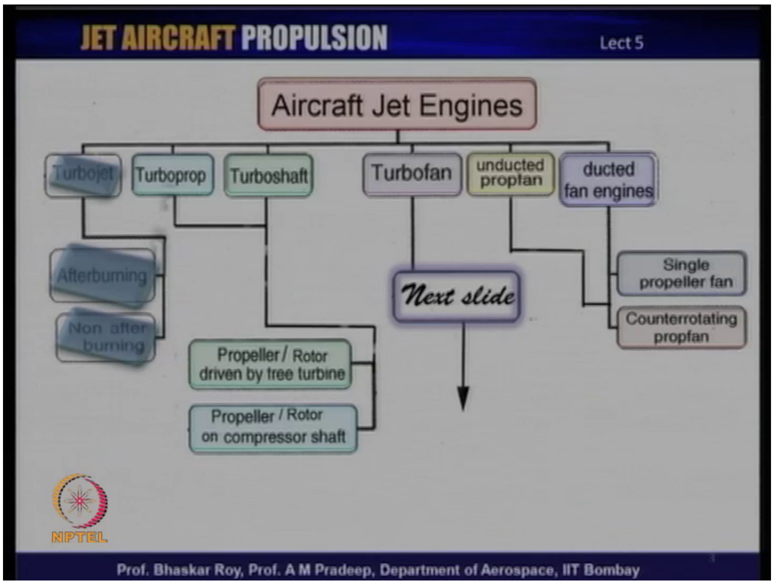

We have talked about that there are so many kinds of jet engines and the same list today we will look at very quickly, you see on the left side there are three varieties the turbojet, afterburning and non afterburning which we have talked about in the last class, so we will not talk about those variants anymore today. We will talk about a little on the turboprop, turbo shaft which are very broadly can also be categorized as jet engines. In the sense that they use the basic engine, which is same as a jet engine that is the gas turbine engine. And we will be talking about the turbofan engines and a modern variant of turbofan or some kind of a cross between turbofan and turboprop that is the prop fan, which has two variants one is un-ducted and other is ducted. And will take look at this prop fan also today to understand how it works. So, let us first start with the variant that is connected to turboprop and turbo-shaft, but let us take look at all the turbofan variations that we will be taking a look at today.

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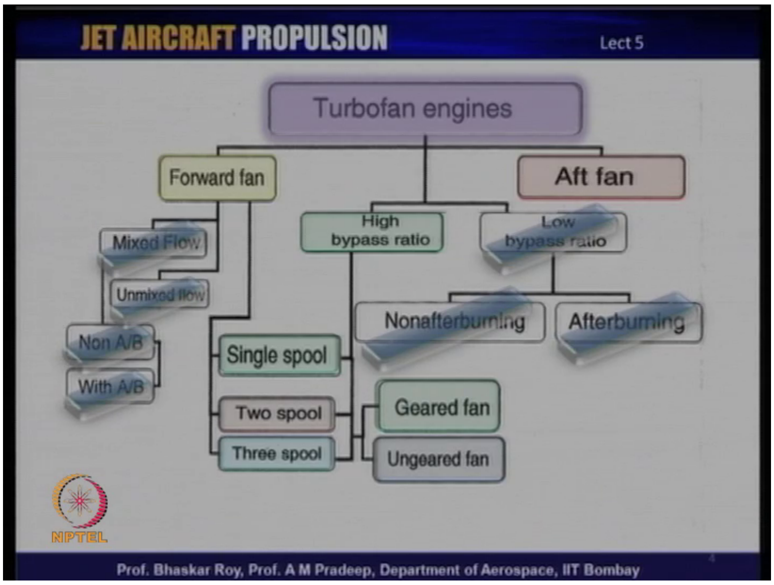

Turbofans come in various shapes, sizes, and of course various thrust categories. Now all the left hand side again we will see a few of them which are mixed flow and unmixed flow, and non-afterburning and afterburning some of these appear on the right side also. These are the ones which we talked a little about in the last class, essentially categorizing them as jet engines and we felt that there is will it different between these low bypass turbofans and basic jet engines and hence we talked about them in terms of how they function, how they work and how to access their performance by using the fundamental performance parameters.

So we will be not talking about those ones, but we will be talking about the other once which are shown in this list here today. Will be talking about the forward fan, will be talking about the aft fan and of course, will be talking about the high bypass ratio fans which come in single spool, two spool, three spool and then of course, will have a look at the geared fan which is special variety of large turbofan engines. So these are the once which will be looking at today in some detail and try to look at their differences and how they function and what there mechanical details or and exactly how they compare with each other.

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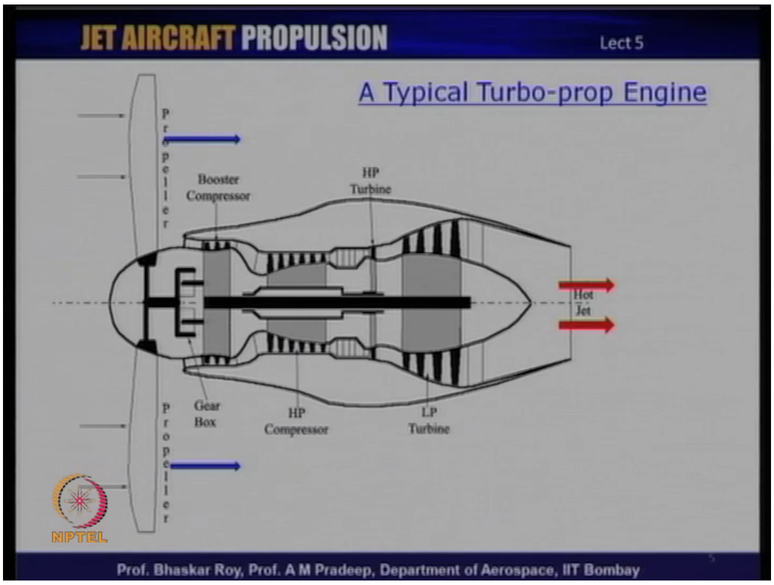

So let us start off with what can be called a basic turboprop engine. Now a typical turboprop engine essentially is run by a basic jet engine, now basic jet engine what it does is it as the capacity now to produce more power than is required to run the compressor.

Now this turbine which is now capable of producing so much of power is now as you can see in this particular diagram as a very large number of turbines in the second group or what can be also called the low pressure turbine group. And in this we can see there are four turbines which means the aggregate amount of power that this group produces is so much more that it can easily run a big propeller and this combination of a basic turbo engine with a propeller is simple called turbo-prop engine. Since this variety of engine also produces a hot jet and produces certain amount of jet thrust. Some people also called it a prop-jet engine, so it is a combination of propeller and jet engine.

Propeller by design produces the bulk of the thrust, so the flow goes through the propeller in a normal cooled air flow and that produces the bulk of the thrust quite often of the order of 80 to 85 percent of the thrust and the balance 15 to 20 percent of the thrust is produced by straight jet that a typical jet engine produces. Now this a particular kind of turboprop engine can indeed come in single spool the one that is shown here is actual two spool, it has two shafts one is constituted shaft as you can see which comes from the low pressure turbine group all the way runs what is also can be called a booster compressor or LP compressor and then through a gear box runs the big propeller. Gear box is an absolute necessary element in our turboprop engine because a propeller never runs at the same speed as turbines. Turbines run at a much higher speed or rpm and it is necessary to reduce the rpm substantially before you run the propeller. However, just before the gear box although same shaft you may have this LP compressor or booster compressor which simple boost the air which is coming inside the basic engine or cold engine and produces sufficient amount of pressurization which is then fed into the main compressor to do the compression before it is fed into the combustion chamber.

