Jet Aircraft Propulsion

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Lecture No. # 02

How the Aircraft Jet Engines Make Thrust

This is the second lecture on jet aircraft propulsion. We are talking about aircraft propulsion and we are talking about jet propulsion. So, when we talk about propulsion the only thing we are going to talk about in this course, in this lecture series is the jet propulsion. And we are going to talk about aircraft propulsion, so when we talk about jet propulsion, its necessary that we keep an eye on the aircraft also, because all the time, the propulsion is to meet the needs of an aircraft; and this is of course, very important that a propulsion needs to meet the needs of an aircraft at all times of flight.

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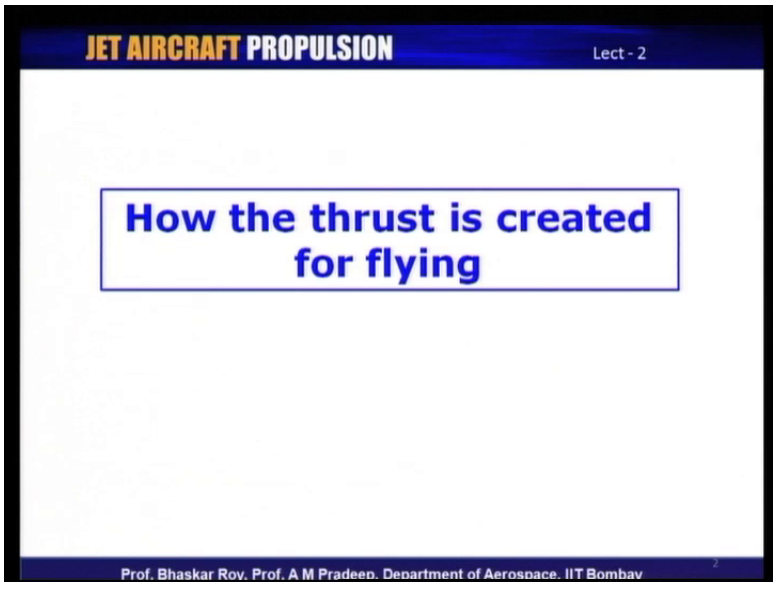

In this lecture today, we are going to talk about how the thrust is created to meet the needs of an aircraft, and for which we need to understand, how the jet propulsion system creates thrust; and of course, how it goes about to begin with meeting the needs of an aircraft. Now, aircraft is a flying body; so the need of the flight of an aircraft is to be met with the

propulsion system. Now the propulsion system that we are creating essentially is something which goes with the aircraft it is part of the aircraft; it is sometimes embedded within the aircraft, let us take a look at how the thrust is created for flying; flying is our main object. And thrust creation is essentially for the purpose of flying. Now for flying purpose the first thing that you need to do is of course, make the aircraft takeoff from the ground, now if you keep an aircraft on the ground, you need to produce a motion for it to move and only then it can takeoff.

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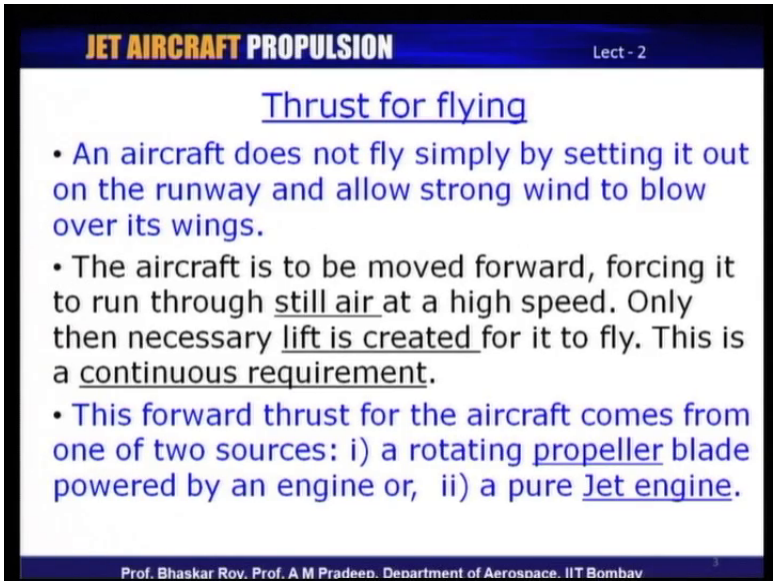

There is a old saying that if you just keep an aircraft on the run way an expect a strong wind to flow over the wings, so that lift can be created that is not going to happen. So the aircraft needs to be moved forward with a motion quite a good bit of motion at a reasonably high speed the take off speed of an aircraft is typically a higher or at least as much as high speed automobile and only then necessary lift is created for the aircraft to takeoff, which means that the point of takeoff the entire weight of the aircraft would need to be balanced by the lift creation, and for that lift creation, a certain amount of lift needs to be created by the motion of the aircraft.

Now this is the continuous requirement from takeoff to climb and various other regimes of the flight, so to meet this continuous requirement of thrust. The propulsion system that is created must provide thrust at all this operating conditions of the flight. Now the forward thrust that is needed to be created is essentially created by two fundamental methods one

which is with the help of a propeller, and propeller is what actually was used for flying the aircraft exclusively for the first 50 or 60 years of aircraft flight, and last 50 or 60 years jet engine has been used for aircraft a flight. Now of course, both the systems are available for aircraft propulsion. So we have a choice of two different kinds and in this course we will be looking more and more into the jet aircraft flying or the jet engines, and the other one the propeller we have discussed a little in one of the earlier courses so, we will not be discussing the propeller based flight system, but we will be discussing essentially the jet engine based propulsion system.

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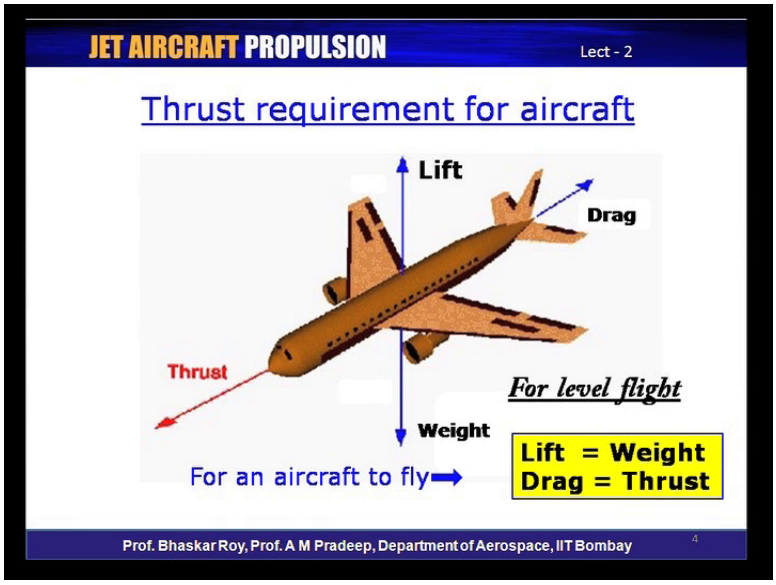

Now let us take a look very quickly at how what happens when an aircraft is flying, and when an aircraft flies the first thing that is required is its weight is to be balanced and this balance is created by the lift that is created by the shape of the body of the aircraft. Now typically the shape of the wing is created to essentially balance the weight of the aircraft this lift creation is dependent on the motion of the aircraft fairly high speed is required or high forward velocity is required to create the lift.

