Introduction To Aerospace Propulsion

Prof. Bhaskar Roy

Prof. A. M. Pradeep

Department of Aerospace Engineering

Indian Institute of Technology, Bombay

Module No. # 01

Lecture No. # 02

Early development of aircraft propulsive devices

Today, we will take you through the development process of aircraft propulsion; the early years of the development in which the various kinds of propulsive devices were thought of. Some of them were actually created as some kind of a prototype, but many of them never quite flew. We will go on to the Wright Brothers, when their craft flew for the first time and what happened there after; how the aircraft engines actually developed over a period of almost 150 years.

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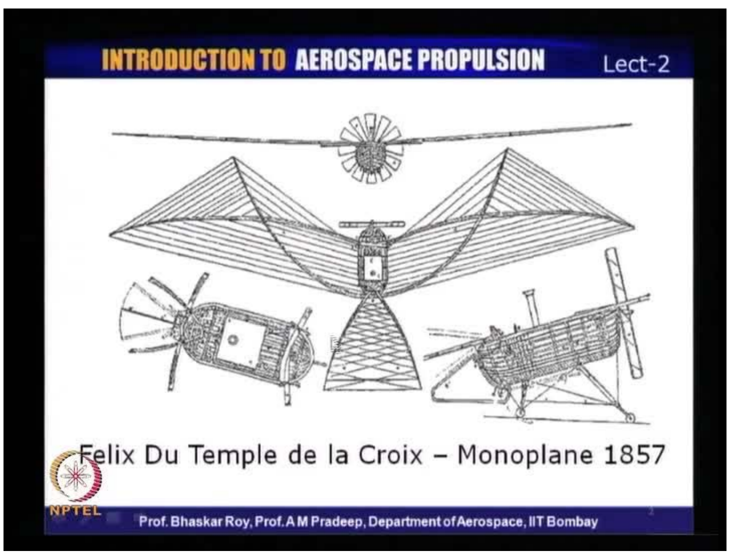

The first aircraft that flew was nearly 150 years back. That did not fly actually, but was created nearly about 150 years back. One of the creations was by Felix Du Temple de la Croix, what was called monoplane at that time and the early ideas were those that resemble that of a bird. This particular picture as you can see here, it has wings very much like a bird, a tail plane that resembles that of a bird and this is the body in which somebody or some things could be placed. You can see the tail; again that resembles that of a bird and the side view, which resembles almost that of a boat in which some thing or somebody could probably sit or be placed over there. Then of course, you see the propeller.

This is the concept that was created nearly 150 years back to fly craft like this through the air. You would need a propeller like device to make it move in air; this is a side view of the propeller which gives the first impression of what mankind thought flight craft could possibly be and this was nearly 150 years back.

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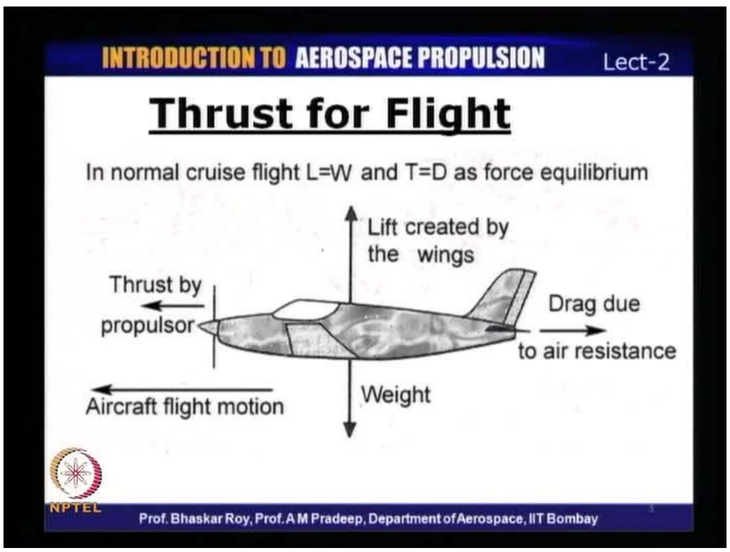

The idea that you need to have thrust created by some kind of a propulsor, it was created around that time it required that if an aircraft is flying the craft, by studying the birds and many other such flying objects, people realized that you need to create lift. The idea at that time was that you create lift by designing a particular kind of aircraft that typically, would resemble something like a bird or one kind of bird or the other.

However, to do that you need a certain amount of force to overcome, what is also known as drag; this is due to the resistance of the air in which the craft flies. Now, when the craft is flying this resistance is continuously active on the body of the craft and this resistance of course, also would change a little depending on the mode of flight.

During this various modes of flight, you need to create thrust that on a continuous basis overcomes this resistance or air resistance and keeps the craft flying at certain predetermined speed in a certain predetermined mode and this creates finally, the aircraft motion. Now, unless you have these balances of forces - the lift - we should overcome the weight of the craft and a thrust created by a propulsor which on a continuous basis must overcome the drag. It is not possible to fly; this is the minimum requirement for a craft to fly.

Our business in this course is to look at how the thrust is created by propulsor which propels the aircraft through the air and various kinds of engines that creates the propulsive power that finally creates the thrust.

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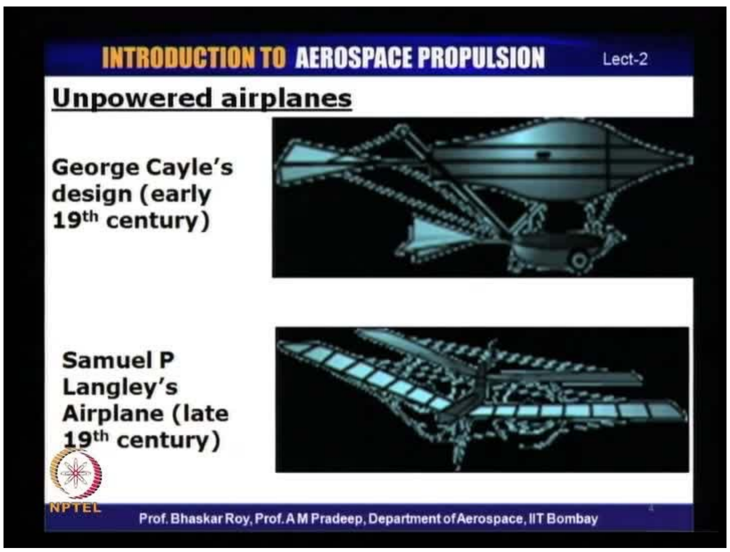

Therefore, early few devices that was created but were in the designer's drawing board; one of them was by George Cayle. Now, George Cayle is quiet often credited with being the father of modern aeronautics and he created much of the science that is used even today for understanding the aircraft flight. What he created was a craft that looks something like this (Refer Slide Time: 05:05) and it had a small boat again and big wing, which helps the creation of the lift and then, again a tail plane that is necessary like a bird to balance the flight. Something like this is what he conceived at the time of creating the science of aeronautics, which is laid down in many books even today.

Little later after that, a gentleman called Samuel P Langley created another kind of craft. Now this had 2 wings, one above the other and is often referred to as a biplane, as opposed to the first one which is often referred to as a monoplane. Now, monoplane had 1 wing on each side, so 2 wings on two sides. This had 4 wings, so two on each side in a symmetric manner and this was a little later in late 19 th century. This was first attempt to create something that could possible fly.

One of the reasons, one supposes that you need 2 wings was to create sufficient lift to make the craft balance the weight. To do that they had to create 2 sets of wings on each side and as a result of which you could also see their 2 sets of tail planes at the rear, which is not exactly what the birds do but, at that point of time people had realized that you cannot have a craft which exactly looks like a bird; you need to create something different and that difference is what appeared as biplane.

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Now, Samuel Langley's biplane was attempted to be flown. However, this particular attempt this picture shows that the first attempt at this flight was unsuccessful. As soon as the craft took off from a ramp on a water body it immediately thereafter crashed onto the error body. One of the reasons possibly was that, the power available was not sufficient for the craft to balance its drag in the air.