Now this main compressor is run by 1 HP turbine which is often sufficient to produce sufficient power to run a whole group of compressors, now that is run by the outer spool over here and hence this is the two spool engine a smaller version of turboprop engine can indeed be a single spool turboprop engine, which means it comes through one single spool and then you have one group of turbine which runs one group of compressor and then through the gear box again runs the propeller, so propeller as to have a gear box before the power is sent to the propeller because as I said the propeller runs at much lower rpm normally of the order of 1000 to 50000 rpm where as the turbine compressor spool often runs at many thousands of rpm quite often of the order of 8000 to 10000 rpm. So this is the typical turboprop engine or as some people called at prop jet engine.

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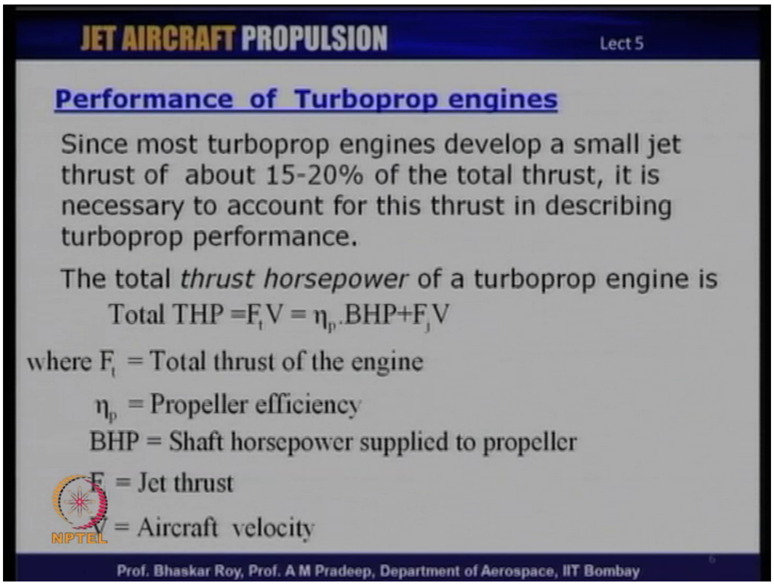

Let us look at how the turboprop engine performances can be estimated. As I mentioned 15 to 20 percentage of the total thrust is can be created by the jet engine, so hence you have two components of thrust making here one by the propeller, one by simple jet thrust.

The total thrust can be written down let us save as F t and then the thrust horsepower can be measured in terms of F t into V. V being the velocity of aircraft flight. And then this thrust power as two components one is in terms on the power supplied to the propeller, which is the break horsepower coming from the engine through that spool, through the gear box and supply to the propeller. And eta p of course, is a propeller efficiency and the second term of course, is a thrust power created by that 15 to 20 percent of the jets straight jet thrust. So two of them together make up the total power consumption of this engine and quite often they are expressed in terms of power rather than in thrust.

One could do it the other way round, but this is basically power driven machine and hence most people would like to categorized our prop performance in terms of horsepower or kilowatts rather than in directly in terms of thrust in kilometers.

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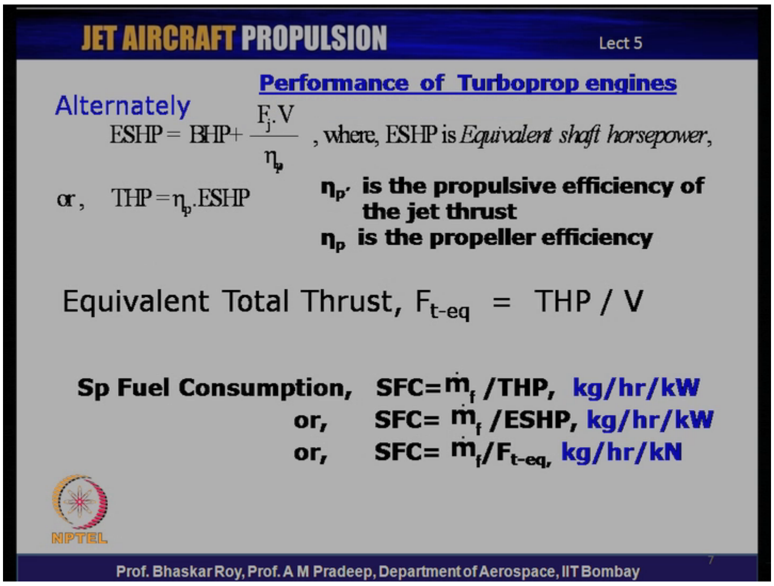

Alternately quite often this can be shown in terms of what is known as equivalent shaft horsepower and this is given in terms of BHP as supplied by the main shaft to the propeller. And the jet thrust that is been created converted to power now this is converted with a small propulsion efficiency of the jet thrust and so we have the second term which is basically a thrust power converted to power which is then added up to the shaft power, and the two of them together makes of four what is also known as equivalent shaft horsepower or ESHP. Now this ESHP as water supplied let us say to the shaft for creation of power.

And hence that power thrust horsepower as we categorized earlier is directly result of ESHP into the eta p, which is a propeller efficiency and hence we can also get THP as a measure of power supply of the whole engine from the ESHP. The total equivalent thrust as I mentioned can also be then written down as F t equivalent equal to THP by simple V a V is of course, is a aircraft velocity. So as a result of which it is possible to write down equivalent total thrust in terms of the total the horsepower that is being consume divided by the aircraft velocity. The specific fuel consumption of this kind of engine is often given in terms of kilograms per hour per kilowatts which is what the power consumption is a normally of a THP or ESHP.

And the definition remains same as before that is the fuel consumes m dot f divided by THP and that is expressed in terms of kilograms per hour or kilowatts. SFC can also be expressed in terms of m dot f divided by ESHP actual value as you can see would be slightly different and it is possible also if you wish to it can be expressed in terms of m dot f by F t equivalent and in which case the units would be kilograms per hour per kilo-newtons, all three possibilities exists however the most common and popularly use one is the first one and that is SFC expressed in terms of per unit power that is kilowatts for turboprop engines, because turboprop engine are normally specified by the power consume and not by the thrust that it produces during flight.

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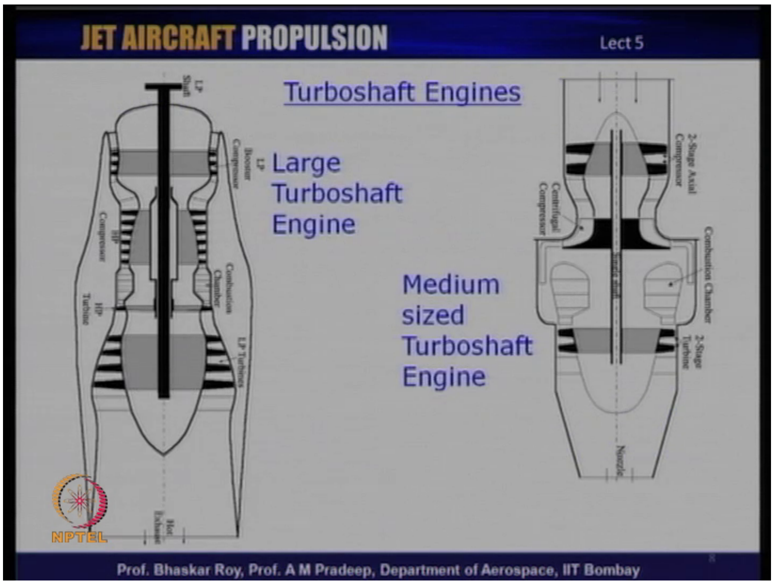

Let us now take look at some of the other variety of engine. Now this kind of an engine is called a turbo-shaft engine it is slightly different from turboprop engine, in the sense that it also uses a basic jet engine or a basic gas turbine engine same as turbojet engines, but it does not produce any thrust at all by the jet propulsion system it produces all its thrust with the help of rotor and this is often not called a propeller it is called rotor and the reason is this kind of a rotor actually runs an a horizontal plane and produces thrust often mostly in the vertical plane.

