Introduction to Aerospace Propulsion

Lect-2

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 .-- some kind of prototype, but many of them never quite flew. And we -- go on to wright brothers when the aircraft flew for the first time and what happened thereafter , all the aircraft engines actually developed over the years over a period of almost 150 years . the first aircraft that flew was nearly 100 and 50 years back. That didn’t fly actually but was created 150 years back . One of the creations was by Felix De Temple De La Croix. Ah --- what was called a 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 tailplane 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 that again that resembles that of a bird and the side view which resembles almost that of a boat in which something or somebody could probably sit or be placed over there and then of course you see the propeller . and this is the concept that was created nearly 100 and 50 years back. But to fly a craft like this you would need a propeller like device to make it move in air. And this is the side view of the propeller which gives us the first impression of what mankind thought a flight craft could possibly be and this was nearly 100 and 50 years back.the idea that you need to have thrust created by some kind of propulsor was created around that time and 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 and the idea at that time was 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.And this is due to resistance of the air in which the craft flies. 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. and during these various modes of flight you need to create thrust that on a continuous basis overcome this resistance or air resistance and keeps craft flying at certain predetermined speeds in a certain predetermined mode and this creates finally aircraft motion. Now unless you have this balance of forces, the lift which would overcome the weight of the craft and a thrust created by a propulsor which on a continuous basis must overcome the drag its not possible to fly. This is the minimum requirement for a craft to fly and our business in this course is to look at how a thrust is created by propulsor which propels the aircraft through the air and various kinds of engines that create the propulsive power that finally creates the thrust. The early devices that were created but a wherein the designers drawing board. One of them was by a George Cayley. Now George Cayley is quite often credited with being father of modern aeronautics and he created much of the science that is used even today for understanding the aircraft flight. And what he created was a craft that looks something like this, ok and it had a small boat again and a 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. Now 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. A little later after that a gentleman called Samuel P Langley created another kind of craft. Now this had two 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 one wing each side so two wings on two sides this had four wings so two on each side in a symmetric manner and this was a little later in late nineteenth century and this was what a first attempt to create something that could possibly fly. One of the reasons one supposes that you need two wings was to create sufficient lift to make the craft balance the weight. And to do that they had to create two sets of wings on each side and as a result of which you could also see there are two sets of tail planes at the rear which is not exactly what the bird’s do. But at that point of time people had realized that you can’t have a craft which exactly looks like a bird. You need to create something different and that difference is what appeared as a biplane. 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 and as soon as the craft took off from ramp on a water body it immediately thereafter crashed on the body. One of the reason possibly was that power available was not sufficient for the craft to balance its drag in the air. As a result of which lot of people looked at various kinds of a oaring devices. And 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 attempt was by aLorin and he created what can be called kind of a jet engine but it was based on the piston engine concept which was prevailing at that time, had already appeared in market. And this means that a piston would be moving like this and would expel the gas as you know probably every second stroke and as a result of which this gas being expelled or ejected would create 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 being that you would get a thrust every second stroke of the piston. This was concept created by Lorin. And as 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 six of them one after another in line. So that six of them could produce thrust also there is a possibility that he could time the piston strokes such that they don’t actually eject a hot gas simultaneously. It could be timed to eject them in a manner that only two of them ejected one time or it could be timed in a manner that allsix of them eject at the same time depending on amount of thrust that needs to be 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 straightforward what we call jet engine in which 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 and this again as per newton’s third law creates an action reaction that would hopefully propel the craft through the air. So this was a concept created by Lorin in 1913 for which he actually took a patent. Now thereafter 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 supposedly looks like a jet engine. It has a concept very similar to present jet engines which we look at detail a little later. It had compressors it had turbines 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. The one engine that definitely flew and created the so called history of flight was the wright’s engine. Now this engine was again quite simple. It had 4 cylinders. These 4 cylinders actually powered one particular shaft and this shaft powered the propeller which flew the wright brother’s plane simply called flier. And this is the detail of one of those pistons which has all the components and those who are familiar with the typical engine would find all the components in the piston engine over here. You have the air intake and you have the intake manifold and then you have the combustion chamber etc. all the component that one is familiar with you would find this here. This was the standard piston engine. And what they did they had enough calculation to back them up. They realized that they need a minimum of 4 engines to create sufficient power to power their propeller. And this is what they have put on their craft which flew for the first time in 1903. Now this was the craft this is historic photograph which some of you may have seen and this shows that the wright brothers flying for the first time in the history of mankind in the beach called kitty hawk in north Carolina USA and this is the flight in which oliver 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 