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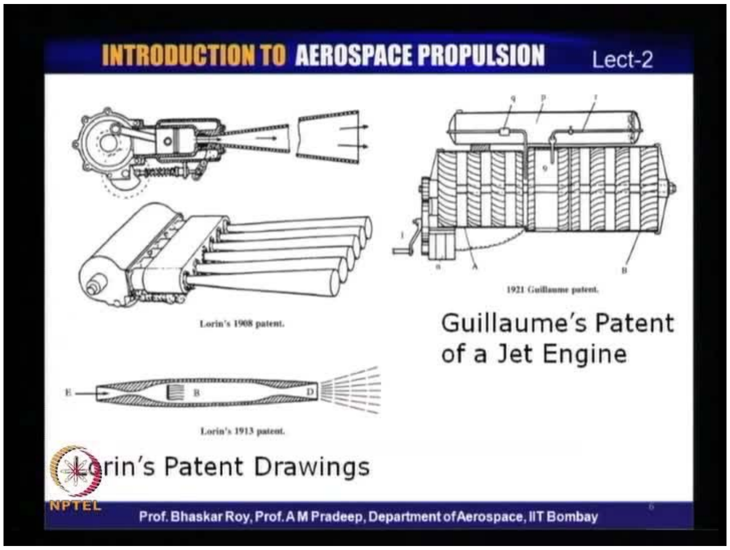

As a result of which, lot of people looked at various kinds of powering devices; the device that would finally propel the craft through the air and provide sufficient power on a continuous basis. Now, this required them to look at creating engines that would drive the propeller by that time it was known that you have to have a propeller to make an aircraft move in air.

The question was, what kind of engine do you require to make the propeller create sufficient thrust? Now, one of the first attempts was by a Lorin and he created what it can be called kind of a jet engine but, it was based on the piston engine concept, which was prevailing at that time and had already appeared in market. This means, a piston would be moving like this and would expel the gas, as you know probably every second stroke.

As a result of which, this gas being expelled or rejected would create a kind of a jet action, which again as per Newton's third law which we studied in the last class, would give a reaction and provide the thrust which means that you would get a thrust every second stroke of this piston. This was the concept created by Lorin. As a result of that, Lorin, what he did? He quickly realized that a single piston quite often would not be sufficient to create sufficient thrust and hence, he lined up 6 of them one after another inline; so that 6 of them could produce thrust.

Also, there is a possibility that he could time the piston stroke such that they do not actually eject the hot gas simultaneously; it could be timed to eject them in a manner. So, that only 2 of them eject at one time or it could be timed in a manner that all 6 of them eject at the same time, depending on the amount of the thrust that needs to be a created.

This engine of course, was a concept; it was never made and certainly never flew. The next patent that Lorin actually went for was a little more simplistic and he went for a straight forward what we call jet engine in which, the air enters a chamber and then, there is a fuel burning that happens over here and then, the hot gas is expelled through a nozzle and through in a jet. This again, as per Newton's third law, creates the act reaction that would hopefully propel the aircraft through the air. So, this was a concept created by Lorin in 1913 for which he actually took a patent.

Now little thereafter, there was another concept of jet engine; this was in 1921 and around this time a gentleman called Guillaume patented a concept which looks like a jet engine; it has a concept very similar to present jet engines, which we look at in detail little later. It had compressors and then, it had turbines and as a result of which it is supposed to create a jet thrust. However, as far as all the records go, this kind of engine was never quite materialized and certainly never flew.

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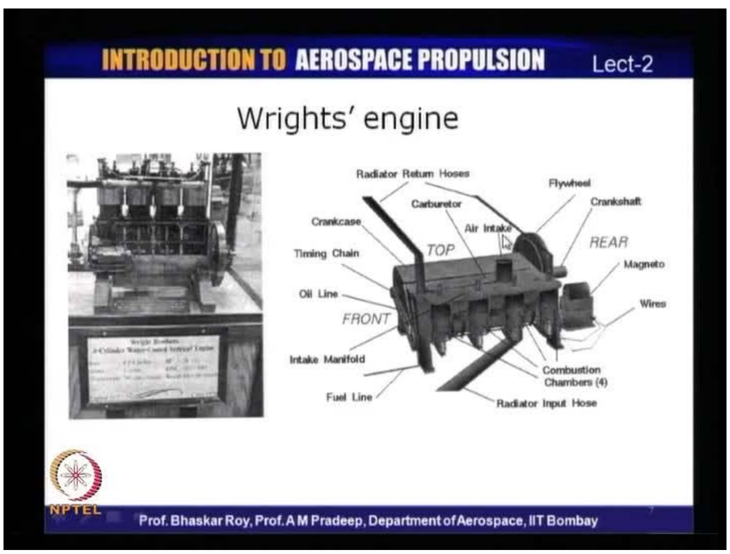

The one engine that definitely flew and created the so called history of the first flight was the Wright's engine. Now, this engine was again quite simple; it had 4 cylinders and these 4 cylinders actually powered one particular shaft and this shaft powered the propeller which flew the Wright brothers plane simply called flyer. This is the details of one of those pistons, which has all the components and those who are familiar with the typical piston engine would find all the components of the piston engine over here.

You have the Air intake and you have the intake manifold and then, you have the combustion chamber etcetera; all the components that one is familiar with, you would find this here. This was a standard piston engine and what they did? They had enough calculation to back them up and they realized that you need minimum of 4 engines to create sufficient power to power their propeller and this is what they had put on their craft which flew for the first time in 1903.

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Now this was the craft; this is historic photograph, which some of you may have seen. This shows that the Wright brothers flying for the first time in the history of mankind in beach called Kitty Hawk in North-Carolina, USA. This is the flight in which Orville Wright was flying and Wilbur Wright was standing over here. On the same day in the morning they flew four times one after another, each brother taking his turn and out of the four; three of the flights are recorded as the first three flights of the human kind.

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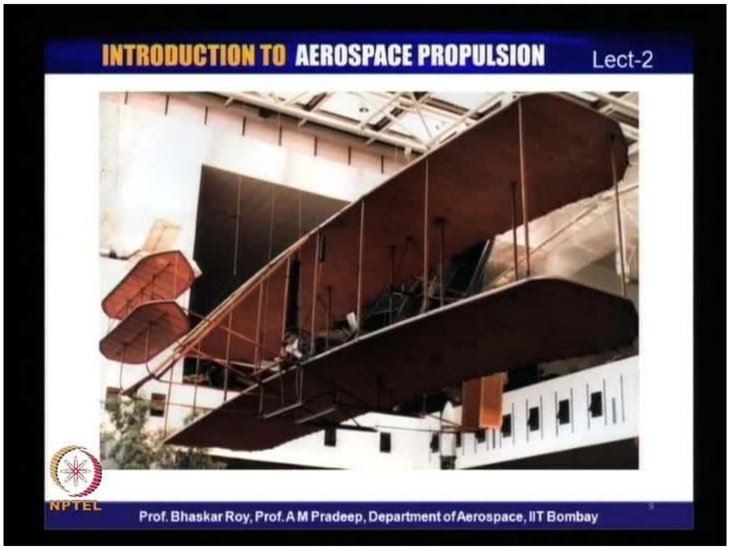

Now, this had the engine which we just seen and it had the propellers which we will have a look at. Now, this the craft which is being preserved in a museum in Washington DC; the Smithsonian Institute a museum and if you people go here, you would be able to see the craft hanging over there even today.

As you can see here, it was a biplane as we were discussing it had 2 wings and it had 2 tail planes. In fact, they were in front and you could see here a person actually lying down. So, Orville Wright was actually lying down on the aircraft because there was nearly no place for him to sit there.

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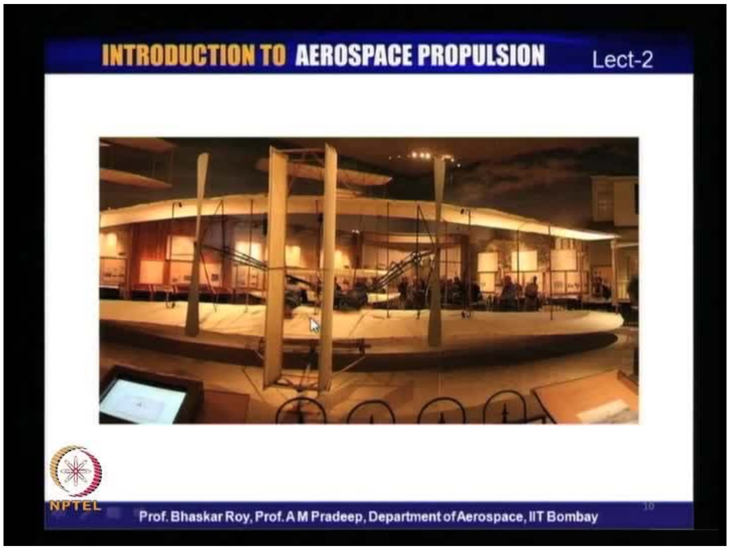

This you can see the craft from another picture in which the 2 wings are very clearly seen and the 2 tail planes are also seen. As we have discussed, this was part of the aircraft design which Wright brothers took a long time to perfect before actually they flew.