So unlike a propeller which runs in the vertical plane and produces the a thrust in the horizon to plane that is in the plane of moved motion of the aircraft. In case of turbo-shaft engine the rotor moves in the horizontal plane and produces thrust in the vertical plane. Now this production of thrust directly allows the craft to be lifted off the ground and this is used for helicopters. This is the kind of engine that is used for helicopters for direct lift off from the ground which requires then the thrust produces to begin with balances their weight of the entire craft. And that is first requirement for the lift off and once it is lifted off the ground the shaft of the rotor can slightly tilt for forward and then it produces certain amount of forward thrust with which the helicopter files forward.

As you can well imagine it is only a small component of the thrust that is being produced by the rotating rotor, and as a result of which the amount of thrust that is available for forward flight is often not very high, and hence the helicopters often do not fly at very high speed, they fly at rather low speed, they also normally do not fly at very high altitude, they fly normally at somewhat lower altitudes or almost well within the eye side. And all this time during the flight remember the helicopters do not normally have wings to support the craft during its flight by creating lift, so there is no lift creating surface or body attach to the craft like wing and hence the rotor as to continuously support the body of the helicopter during its flight the weight of the helicopter, so it is a continuous weight balancing thrust that the rotor as to create during its entire operation and during entire flight.

So only a small part of that thrust is available for forward flight. So this is the kind of engine that is simple called turbo-shaft engine because it produces a short shaft power and makes a rotor rotate in the horizon to plane. And it is simple called a turbo-shaft engine.

So let us take a look at this turbo-shaft engine which you shown in the diagram saw here. Now as we can see here on the left hand side this shaft is coming out of the engine, at the end of the shaft you would again have a gear box and you would have big rotor which we will be powered by this engine.

Now this is a straight forward turbo engine or gas turbine engine. And this is a big turbo-shaft engine which is a two spool engine. The inner spool is what is coming out to run the rotor the outer spool runs the basic compressor turbine loop creating the power or the power generating system. On the right hand side we have slightly smaller engine a medium sized a turbo-shaft engine in which what has been deployed is a combination of axial flow compressor and a centrifugal compressor. And this combination is very popular in turbo-shaft engine because it provides a very compact engine producing sufficient power through the shaft to run the rotor.

So here also this rotor shaft would be coming out over here and they of course, would have to be gear box to run the rotor. The rotors also typically run at very low speed like the propellers quite often even lower speeds less than even may be 1000 rpm and these rotor size is are much bigger than that of the propeller. The rotors can be as big as 8 to 10 meters in diameter and as a result there rpm would have to be somewhat restricted for various structural and aerodynamic reasons connected with rotor motion.

Now this is one kind of turbo-shaft engine which I mention is very popular where you have combination of a centrifugal compressor and axial compressor or a set of axial compressors which of course, a run by a single shaft of set of turbines in between of course, you have the combustion chamber. On the other hand there are other varieties which we can take a look at.

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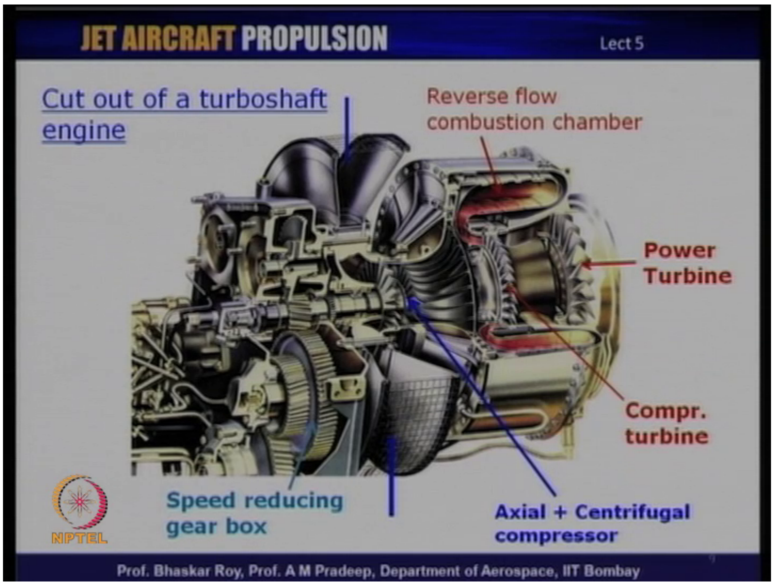

Now look at this engine which is taken out of a typical turbo-shaft engine. Now what you see here is you have a combination of an axial flow compressor and a centrifugal compressor as you can see here a centrifugal compressor is quite large and produces a substantial amount of compression. Then it delivers the air into this combustion chamber which is a kind of reverse flow combustion chamber in the sense the flow goes into the combustion chamber and kind of back tracks back in the axial direction, so actually its sort of comes back through the combustion chamber and then gets delivered on to the turbine.

So this combustion chamber is something like a rape around combustion chamber around the entire engine, so it is a combustion chamber the rapes itself around the entire engine inside which you have the turbine. And as a result of which this is a typically a reverse flow combustion chamber which as I mentioned, then delivers the hot gas into this a turbine. Now this is the compressor turbine runs this compressor combination of axial and centrifugal flow, so this basically supply is power a through the shaft to the compressors together.

And then it delivers the flow through this ducting system on to this bigger turbine which is the power turbine. This power turbine then runs another shaft inside which comes through and then it runs this gear box. Now you can see this speed reducing gear box over here, so this you know shaft they comes through the outer shaft come here, and then through this gear machine system reduces the speed substantially because as I mentioned the turbines speed are likely to be of the order of 8000 to 10000 rpm sometime even higher. A typical turbo-shaft engine can have a compact engine like this could have the speeds of the order of 30000 to 40000 rpm. That is a kind of speed at which many of the turbo-shaft engines could actually be running.

And as a result of which the power generation is very high order however, the rotor cannot possibly run at anywhere near that speed so you have huge reduction that needs to be done and you have almost something like a gear train through which the reduction needs to be done in a efficient manner and this reduction could be of the order of 1 is to 100 or something, and as a result of which you can see a huge wave gear box. Now gear box is a heavy element and hence it adds of substantially to the weight of the whole engine or the whole engine system, and as a result of which a typical turbo-shaft is likely to be rather heavy and that is also another very good reason wide in the engine designers.

The turbo-shaft engine designers try to make the basic engine as compact and as light is possible because it as to make way for the gear box which is absolutely essential element in the turbo-shaft operation. So this is the kind of typical turbo-shaft engine used in many helicopters all around the world based on basic gas turbine engine which is same as the various kinds of jet engines that we are discussing.

