Introduction to Aerospace Propulsion

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Module No. # 01

Lecture No. # 03

Development of Jet Propulsion for aircraft

Today, in this third lecture of this series we will look at some of the jet engines that have developed over period of last 60 years and have powered various kinds of aircraft flying around the world. This is generally referred to as jet propulsion.

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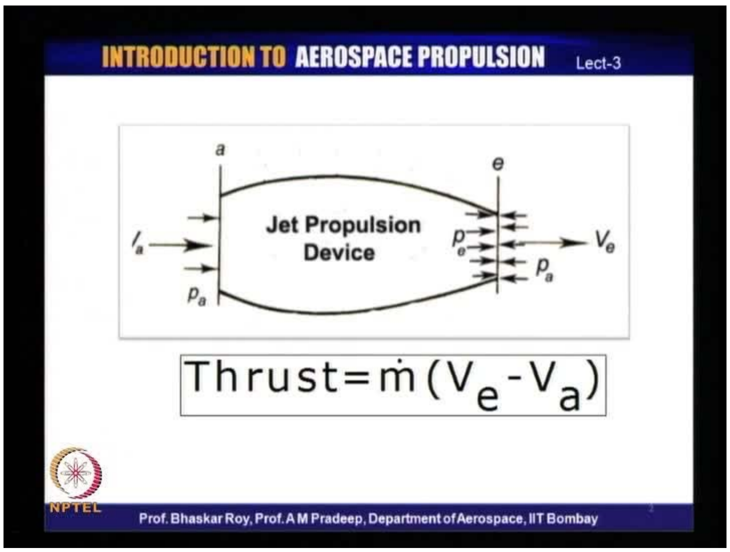

The basic concept of jet propulsion comes from the simple concept or an idea that if you have a device in which a certain amount of working fluid and in our case this working fluid is almost, invariably air. As a result of which, all jet propulsion devices that we are talking about are essentially air breathing engines. These air breathing engines have propulsive method by which this is illustrated in this picture.

In this method, the air is inducted into a propulsive device and this working medium is then accelerated through the device and the air is exited from the device with slightly higher velocity. As a result of this the working medium actually acquires a change of momentum. This change of momentum is what finally manifests itself, in the form of force or more specifically the action of the exhaust jet. The propulsive device creates the reaction, which is the propulsive force or what we would more specifically we always referring to it from now onwards as thrust.

The thrust is a result essentially or a reaction to the change of momentum that occurs across the propulsive device. This is the basic understanding on which all propulsive devices that we are looking at today would be essentially based on. Now, this requires that the air which is again our working medium going into the propulsive device has certain properties in terms of pressure, temperature and velocity. It goes out with another set of properties again another set of pressure, temperature and velocity. A change of these properties is what produces the change of momentum.

Basically, the change of momentum that we are looking at refers to the change of velocity; velocity as you know has a magnitude and a direction. The direction as shown in this picture, in the same line that means the incoming velocity and the outgoing velocity are exactly in the same line. As a result of which the action of the exhaust velocity and the reaction produces a thrust in the same line in which the velocities have come in and gone out. As a result of which a thrust is produced in the line of action of the production of exhaust velocity or exhaust jet more specifically.

Now, as you can see in this picture here, the flow goes out with a certain pressure which is more specifically a static pressure. This pressure if we call it P e as the P exit pressure may be equivalent or may be different from the pressure that is existing outside in the atmosphere, which we refer to as P a. Now, in this particular instance at this moment, we are considering that the exit pressure has indeed reached the atmospheric pressure P a by the time it exhausts from the propulsive device.

As a result of which at the phase marked e at that particular station the difference between the two pressures is 0. Hence, what we get? A thrust dependent only on the change of momentum and are often referred to simply as the momentum thrust.

Now, this is a very ideal condition; we shall see later on, just little later. Today, in case, your exit pressure P e happens to be different from the atmospheric pressure P a we would have a thrust value, which would look somewhat different from what we are looking at right now. We will come to that in a few minutes.

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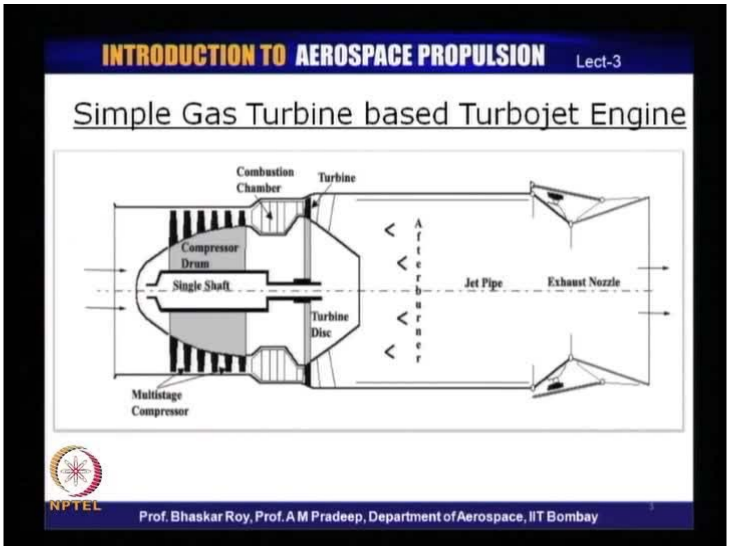

Let us look at a real propulsive device. What we had just looked at is an ideal concept of a propulsive device. If you look at a real propulsive device or what more specifically can be called a gas turbine based turbo jet engine. We have number of components here. We have as usual the air coming in, we have the air coming in from this end that is often referred to as the intake and this component here is a common element in all kinds of jet engines that you have to have some kind of intake at some point of time; later on maybe we will discuss the importance of this intake. Then, the flow goes through a process of compression through a compressor.

So, this is a compressor and in which the flow actually gets compressed or the pressure actually goes up and then we have a combustion chamber in which the flow actually, acquires burning fuel.

The fuel is burned into the air and a mixture of burnt fuel and air then is passed on to the turbine. Turbine extracts work from this hot and compressed air or gas and part of the work it extracts is now passed on through the shaft on to that compressor. So, the turbine takes out certain amount of energy in the form of work and runs the compressor.

Compressor does the compression, passes on to the combustion chamber, so there is an energy loop here. Through the turbine and compressor certain amount of energy is continuously looping, this is necessary for sustenance of this engine. So, certain amount of energy that is actually in the gas over here is used to continuously sustain this loop.

Balance of the energy that is available now, which is hot and which still has sufficient amount of pressure is now passed on through a various kind of conducting system. Then finally, through a jet nozzle which then exhausts the flow in a jet with a high velocity.

Now, the engine that is shown here, you can see here, an element called after burner; we will probably have a chance to discuss the details of this little later. As the name suggests, you have another round of fuel burning over here and the temperature of the gas. This gas may be raised to even higher values and then only it is exhausted through the nozzle (Refer Slide Time: 08:37). As a result of which quite often, you end up getting a higher amount of thrust. So, these are additional options that some of the jet engines have; not all the jet engines.

Many of the jet engines do not have any after burner. So this is an optional item; quite often it is used during for the military aircraft engines and most of the civil aircraft engines do not have any kind of after burner.

This is a kind of a sketch or a layout of a real engine in which it passes through various components. Let us go through them quickly again (Refer Slide Time: 09:15). You have a compressor, you have a combustion chamber which actually burns the fuel and inputs the energy from outside. Then, you have the turbine and then it goes through a jet pipe and then through exhaust nozzle. At the end of which you have a net increase of velocity and more specifically net increase of momentum of the air that has come in. As you can see, once the air comes in through the intake it has nowhere else to go, it has to go through all the components and exit through the nozzle; it has nowhere else to go.

The amount of air or the mass of air that comes in here would be approximately same with the addition of fuel. There will be a little more that exists. Finally, from the propulsive device that is through the nozzle and that produces the change of momentum. This change of momentum produces the action, which of course, as we have discussed, produces the reaction which creates a thrust.

So, this is the process through which a real engine actually operates. We shall be talking about these processes more and more as we go along. The understanding that we have from the previous diagram and from the present diagram is that a certain amount of air mass is captured, it is processed through various processes and then it is exhausted in a jet at a higher velocity with a higher momentum and that creates a thrust.

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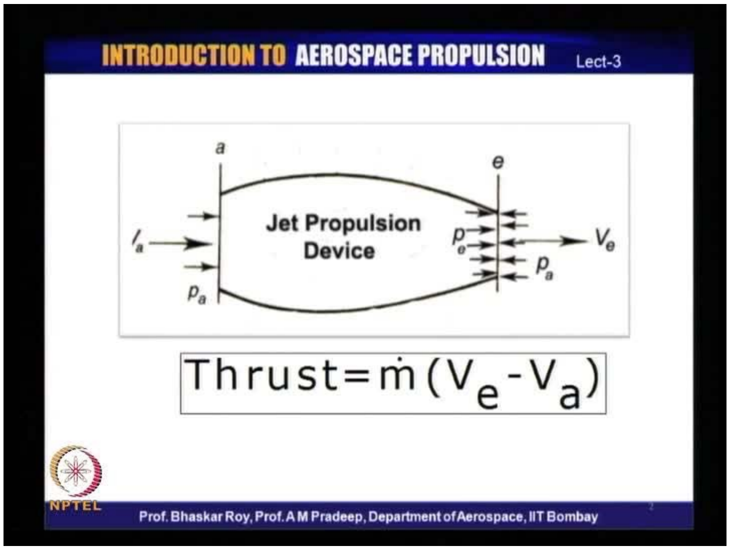

Now, this is the understanding which we have based our idea that the thrust can be created through the reaction process. It is easier to understand it that way; it is easier to put it in simple mathematical form as we can see here, you can write down the thrust equation here based on the mass flow as we are talking about. The change of velocity from intake velocity or air velocity to the exit velocity and that gives you fairly accurate mathematical estimate of the thrust that may be produced by the propulsive device and in this particular case, a particular engine.