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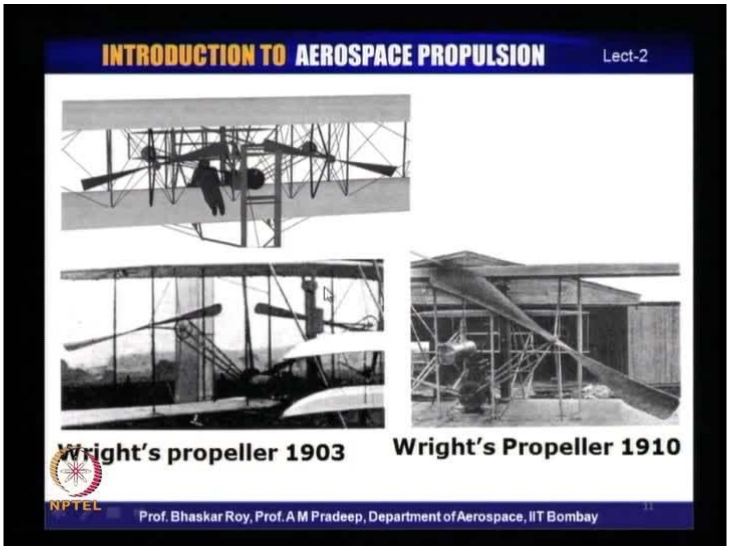

Then now, you can see the propellers which they used in the 1903 flight and the propellers they used later on - a little later- around 1910 and over the years the shape of the propeller which they used actually changed a lot. The propeller you can see here (Refer Slide Time: 14:44) is a simpler propeller; it is a paddle type, here the propeller as you can see 1910 is a little twisted - far more twisted - bigger in size and probably has much better shape for creation of thrust. So, there was a evolution of propeller even with the Wright brothers over a period of 17 years in which they were involved in the various kinds of flying crafts.

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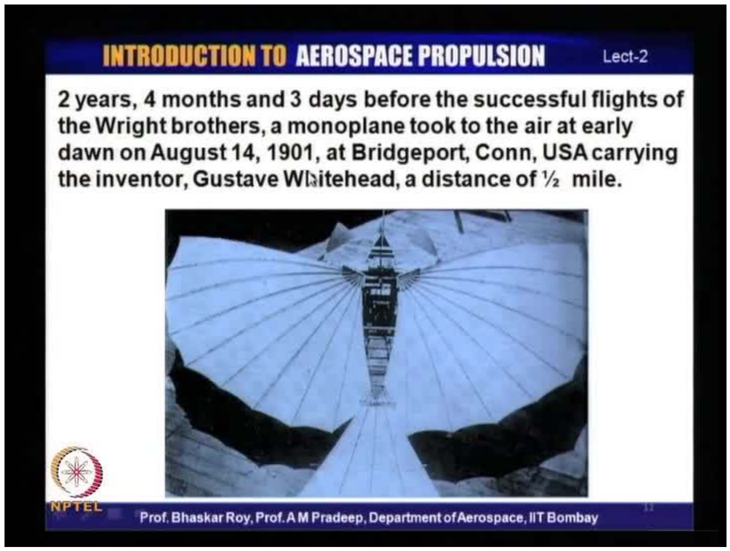

There is a historical clean made by a gentle man called Gustave Whitehead that 2 years, 4 months and 3 days before the successful flight of the Wright brothers. A monoplane actually took to the air on august 14, 1901 that is nearly two and a half years before the Wright brothers flight.

Somewhere in US, Connecticut carrying and it was carrying its inventor Gustave Whitehead and it is reported to have flown by about half a mile which would be far more than what the Wright brothers flew.

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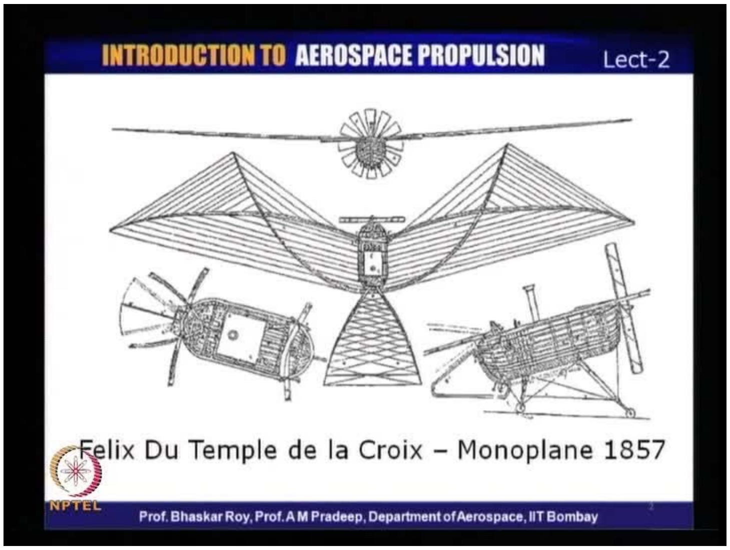

What the write brothers flew? For example, its flight was the distance which is now recorded as equivalent to the wings fan of today's Boeing 747. It was a very small hop so to say but, the flight claimed by Gustave Whitehead or his successors later on claims to have been flight of nearly half mile. There is no record except for this particular picture it was supposed to be monoplane resembling that of same picture that we have seen for Felix Du Temples monoplane.

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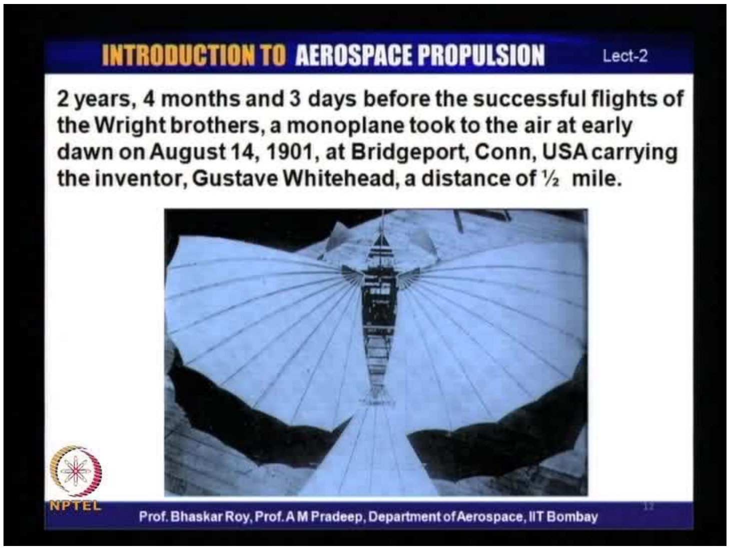

Somewhere 50 years after Felix Du Temples monoplane, somebody a gentleman named Gustave Whitehead is reported to have created a similar monoplane and actually flew it. However, this is not been scientifically accepted. As far as all the historical scientific records are concerned the first flight is credited to the Wright brothers.

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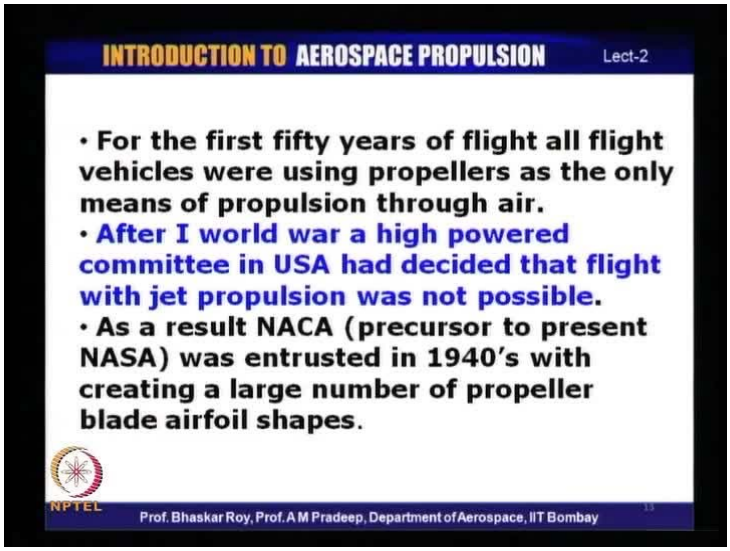

What we see now is that all the flights that were recorded over a period of first 50 years of flight all flew with propellers as the only means of propulsion, which means that jet engine, as we know today were not the means through which propulsion was done; it was propellers all the way for over a period of half a century. In fact, according to the records in various scientific recording manuals sometime after World War one, high powered committee in US went in to the decision making whether a jet propulsion could be used for various kinds of flights.