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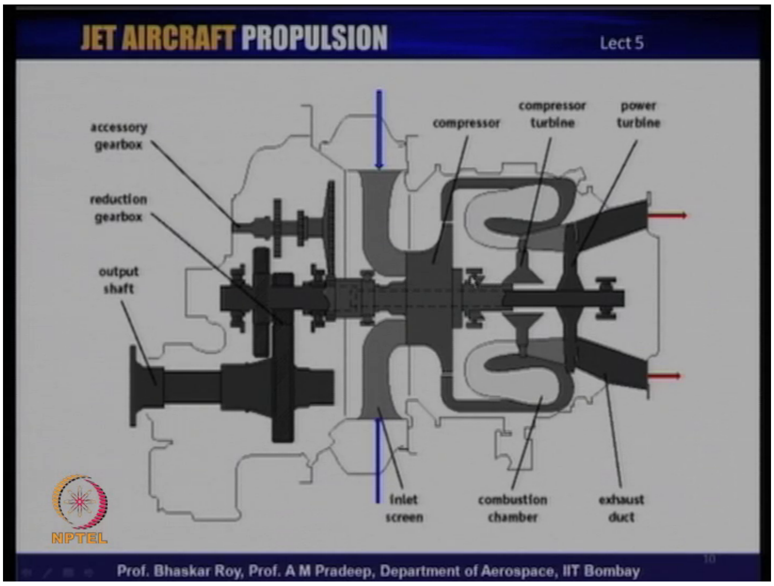

This is a schematic of a turbo-shaft engine. The kind of engine what we were looking at just now, it has this compressor, it has the compressor turbine and then it has a power turbine and this is the shaft through which the flow comes, the power comes through and then you have this output shaft over here which runs the rotor and then you have the huge reducing gear box which reduces the rotating speed by a factor of 50 to 100.

And these are the systems which you have, and this is the inlet, so you have side vise inlet of air going into the basic engine and quite often the exhaust also could be something like this sideways, as I mentioned they do not produce any direct thrust so essentially they are exhaust gasses all the energy has been taken out by turbine and its simply goes out without any power or any residual energy left in it. It goes and mixes with the atmosphere. So this is a simple schematic of the kind of engine. We just had a look at here so this is the basic engine picture. And this is the schematic of how it is or its layout inside that engine.

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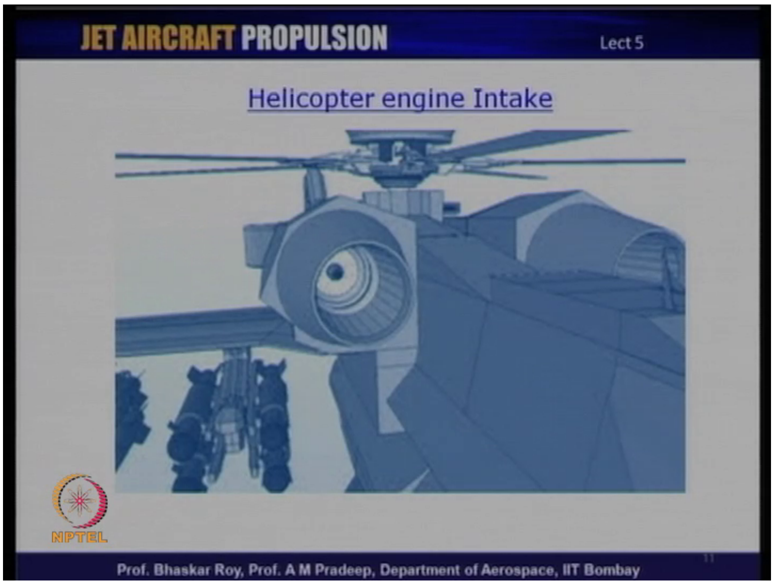

This is the kind of helicopter engine that you would see in a helicopter. These are the rotor that I was talking about. These rotors are very big and they are a fixed here with very strong mechanical fixing arrangement, some of this rotors could have variable picture arrangement to which we may talk about a separately, and these are the intakes to the engine in this particular sketch you can probably see there are two possible intakes one of this side another on the other side.

And that is what we saw here there are two intakes one of this side one on this side the feed into the same engine. And you could be having similar arrangement here that you could have one intake on this side, one intake on this side feeding into one engine which reduces the shaft power that runs this rotor for helicopter. This is the other side of the helicopter engine, you have the exhaust. The exhaust coming out over here without producing any jet thrust and this is just exhausting the used up burned gas through various ducting arrangement, so that do not produce much interference with the main operation of the helicopter how the engine.

And these are the big rotors that produce the direct thrust for lift of the helicopter and for the helicopter flight. So that is how the turbo-shaft engines are mounted on a helicopter and that is how they actually operate to make the helicopter fly.

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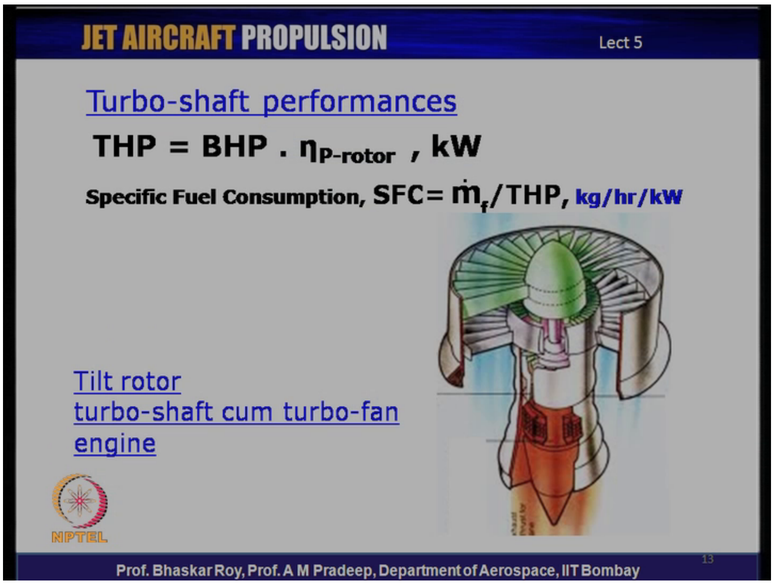

The performance of turbo-shaft engine can be simple down in terms of THP is equal to BHP into the propulsion efficiency of the rotor and is expressed in terms of kilowatts. The specific fuel consumption can be written down in terms of m dot f divided by the THP and also is expressed in terms of kilogram per hour per kilowatt, so turbo-shaft and turboprop engines both have power as the specification of the engine and SFC is shown in terms of kilograms per hour per kilowatt.

The shown here is a picture of a very interesting engine that has been demonstrated and even flown it as in quite become very popular as yet. And this is simply called a tilt rotor engine in which this is basically a turbo-shaft come turbofan engine. This particular rotor is more like a fan and this engine can actually tilt itself it can go vertical as it is shown here or it can become horizontal to become something like a turbofan and this capability makes mix it or give its name tilt rotor, so whole thing can be tilted.

So while taking off like helicopter it can be position like this and it directly produces thrust for lift off balance in the weight of the craft, now once it is air bond it can start producing power for forward thrust by simple titling the whole engine front line this, so form vertically alien engine it can become horizontally alien engine and the rotor instead of rotating on the top become behave more like turbofan and it rotates in the vertical plane producing directly thrust.

Now this is why it is called a tilt rotor it can tilt from vertical position to horizontal position producing direct thrust during flight and again during landing it can be tilted backwards to have direct vertical landing.

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So it can have vertical takeoff it can have vertical landing in between it can tilt forward to create forward motion and directly provide forward thrust for the aircraft to fly. In this kind of engine has been made they have been flow but, the mechanical arrangement of making it fly during making tilt during flight is rather complicated and a little risky in the sense there are some chance is of failure in which case, it could be catastrophe.

And because of that it is probably not become away popular kind of an engine even today even though technologically it is proven variety of engine.