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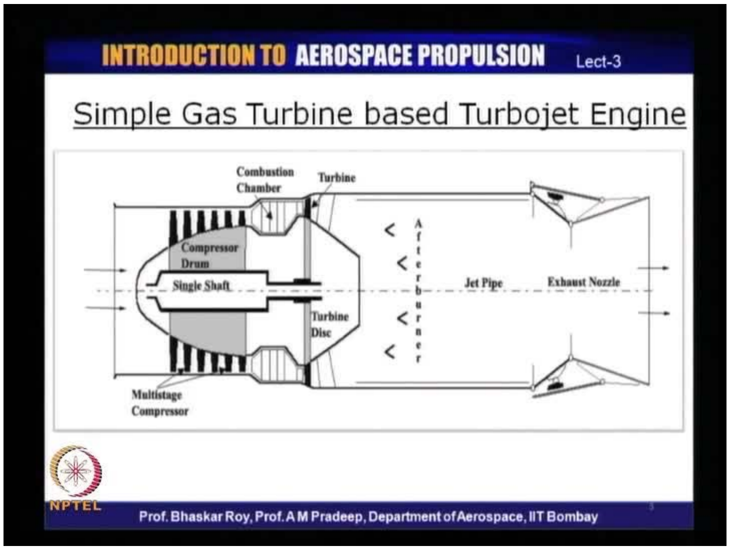

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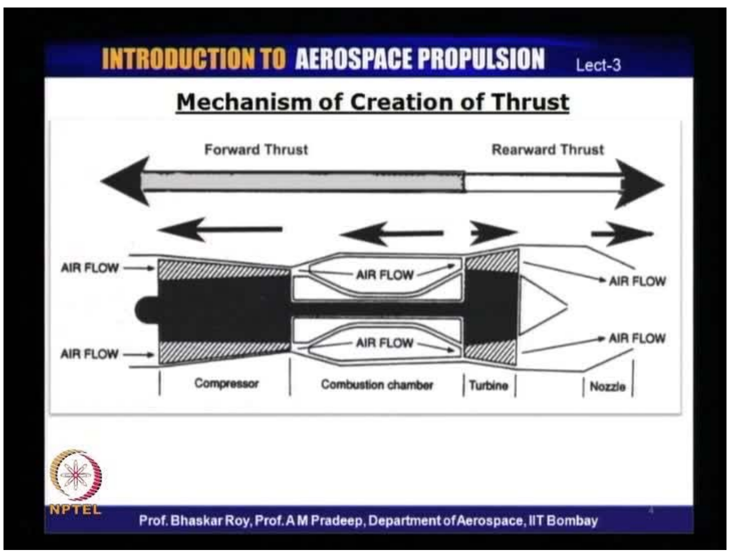

However, the actual thrust production of a real engine often happens in a slightly different way. Conceptual basis of change of momentum as I mentioned, is the easier way of understanding. However, actual method by which the thrust is produced is slightly more intricate.

Let us go through again, a sketch which is a representative of a real engine. We have an air flow again coming through an intake; we have a compressor over here through which the flow undergoes certain amount of compression. So, at the end of the compression process this air actually has a very high pressure at this point. So, at this station the air has very high pressure for the same mass.

Now, simple fluid statics will tell you that if air or any fluid has a higher pressure at this station it will exert a pressure or a force across this body from this side to that side and that is what is shown here (Refer Slide Time: 12:50). At the end of the compression process the entire body of the compressor, which is a solid a mass actually made of blades would experience forward force, which is shown by the arrow over here.

Then, the air actually goes through a process of combustion in which the fuel is burnt inside which the air undergoes again some change in temperature, some change in pressure. As a result of this change of temperature and pressure at this station over here, it is very likely now that the air or the gas at this moment with the burnt fuel would have pressure and temperature that are quite different from the pressure and temperature that came in over here.

The collective pressure that can be integrated over this surface can give you pressure that is a net pressure that may be acting in the forward direction or that may be acting in the backward direction too. So, the combustion chamber here if you integrate the pressure over the entire surface of the combustion chamber, you would probably get a net pressure acting over this entire volume, which could be in a forward direction or it could actually be in the backward direction. Then, of course, the air is exited to the turbine which does the work and which supplies through the shaft work to the compressor.

Now, this turbine; through the turbine what happens is, the work is extracted. As a result of extraction of the work the air actually loses certain amount of temperature and pressure. The pressure at this end of the turbine is substantially lower than the pressure at this end at the forward end. So, the air mass actually exerts again, from fluid statics.

The air mass would exert a certain amount of pressure through the body of the turbine and that exertion of pressure or force is the net pressure over the entire area would be a force and that would be in the backward direction. So, the turbine essentially produces a backward force while operating inside an engine. Now, as the flow is exited from the turbine with the reminder of temperature and pressure, it passes through a jet pipe and then it passes through a nozzle and it exits from the entire propulsion device or engine over here. In the process it has pressure over here, which is quite different from the pressure over here (Refer Slide Time: 15:50). One can very well imagine that the pressure over here could be substantially less than the pressure over here. So, this difference of static pressure again from fluid statics is most likely to create a pressure field, in which net pressure would be acting in the backward direction.

As a result of this, the net of all these forces if you take, you have a certain amount of force that is acting in the forward direction, which we could call forward thrust and there is certain amount of force which is acting in the backward direction, which we would call probably rearward thrust and the net of the two is what we would call net thrust.

As you can see here, in this diagram, all the components that are part of the engine actually participate in the process of creation of thrust and our understanding that the momentum different between here and the last station here gives the thrust is essentially a concept. It is a very handy and convenient way of estimating the thrust quite often reasonably accurate.

However, a more accurate and more detailed measurement or estimate of thrust can be obtained only after we have all these components rather accurately determine. The final value of the net thrust from here should be pretty close to the estimate that we had made earlier on the basis of net change of momentum. So, this is the mechanism by which the thrust is actually created inside a jet propulsion device.

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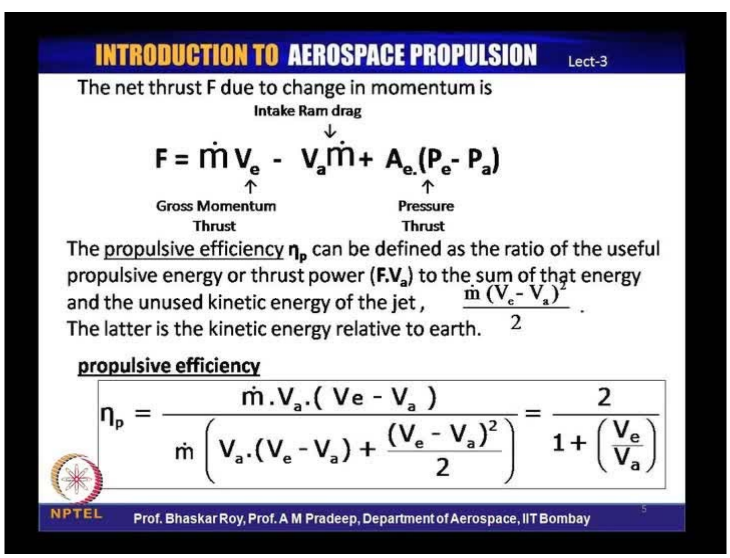

Let us now, look at the equation that we were talking about; the thrust equation we had seen the first part which constituted what we had called the momentum thrust. The first part of the momentum thrust can be called the grass momentum thrust, which is the reaction principle at the exit of the propulsive device of the engine. This is normally the component, which is produced by the incoming flow and this is often referred to as the intake ram drag.

The difference of the two is the net thrust that is normally produced by any propulsive device because of the change of momentum. So, this is the incoming momentum, this is the outgoing momentum and the difference of two is the net momentum thrust.

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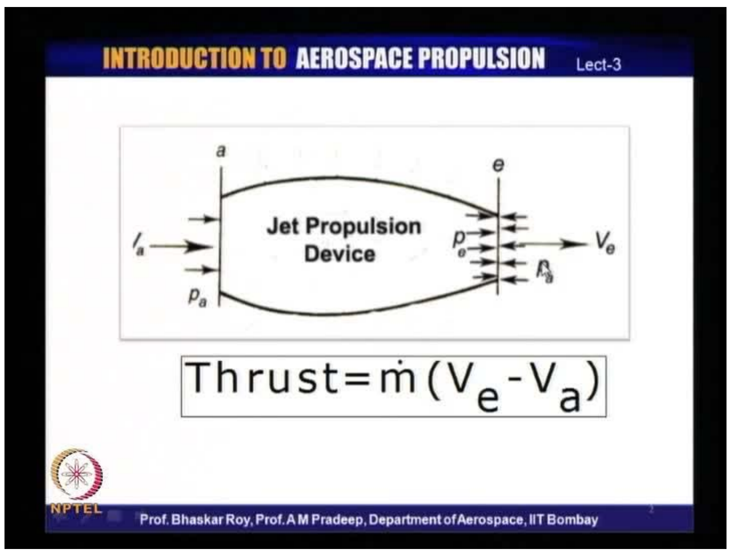

Now, as I mentioned in the earlier diagram if you can quickly go back the pressure over here need not always be same as the atmospheric pressure or the ambient pressure that is existing in the atmosphere (Refer Slide Time: 18:53).