They came with the decision that jet propulsion was really not possible within the forcible future and hence, they interested NACA that is a National Administration of Civil Aviation which was created in US with a creation of a large number of propeller blades and these propellers blades were created by NACA in between the two World Wars.

As we shall see later on, by the Second World War jet propulsion had actually come in to being and the prediction made by the so called high powered body had proved to be erroneous.

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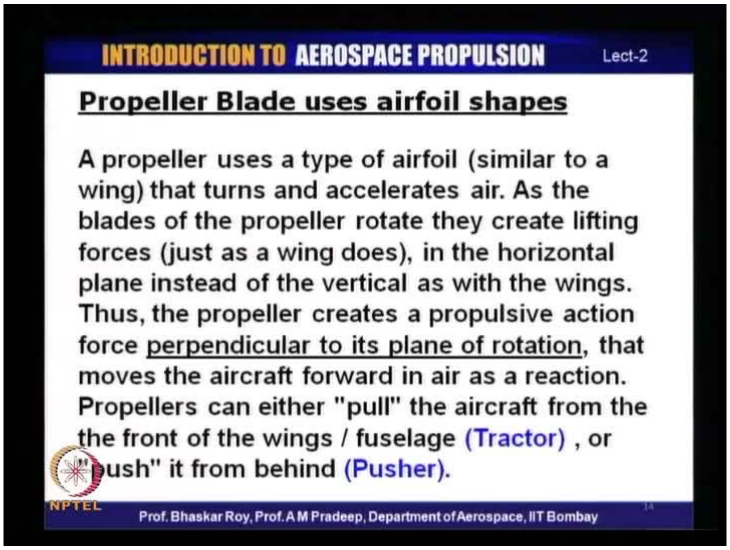

We will come to that in a few minutes. Let us go through the development of propellers. Propellers what they do is, they use airfoil shapes; airfoil shapes were created - as we know - by George Kelley nearly 150 years back and it was proven that many of the birds and fishes do have these kinds of airfoil shapes that allow them to move through the air or water in case of fishes very smoothly.

So, that shape is what today we call airfoil shape and this is what is used in the propellers also. Propeller uses the shapes and as a propeller rotate, as per the shape characteristic they create lift and a component of the lift is then utilized as thrust.

Now, this thrust is created in a direction which is perpendicular to the plane of rotation of the propeller and this is to be designed in to the propeller. So, it is necessary that person who designs a propeller for a particular aircraft is knowledgeable about the science of propeller, so that when he creates a propeller for a particular aircraft the propulsive action is created exactly perpendicular to the plane of rotation that meets the demand of the particular aircraft.

Propellers can be broadly into two types, one that pulls the aircraft from the front that is, its position at the front of the aircraft either the nose of the aircraft or mounted on the front of the wings and these are called tractor type propellers.

There are the other types where sometimes the propellers could be mounted on the rear of the aircraft, which could be at the rear of the fuselage or body of the aircraft or at the back of the wings and it could actually create thrust from the rear of these bodies and they are called the pusher type, as if they are pushing the aircraft from the rear. So, these are the two kinds of propellers that have been around for quite a long time. Most of the propellers that we see are the tractor types but, there are quite a few pusher type propellers that have also been used over a period of last 100 years.

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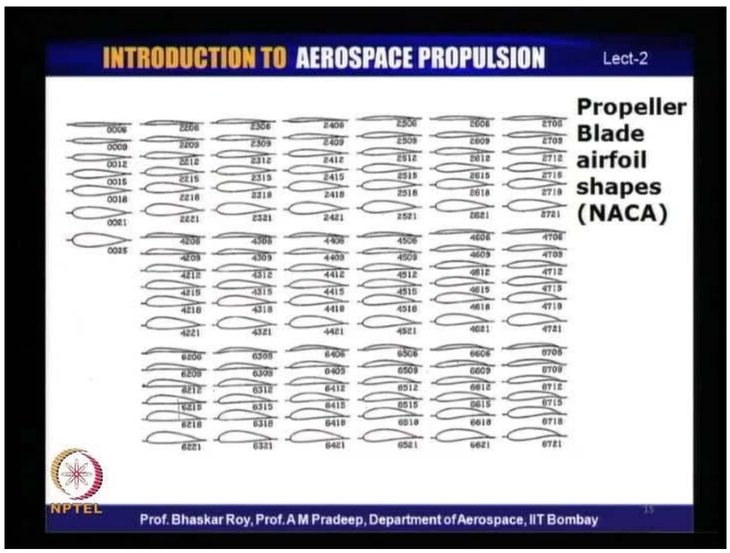

These are the various propeller blade airfoil shapes created by NACA more than 60 years back. As you can see, these shapes are so many; there are more than 100 shapes over here and they have served the purpose of creation of literally 100s and 1000s of propellers that fly various aircrafts around the world. So, this was the basis or the beginning of creation of propellers there are number of companies who are specialized in using this airfoil shapes for creating the propellers.

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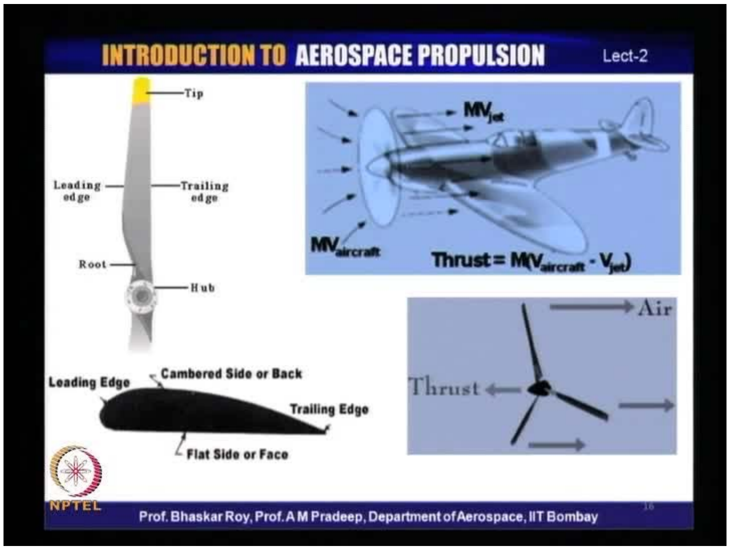

Let us quickly take a look at how the propeller actually operates? Because that is what made the aircraft fly for nearly half a century. In fact, propellers are being used even today for flying many aircrafts. So, the history of propellers flying the aircraft is more than 100 years old and they are still active in flying many aircraft.

Let us take a quick look, what the propellers actually do? The propellers actually if you look at the picture over here they are mounted somewhere at the nose over here, which is what we would call as tractor type of propeller and by virtue of its rotation and the airfoil shape that is given to it. It actually sucks the flow from the front and then it pushes behind, so this suction of the air is aided by the motion of the aircraft.

So, as soon as the aircraft starts moving, the motion of the aircraft allows the air to move into the propeller and as the propeller rotates, it also applies the suction. When the aircraft is moving in air, the suction of the propeller is expected to match the motion of the aircraft so that the amount of air that is going through the propeller is actually matched between the propeller and the aircraft movement.

Now, when that happens the flow through the propeller then goes through the disk like this (Refer Slide Time: 32:48) which we would call the swept area of the propeller and then as it goes through, it acquires a little bit of extra energy or extra momentum. This momentum difference as we know from Newton's second law provides the thrust. So, this is the momentum of the jet that is being pushed by the propeller; this is the momentum of the air that is coming into the propeller and this provides the thrust that makes the aircraft move. This thrust must balance the drag that is experienced by this entire aircraft. This propeller matches the entire drag created by this entire - including the drag of the engine - and the propeller itself. So, it is the only thrust in body mounted on an aircraft.