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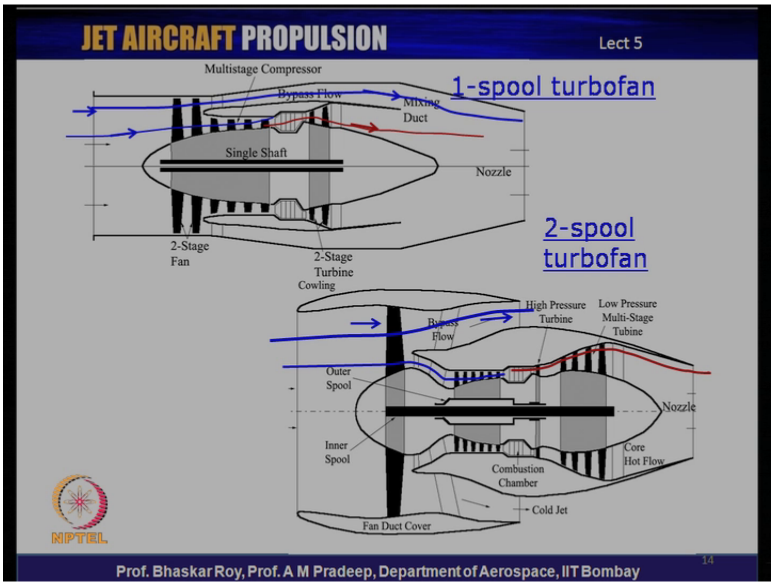

Now let us start taking look at various kinds of turbofans. Now turbofans can be various kinds, one is we could categorized them in terms of single spool or two spool or three spool, so in terms of spools. Let us take a look at single spool and a two spool turbofan engine. The first one that you shown on the left is a single spool turbofan. A single shaft run by a set of turbine produces a sufficient power to run the compressors and the fan in front of the compressors. Now the fan is a bigger compressor as we have talked about before.

And they are called fin simply because they are bigger look like fans, but they produce compression as much or more than compressors axial compressors and after the fan you have this bypass. So in this turbofan engine there is a certain amount of bypass and then this is cold flow that goes and bypass is the basic hot engine and mixes much later in the jet pipe and the mix flow goes out through the common nozzle. In the mean time a certain amount of cold flow goes through the compression process goes through the combustion chamber through the turbine and that is the hot gas produces power, so the power is produced only by the inner flow. The outer flow does not participate in the power production, it simply consumes the power.

The inner flow produces the power through the turbine and then it goes out and mixes with the cold flow in the mixing zone and then goes out through the nozzle, a mixed flow not very hot anymore, but the mass flow of the exhaust flow is now so much more. So the thrust production is a first slightly higher order. And as we have seen before this simple method of bypass in certain amount of flow and later on may be mixing them produce a certain amount of SFC benefit, a specific fuel consumption benefit and that benefit people have been trying to hardness for a long time by various versions of turbofan engine, so various versions of turbofan engines are typically bypass engines so that is an another way of looking at turbofan engine.

So we can look at them in terms of spools or we can look at them in terms of bypasses, the amount of bypass they produce. When it is comparatively low bypass of the order of one or two or not more than three, one could possibly have this kind of mixed flow, where it later on mixes with hot flow and single exhaust mixed exhaust goes out producing thrust. The other version which is often a two spool turbofan, now two spool turbofan means that the turbine works in two groups. One which is often called the high pressure turbine group which may be single or two a turbines. And then you have the low pressure group which is often multistage a turbine group and they produce power over two shafts.

Now the HP 1 actually sends power through the outer shaft which is as you can see hallow shaft very much to this group of compressors which is also called HP compressor. Now this HP compressor run by HP turbine creates this so called HP loop a which is a raped itself around the combustion chamber and this is the core engine and quite often simple refer to as the gas generator, because this loop of compression combustion and a turbine produces the basic gas of the gas turbine engine.

So this is simply called the gas generator and then of course, the next group of turbines produces a lot of more power and this power is send through this inner shaft to this big fan. Now this big fan is a one different shaft, so it is called two spool engine. And the other way of looking at it is this big fan now produces very large bypass. Now this bypass is so large that you cannot possible have the whole engine again covered up and mixed together later on, in the sense the bypass is far more than the inner core flow. Mind you again the basic power produce by the low pressure multistage turbine is still by the inner flow only.

So the inner flow only participates in production of power and that power if sent to the big fan. And big fan then pressurize the cold air and sense it out as a separate jet and this separate jet to produces cold thrust, so that is the essence of a bypass turbofan engine, a high bypass turbofan engine where cold thrust is produced in addition to the hot thrust. And as a result of which certain amount of benefit in terms of the pulse efficiency is obtained. So this is the two spool high bypass turbofan engine. The first one was a single spool which could have been two spool there is no reason why a mixed flow cannot be two spool.

So this could possibly be two spool also, but it would be a mixed flow engine of a low bypass variety. Bypass of the order of two or less whereas, here it is bypass of the order of three or more and quite often now days of the order of four or five. Now this is a two spool turbofan engine which is a very common variety of turbofan engine used in most of the aircraft these days which are flying around.

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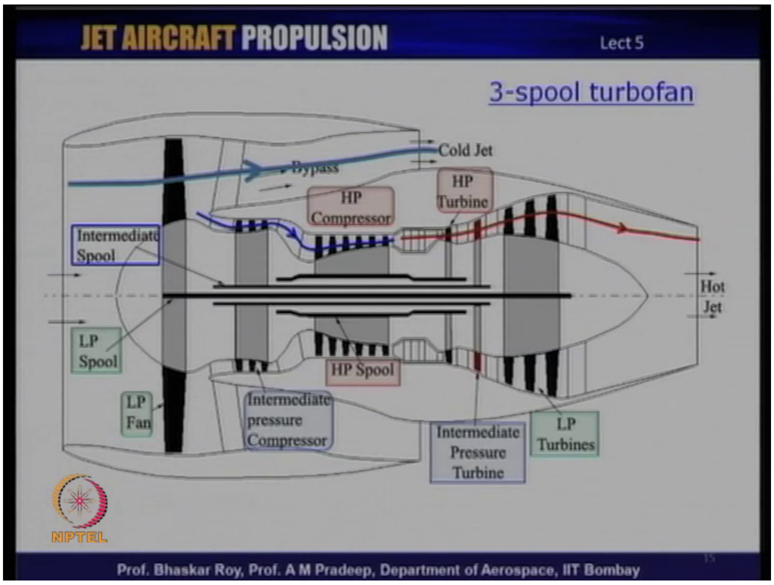

The more modern version of turbofan engine is a three spool turbofan engine which is not very popular as yet, but it is already been used by some of the engine manufactures such as the Roads Raj company and they have been making three spool turbofan engine.

There is a certain mechanical complex city here because as you can see there are three constitute shafts. The inner core of the shaft carries power from the outer most turbine or LP turbine through this inner shaft and carries power to the outer most compressor which is the big fan, which is the LP fan. So that spool or LP shaft essentially carries a huge amount of power from this set of LP turbines or to the LP big fan. The other two spools are the intermediate pressure turbine which carries power to the intermediate set of compressors.

And the HP turbine which supplies power to the HP compressor of course, this inner path of the flow which carries the air in through the intermediate compressor through the HP compressor into the combustion chamber into the HP turbine and then into the intermediate pressure turbine is the inner flow that is the basic gas generating flow, that is also the basic power producing flow and then also goes out in the form of a hot jet which produces certain amount of hot thrust. In this kind of engine it is almost in variably. It is a very high bypass engine of the order of five or six and this cold thrust that is produced is substantially higher than that of the hot thrust and the ascent is on sending a very large amount of power to this big fan which activates or processes or very large amount of air mass, and that produces the large amount cold thrust.