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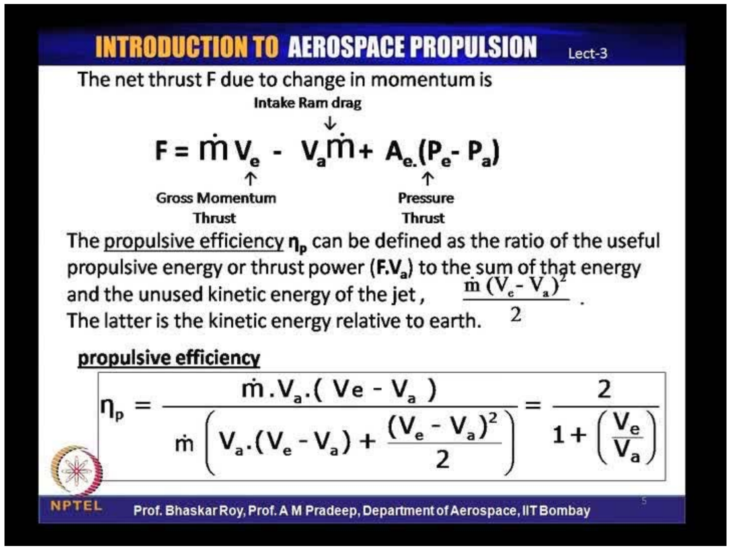

If the pressures are different in many operating conditions of the engine, it is entirely possible that this pressure would not be same as this pressure. As a result of this difference - if it is a positive difference - the area at the exit of the engine of the propulsive device multiplied by the difference in the pressure gives you a force and this is what we call pressure thrust. Now, this pressure thrust normally then comes into existence when the net pressure at the exit phase is not equal to the atmospheric pressure.

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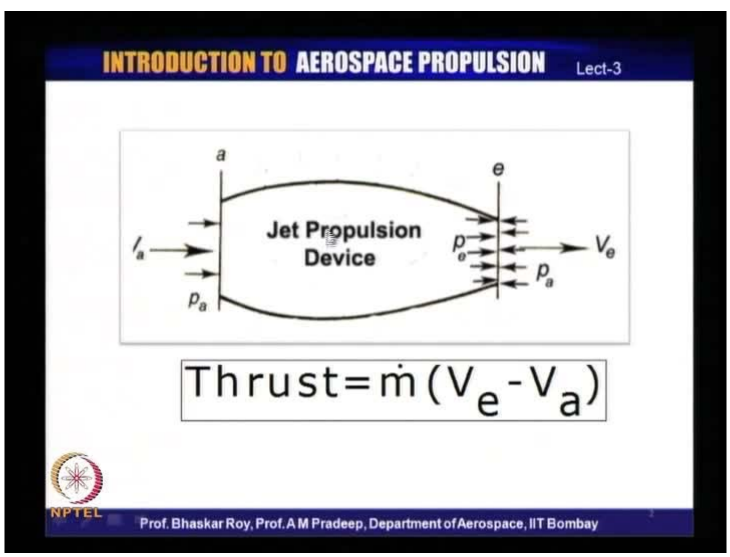

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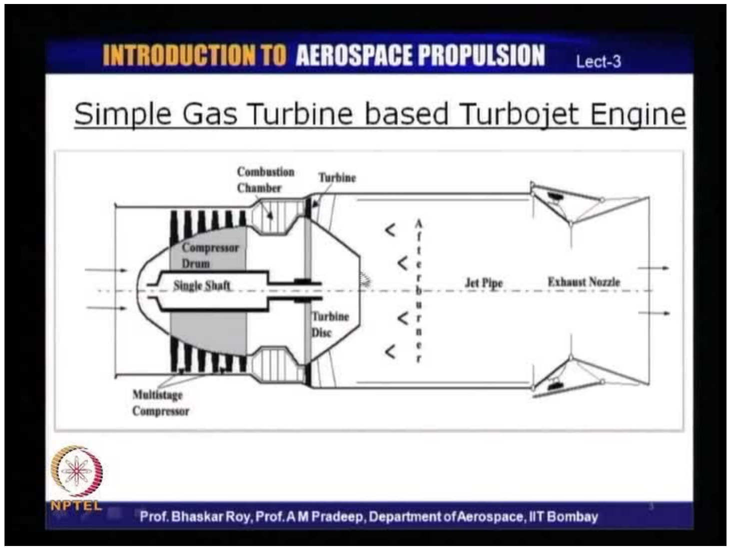

From this equation it would see that this is some kind of an additional thrust that is coming into picture. One need to understand that this pressure thrust actually appears when this velocity - the exit velocity - is not at it is maximum and a reminder of the kinetic energy that is being produced through the propulsive device appears as a pressure and gives you pressure thrust.

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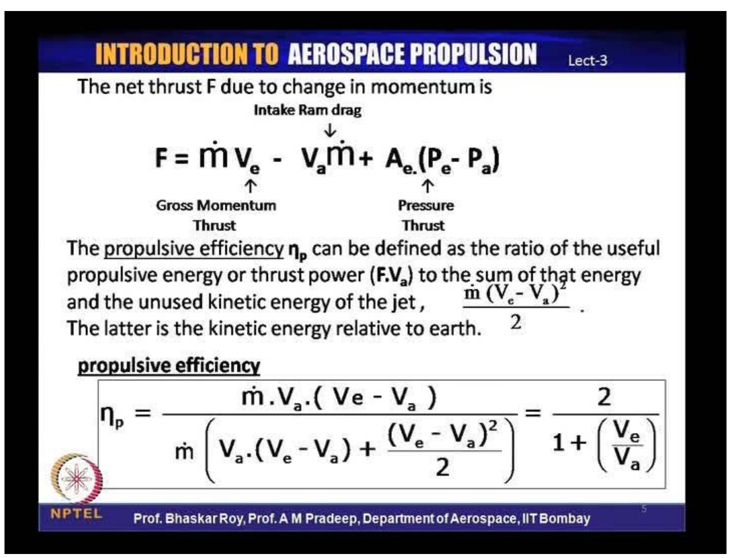

The momentum here at the exit would be a little less than the maximum. As a result you get a little less of the momentum thrust but you get a little of the pressure thrust and quite often, if you quantify the values you would probably find that the total thrust inclusive of the pressure thrust would actually be little less than the maximum momentum thrust that you can get, when the exit pressure is equal to the atmospheric pressure.

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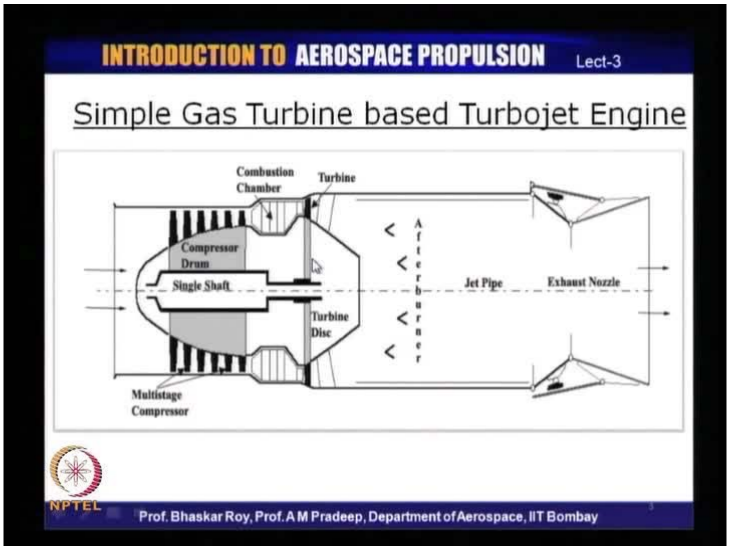

This is when the flow is said to have completely expanded through the nozzle that means the nozzle has completely used up all the kinetic energy that is available, all the energy that is available into velocity into kinetic energy or the sorry or the potential energy that is available into kinetic energy. As a result of which the pressure over here now equals to the atmospheric pressure.

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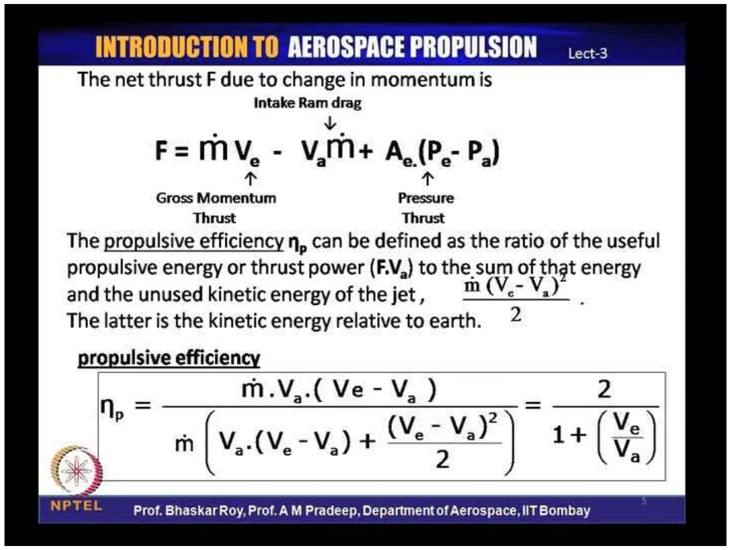

Now, the engine designer has to be very careful in designing the nozzle to ensure that under no operating condition the exit pressure P e should be less than the atmospheric pressure P a, because if that happens we are going to have a negative component over here and we are actually going to get a negative thrust.