If you look at the typical propeller; this is a typical propeller, it would look something like this (Refer Slide Time: 24:44). There are various kinds of propellers, various shapes; we will probably have a chance to go in to it later on in this course. In this particular diagram as you can see, there is propeller shape; this is the tip of the propeller, which is what you would see some are over here. This is the route of the propeller which is at the core of the propeller and is connected to the shaft which comes out of the engine. This shaft goes inside over here and quite often this shaft is covered by a nice - what is known as - a nose cone to make head aerodynamically smooth that is in front of the propeller. So, flow goes over the nose cone and then enters through the root and then flows over the body of the aircraft.

If you take a cross section of the propeller over here - just anywhere - you would probably see a shape like this and this is an airfoil shape. As we have seen, there are so many kinds of airfoil or so many shapes of airfoil that could be used. Typically, in one single propeller all the way from here to here, we would call this the working part of the propeller which creates a thrust.

You could probably see various propeller airfoil shapes. So, the airfoils that are used in a propeller from root to the tip of the propeller actually change. There are various kinds of airfoil. So, propeller near the root typically would be a thick propeller whereas, the propellers near the tip would typically be a very thin propeller.

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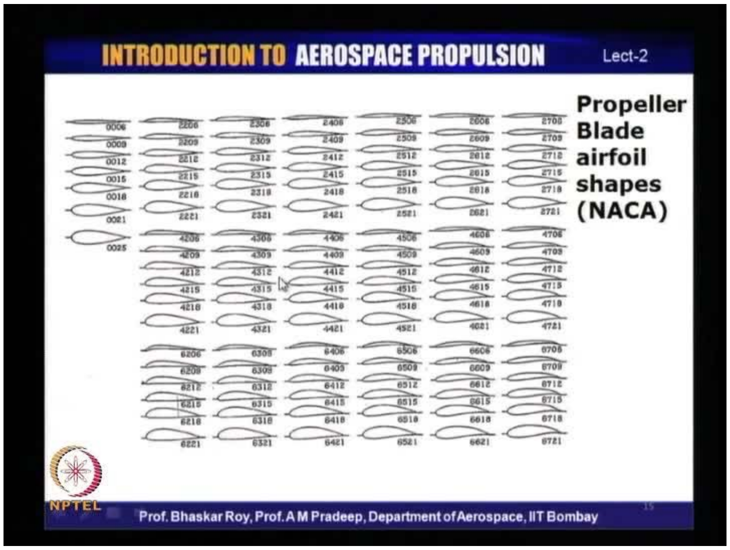

Let us take a quick look. Some of the thick propellers airfoils that you see here are likely to be used near the roots. So, this is how a typically, you would probably have a root propeller here and then, slowly they become thinner and as you go towards the tip, you would probably have a thin airfoil like this. So, each such set probably could serve the purpose of one propeller and that is how the propellers are utilized, airfoils are utilized in a propeller for creating the thrust.

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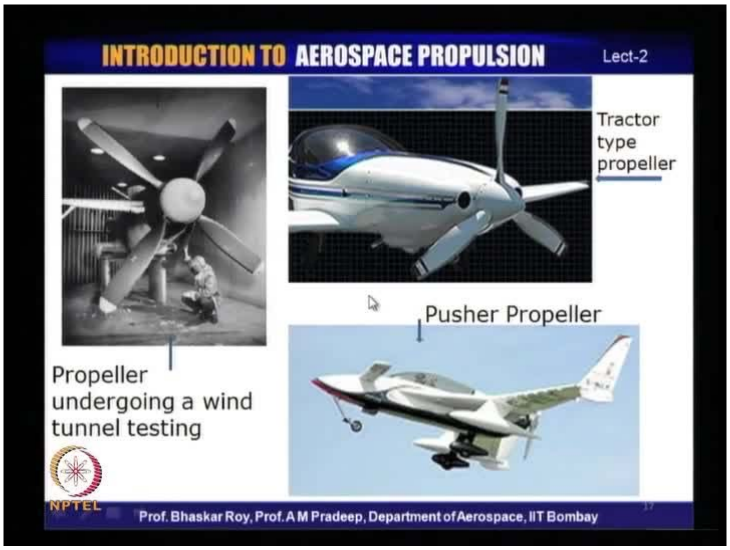

These are the various kinds of propellers that you would probably see today. If you go around for example, a propeller that is after it is being made the propeller needs to be proven and one of the means of proving it is to actually test it in a wind tunnel. A wind tunnel is actually just a land based grounded facility in which various bodies can be put for aerodynamic testing and propeller is also one such element that can be tested inside a wind tunnel. Inside the wind tunnel you test the aerodynamic capability of the propeller, you measure the thrust that it is creating.

As I have mentioned before, it is necessary that you have exact estimate of the thrust that the propeller would create because, when the aircraft is flying in air the exact matching is an absolute necessity. If there is any miss matching remember the aircraft is not going to fly. If the thrust fall short of the drag, the aircraft is going to fall and if there is any passenger they are going to be hurt or they are going to be killed. So, it is absolutely necessary that the thrust of the propeller is very accurately predetermined even before it as flown.

You can see here a propeller (Refer Slide Time: 28:33). Now, this is a propeller where you can see, you have 4 blades. Now, this is a propeller where you can see, you have 3 blades. Many of the propellers that fly quite often have 3 blades. Now, this is a tractor type of propeller where the propeller is at the nose of the aircraft - in front of the aircraft - this is an aircraft in which the a propeller is the rear and what we call the pusher kind of a propeller, so it is at the rear of the propeller at the tail of the aircraft. This is a typical design in which it was thought that putting the propeller at the nose may not be an appropriate thing to do for this particular design whereas, this particular aircraft design accommodates a propeller right at the nose and it is a tractor type of a propeller.

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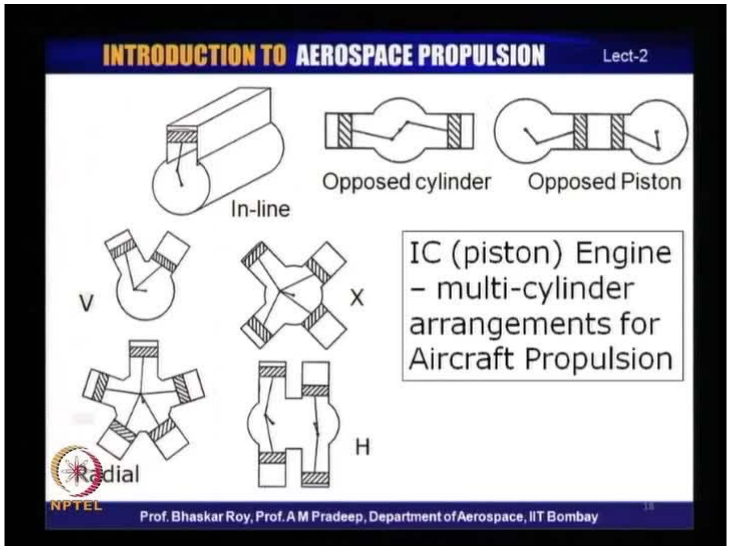

Now to run a propeller you need engines. As we have seen 100 years back the kind of engines that everybody was familiar with were the piston engines, which were already powering the automobiles and other vehicles moving on the surface of the earth. They were also powering various kinds of engines that powered the boats that went over the waters.

This kind of engine had certain specific requirements. To make an engine that it will go inside an aircraft and will fly with the aircraft needed that they should be very light; they should create sufficient power to power the propeller, they should create thrust to fly the aircraft and the one of the prime requirements of anything that goes on aircraft that is it has to be light and it has to be very compact and very small in size. Now, this was a requirement that was specific to the aircraft engines and as a result of which the engine arrangement needed to be looked in to.

What people did? They look at various kinds of arrangements. If you have pistons let us say lined up one after another inline, those are simply called Inline engines. All this pistons would drive in one single shaft over here and this is your piston drive. So, the piston movement could be timed such that there is a continuous power supply to the shaft which of course, drives the propeller.

The other way of doing it is what is known as the opposed cylinder; that means, instead of having all the pistons on one side and lining up them up one after another to get certain amount of aggregate power. You have 2 pistons or 2 cylinders on two sides powering a central shaft. You have 2 pistons on two sides and they are timed in such a manner that the power strokes of the 2 are staggered in time.

Another variant of this is to have opposed piston within one body of a cylinder. You have two pistons and it is actually powering on 2 shafts - one this side, one on that side quite often we shall see later on that they would go on to power a single propeller.