So three spool engine has been a proven variety that is been flying around for quite some time now, but it is still not very popular all across the world not every manufacturer uses three spool engine, and some of them prefer to still continue with two spool engine, and an its essentially a difference option in terms of the mechanical complexity of the engine. Rolls Royce Company seems to be comfortable with this mechanical complexity whereas, some of their American counter parts or not convinced of the mechanical complexity that is required to create high bypass turbofan engines.

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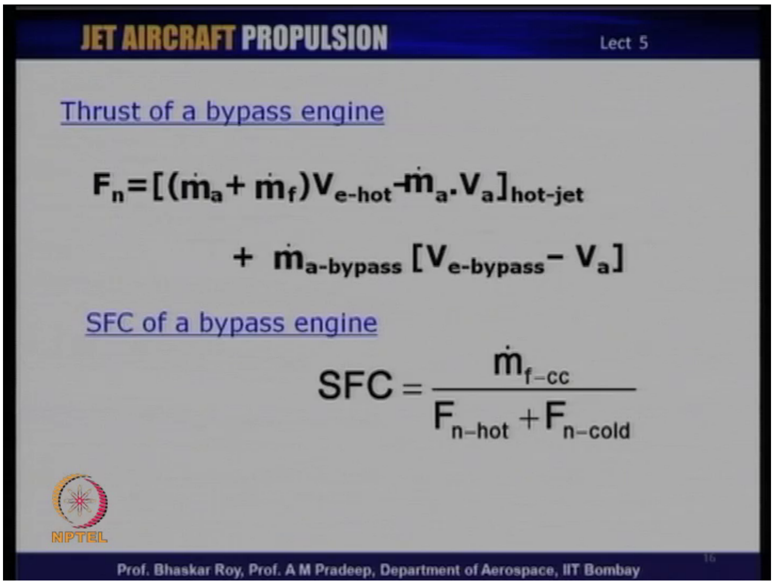

Let's take a quick look at the thrust that is produced by these bypass engines. As we have written down before they have two components. One is the hot component which produces thrust by creating hot jet, so you have the inner flow that is going inside the hot gas generating unit and then that producing the hot thrust. This is the inner flow that is going in this is the mass flow of the fuel that is being pumped into the combustion chamber and this is the hot jet velocity that is being produced. The second part of the thrust production is the bypass mass which produces a bypass jet which we may call V e bypass, now that as to be more than the V a with which is the flow is going into the big fan, and this difference produces the momentum change.

Now in this second component the more important aspect of the thrust production is not the different between the two velocities, but the huge amount of mass that is being activated. So in the second thrust producing component here the mass of air that is being activated through bypass system or a bypass cold jet is indeed very high, and that is what produces very high cold thrust from the second component whereas, in the first component as we know it is the V e hot which produce which is most important aspect of thrust production because the mass flow there being process is not a very high order.

The SFC of an such engine is simply refer to in terms of the mass flow that is pumped into the combustion chamber divided by the total thrust that is been produced, the combination of hot thrust and the cold thrust and that total together gives you the SFC. And now one can realize looking at this figure why there is a huge SFC benefit when you use bypass engine and we will of course, we talking about this more and more of this benefit of SFC of bypass engines.

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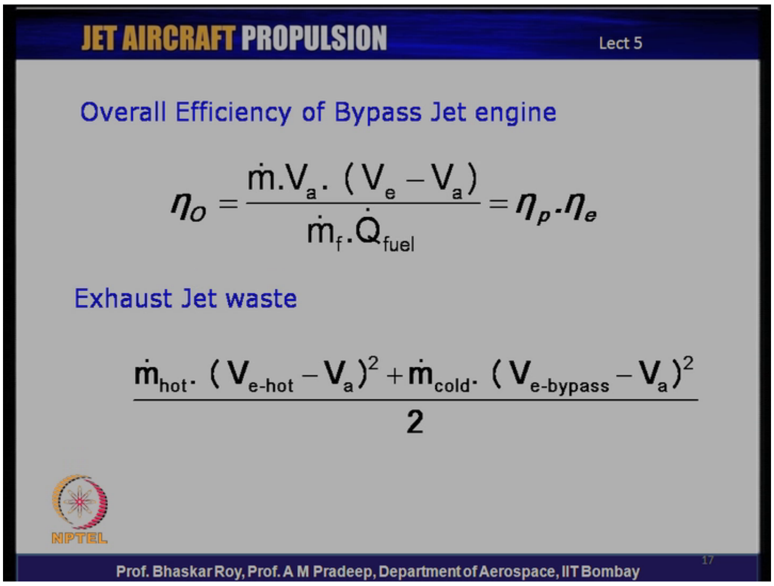

The overall efficiency of bypass jet engine can again be written down in terms of a eta e and as we know this combination of propulsive efficiency and the energy efficiency, as we have done before where the exhaust jet energy is now as two components, one is the hot component and one is the cold component.

And as you can see here the cold component as very high mass flow what very low a jet energy. The hot component has very low mass flow, but very high jet energy of its own. So the energy waste of per unit mass flow for the cold component is going to be very low, so per unit mass flow cold component jet waste is of a very low order and that is one of the reasons one can conceptually understand why a bypass engine would have higher propulsive efficiency.

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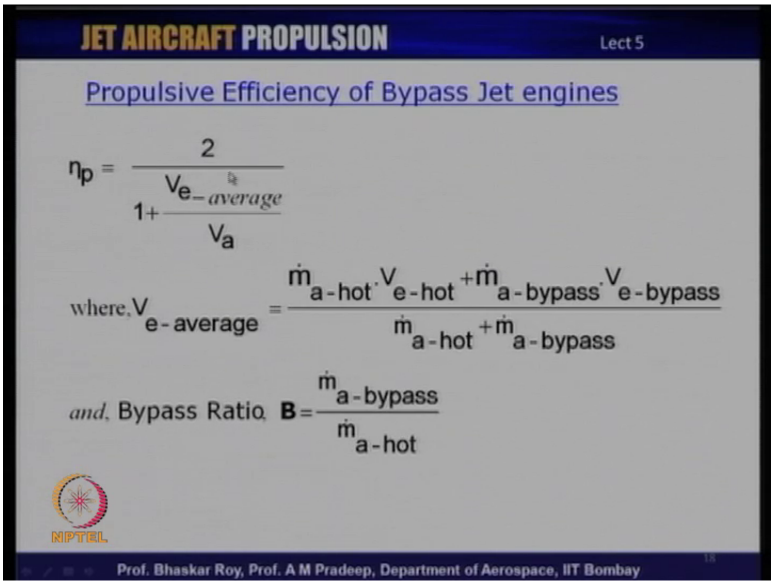

We can take a look at this simply mathematically, propulsion efficiency has been defined before a simple by two divided by one plus V e by V a now here we can write V e as V e average of the hot and cold which we can write down here as a mass averaging and if you do that the V e average will be substantially lower than that of V e hot, and as a result of which this propulsive efficiency is now going to be of a very high order compare to any other kinds jet engine it will be approaching that of the propeller or turboprop propulsive efficiency or propeller efficiency.

And this is the huge benefit that the bypass engines are the turbofan engines bring to the operation of aircraft jet engines. So we can now write down this bypass in terms of a well accepted by bypass ratio parameter which is used in every book and a refer to by bypass engine in specifications this is simply the bypass mass divided by the core flow that is going into the basic engine. So the cold flow divided by the hot flow simply is the ratio of these two is the bypass ratio, and this is simply refer to as bypass ratio in all turbofan specifications and engine specifications.