Now, that is obviously not a very desirable thing to happen and as a result of which it is necessary that the engine design specifically, the nozzle design is made such that under all operating condition the pressure thrust that is produced is either positive or 0 but, never negative. Quite often, the engine designers try to keep a small margin and as a result of which you always get a small pressure thrust but never a negative pressure thrust.

The other parameter which often defines the action of a propulsive device is simply referred to as propulsive efficiency. Now, propulsive efficiency which we had a look at in the previous lecture can be formally defined now, as a ratio of the useful propulsive energy that is available at the end of the propulsive process to the thrust power that is produced and that if you take the ratio to the energy that is used and unused kinetic energy of the jet.

Now, when the jet is going out of the propulsive device a certain amount of energy is spent through the process of the exhaust process and this kinetic energy is a lost cause. As a result of this a large amount of energy in the form of kinetic energy is exiting the propulsive device without getting any work done out of it. Now that as I mentioned is a lost cause. So, propulsive efficiency tries to capture how much of the energy that is available at the end of the propulsive process that is the useful propulsive energy and how much of that is used and how much of it has actually been left unused and ratio of these two finally gives you the propulsive efficiency.

Just to explain that the kinetic energy that is going out of the jet, this is often referred to as a kinetic energy relative to the earth with reference to the moving air craft is considered as a stationary body. So, the formal definition of the propulsive efficiency can now be written down as, this is the thrust power which we are written down here and thrust being now expressed in terms of power and this is the energy that is available, so this is again the thrust power and this is the energy with which the flow is going out of the entire propulsive device and this energy will not be available for any propulsive purpose anymore, once it exits the propulsive body (Refer Slide Time: 24:34).

Simpler derivative of this full form appears in the very simple form over here. As you can see here, the propulsive efficiency is thus dependent solely on the ratio between the exit velocity and the entry velocity of the working medium that is air and that clearly gives us a quick and handy idea, what is the efficiency with which this propulsive device is most likely to work.

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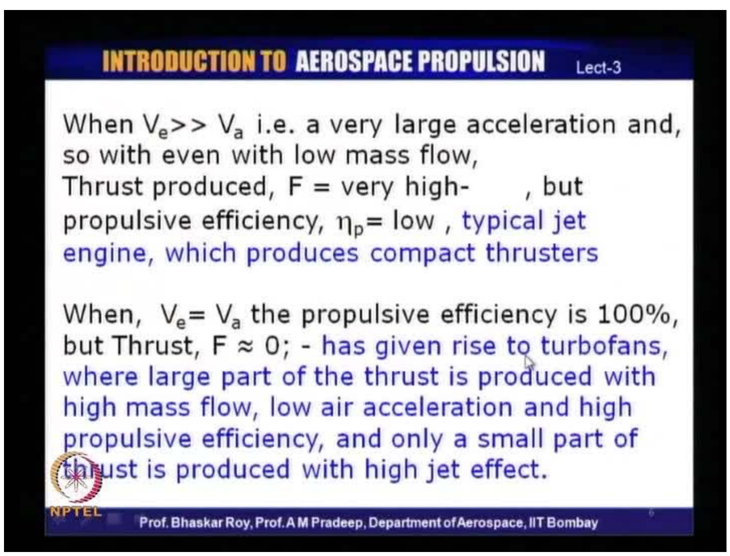

Now, the fall out of this very simple propulsive efficiency definition actually tells us of few stories. Let us see, what actually can be extracted from this very simple definition of propulsive efficiency. For example, your exit velocity is rather large compare to the entry velocity of the air that means a very large change of velocity or a large amount of acceleration as occurred through the propulsive device and quite often that happens with a rather low mass flow.

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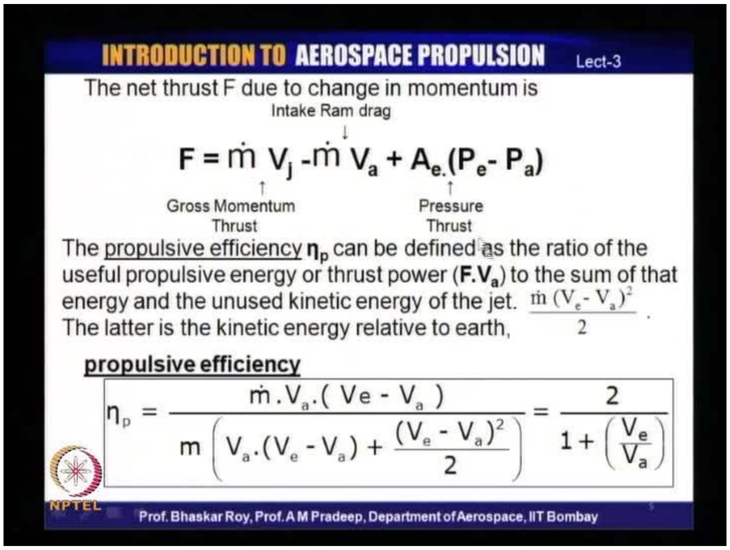

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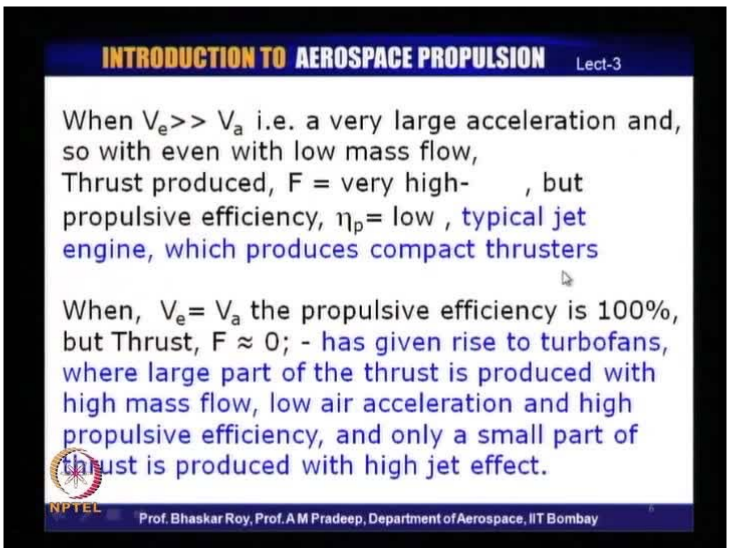

You could get a reasonably good amount of thrust produced but in such a case the propulsive efficiency is going to be low because this ratio is now rather big. The denominator here is going to be much higher than the numerator which is 2 and the propulsive efficiency thus would come out to be somewhat on the lower value. This is typical of a jet engine in which normally a large exhaust velocity is observed.

Jet engine operates with a comparatively low mass flow but, still produces reasonably good amount of thrust and that is why the jet engines are so attractive, their compact and small produce a large amount of necessary thrust. However, we have to keep an eye on the fact their propulsive efficiency is not actually very high they may compact thrusters but, they are not very high in propulsive efficiency.

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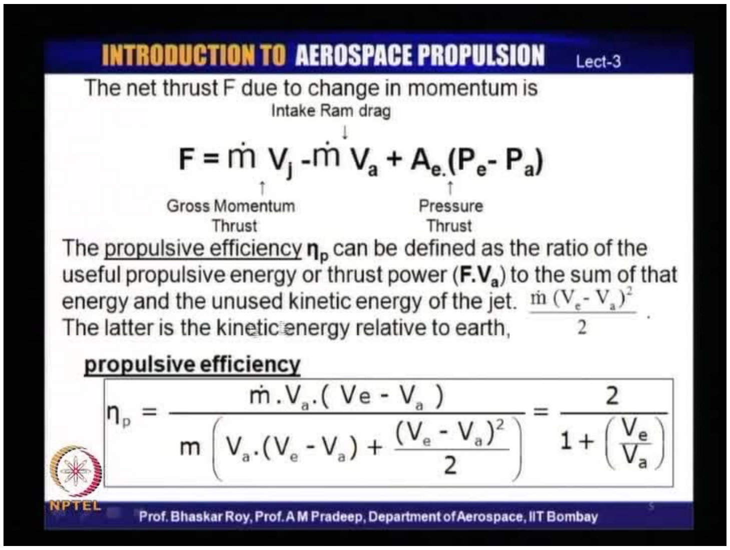

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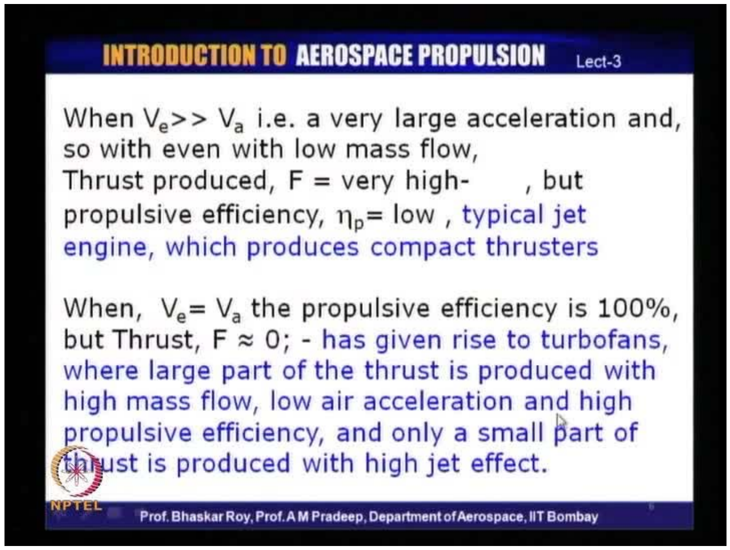

We shall see later on that this propulsive efficiency does have an impact on the fuel efficiency that everybody is so concerned with. The other end of the picture is supposing, when the exit velocity is equal to all let us say, almost equal to the entry velocity V a then, the definition tells us that numerator will be equal to the denominator both would be 2 and as a result of which your propulsive efficiency is actually going to be 100 percent or very close to 100 percent.