Now in the process of creating this forward motion the aircraft moves through the air and when it moves through the air it experiences a drag; the drag is the air flow over the whole body of the aircraft and which experiences certain amount of friction and as the resistances all this resistance is put together is drag of the whole aircraft. The requirement of thrust from the propulsion system is essentially to overcome the drag if at every point of your flight you

successfully overcome the drag at that particular point of flight. Then you are in position to create sufficient amount of lift to overcome the weight at that particular point of flight.

So at every point of flight whether it is a steady flight or any other kind of flight the balance of these forces is absolute requirement for the flight to be sustained, if any of these balances are not met the flight would not be sustained. If the lift is not created to balance the weight the aircraft is will fall off the ground if the drag is not met with thrust again the aircraft will either slow down or it will again a fall of the air. Now this is something which a needs to be met primarily then with the thrust creation which creates the motion allows the thrust allows the body to overcome the drag and create the motion and then the motion allows the lift to be created this lift is then used to overcome the weight of the aircraft.

And this is a continuous balance during the entire flight of the aircraft or any aircraft, so which means if you take any kind of aircraft every aircraft of its own as lift characteristics it as its own drag characteristics, so that particular aircraft will have to have particular engine which will meet its lift and drag characteristics under all flight conditions. So which means that every aircraft needs a particular kind of engine and unique engine and as a result of which lots of engines are required to meet various kinds of aircrafts small aircraft, medium size aircraft, large aircraft, low speed aircraft, high speed aircraft, super ceiling aircraft all of them need different kind of jet engines. Unless these jet engines are met and actually fixed on the aircraft during its flight.

And essentially design to meet all this requirements of the aircraft will actually not fly so, the prolusion system that we need is essentially to meet the unique requirements of the aircraft, and as a result every engine is essentially and unique engine is very rare that you have engines that are convertible or can we easily change from one version to another that is very rare most of the engines are an created or unique engines. For study a level flight we know that the requirement is that weight is equal to the lift and thrust is equal to the drag, now this is what needs to be achieved when you are flying straight and level.

Straight a level is when the aircraft is just crews and this crews requirements is that the whole four primary forces are absolutely balanced, when however you are making all kinds of other man over all kinds of other requirements of the thrust required sometimes a thrust requires to be more, when you are claiming that thrust required is more when you are descending the thrust needs to be a little less than what the drag is so that the flow aircraft slowly descends.

So, all this very settle matchings are required to be done during the flight itself quite often by the flight control system. And the pilot, and as a result of which, the engine needs to be created to create this slide mismatches whenever they required in a control manner. And these are the fundamental requirements of the propulsion system without which you cannot really have sustained control aircraft flight.

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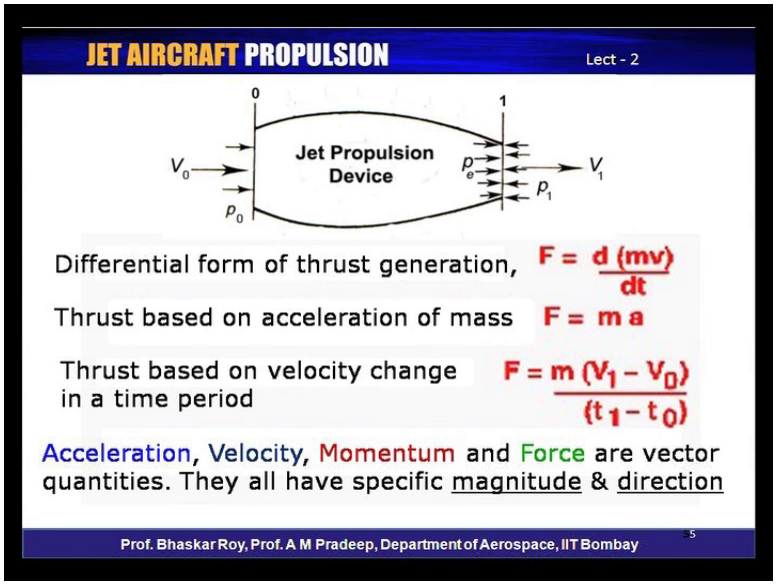

Now let us take a look at what are the fundamental requirements that the thrust generation needs to be a created. If you look at the thrust generation that needs to be done there are two or three fundamental ways of looking at it. One is you can have differential form of the thrust equation and that can be written in terms of the momentum change in a certain time, and this momentum change across the body of the propulsion system can be written down in terms of d m v d t and m v is the momentum and d m v dt is a rate of change of momentum which creates a thrust. Now d m v dt is something which means that you have to have a continuous control over the momentum change of the working medium as we have discussed in the last class.

The working medium in arcs list because is the air so we need to have continuous change of momentum of air through the propulsion system for the thrust v generated an at this is to be done at every instant, so at every instant the momentum change will create certain amount of thrust. The next way of looking at it is that you have acceleration of the mass a certain amount of mass that is available for thrust creation and this mass is accelerated by propulsion

system, so that is another way of looking at thrust generation. And this acceleration is measured through the propulsion system of the mass of air that is going into the propulsion system so acceleration of mass of activation is equal to the thrust generation.

The other simple way of doing it is the thrust is written down in terms of the velocity change in a time period the working medium that is air takes a finite amount of time for it to get inside the body of the propulsion system, and then after a certain small time it goes out of the body within this time system from t0 to t1 the velocity changes that a save from v0 to v 1. And this change in velocity of the mass of activation that is m over the time period from t0 to t1 can be said to v the generation acceleration of the entire mass of air or the change of momentum as we were written down before so, the earlier to can now we recast in a manner in which the change of velocity in a given change of time is now equated to thrust generation.

Now let us understand the fact that we are talking about you know quantities which are acceleration, velocity, momentum and of course, these are all vector quantities. And so the all of them have specific magnitude and direction, which means a thrust that is generated would in variably have a certain magnitude which we require and it will have a direction. Now this direction is important that direction in which a thrust is generated prima facie the aircraft will move in that direction so, directionality of the thrust is also extremely important because aircraft will move in that particular direction whenever we need to have a change of direction of the aircraft.

The thrust generation would need to be controlled and this control would have to be exhausted through the control system by the pilot, so that the aircraft motion can then be control so the direction of generation of the thrust is also an important issue along with the magnitude of direction of thrust. Most of the time when the aircraft is flying the magnitude of the drag is indeed rearwards, which means a thrust generation would have to counter that with a forward force. So the forward force of the thrust generation is essentially a counter to the rearward drag generation that occurs due to the motion of the aircraft. Now this directionality has to be kept in mind all the time during the aircraft flight.