We are been talking about various kinds of turbofan engine. We mentioned two, three spool engine, two spool engine and some around there we also mentioned that not everybody is comfortable with the three spool variant for every high bypass turbofan engines.

The Americans especially the American manufactures is the general electric company and the pragmatic company, they over the airs prefer to use what is called a gear turbofan engine. Instead of going three spool they prefer to use a gear turbofan engine, instead of a three spool variant. Let us take a look at this gear turbofan engine which is basically a turbofan engine, a bypass engine or high bypass engine but, uses is a different kind of mechanism, Let us take look at that

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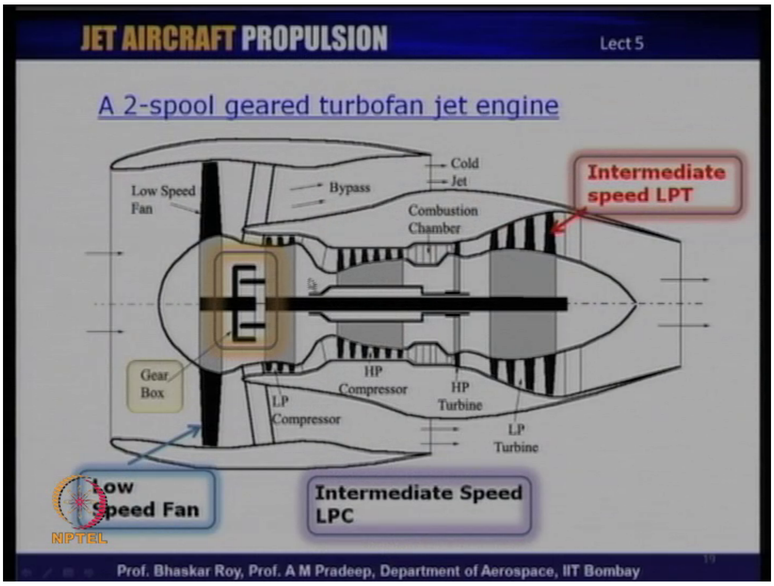

You see, this like a propeller there is a huge gear box that is placed over here. Now this gear box is run by this intermediate speed LPT. This is a LPT a low pressure turbine as before, now this is powering this inner shaft which is bringing out the power from LPT.

And on the shaft is also mounted a LP compressor which produce a certain of pressurization when it is fed into the main core compressor, so that is bit of booster compressor and then this power shaft goes and meets with a reducing gear box. And then this gear box then produces a very low speed shaft power on to this low speed fan. Now low speed fan is very similar to let us say a propeller not as low speed as a propeller. Propeller is I mentioned around set 1000, 1200, 1500 rpm this low speed fan may be running at 2000 to 2500 to 3000 rpm maximum.

However that kind of speed is very unbeneficial or not very profitable for turbines to run. If a turbine runs at as low speed as 3000 rpm it is power producing capacity will be very low. For a turbine to produce a substantial amount of power by itself it should run at high rpm. We have seen in case of turbo-shaft engine just a while before that it runs at very high rpm of the order of 20000, 30000, 40000 rpm. And then runs the rotor through a reducing gear box. Now the idea that turbine produces more power or more power efficiently, if it runs at high rpm is a very well known phenomenon, it is very well known in gas turbine industry and as a result most gas turbine designers would be like to run the turbine at a rather high rpm. So this intermediate speed LPT actually runs at rather high rpm may not be as high as the HP turbine but, still reasonable high of the order of 7000 to 8000 rpm and if it runs at that kind of a rpm it can produce sufficient power with the help of certain number of turbines, if it as to run at lower rpm like 3000, it would actually probably need a large number of turbines many more instead what you see here is four turbines it may need 6, 7, 8 turbines to produce the same amount power in which case the weight of the engine would not go up tremendously, so reduce the weight of the size of and. The size of the engine this turbine needs to be run at high rpm if it is to be run at high rpm you cannot run the fan at that high rpm and hence the gear box.

So you can do with gear box in between to reduce the speed and run the low speed fan producing a very high bypass and a very high cold thrust, but still leave the turbine to run at reasonable high rpm with a reasonable number of sets of a stages of turbines to produce all the power that is required to run the big fan.

So this is a mechanical combination which many of the big turbofan designers have adopted that they have gear turbofan and this gear turbofan allows them to go very high bypass and as a result of which all the benefits of very high bypass can be obtained by producing this kind of engine, you need gear box now very similar to turboprop or turbo-shaft to run the turbofan. So now we have gear boxes inside turbofans not only inside turboprop or turbo-shaft but, also inside the turbofan engines, the modern turbofan engines.

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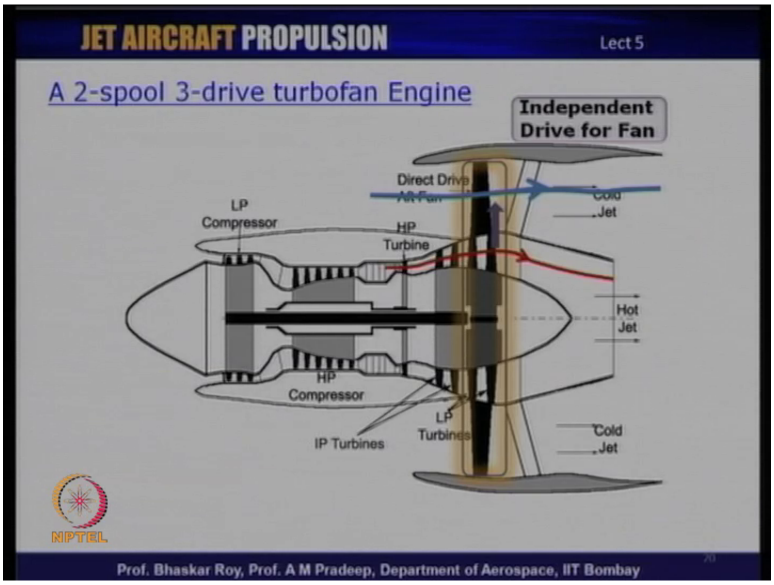

This is a two spool three drive turbofan engine. Now as you can see here you have two spools, one spool that is the outer spool which is run by one set of turbines and it runs the LP compressor. The inner sets of compressors are run by the inner set of turbines which is what we called the gas generator.

And then this hot flow it flows through a third set of turbines over here before it goes out as hot jet and producing thrust. This third set of turbines over here actually has a big fan mounted ride on top of it or right around it circum parentally. So it directly sends power from the inner turbine blades to the outer fan blades, big fan blades and which actually activates for very large amount of air cooled air mass flow and produces the large bypass flow. Now this bypass flow of course, produces the cold bypass thrust. S o we have hot inner thrust and a cold outer thrust producing cold air.

And this combination goes out producing very large amount of thrust now this is often called unaft fan because the fan is not in front of the engine, but somewhat what is aware of the engine and the peculiarity of the engine is less of this particular design is that it does not have shaft to convey the power from turbine to the fan, but the power is directly conveyed from the blades of the turbines to the blades of the fans which rotate together on the same inner shaft. So that is third shaft here which does not convey power, but it simply runs the combination of turbine and fan together on that shaft, so it is basically a three drive one make all it three spool if one stow. And it is a kind of aft fan which means the fan is somewhat towards the wire of the engine.