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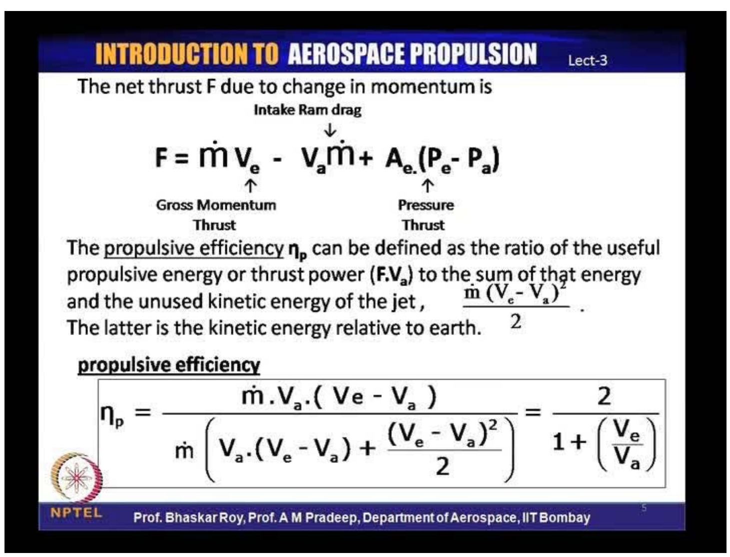

However, if that happens from the earlier equation over here assuming that this pressure thrust is 0 the trust produced actually be pretty close to 0; that means when the propulsive efficiency is 100 percent the thrust produced would be 0 obviously, such an engine is of no use to us. The solution is that if you have very small change in the velocity, which operates on a very high mass flow, then a substantial amount of thrust can be produced.

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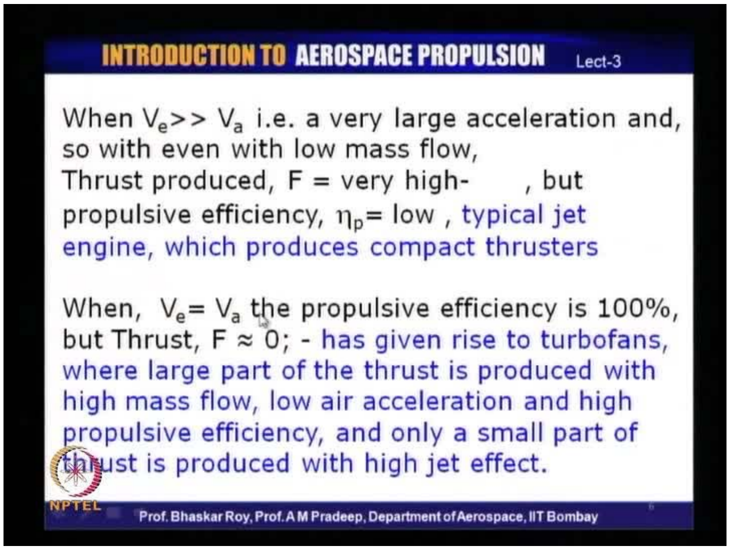

So, we now turn our attention to the mass flow and not the change of velocity. If we can have a propulsive device when the operative mass flow is very high in such a case, you can produce a requisite amount of thrust, a substantial amount of thrust, and that trust production mind you, now is going to be with very high propulsive efficiency.

Now, this is obviously a very desirable phenomenon, your fuel efficiency is going to be quite good. This is the kind of engine that normally, we can see in propellers when we operate with propellers. Propellers, typically operate with low acceleration, operate with a very high mass flow and operate with very high propulsive efficiency.

If you have a turbo fan, which is a normal jet engine these days, a large part of the trust is produced this way that means with a very large mass of air going through very small change in velocity working with very high propulsive efficiency and comparatively small part of the thrust is produced by the jet effect, which has a large change in velocity and operates with a comparatively smaller propulsive efficiency. Combination of these two is what we see today in the form of turbofans and a judicious mix of the two would give you over all propulsive efficiency which would be quite good.

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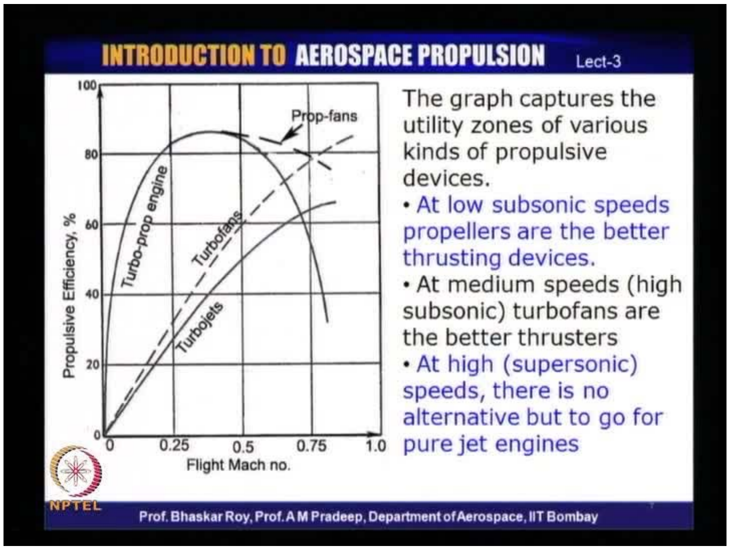

This graph here, now tries to capture the various kinds of propulsive efficiency variations with flight mark number for various kinds of engines or propulsive devices.

If you look at this graph now, the turboprop engine which as I mentioned operates with a high mass flow and a small change in momentum operates with a high propulsive efficiency almost through it is entire operating range and somewhere over here, it starts dropping when a flight mark number is high or high subsonic. The reason we had mentioned was that the propellers tend to go supersonic, which produces a low propulsive or propeller efficiency.

The turbofans, on the other hand have good propulsive efficiency only at high values. Now, turbofans as I mentioned, is a mix between pure turbojet and a certain aspect of turboprop or a propeller and a fan is essentially somewhere in between a propeller and pure compressor; the size of the fan is such that it is somewhere in between in terms of size. As a result in a turbofan, as I mentioned in the previous slide, it operates with a high mass flow through the fans and produces a high propulsive thrust and a small mass flow as a jet and produces a low propulsive thrust and combination of the two gives us turbofans, which are generally of higher propulsive efficiency.

As a result of which these turbofans become more and more competitive at a higher mass flow and at a high subsonic mass flow, these turbo fans are clearly the more efficient and more desirable propulsive devices and that is a reason why most of the aircrafts today fly with turbofan engines.

The turbojets are often referred to as pure jets operate with - as we have seen rather- low propulsive efficiency. However, as we can see here, when you need very compact engine specially in very high speed aircraft, you do not have a choice but you go for the compactness of the engine because the turbofans and the turboprops they tend to be very large in size.

When the size is really the most important thing, you have to have, a very small sized engine quite often to be put inside an aircraft in a supersonic aircraft you need turbojets. So, when the mark number of the flight is clearly more than 1 in supersonic aircraft the choice often goes back to the turbojets or pure jets in which you can get substantial amount of thrust in a compact engine. However, let us remember their propulsive efficiencies are never going to be very good.

In case of supersonic aircraft, we consciously go for turbojet engines because of their compactness knowing full well, their propulsive efficiencies are going to be somewhat on the lower side in comparison to the other kinds of propulsive devices, which are the turbofans and the turboprops, which as I mentioned are often used in the lower mark number ranges.

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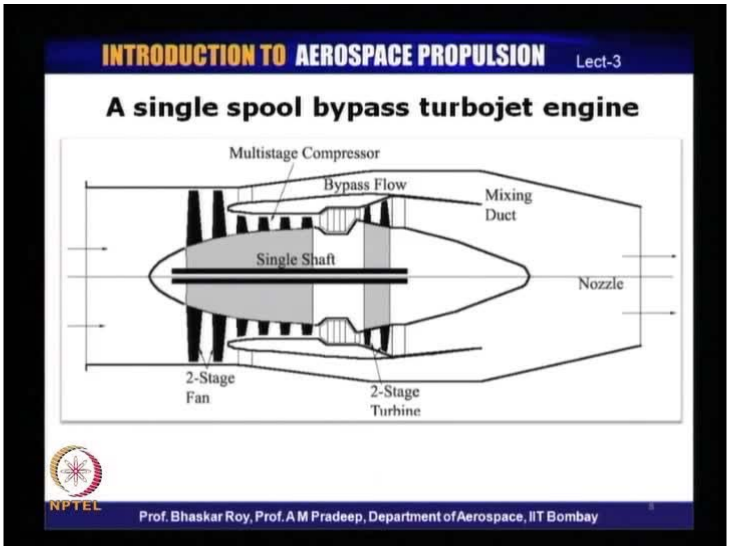

Let us look at various kinds of jet engines that are operational today in various kinds of aircraft. As we look at these various kinds of jet engines, we shall be able to identify them for what kind of aircraft they are used these days. The first one that we have here is a very simple single spool bypass turbojet engine. Now, this operates on the principle that we have talked about it has a compressor and in this particular case it has a larger compressor and a smaller compressor, so it has 2 sets of compressors on a single shaft and the 2 sets essentially, do two slightly different functions.