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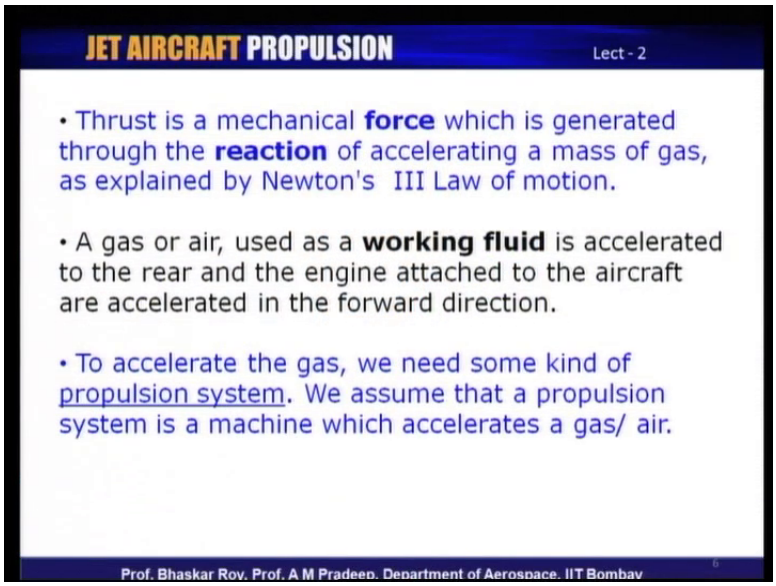

Now let us take a look at what happens when you have thrust that is generated remember the thrust is essentially mechanical force. Now it is generated essentially through what we now know as a reaction of accelerating of a mass of gas now this of course, happens as per Newton laws of motion specifically Newton's third law of motion and in the process we shall as we go along we shall see in fact all the laws of motion are essentially important or involved in the whole process of generation of thrust. Now the gas or air is the working medium which is used as a fluid and when fuel is burned inside the propulsion system we may called it gas so it goes inside the propulsion system as a pure air.

And then it goes out of the working propulsion system as a gas and then this is attached to the aircraft so, when the engine expressions or creates a force the force is transferred to the body of the aircraft by virtue of the fact that the engine is rigidly attached to the body of the aircraft, and hence forward portion is created. Now to created acceleration of the gas we have the propulsion system which we called jet engine. And we assume that a propulsion system is a machine, which a fundamental job of which is through accelerate the working medium which is air to began with an gas as it goes out through the propulsion system. So the propulsion system is fundamental job is to create acceleration of the working medium through this propulsion system now when that happens in a certain magnitude and in a certain direction we get thrust that is useful for flight of a aircraft.

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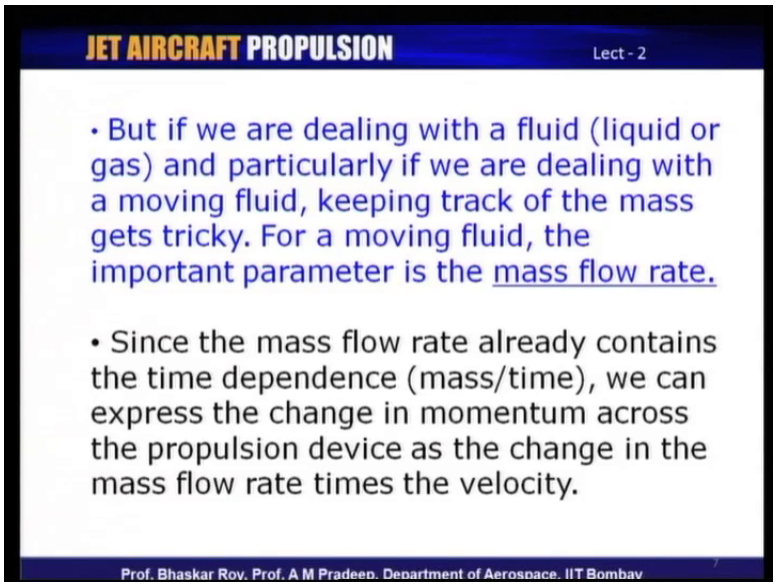

Now we are dealing with a fluid and we are dealing with moving fluid which is in our case air or gas and you are trying to keep track of them mass if you are required to find out the quantity of the thrust you want know what the mass of the working medium is keeping track of the mass is little quickly because it is gone inside to propulsion system has we shall see over the course of this lecture there are lot of things that are happening inside the propulsion system of the jet engine. And it is difficult to keep track of the mass per say so what quite of in we talk about is mass flow rate note the mass per say but, mass flow rate and hence important parameter in jet engine performance estimation is mass flow rate and we shall we talking about mass flow rate all along the course of this lecture series.

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Now mass flow rate as you know already contains a time dependency that means a mass of air over a certain period of time is what we call mass flow rate. And this time dependency is now build into the mass flow rate and as a result the momentum across the propulsion device can now we configure from the mass flow rate and the velocity change across the propulsion system and as a result of which we can say that if we have a measure of the mass flow rate and if you have the measure of the velocity change across the propulsion system we can have a measure of the thrust force that is generated by this propulsion system. So we shall be talking about mass flow rate and we shall be talking about velocity change across the propulsion system to take a measure of the thrust that is generated by this propulsion system.

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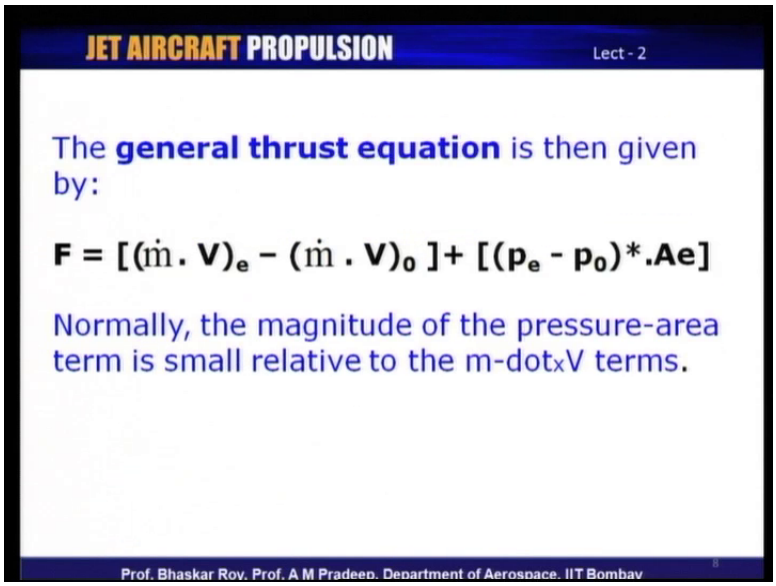

Hence we can know write down that the trust generated by the propulsion system can be written down in terms of thrust f which is m dot v substitute e which is exit or exhaust momentum minus m dot v subscript zero that is the inlet or incoming a momentum. So the first a term within the third bracket together create what is known as momentum thrust that is the change of momentum across the propulsion system can be called the momentum thrust, and this is what we are talking about earlier that the Newton's laws of motion essentially point towards creation of this momentum thrust, due to the change of momentum across the propulsion system and as we have just seen m dot across is the mass flow rate through the propulsion system and v is the velocity had a particular phase.

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In this case the v is the velocity of the exit phase and v zero is the velocity at the inlet phase and the different between the two together give as what is known as thrust or most specifically momentum thrust. Now m dot can change slightly from e two 0 to e because fuel has been added some are inside the propulsion system, so that small addition of fuel could make a difference of m dot between 0 and e. And that difference would have to be factor into this calculation to get a more accurate estimation of the momentum thrust. The second term that we see here is the pressure differential at the exit phase now p 0 is the pressure that is the ambient pressure existing outside the body of the propulsion system p 0 was there when the

air came in p 0 would be ambient pressure, when the air or gas is going out to the propulsion system.