The other arrangement which people came up with is simply called the V type where the pistons are arranged in a V formation and they again power the central shaft over here (Refer Slide Time: 32:20). In this V formation, you can again put them inline like this single engine. You can have V engines lined up one after another or one behind the other. For example, you can have 2 engines in V formation or you can have 4 engines, you can have 6 engines, you can have 8 engines or you can have 12 engines lined up inline in V formation. Many of the modern aircraft do actually have up to 12 engines lined up to supply the aggregate power to run the propeller.

The other way of looking at power generation is to have X type, where you have 4 of these pistons powering a central shaft and again the timing of the 4 pistons as such that this central shaft is continuously being supplied with power and which runs a propeller. You can have 4 of them now lined up and then, you can have 4 engines doubled up you can have 8 of them lined up creating power to run the propeller.

If you have more than 4, one of the ways of doing is to have a radial arrangement, so that you can arrange them around in a circular formation. You can have 5 of them typically, you can have 7 of them or 9 of them and then, you can again double them up that means you can have 2 sets in aligned with each other. Instead of a single piston, you can have radial arrangement inline at least two sets inline. So that you can have total of 10 cylinders or 14 cylinders or 18 cylinders powering one single central shaft.

The other arrangement is of also simply known as H type, which again uses 4 cylinders and this time it is trying to power 2 shafts to create power that is supplied to the propeller.

These multi-cylinder arrangements for aircraft propulsion were created essentially to go into the aircraft. The various cylindrical arrangements that we are looking at were created essentially for the aircraft power plants.

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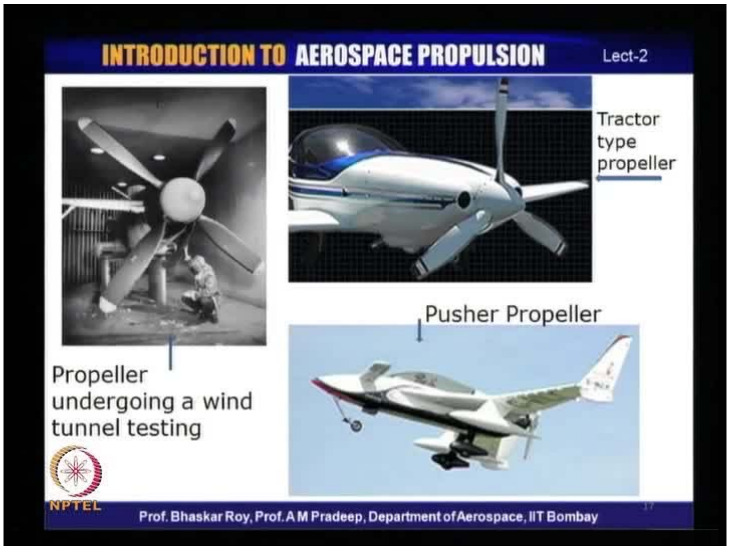

Now, as we have seen in the earlier pictures these aircrafts have shapes. These shapes are created by the aircraft designer to create lift, to create minimum drag and of course, to house a passenger or passengers to fly in the aircraft. Now, once you create this shape that is supposed to create minimum amount of drag, your engine needs to be somehow accommodated within this shape. This is the important issue that your engine arrangement must conform to the shape of the aircraft that has been created.

So, various kinds of engine arrangements were created to go inside these shapes. For example, this tractor type of propeller it has a shape of the front of the body inside which one can guess the engine is housed. We can only see the propeller here and this engine must have certain amount of space in a certain shape and that shape is likely to be accommodated by something like this or something like this (Refer Slide Time: 36:07). That particular aircraft is most unlikely to have a radial kind of an engine. The shape of the aircraft here does not quite throw any promise of accommodating a radial kind of engine.

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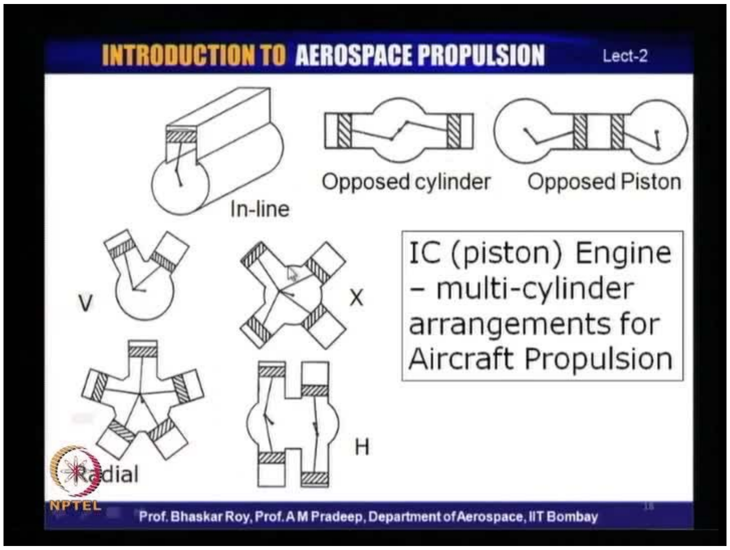

Those are the various issues that govern the choice of the arrangement of engines and the kind of engine shape or arrangement that would be finally selected for aircraft. The number of cylinders is decided by the kind of power that is required - the amount of power that is required - and this is to be decided by the thrust that is required by the aircraft. So, to accommodate the aggregate power that is required, the number of cylinders can be increased. Number of cylinders is decided by the thrust power that is to be delivered by the powering propeller.

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These are the pictures of the various arrangements that we were talking about. This is typically an inline engine, as you can see now they have been created in a shape - in a very compact shape - that could go inside an aircraft and you could have your propeller mounted over here. This is the opposed cylinder type, where you have 2 over here and 2 on the other side and this is where your shaft is coming out, which is the central shaft powered by all the cylinders and this would power your propeller.

This is the V-type, where you can see one cylinder here and other on the other side. You have so many of them lined up and they power the central shaft which is coming out over here and that runs the propeller. This is the arrangement which typically would go inside an aircraft and conforming to the aircrafts stream lined shape or the low drag shape. This is a radial kind of propeller as you can see here, there are so many of them mounted in a radial formation and they have the central shaft and you can see here the propeller actually fixed to the engine.

These are the various kinds of arrangements that have been used over the years for example, these are the ones you are likely to see in small aircraft. These upper 2, you are more likely to see in the small aircraft which probably fly 2 people or not more than 4 people whereas, the lower ones you would probably see powering aircraft, which fly may be 6 people or 8 people. Radial engine which accommodates more cylinders which means, more power and more typically be used for aircraft which fly more people something like 10, 12 people in one aircraft.

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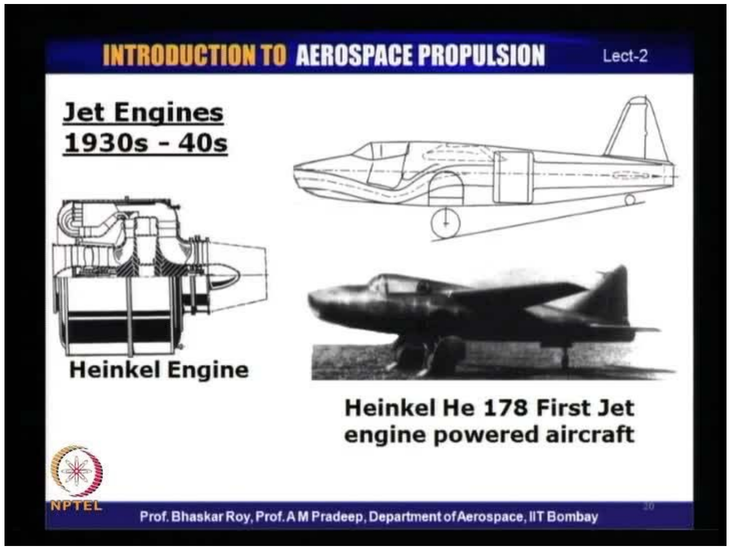

Then, we look at the various kinds of jet propulsion devices has have been used in last 60 years or so. The first jet engine that is recorded to have flown actually is the Heinkel Engine created by Ohain in Germany.