In the first set, which sometimes people would like to call as fans air goes through them experiences compression and then get split up in 2 parts. The outer part, which is often referred to as bypass and hence forth, we shall also refer to that as bypass flow and then this bypass flow actually goes over here, bypasses the entire engine inner engine and that is why it is called bypass flow. It bypasses the entire inner engine and comes out towards the rear, whereas a certain amount of flow goes through the inner compressor or the smaller compressors gets compressed further. So, at the end of this process it has undergone a large amount of compression and then this highly compressed air is now taken inside the combustion chamber and then goes through the turbine which extracts the work.

After this the hot gas and still highly compressed gas comes out from here and over here the cold bypass air and the hot gas mix up and then this mixture certain amount of length is given for them to mix properly and then this mixture of hot and cold which is finally, exited from the exhaust nozzle. This is not so hot anymore and it is not so hot, not so cold and a medium temperature gas now exhausts from this nozzle producing net change of momentum across this entire device which of course, as we know produces the thrust.

So, this is the simplest form of bypass engine that came into being, when it was realized that you could have a cold bypass engine and you could get some benefit out of the fact that certain amount of mass can be used to get thrust in a higher propulsive efficiency. The concept of propulsive efficiency is been brought in to the picture that this bypass mass undergoes small change in the energy and then this energy essentially, produces a very small change in the thrust.

However, here what we get is a mixed up thrust production. If we consider the bypass as a separate entity it would actually produce it is in the process of producing by the time it is here thrust in a higher propulsive efficiency. So, the combination when it comes out actually produces thrust, which is of a higher propulsive efficiency than, if it had been a pure jet engine which would have had a higher exhaust velocity, which means it would have had at higher temperature and higher kinetic energy at the exit. As I mentioned this higher kinetic energy would have been a complete loss.

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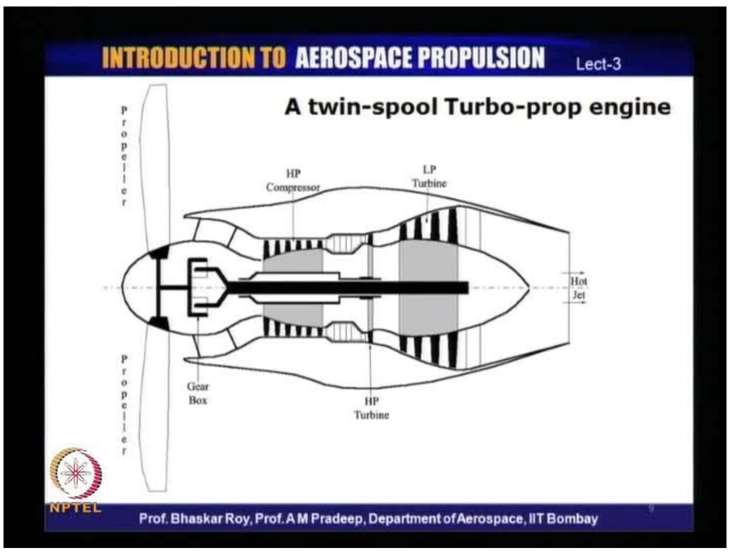

Now, the kinetic energy exhausting from here is of a lower value. As a result, the amount of energy that is going out and that we can say is a lost cause is of a lower magnitude.

Hence, the propulsive efficiency of this bypass engine is of a higher value than a pure turbojet engine and that is a reason why most of the engines today tend to be bypass engines. This of course, is what we call a turbo prop engine where one utilizes a gas turbine engine as we are talking about, to drive a propeller (Refer Slide Time: 39:00).

Now propeller by now is our old friend. Propellers have been flying aircraft for last more than 100 years, 107 years, to be exact as of today. As a result of which they are useful devices and as we have seen from the propulsive efficiency point of view propellers are indeed the more efficient propulsive device within a certain flight mark number. Now, as a result of which the propellers continue to be use in low flight mark number aircraft.

However, arise of the gas turbine engines is given us the option. The propellers can now driven by gas turbine engines, which means you have air coming in over here going through the processor compressor, combustion chamber, turbine and then it produces a separate power through the shaft. Let us say, we can split the turbine in two sets: one set is over here, which drives the compressor supplies power to the compressor. There is another set is over here, which produces very large amount of power and then this drives the central shaft and runs the propeller through this gear box.

As a result of which this is what we call a twin spool engine. It has two concentric shafts: one which runs the basic engine comprising of the compressor, combustion chamber and the turbine, some people call it the core engine. The outer turbine or often referred to as the LP turbine or low pressure turbine operating at somewhat lower pressure than the HP turbine, which operates at higher pressure.

This runs only the shaft and this shaft runs the propeller and the propeller produces the thrust a main thrust. In case of turboprop engine propeller produces as much as, 85 percent of the thrust, 85 to 90 percent of the thrust. A very small amount of thrust may be available through the jet that is coming out in the form of exhaust jet and this produces very small amount of thrust.

In this engine, the way it is designed right from the beginning the jet thrust that is available here and as we know now, this will be produced with a very rather small propulsive efficiency and this is going to be very small whereas, the large thrust it should produce by the propeller would be produced with a very high propulsive efficiency. A combination of these two is going to give you the total thrust that is produced by a typical turboprop engine. So, remember in a turboprop engine propeller produces the large thrust 80 to 90 percent of the thrust most of the time. The jet that you see here produces only a very small portion of the thrust typically 10 to 15 percent very rarely more than that.

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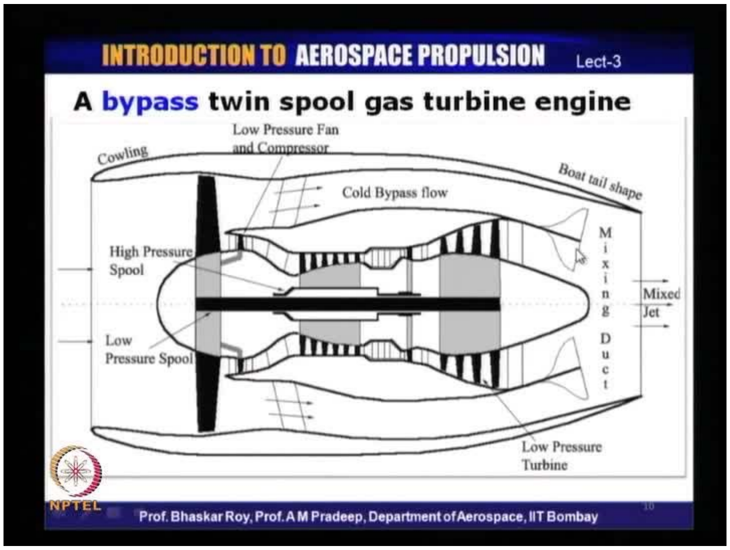

Now, we can look at a little more of the bypass twin spool engine. This is as oppose to the earlier bypass engine a twin spool engine, which means is now has two shaft spool of course, refers to the shaft. It is an old terminology which people have used over the years and it refers to two shafts. Typically the two shafts are concentric, there is an inner shaft which runs through and there is an outer shaft which normally is used to drive the core engine, which comprises the one turbine which is the HP turbine, one set of compressors which is referred to as the HP compressor (Refer Slide Time: 42:37). Hence, this spool is referred to as high pressure spool or HP spool whereas, the inner concentric shaft which runs right through is run through the low pressure turbine, which is a set of turbines quite often and which powers through the shaft this a big fan and sometimes a small compressor over here.

So, this produces a large amount of power and it is often referred to as the low pressure spool. This mechanical arrangement that people have a device essentially creates two mechanical arrangements: one which is a low pressure arrangement, another which is a high pressure arrangement - two mechanical arrangements. Now, this allows us essentially to run the two spools at two different rotating speeds or rpm.

As a result of which most of the engines today, the HP spool runs at a higher rpm and the LP spool runs at much lower rpm; the reason for which we shall come to know as we go along. As a result of this independence of the two spools, the designer now has the flexibility to design the two spools in a manner such that they independently operate at their best and most efficient operating condition. One can well imagine and as we will go more and more, you would probably become familiar with these components and you would realize this independence space very important for operating each of them at their best efficient operating conditions.

There are a few other components that are very important for the efficient operation of a jet engine. The first thing is, as I mentioned earlier, every such jet engine has an intake. Now, this is the intake that all jet engines would have and flow comes in through with hence it is called an intake.

Now, design of this intake is very intricate affair, it is not simple and this shape of the intake over here often referred to as cowling is very important for the aerodynamic efficiency of the operation of this jet engine, when it is flying with an aircraft. In a high speed aircraft the design of this cowling appears in a very important issue, it appears in the design right in the beginning and it is a very long drawn out air.

The entire outer surface of the engine needs to be appropriately designed. As you remember, quite often, in many of this aircraft that you may have seen this engine is seen to be hanging outside the aircraft quite often hanging from the wings and this entire outer surface is opened to the air that is flowing.

So, certain amount of air is coming in and that is going through the propulsive device to give you a jet which creates a thrust. There is a certain amount of air that is going outside flowing over the surface and this air actually produces drag that is additive to the drag of the aircraft itself. Remember, the thrust that is produced by this engine would have to overcome this drag for the aircraft to fly. Now, the engine designer has a job to make sure that the engine itself does not produce a large amount of drag.

Hence, the outer shape over here and quite specifically over here is often referred to as boat tail shape and this ensures that the external flow over this propulsive device does not produce large amount of drag, which as you know would have to be overcome by the thrust produced by this itself.