And this differential creates a certain amount of thrust a static thrust at the exit phase so, it is multiplied by the exit area of the flow and this static thrust is an amount of thrust that is created at the exit phase of the propulsion system. And this is something which is often the case when p e is not equal to p 0 or p ambient and this differential creates what is known as the static pressure thrust. And this pressure thrust is created when award the momentum thrust is not maximum let us understand these very a little more when the momentum thrust is maximum then entire momentum changed across the propulsion system would happen.

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When the momentum thrust is maximum the thrust is indeed going to be maximum. So let us remember this that the momentum thrust is what are aim is sometimes quite of an during the flight you do not have maximum momentum thrust, but you get certain amount of momentum thrust and a small amount of pressure thrust. And this pressure thrust is created because the exhaust pressure is slightly on the higher side than the ambient pressure it is entirely possible that under certain circumstances. The exhaust pressure maintain to go below the atmospheric pressure that is something which we would not like to happen, because from this equation you can see that insertion event the second term would actually be negative it will be contributing negatively to the creation of thrust. And we certainly do not want that and hence we should ensure that the second term is positive or zero and should never be negative, so we need to keep an eye on these two terms for creation of thrust.

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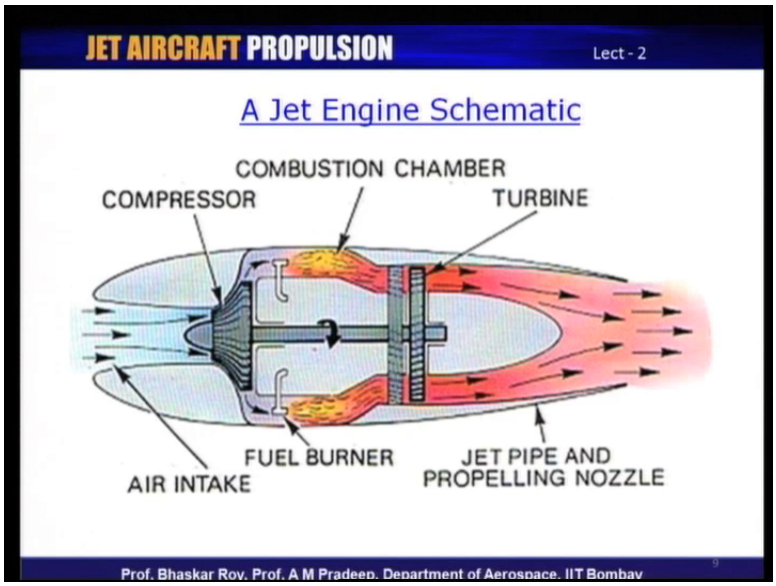

Let us take a look at a simple jet engine device we have a compression we have a compressor chamber inside which we have a fuel burner and which actually injects a fuel inside the compressor chamber and the burning of the fuel creates the hot gas, which is a mixture of air and burned fuel and then this hot gas goes to the turbine and then goes out in a jet and then this jet has high kinetic energy of momentum. And hence the momentum change across this entire jet engine is created by the fact that the hot gas actually has the momentum substantially higher than the incoming cold air; the cold air that is coming in here is without any what being done upon it now the work is done upon it first by the compressor which raises it to high pressure then the fuel burning raises to high temperature and then this high temperature and high pressure gas goes to the turbine and then it the turbine extracts work out of it to run the compressor. So turbine in compressor essentially have some kind of a closed loop within which certain amount of energy is continuously exchange so certain amount of energy is taken out of this hot and high pressure gas to maintain this compressor turbine loop and then the remainder of energy is then let out through the exhaust and that creates the high momentum jet. So a certain amount of energy is always into this compressor turbine loop and it is been continuously taken out of this high energy gas and remained there of energy is continuously going out as a jet for continuous creation of thrust so this is the fundamental mechanism by which a jet engine actually works.

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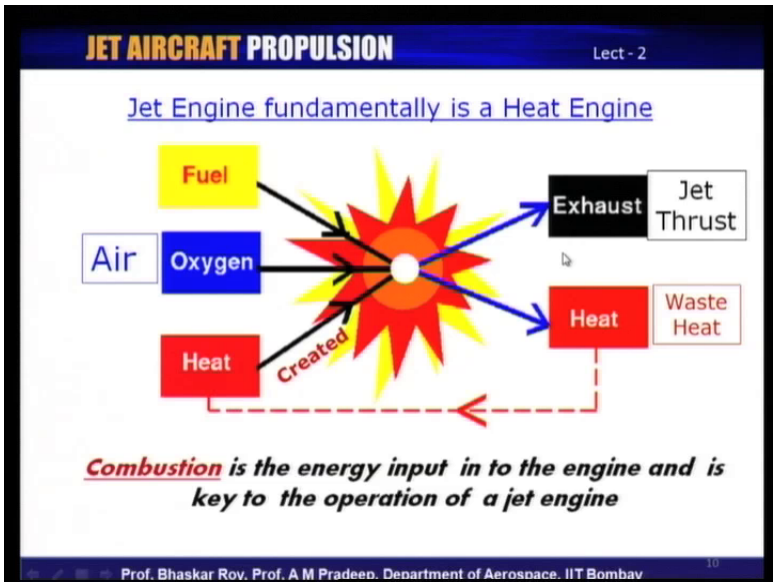

Now there are various version of jet engine let us take a quick look and see, what is the fundamental concept of a jet engine. A jet engine is fundamentally a heat engine; let us remember the fact that we are dealing with a some kind of a heat engine there is no question about the fact that it is based on fundamental concepts of a heat engine, which indeed existed many of which indeed exited before the jet engines came in so all kinds of heat engines the i say engines the pistol engines, the steam engine that have a existed before that where fundamentally heat engines. So the concept of making an engine by using heat is something that was known to mankind well before the jet engines came in and the theory of the heat engines have existed from more than hundred years.

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And in the course of this lecture we shall be doing certain amount of concepts of thermodynamics and concepts of aero thermodynamics and how to deal with this fundamental issue of heat engines would we covered in the course of this lecture. Today let us take a quick look at the fact that a jet engine is a heat engine and what happens to execute a heat engine we need a process of combustion and to do the process of combustion we need oxidizer.

And we need fuel because a process of combustion is fundamentally a process of oxidation and so, we need oxygen which in our case is being supplied by the air is available in the atmosphere and that is the fundamental supplier of the oxidizer fuel is the amount liquid fuel

that we carry with the aircraft; and it is injected in through the propulsion system in the compression chamber mixes with this air; and creates the hot gas through the process of combustion.

So the process of combustion essentially when the fuel is burned mixes with the air it creates heat and this heat is created in the combustion chamber. This is the fundamental concept of heat engine that heat needs to be created by burning of the fuel and burning of the fuel provides the fundamental energy, which use than converted to some form of work this heat converted to work is what we called heat engine.

And this heat engine is also used as a concept for jet engine so fundamentally we are talking about fuel being burned in a compression chamber for creating heat. What is done in a jet engine is this heat is then mixed with a working medium air; and air is elevated to high temperature and high energy gas is then exhausted; and then we get a jet thrust now in the process of creating the jet thrust a good amount of heat is also exhausted with the exhausted air.