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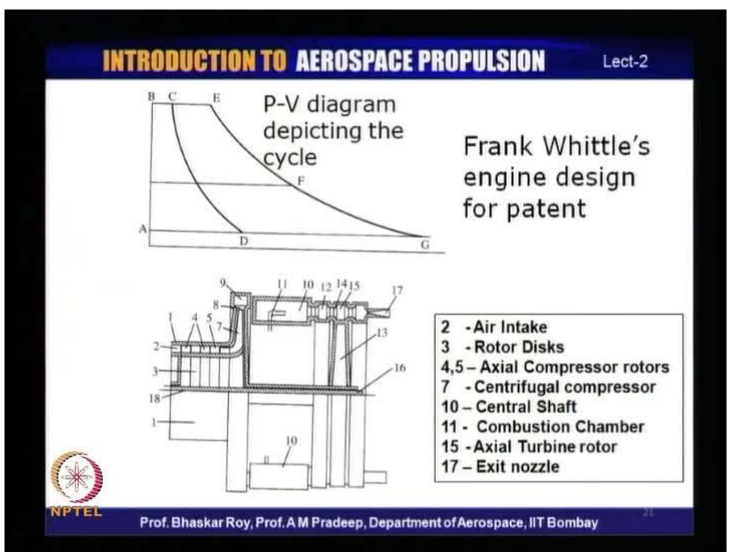

However, Heinkel engine is not the first recorded jet engine. That credit goes to is given now to Frank Whittle even though historically it is pretty much understood that the creation of Heinkel engine by Von-Ohain and that by Frank Whittle in England Von-Ohain in Germany were going on simultaneously independent of each other. They came out with the engines almost simultaneously, in their respective countries. The Heinkel Engine flew for the first time with on an aircraft; Whittle's engine actually flew a little later, this is the Whittle's engine which he patented (Refer Slide Time: 40:14).

You can see here that he had all his concepts in place. It was blazed on a thermodynamic concept of cycle and it is an heat engine, so it supposed to conform to a known cycle and he already had the idea that what kind of cycle he would use.

These are details of the engine in which he used actual compressor. He used a centrifugal compressor which then supplied the air to the combustion chamber, which drove an actual flow turbine which in turn drives the compressors and then, you have the jet over here which our exit nozzle or which is supposed to finally go out in a big jet to create the thrust. So, this is the conceptual design which Frank Whittle finally patented and was granted the patent and that was supposed to be the historically the first patent granted for a jet engine.

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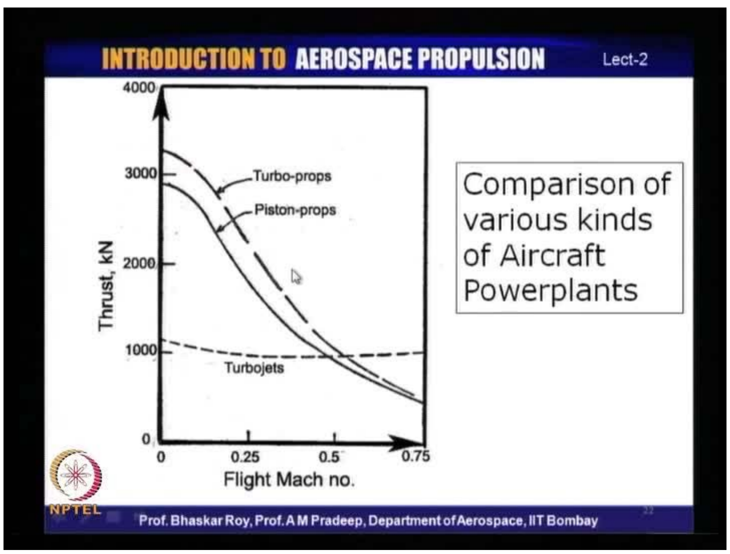

The kind of aircraft power plant that we have today there are many of them. We have just seen that the early 50 years most of the aircraft are flown with what is known as piston props that means, the piston engines powering propellers. As soon as the jet engines came in, one of the varieties that immediately sprang up was what we today known as turbo props that means, these were the jet engines but they were powering the propellers that means, the jet thrust that was available was not the main thrust making device but it is a propeller which creates the main thrust.

However, immediately thereafter the actual pure jet engine started coming and this is the thrust characteristic of these three basic kind of engines, all three of which are in operation even today. You can see here, as a flight Mach number increases from 0 to let us say 0.75 which are still subsonic flights.

The effectivity of the turbo props or the piston props or the propellers starts going down and somewhere around Mach 0.5. The effectivity of the propellers has gone down to the level that the turbo jets become more and more effective means of powering an aircraft. This was realized more than 50 years back and people wanted to fly higher, they wanted to fly faster and when flight of Mach 0.5 became eminent immediately after the World War two. Most of the aircraft designers started looking for jet engines that would give them the necessary power to fly the aircraft at high speeds.

Now, some of these are known today and as a result of which most of the flight today at a higher flight Mach numbers are powered by jet engines. Most of the flights even today at lower flight's Mach numbers are indeed still powered by propeller driven power plants. So, there is a clear divide here, at low speed you would probably like to go with the propeller driven power plant at high speed you probably invariably look for pure jet engine or turbo jet engine to power your aircraft.

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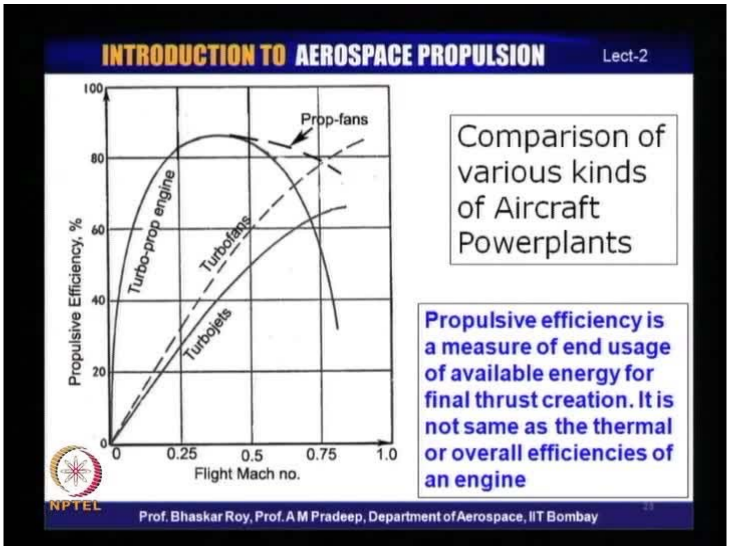

If one stretches little more with the use of what is known as propulsive efficiency, which is actually a measure of the end usage of the available energy for final thrust creation. It is not same as thermal efficiency or the overall efficiency of an engine as determined from the thermo dynamics. This is the propulsive efficiency that is how much of energy that is available at the end of the engine action that is finally converted to thrust.

All the energy that is available for thrust making does not finally create thrust. So, this propulsive efficiency is the measure or efficiency of the end use of the available energy. Now, this provides quick glimpse of what happens to various kinds of engines. The turbo prop, the efficiency can be very high at low flight Mach numbers; it peaks at somewhere around Mach 0.4 or 0.5 and then, it starts dropping very fast.

Then, if you look at the jet engines and its variants, the turbo fan engines, they start raising and from flight Mach number 0.5 onwards they become competitive. The modern variant of the propeller which is some kind of a mix between propeller and fan is called prop fan. This prop fan extends the propeller utility a little more up to Mach 0.7, 0.5 or 0.8 and keeps in a competitive market after which again the turbo fans and the turbo jets would need to be used to power the aircraft.

These are pretty much known today that if you have pure propeller, your effectivity or efficiency would start growing down very fast - very fast indeed- around Mach 0.5 and with the modern prop fans. We will have a quick look at it today you can extend it to around 0.75 but thereafter inevitably, its efficiency would start going down. One of the reason is the propellers suffer from the efficiency defect is because the flow over the propellers - we have seen they are made of airfoils - the flow of the airfoils do become supersonic.

The airfoils that are used in propellers cannot negotiate those supersonic flows in rotating formation and as a result of which the efficiency starts dropping due to the appearance of the shock waves due to the supersonic flow. In the prop fans that are used in the modern aircraft and you would probably see more and more of them in the years to come. Some of the supersonic flow is been accommodated; low supersonic flow has been accommodated but, even today high supersonic flow or clear supersonic flows cannot be accommodated through the rotating propellers. As result of which the efficiency drop starts appearing and hence, you would need to use variety of jet engine either pure jet or turbo jet to power your aircraft.