Towards the exit of this propulsive device as we have seen, we have a cold bypass flow in this bypass engine and we have a hot inner flow or a core flow and then there is a mixing over here (Refer Slide Time:48:01). This mixing needs to be done very uniformly, so that the jet that comes out has a uniform temperate and pressure at the exit phase.

Now, this is very important and hence the design of this nozzle system over here, all the way from here, the shaping over here is extremely important in terms of aerodynamics and the gas dynamic because at the exit phase right over here, we want absolutely uniform temperature and pressure profile because if the pressure profile is not uniform remember, the thrust that is produced is not going to be a linear or thrust in the direction of the jet, but it will be a thrust produced which will have all kinds of components side wise or upwards or downwards components, which will render the aircraft movement in the flight in various kinds of directions (Refer Slide Time: 48:20).

As a result, the aircraft will tend to have motions, which could be a pitching motion, which could be a hoying motion because the jet that is coming out here is not uniform and is not producing thrust that is a unidirectional but, producing multi directional thrust. So, the flow here needs to be extremely uniform as it is going out and hence the design of these components here is of great importance.

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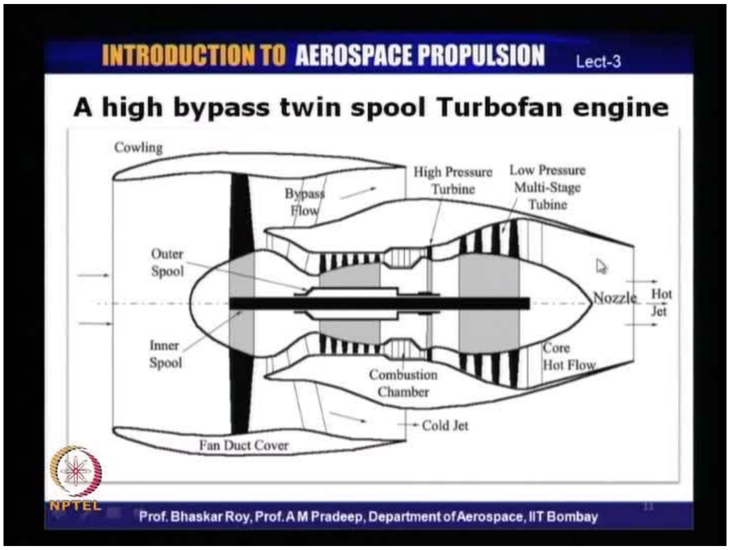

Some of these things, we will probably talk about more and more as we go along. The next kind of engine that we are looking at is high bypass engine as we have seen from the propulsive efficiency concept that the higher the bypass flow, higher the mass of activation, more is the propulsive efficiency.

We now know that this bypass flow acts in a manner that produces high propulsive efficiency thrust whereas the inner flow produces a low propulsive efficiency jet thrust. So, more and more aircraft engines are being produced today which have high bypass flow and comparatively lesser amount of inner flow. This has a huge big fan and as we go along we shall see that these fans are getting bigger and bigger.

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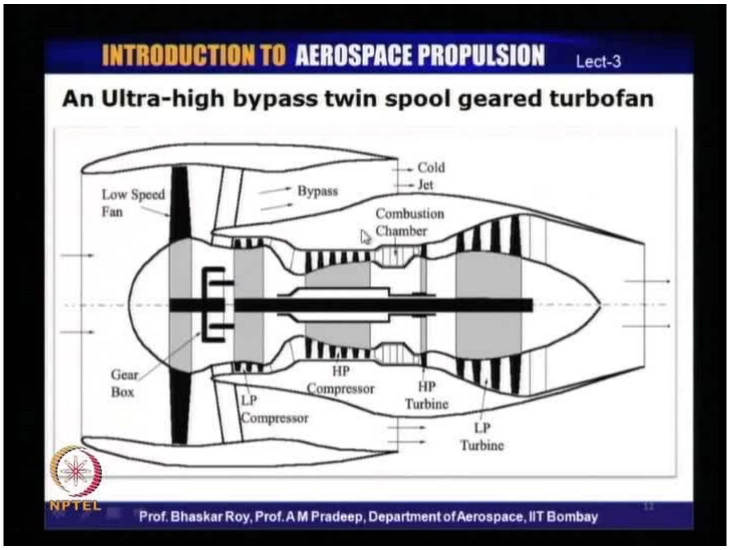

This is ultra-high bypass twin spool. The fan is gone bigger and its size is now substantially bigger than the cold engine, as so much so that the fan needs to be run at a lower rpm and quite often they come with a gear box. This gear box is reminiscent of the gear box that is used in propellers. So, it is almost becoming the size of the propeller hence you need a gear box to run this fan at a somewhat lower rpm. So that they are mechanically and aerodynamically quite efficient and produce a thrust of a very high order through the bypass and as a result the overall propulsive efficiency now would be very high.

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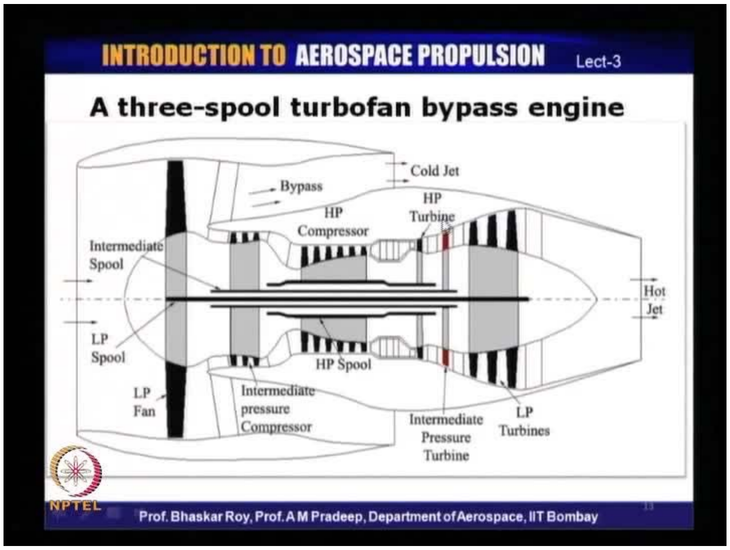

This is a three spool bypass, now it has three spools: the inner shaft goes right through runs only the fan, we have an intermediate pressure compressor that runs through an intermediate shaft spool and then of course, you have the HP spool which is the outer spool, so we have 3 shaft arrangements and some of the modern engines today do have these three spool arrangement. It gives the design of the independence of running three spools at three different rotating speeds or rpm and designs them accordingly.

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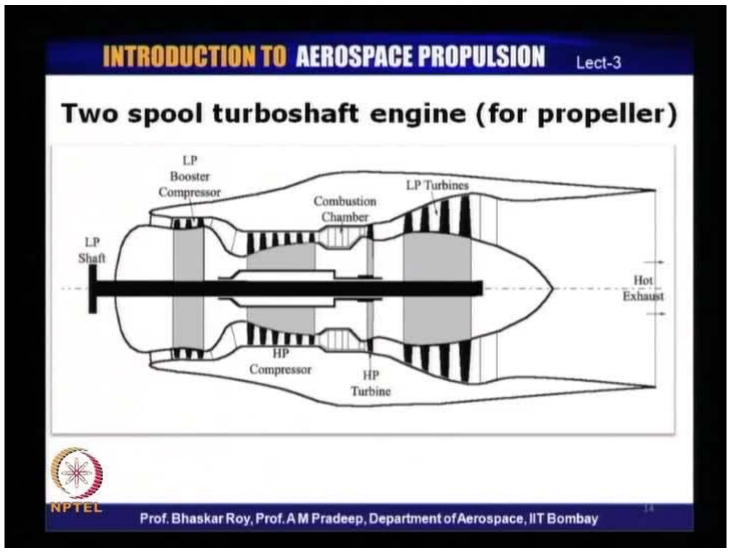

This is a kind of engine that is used normally in flying helicopters and these are called turbo shaft engine; this typical two spool turbo shaft engine these are used for running the propellers or the routers of an helicopter.

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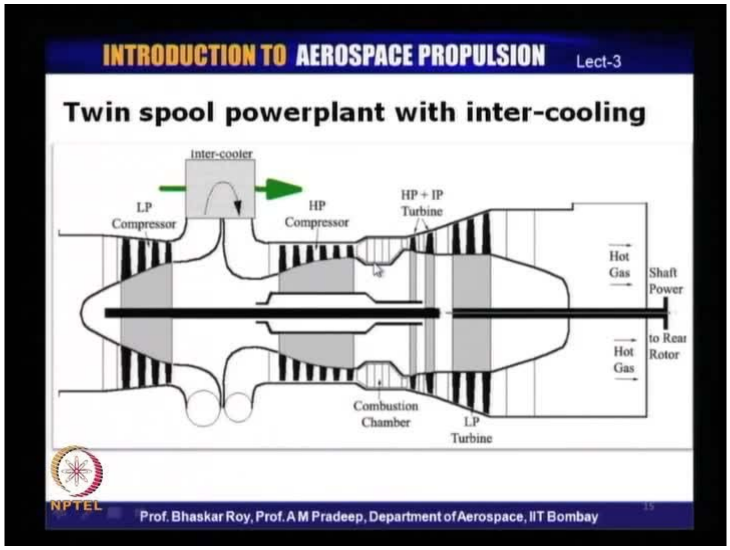

This is a twin spool power plant a variant of gas turbine engine often used in land base gas turbine in which a inter cooling is used; that means between two sets of compressor the air is cooled down and then again compressed and this inter cooling as we shall see later on through the process of thermo dynamics produces a higher efficiency of the entire engine and this higher efficiency of the engine is often used in various power plants. More specifically at this moment they are used in many of the gas turbine land based power plants with high efficiency operation.