And this is actually a waste heat so that this heat is essentially wasted an it has no other use what so, ever and as a result of which the jet engine suffers a little in terms of heat efficiency or thermal efficiency; and we shall have a measure of some of these things as we go along in the course of this lecture. So combustion is the fundamental issue of jet engine operation and it is the it is the only energy input into the engine; and that energy is what is hardness in creating thrust so remember combustion is the energy input and that energy needs to be hardness in some manner through the propulsion system in creation of thrust. So our energy input into the system is actually combustion then how we if use the combustion generated heat is what this lecture series is all about and finally, we create thrust for flight of aircraft so this is what we are going to talk about in the course of this lecture.

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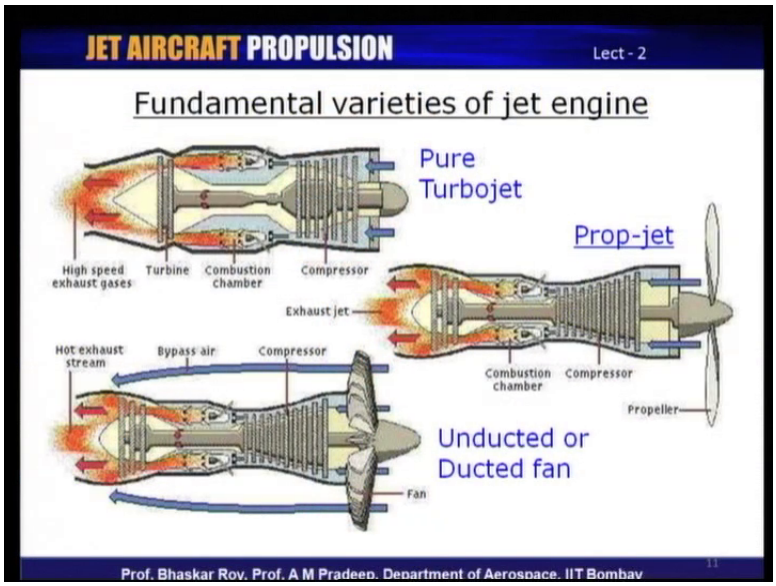

Let us have look at various kinds of jet engines that we will taking about over the course of this lecture, now in the last lecture Mr.Pradeep had told you that there are so many kinds of a jet engines. Let us take a quick at a few of them and we will quickly discuss what we will talking about over the course of this lecture. The first kind of a jet engine is what is also known as pure turbojet or simply turbojet; and this is what the main turbojet comes from the flat that it as a turbine and this turbine is essentially what is running the compressor; and that turbine compressor is raising the air to a high pressure which is then used in the compressor chamber to burn fuel.

And then this high energy that is high pressure high temperature gases let out and hence we it is a turbine based jet engine and hence it is called a turbojet engine. The next variant that came along historically is what is also known as prop-jet engine, and this is the kind of engine in which of fundamentally turbojet engine or turbo engine is essentially used to actually drive a propeller, now propeller as we know as been around for more than hundred years for making thrust for the aircraft. But in this case gas turbine based engine is used to run a propeller and creates thrust.

So in this prop-jet version you get good amount of thrust from the propeller what you get certain amount of thrust from the jet and hence it is often called a prop-jet engine. The other version which is the most modern version of the jet engine is the fan engine or turbo fan engine, which has two different versions one is the unducted fan and other is a ducted fan.

Most of the turbo fan engine is that you see today are ducted fan engines there the big fan that you see is in front here is covered a inside duct and we shall see more of them as we go along in this lecture; and some of the most modern versions that are coming up are likely to fly in future are the unducted versions in which the big fan is unlikely to be covered with a duct so, there are simple called unducted fans.

If they become little bigger than jet a fan sometime they are called prop-fans these are been mentioned in the last lecture. We shall be looking at some of these versions as we go along and we shall we have already seen and Professor. Pradeep as already said that turbo fan itself as a number of variants we shall be looking at some of these variants also as we go along. Now in this particular turbo fan version what happens is after the fan the cold air bypasses the main engine and goes out as a separate jet or a cold jet, where as the main engine takes in the flow from the fan it takes it through the compressor and it takes it through all the combustion chamber, turbine and let it out as a hot jet.

So in a typical turbofan you have two jets a cool jet and a hot jet. The cool jet creates substantial amount of thrust in some versions of turbo fan actually the cool jet creates more thrust than the hot jet. And we shall be talking about some of these variants as we go along we may be actually even doing a few problems to actually quantify some of these thrust creations of certain particular kind of turbo fan or turbojet engines.

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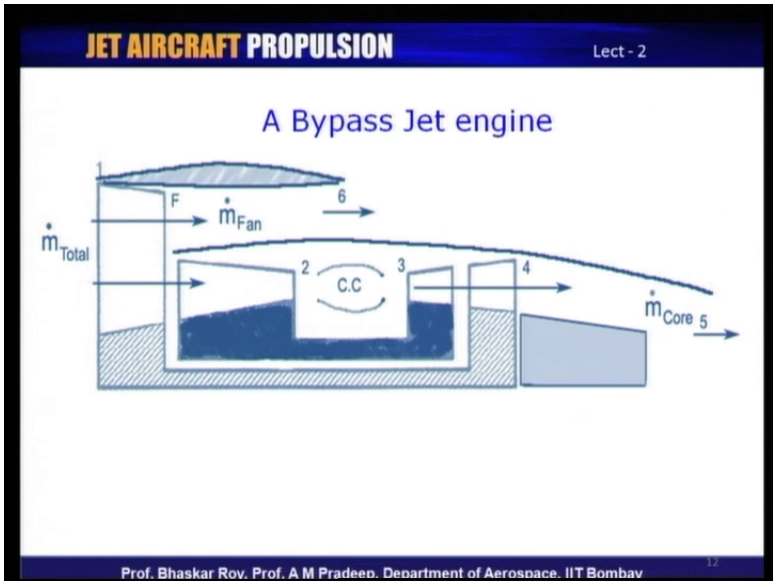

So these are the variants that we will talk about; and these are the three fundamental variants of various versions of jet engine that are flying around today for a flying the aircraft. Now let us take a look at what is simply known as a bypass engine typically has a fan in front of it and this fan actually pressurizes the air, which is coming in from the front and as the air is pressurized this pressurized air itself is a let out as a cool jet, so that means the cool jet itself as a certain amount of pressure and this pressure is sufficient to create a cool jet. The rest of the air or the core air as it is quite often known goes through the process of compression combustion chamber and then turbine and then it goes out through the jet or core jet as a hot jet and as a result it creates a hot thrust.

So bypass jet is quite often used to have two kinds of jet the cool jet and the hot jet and this is what is often what we call also turbo fan, so all turbo fans are typically bypass jet engines and we shall see some are within them they are various variants of bypass jet engines. There has been a bypass jet engine, which was not at turbo fan which was a supersonic jet engine and in this supersonic jet engine the air was bypass after the intake and the intake created the pressurization at supersonic speeds and as a result the supersonic intake pressurization created sufficient pressure to create a bypass system. This was used in concede engine earlier however that particular aircraft and the engine as now been retard from service, and that particular kind of engine is no more in action. So all the bypass jet engine that we will be seeing are essentially some version or other of turbo fan engines.