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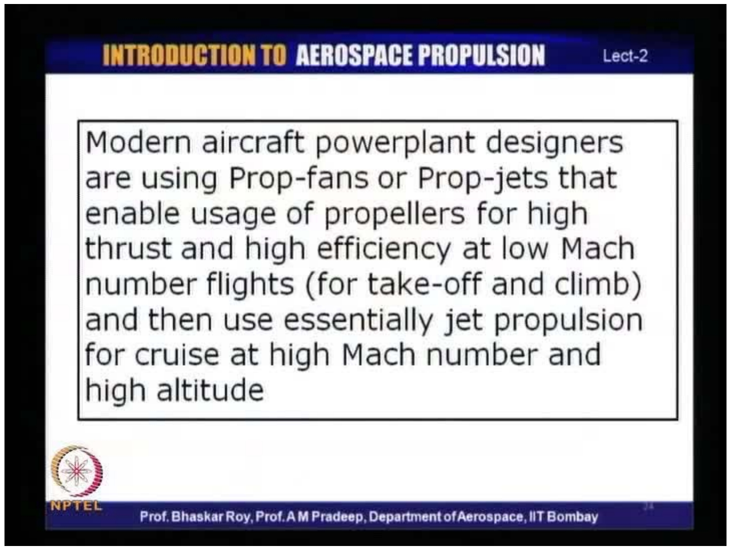

The use of prop fans also called prop jets, extends the use of the propellers to high Mach numbers and this extension is been possible by redesign the propellers with new kind of airfoils; when we go to the propeller chapter. We will probably have a look at those airfoils as to what allows them to negotiate higher Mach numbers, as they are flowing over the propeller blade; which as I mentioned, could actually go supersonic.

As a result of which the jet propulsion became more and more important specifically after the World War two. Today one of the prime means of aircraft flying around the world is the jet propulsion which we will look at more in the next class.

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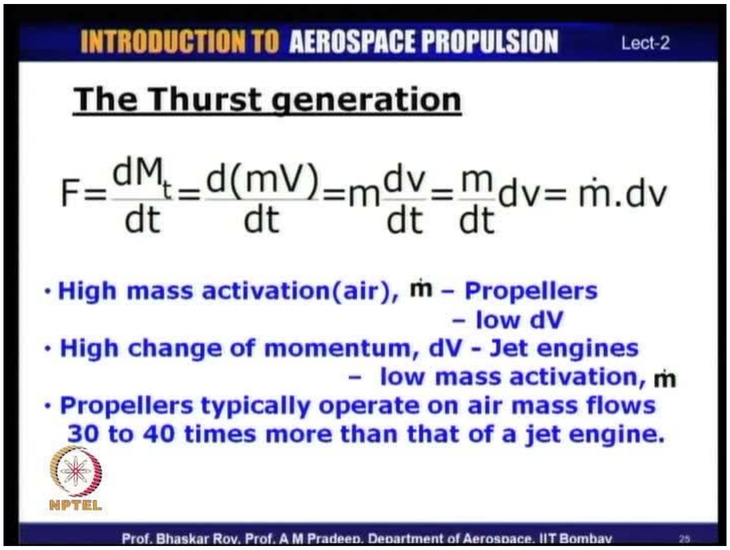

Let us take a quick look at the fundamental issues that we are bothered with here. The thrust generation as we have seen by using the Newton's second law and this creates the thrust which is finally equated to the mass of air and the acceleration, we can now rewrite that as mass flow and the change of velocity and this is the mass flow that we have. Now, this mass flows, if it is very high and the change of velocity is indeed very small, what we have are what we call propellers.

A very high mass of activation is what the propellers do with very small change in velocity. On the other hand, a very large change of momentum or acceleration is created by the jet engines, which actually operate with a very low mass of activation. So, very small mass is activated through a large change of momentum is what is jet engines a very high mass of air activated through a very small change of momentum is what the propellers do.

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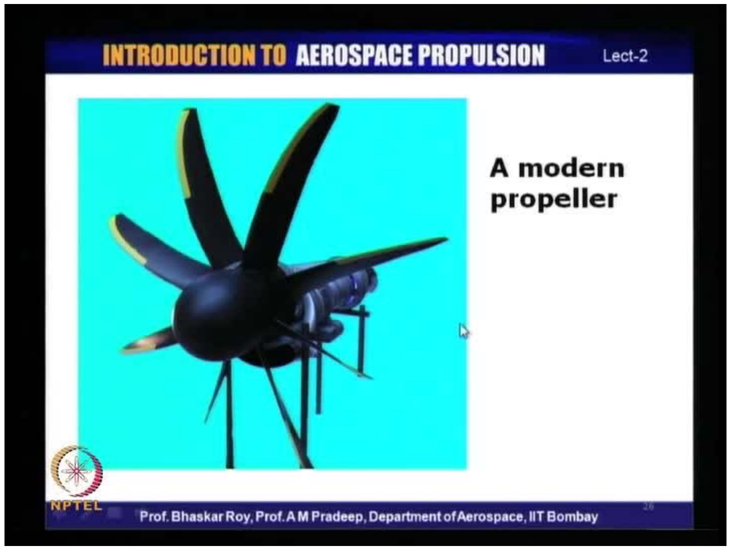

Typically, a propeller would operate with air mass flow which could be of the order of 30 to 40 times more than that of a jet engine of the same size. The propellers and the jet engines operate on same principle but, they use the air mass in different ways. This is a typical modern propeller; it is a large propeller as you can see here.

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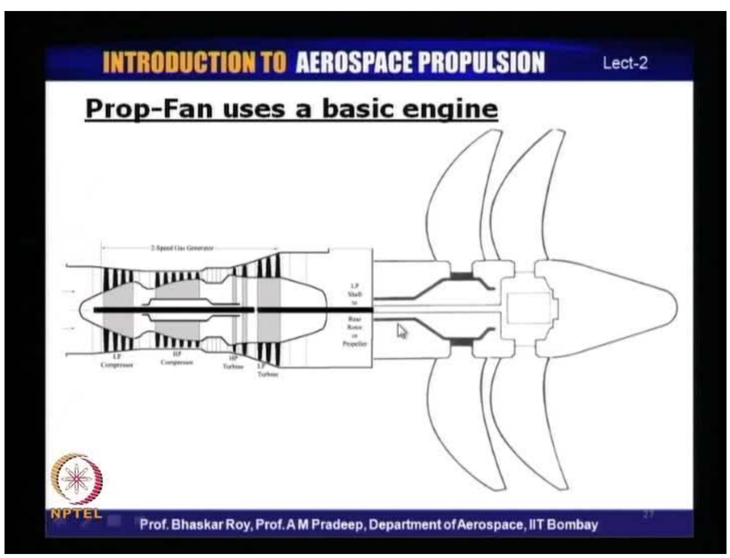

The propeller body is much larger than the engine body, so it is actually geared to use a large amount of air mass. On the other hand, modern prop fan as I mentioned and we shall study these afterwards uses a propeller which is mounted at the rear of the engine and you can see here 2 propellers. You can see here, the propeller here, still very big compared to the size of the engine.

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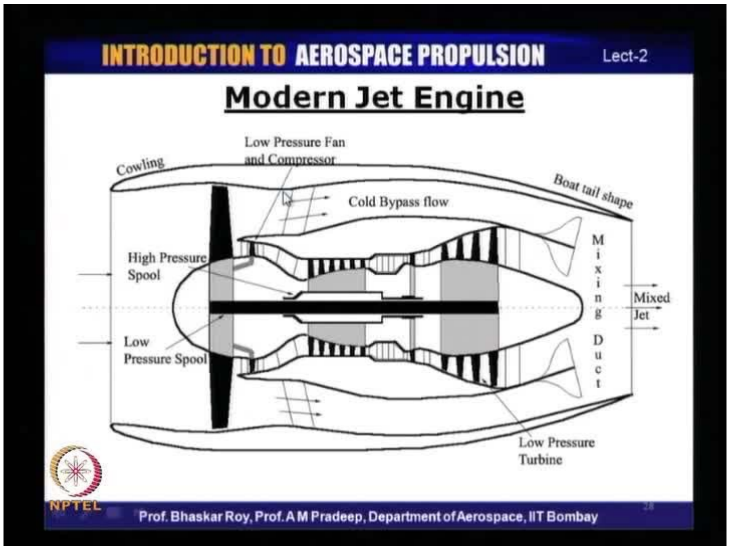

In the next class, we will have a look at a modern jet engine. We shall look at the various components of the jet engine, how they function and finally, how they create thrust by using all these components together in a matched manner so that, we have a net change of momentum which finally creates a thrust that makes an aircraft fly. We shall cover the modern jet engines, various kinds of jet engines in the next class.