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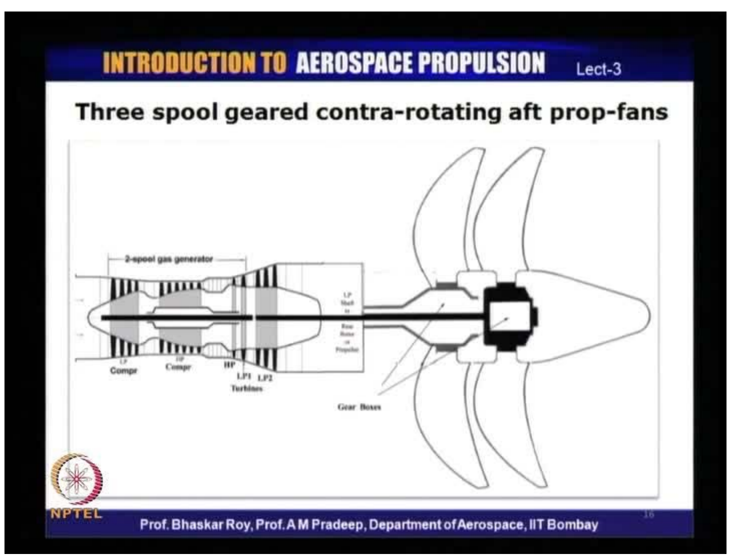

This is a kind of modern engine that is being designed today and likely to fly a very soon. It is three spool combination of engines where the main engine is two spool, the third spool comes out from here from this set of turbines and runs the big fans, which are now referred to as prop-fans and these two prop-fans have two gear boxes, so that in some of the modern engines the second prop fan actually runs opposite in rotational direction to the first fan. Hence, they refer to as contra-rotating prop-fans they are behind the engine, so they are often referred to as aft fans. So, these are the kinds of devices that are likely to fly very soon with various kinds of aircrafts.

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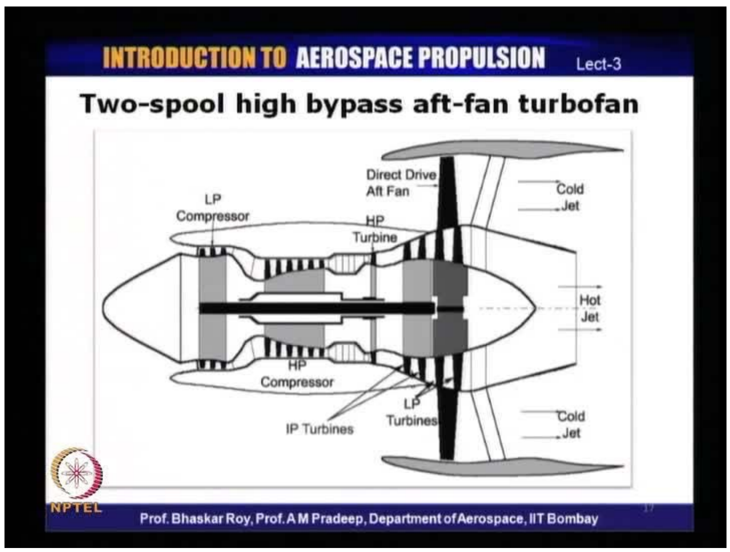

This is an aft fan in which the fan is at the rear, which is mounted actually on the turbines. So, the turbines are directly running the fan, you do not have a shaft here and as a result of which the transmission efficiency here is almost 100 percent there is no shaft. This is a two spool arrangement this is virtually the third shaft or third spool, which are running independently of these two spools.

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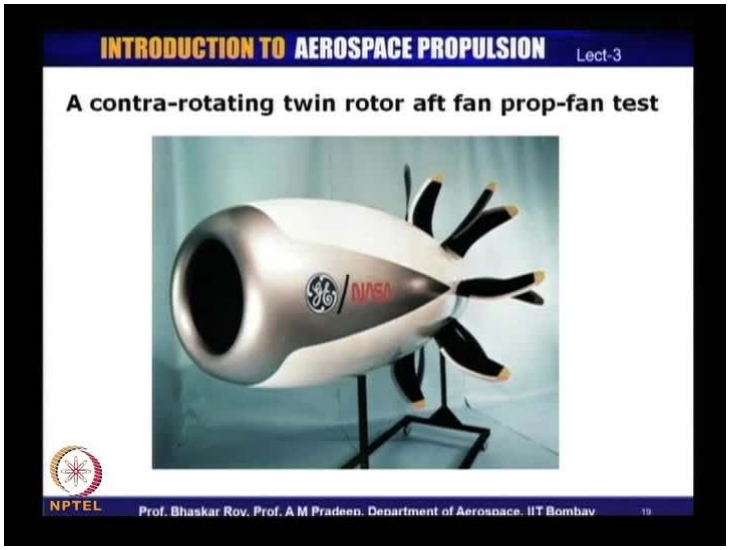

This is a frontal view of a geared two spool very high bypass turbofan engine that is already being flown. You can see that the fan sizes are huge the size of this is huge each blade here is probably of the size of a full grown human being.

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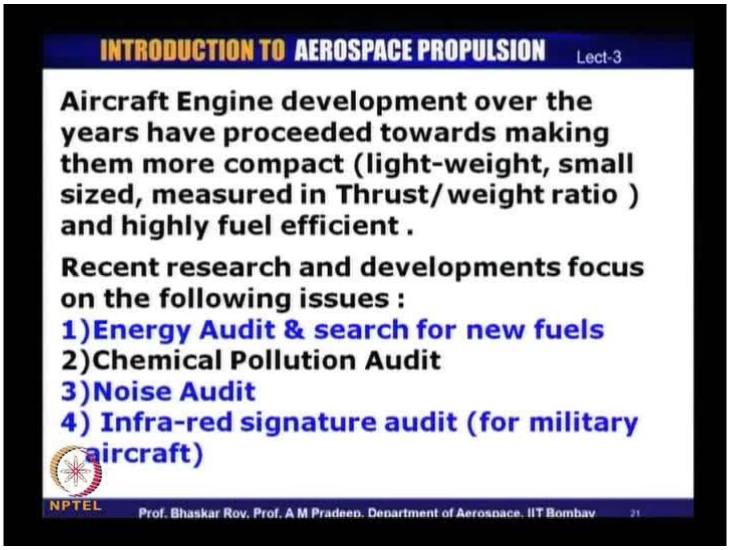

This is a twin rotor aft fan that is in test bed, is being tested and you can see here the twin aft prop fans and this is undergoing test. This is a picture in which the twin rotor aft prop fan is undergoing flight testing actually mounted on aircraft. As I mentioned some of these engines are flying devices you would be able to see a very shortly flying all around the world.

We can say that at the end, that the various engine developments over the years that has taken place, has produced more and more fuel efficient engine that starts with the high propulsive efficiency. They also are tending to be more and more compact with the various kinds of mechanical designs that are possible and as a result of which the thrust weight ratio, which is the final measure of their utility value for aircraft engine is becoming higher and higher.

The research that is going on these days tends to look at some of the new issues. We would need to have energy audit and search for new fuels in the coming years. We would need to have an engine that creates lesser pollution; we would need to have engine that creates less of noise. There are lots of regulations in place these days about noise, about pollution and unless the engines actually conformed to those regulations they cannot actually be used or flown. For military aircrafts, there is an additional requirement that quite often they need to have infrared signature devices which would need to be installed in the engine. So, these are the various kinds of directions in which the engines are developing these days.

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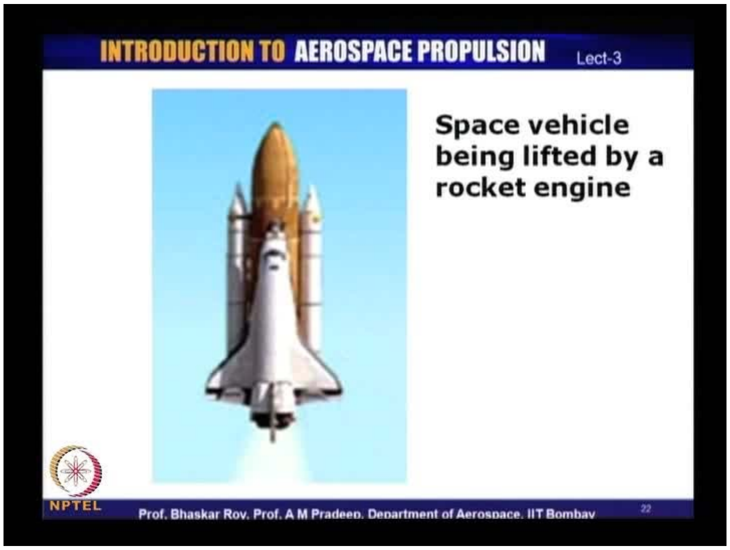

We shall later on, in this course, we will also have a look at the space propulsion devices which would be coming toward the end of this course and which will discuss some of these kinds of crafts and the engines which power these kinds of crafts. So, the various kinds of propulsive devices that power various kinds of engines the aircrafts specially the aircraft we had look at today. As we go along, we will have a look at the science of some of these devices in the form of thermodynamics, in the form of aerodynamics and various other sciences that are required to understand how this various engines actually work and produce a thrust that fly various kinds of aircraft.