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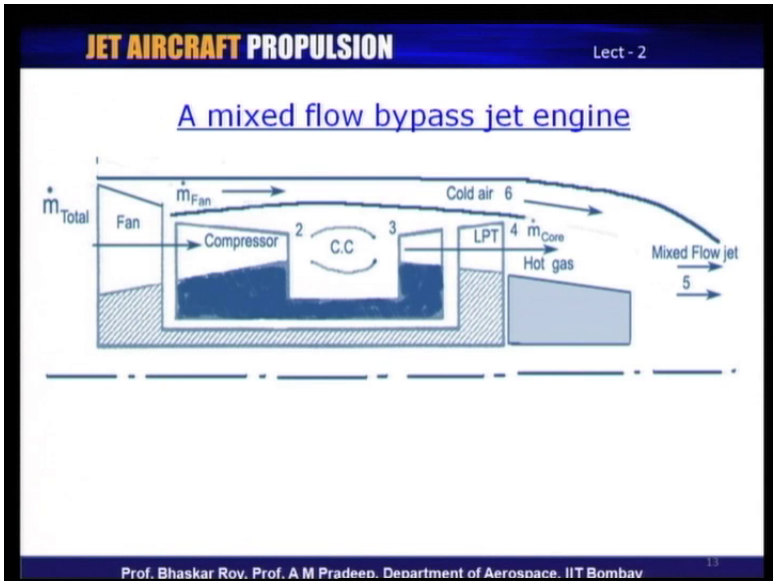

Now, this is what we call mixed flow bypass a jet engine where the cold air does not create a thrust of its own the cold air bypasses the main engine; and then towards the end the entire bypass is also covered and under the cover it is guided or to the exits towards the exists exhaust of the jet engine where it mixes with the hot gas.

And the mixed flow is then let out as a jet exhaust so we have mixed flow jet which is coming out of the exhaust a combination or a mixture of hot and cool gas and this is often used as mixed flow bypass jet engine these are often are used in flow bypass jet engines and quite often we shall see that these are fundamentally or typically used in various versions of military aircraft. So mix flow engines are normally used in military aircraft where as the earlier one that we saw the bypass engine which is unmixed flow let say use typically used in various kinds of transport or passenger aircraft. So these are the two fundamental variants of turbo fan bypass engine that is used in aircraft all over the world in various kinds of aircraft.

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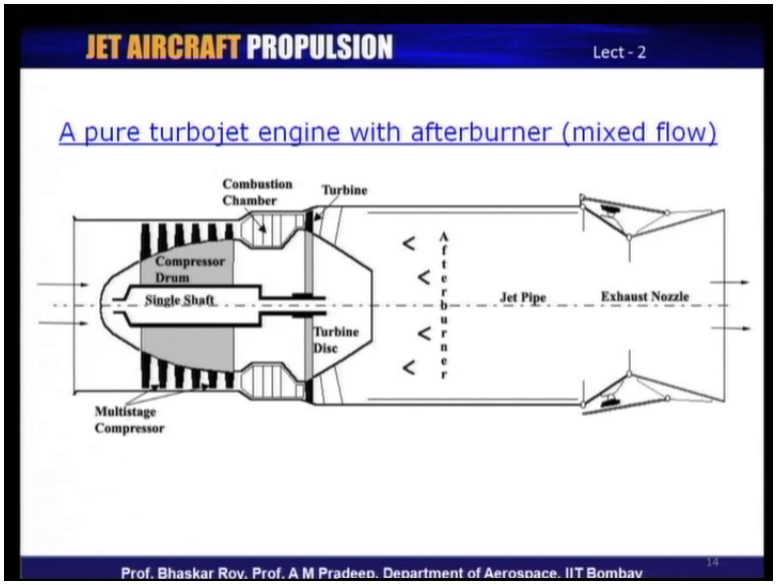

Let us take a quick look at the pure turbojet engine and this is with afterburner now one of the reasons. I am kind of show you pure turbojet engine with afterburner is because they are very few engines, now hardly any in which your turbojet engine works with out after burner so, all the engines a turbojet engine that are working today are essentially with afterburner. Long back turbojet engine used to work without afterburner most of the turbojet engines pure turbojet engines that work with afterburner however this engines can work when the afterburner is switched off.

So these engines can work in two modes with afterburner or without afterburner. Now let us take a quick look at how they function the flow come into the compressor its gets compressed to high pressure it goes to the combustion chamber fuel is added heat is added so, now we have a high pressure high temperature it goes to the turbine as we have seen runs the compressor and then this is the loop, that we are talking about the turbine compressor energy loop. So certain amount of energy is continuously going into the loop and then the rest of the flow with the rest of the energy balance of the energy is now going into this long jet pipe inside which there is an afterburner. The job of the afterburners is raise to temperature of the this gas again because turbine is taken out some of the energy.

So it is to reenergized to high energy all over again and then this elevated energy gas is let out through a exhaust nozzle so, whenever we have a afterburner which your technically quite often is a to reheat. We would almost invariably would have exhaust nozzle which would be looking something like this and this is a convergent divergent nozzle so, when we have pure turbojet engine with afterburner we also invariably have a convergent divergent nozzle; and we shall be talking about these kinds of nozzles are various kinds of nozzles in the nozzle chapter in this lecture series later on. So the jet is created at high speed after get letting it out through this exhaust nozzle and this is how the thrust is created in a pure turbojet engine.

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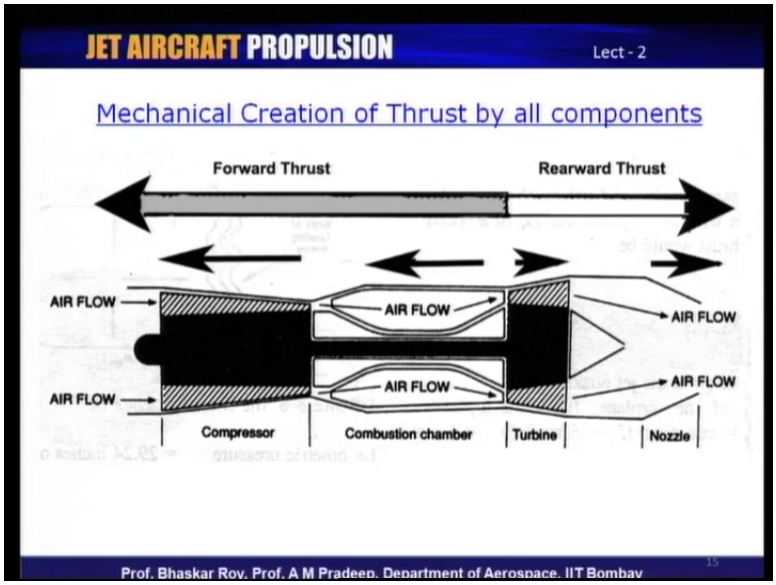

The mechanical creation of thrust is slightly different from what we are talking about we had looked at the thrust equation in which, we say the thrust is created by the overall change in

momentum across the entire propulsion system. What we shall see now is thrust is indeed created by all the components; and all the components that we are talking about the compressor of the combustion chamber at the turbine the nozzle all of them actually participate in the process of thrust. If you considered it as a mechanical force and this mechanical force is indeed created by participation of all the components.