4 3 of the flights are recorded as the first 3 flights of humankind. Now this had the engine we have just seen and it has the propellerswe will have a look at. Now this is a craft which is been preserved in a museum in Washington DC , the Smithsonian institute museum. And you people go there you will 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 ok, and it had 2 tailplanes , in fact they were in front. We could see here a person actually lying down. So Orvil Wright was actually lying down on the craft, because there was nearly no place for him to sit there, ok, and this you can see the craft from another picture in which the two wings are very clearly seen and the two tail plane are also seen. As we have discussed this was the part of aircraft design which wright brothers took a long time into perfect before actually they flew. And then now you can see the propellers which they used in the 1903 flight. One of the propellers they used later on, a little later around 1910, and over the years the shape of the propellers which they used actually changed a lot. The propeller you can see here is. It’s a simpler propeller it’s a pedal type here the propeller as you can see in 1910 is a little more twisted-- far more twisted, bigger in size and probably has much better field for creation of thrust. So there was 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. There is a historical claim made by a gentleman called Gustave Whitehead, about 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 and it was carrying 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. What the Wright brothers flew for example in its flight was the distance which is now recorded as equivalent to the wingspan of today’s Boeing 747. So it was very small hub so to say but the flight claimed by Gustave Whitehead, or his successors later on claims to have been a flight of a nearly half a mile. there is no record except for this particular picture . it was supposed to be monoplane resembling that of a same picture that we have seen for Felix Du Temple’s monoplane . so somewhere fifty years after Felix Du Temple’s monoplane a somebody gentleman named Gustave Whitehead is reported to have created his similar monoplane and actually flew it. However this is not being scientifically accepted and as far as all the historical scientific records are concerned the first flight is credited to the wright brothers. And what we see now is that all those flights recorded over first 50 years of flight, all flew with propellers as the only means of propulsion, which means that jet engine as we noted were not the means through which propulsion was done . it was propellers all the way over a period of half a century. In fact according to the records in various scientific recording manuals, sometime after world war 1 a high powered committee in US went into the decision making whether a jet propulsion could be used for various kind of flights and they came with the decision that jet propulsion was really not possible within the foreseeable future and hence they entrusted NACA that’s the national administration civil of civil aviation which created this which was created in US with the creation of large number of propeller blades and these propeller blades that were created by NACA in between the two world wars. As we shall see later on by this second world war jet propulsion had actually come into being and the prediction made by the so called high powered body proved to be wrong. We will come to that in a few minutes. Let’s go through the development of propellers. Now propellers what they do is they use airfoil shapes. Now airfoil shapes were created as we have seen as we know by George Cayley nearly 150 years back and it was proven that many of the birds and fishes do have these kind of airfoil shapes that allowed 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 propellers also. Propellers uses the shape and as the propeller rotates as per the shape characteristics they create lift on account 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 to be designed into the propeller so its necessary that person who designs the propeller for a particular craft is knowledgeable about science of propeller so that when he creates the 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 in two types one that pulls the aircraft from the front that its position is the front of the aircraft either the nose of the aircraft or mounted on the wings on the front of the wings and these are called tractor type propellers. There are the other types where sometimes a propeller 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 this is are two kinds of propeller that have been around for quite a long time. Most of the propellers that we see are tractor types, but there are quite a few pusher type propeller that have also been used over a period of last 100 years. These are the various propeller blades. Airfoil shapes created by NACA more than 60 years back as you can see these shapes are so many. There are more than hundred shapes over here and they have served the purpose of creation of little hundreds and thousands of propellers that fly various aircraft around the world. So this was the basis or the beginning of creation of propellers. There are number of companies who specialize in easing these airfoil shapes for creating the propellers. Let’s quickly take a look at how the propeller actually operates because that’s what make made the aircraft fly for nearly half a century. In fact propellers are being used even today for flying many aircraft. So the history of propellers flying the aircraft is more than hundred years old. And they still active in many aircrafts. So let’s take a quick look what the propellers actually do. The propellers actually if you look at the picture over here they are mounted let us say somewhere at the nose over here which is what we would call a 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 it behind ok. 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 propellerand as the propeller rotates it also applies the suction. So 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 lets say a disc like this which is what 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 and this momentum difference as we know from a a 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. So this propeller matches the entire drag created by this entire, including the drag of the engine and the propeller itself. So it’s the only thrusting body mounted on an aircraft. If you look at a the a typical propeller. This is the typical propeller it would look something like this there are various kinds of propeller various shapes. We probably have a chance to go into it later on in this course but in this particular a a diagram as you can see there is a aa propeller shape which this is the tip of the propeller ok which is what you would see somewhere over here and this is the root of the propeller which is at the core of the propeller and is connected to the shaft which comes out of the engine ok and this shaft goes inside over here and quite