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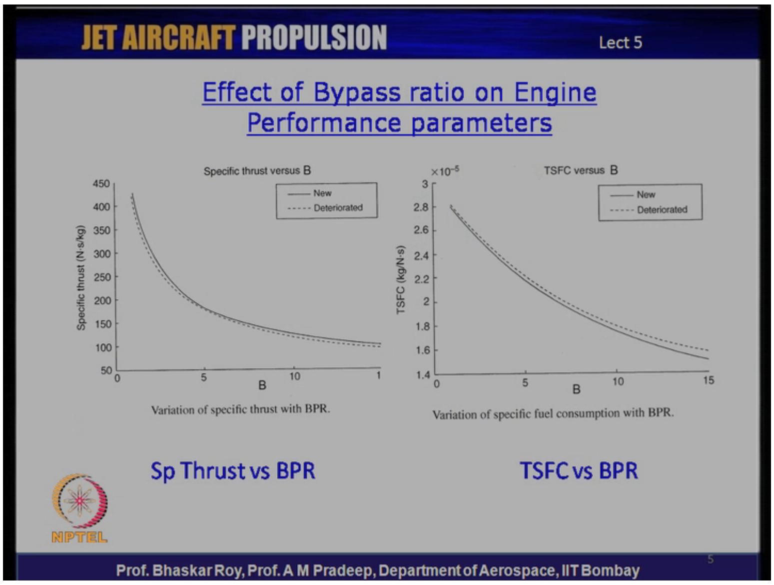

Let us take quick look at the bypass ratio benefits that normally comes you can see of the gropers specific thrust verses bypass ratio. As a bypass ratio increases this specific thrust comes down which means the thrust produce per unit mass flow is coming down. This is pretty much well known that if you increase bypass ratio your specific thrust production is actually go down so when you desperately needs specific thrust or thrust you go follow bypass engine and that is what is used in neutron aircraft.

But when you need thrust very high thrust at very high efficiency you go for high bypass, in which case specific thrust that is thrust per unit mass flow is not very high, so the lower end of the bypass is basically a thrust producing engine whereas, the higher end of the bypass is a very high efficiency thrust producing engine, so the two ends are use for two different purposes, one for military purpose, the other for commercial economic purposes. And that economic is showed on the right hand diagram here. The SFC is continuously following with the bypass. There is a dotted line here which shows that over a period of years of usage that thrust actually reduces slightly with over of usage where as the SFC actually may slightly improve with over a years of usage it of course, flows with bypass ratio, so at very high bypass you actually a very low SCF of turbofan engines.

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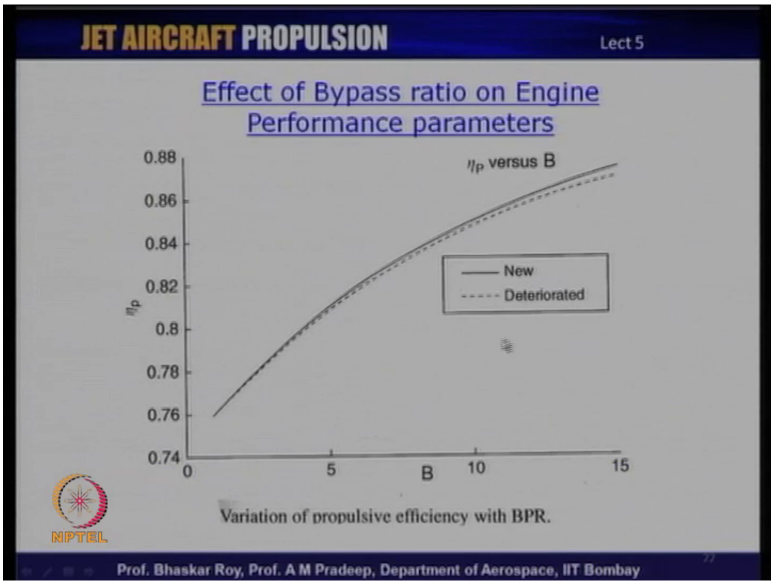

This translates to most prominently in the propulsion efficiency where the increase of a bypass ratio simply increases the propulsion efficiency to very high values as you can see here with years of usage it may slightly due to the rate but, still it produces very good propulsive efficiency computed with any other kind of jet engine that one can think of. And this is the reason why turbofan engine are used in all commercial jet aircraft today because it produces very high propulsive efficiency and this is the kind of engine that we would probably like to look at more and more. I will leave you today with one more engine which actually is called prop fan engine.

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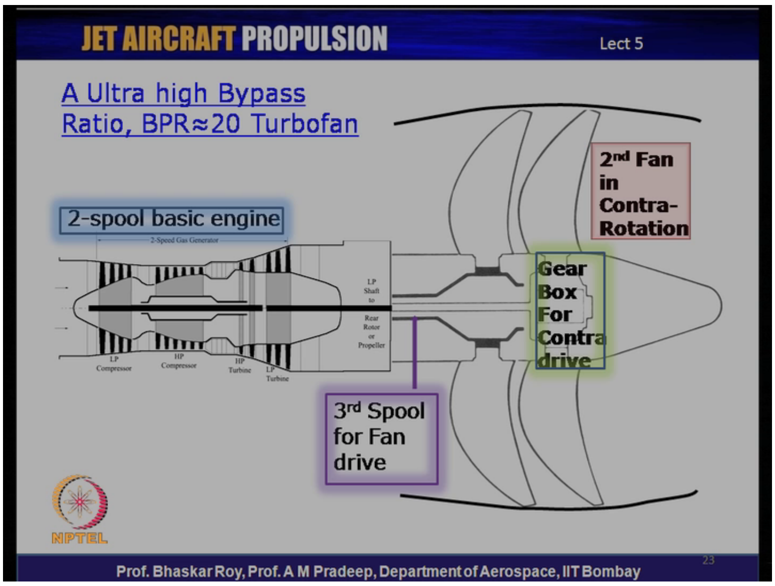

This is a very high bypass BPR or bypass ratio of order of 20. And this has huge big fans comparatively you can see the fan size is much bigger than the basic jet engine which is a which could be a two spool basic jet engine. And this produces a third spool which comes out it may run through a gear box because you may like to run the fans at a somewhat lower rpm. And one more variant is that the second fan over here you may have two fans running one after another similar to the two compressors running one after another. And if you have two fans it is entirely possible and it is been demonstrated that through the gear box you can run the second fan in opposite direction that is the counter rotation and if you do that you get a huge benefit in terms of thrust production and in terms of SFC.

So this is the kind of very high bypass ratio of prop fan that the fans are so big there almost approaching the size of propeller, but not quite and quite often even today. They are ducted with this kind of ducting because this ducting actually allows certain amount of noise separation and hence even today people would like to use ducts essentially to separates the noise that is created by this big fans or prop fans and hence in the noise is kept under certain amount of regulatory control. So this is a kind of big prop fan an extension of turbofan with very high bypass ratio some people call them ultra high bypass ratio turbofans or prop fans. So this is a kind of engines that you are likely to see more and more in years to come.

So those are the kind of various engines that we have looked at today, the various kinds of turbofan engines, the bypass ratio is going higher and higher making them more and more fuel efficient noise is being taken care of why various designs and if we do that we have more and more efficient engines coming up in the years to come to power there aircraft flight. In the next class onwards they will coverage of the basic aerothermodynamics of this flow through this jet engine that we have been talking about through the cycle analysis this will be covered by Professor Pradeep over the next few lectures. So in the next few lectures you will doing the aero thermodynamics analysis or the cycle analysis of all the engines that we have covered in the last few lectures.