Now in this we just try to show that the compressor actually creates a positive thrust that means a forward thrust by virtue of the fact that the pressure of the gas at the rear is higher. So, simple fluid statics will tell you that high pressure will exhaust a forward force towards the front. The combustion chamber also on the other hand experience forward thrust is most slightly to experience a forward thrust, and then the turbine is a most slightly to experience a rearward thrust which means the pressure over here is actually following so, pressure at the beginning of the turbine is higher than the pressure at the exist of the turbine and this again from fluid statics you would know would create thrust in the rearward direction. Now it is a same in the nozzle where the pressure is actually following by version of the fact the flow is an expanding flow it is the pressure is continuously following so, the fluid statics will tell you that the inside the body of the nozzle the force experience would is lightly to be rearward of course, as a flow goes out the reaction force form the jet is the forward thrust. So all of it together we should be getting set amount of forward thrust so, when you compound all the forward thrust and all the rearward thrust together, the some of the tool should give us the net forward thrust which is what will make the aircraft fly. Let us take it to typical example of how the forward thrust may be looked at.

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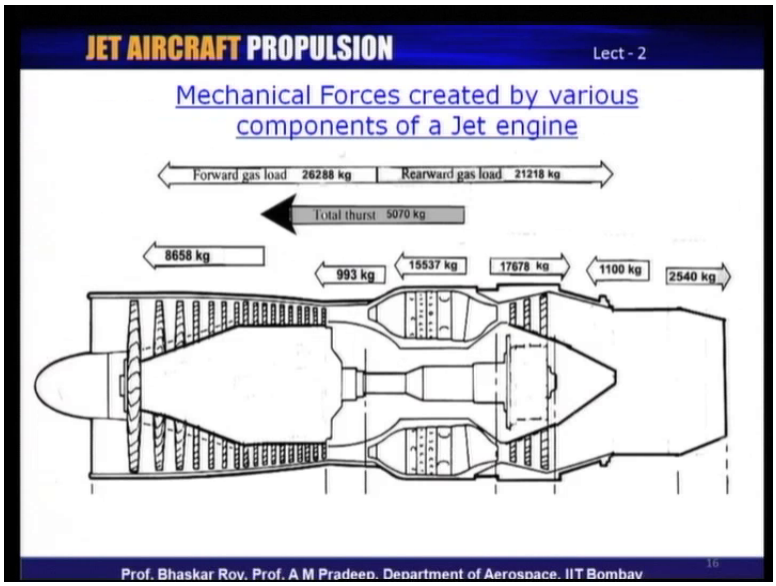

If you take a typical example we shall see that certain amount of forward thrust is created by the compressor certain amount may be created by the duct in between than as certain amount of thrust is created for the combustion chamber by virtue of integrating all the pressure inside the shape of the combustion chamber. This is rather complex process and if you can do that successfully you get certain measure of the thrust actually created by the combustion chamber itself.

And then of course, you have the thrust created by the turbine by virtue of the fact the flow is expanding through the turbine for creating work. And then of course, you have the jet pipe which it variants a certain amount of thrust which may actually be forward thrust and then the nozzle the body of nozzle; the inside body of the nozzle again if you integrate the pressure inside you almost likely to get a rearward looking force. So when you put all the forward gas loads or forward thrust of created by the movement of the air or gas inside the body of the propulsion system. You would get this much of forward and gas load or forward thrust and this much rearward gas load or rearward thrust and the combination of the some of the tool is what we call total thrust or net thrust that is created by this jet engine.

So its complex process by which the thrust is indeed created and to get a measure of it is quite a complex process so, we have simplified the whole thing by saying that the momentum change across the whole engine gives as the thrust which is a reasonable good thrust cut measure of how much thrust is created. A more regress method is what we are looking at right

now and as you can see it is a pretty complex process by which you get a very regress; and more accurate estimation or what the thrust is lightly to be the first cut measure that we have talk about, and we shall be talking about through the course of this lecture is a reasonable accurate measure of the thrust that is created by the jet engine; if you now take a look at the various fluid pressures that are existing inside the body of the propulsion system.

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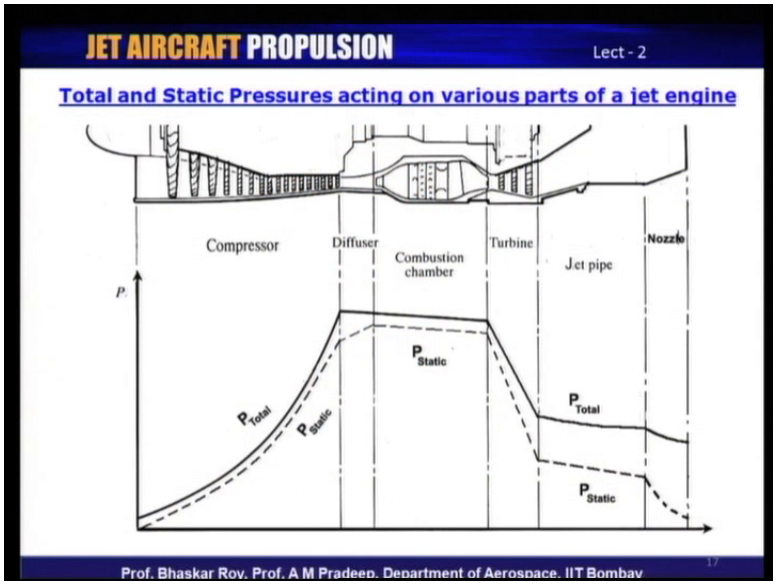

It will tell us why this component gas loads are been created the component gas loads are obviously created by the existing pressures inside the body of the propulsion system. Now this propulsion system as a gas or air to begin with which becomes gas later on and it flows through the engine and it experience is change of pressure as it flows. Let us take a look at the change of pressure, that is occurring the pressure that change that is occurring it under goes a huge change of a pressure through the compressor then it has small diffuser, and then it goes through a combustion chamber, and then it goes to the turbine it losses the pressure, and then it goes through the jet pipe in which continuously losing its static pressure; and in the nozzle it losses the static pressure very fast and the different between the two of course, is that nozzle which creates the jet velocity which we say this actually giving as a reaction thrust.

So this is the process by which indeed the gas force is gas path is executing inside the jet engine and finally, letting out the jet exhaust allowing us to get the measure of the thrust. It is possible to actually very rigorously find out exactly what is happening and when you do find

out it is possible to accurately estimate the thrust that is been created in the process of this execution of this path of the gas through the jet engine.

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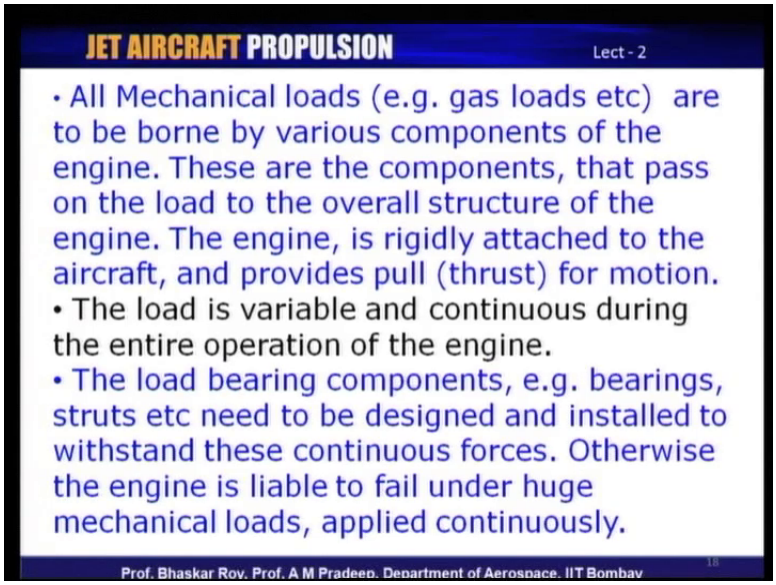

So all the mechanical load that are being bond by the components of the engine are indeed to be actually bond by the various mechanical parts of the engine, and as a result they have to be mechanical design to which stand this forces you have bearing struts, and many of the mechanical components they have to bear this forces which are coming on the various parts of the engine and these forces are then passed on to the aircraft.

Now these loads are variable and they are continuous during the operation of the engine that means during the entire flight of the aircraft and they are variable, which means loads are varying they are going up going down depending on how much thrust is being created and they have to be with stood all this time during the operation. The load varying components which are the bearings struts they have to be design to which stand these variable loads, and install to which stands this continuous forces because, if they do not when you have transients when the load is suddenly going up when aircraft suddenly executing acceleration. The thrust is suddenly more and these loads have to be bound by the various components only then you pass it on to the body of the engine, and then on to the body of the aircraft for the aircraft to actually a executed its motion.

So, this load bearing component would have to be design to withstand this mechanical loads on a continuous basis, and as we see this loads are actually variable loads. So the mechanical

design of this components is another business we will not be talking about those things in the course of this lecture, but remember there is a whole out of the mechanical engineering and mechanical design inside this jet engine, which we will not be talking about in the course of this lecture.

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Let us take a look at some of the issues that are involved here the thrust that needs to be created we have take off we have climb we have cruise we have various maneuvers we have acceleration and deceleration, and then the aircraft as to descend and then finally, it as to land.

So during this various processes the thrust that is created would be different during takeoff it needs to be maximum thrust during climb it is likely to be slightly reducing during the process of climb. Cruise is normally a very low thrust that is why you cruise there during maneuvers you have variable thrust during acceleration and deceleration it is variable to execute the acceleration and deceleration of the aircraft, and then descend you are normally descending at a low thrust and during landing you have slightly lesser than the maximum thrust to balance the weight of the aircraft. So all these requirements of the aircraft fly wood have to be met by the propulsion system; and only then you have a propulsion system that is actually useful to the aircraft.

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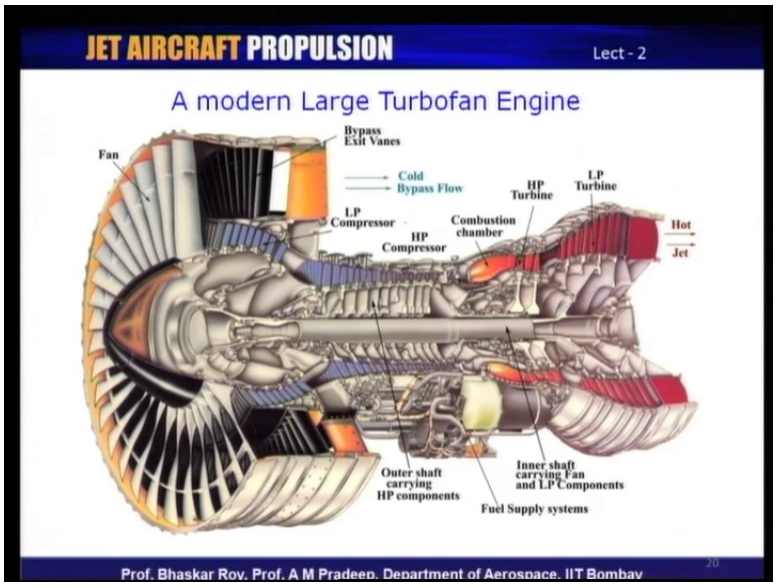

Let us take a quick look at a modern jet engine in which you have the compressors you have big fan over here you have a whole lot of compressor system, and then you have a two groups of compressors one is the low pressure in which the average pressure is rather low hence it is called low pressure. And then you have high pressure compressor where the average pressure is high.

And hence you have high pressure compressor you have the combustion chamber and then you have what is called a high pressure turbine because the average pressure air is high and then you have low pressure turbine, because average pressure here is low and then you have hot jet and you have cold jet so you have cold jet and you have hot jet. So this is the typical turbofan engine how much the cold jet is and how much the hot jet is decided by the so called bypass ratio, which we will be talking about in the course of its lecture a little later in one of the lectures.

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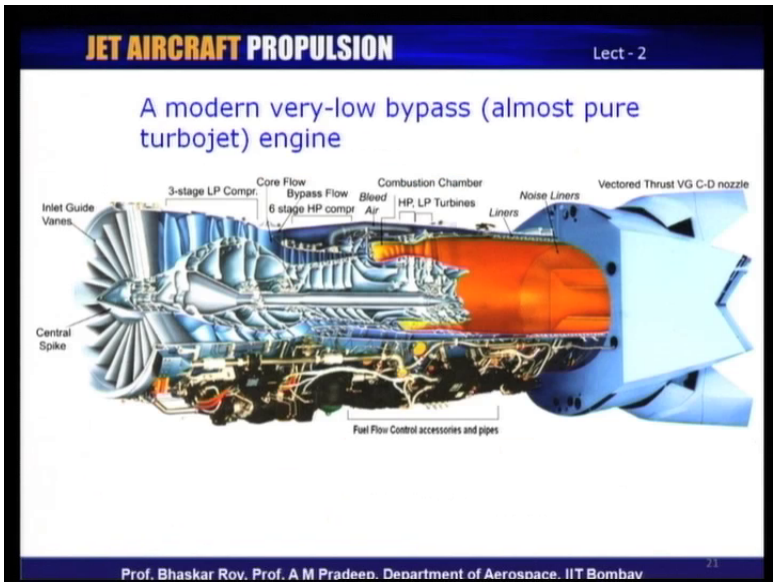

And then you have the very low bypass engine in which it is almost pure jet engine a very small amount of air bypassed which is very small really most of the air goes to the compressor system through the combustion chamber and a hot jet, and then a very small bypass later on mixes with this hot jet and goes out through very complex C D nozzle; very complex nozzle system we shall be talking about some of these things later on in this course.

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So this is the kind of very modern low bypass a nearly pure jet engine which is used for will aircraft. So these are the kinds of a engines that we will be talking about and we will be talking about what is happening inside this through the compressor through the combustion chamber through the turbines and through the nozzles in great detail in the course of this lecture. In the next class will be talking about some of the jet engine performance parameters when you want to have a good idea about how the thrust is created, how the thrust is to be calculated we need to set down the parameter that will be talking about we talked about mass flow parameter. And now we will be talking about all the other parameters that you need to quantify as accurately as possible to get a measure of the thrust that is created to get a measure of the fuel efficiency with, which the engine is operating and as a result of which we need to create a number of parameter with the help of which we can have a good estimation of the performance of a jet engine, and this is what we will be doing in the next lecture .