often the shaft is covered by a nice body known as a nose cone to make it aerodynamically smooth and 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. Now each if you take cross section of the propeller over here just any anywhere you would probably see a shape like this and this is airfoil shape and as we have seen there are so many kinds of airfoil 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 the 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 kind of airfoils. Propellers near the root typically would be a thick propeller whereas the propeller near the tip would typically be a very thin propeller. A lets take a quick look. Some of the thick propellers airfoil that you see see here are likely to be used near the roots so this is how a typically a a you would probably have a root propeller here and then slowly they become thinner and as you go toward the tip you would probably have a thin airfoil like this. So one such set each subset 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. These are the various kinds of propellers that you probably see today. If you go around this is for example a propeller that is after its being made the propeller needs to be proven and one of the means of proving is to actually test it in a wind tunnel. A a wind tunnel actually is is just a land based grounded a 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 and inside a wind tunnel you test the aerodynamic capability of the propeller you measure the thrust that it is creating and as I mentioned before its 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 in if there is any mismatching remember the aircraft is not going to fly if the thrust falls 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 has flown. You can see here a propeller now this is a propeller, you can see here you have four blades. Now this is a propeller where you can see you have three blades. So many of the propellers that fly quite often have 3 blades . Now this is a tractor type of propeller where the propeller is at nose of the aircraft in front of the aircraft. This is an aircraft in which the propeller is the rear and what we call the pusher kind of a propeller. So its at the rear of the propeller or the tail of the aircraft and this is a typical design in which it was thought that putting the propeller at the nose may not be appropriate thing to do for this particular design whereas this particular aircraft design accommodates a propeller right at the nose and it’s a tractor type of propeller. 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 engine which were already powering the automobiles and others vehicles moving on the surface of the earth, a they were also powering various kinds of engines that all the boats that went over the water. Now this kind of engine had certain specific aa requirements. To make an engine that 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 which would create thrust to fly the aircraft and the one of the prime requirements of anything that goes in aircraft that 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 into. So what people did they looked at various kinds of a arrangements if you have pistons let us say lined up one after another ok in line they are simply called inline engines. All these pistons would drive 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 this shaft which of course a 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 them up one after another to get certain amount of aggregate power you have let’s say 2 pistons or 2 cylinders on two sides ok powering a central shaft. So you have 2 pistons from two sides and they are timed in such a manner that the power stroke of the 2 are staggered in time. Another variant of this is to have a opposed piston within let’s say one body of a cylinder.So you have 2 pistons and it is actually firing on two 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 that people came out with is simply called V type where the pistons are arranged in a V formation. They again power the central shaft over here. In this formation you can again put them in line like this single engine. So you can have V engines lined up one after another or one behind the other and so you could for example have 2 engines in V formation or you can have 4 engines or you can have 8 engines or you can have 12 engines lined up inline in V formation. Many of the modern aircrafts do actually have upto 12 engines lined up to supply the aggregate power to run the propeller. The other way of looking in at power generation is to have let us say X type where you have 4 of these pistons powering the central shaft and again the timing of the 4 pistons are such that this central shaft is continuously being supplied with power and which runs the propeller . so you can have 4 of them now lined up and then you can have 4 and then 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 ways of doing this 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 again you can double them up. That means you can have 2 sets inline with each other you know so instead of a single piston you can have radial arrangement in line at least 2 of 2 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 also simply known as H type which again uses 4 cylinders and this time it’s trying to power 2 shafts to create power that you supply to the propeller. These multi-cylinder arrangements for aircraft propulsion were created essentially to go into the aircraft ok. The various cylindrical arrangements that we are looking at the cylinder arrangements that we are looking at were created essentially for the aircraft power plants. 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 minimum amount of drag your engine needs to be somehow accommodated within the shape. This is important issue that your engine arrangement must confirm to the shape of the aircraft that is being 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 propellers here and this engine must have certain amount of space in a certain shape and that shape is likely to be let’s say accommodated by something like this or something like this ok. That particular aircraft is most unlikely to have a radial kind of engine. The shape of the aircraft here doesn’t quite throw any promise of accommodating radial kind of engine. So 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, 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. So number of cylinders is decided by the thrust power that is to be delivered by the powering propeller. 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 that could in a very compact shape that could go inside an aircraft and you could have your propeller mounted over here. And 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 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 and you have so many of them lined up ok and they power the central shaft which is coming out over here ok and that runs the propeller. So this is the arrangement which typically would go inside an aircraft and confirming to the aircrafts inline 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 propellers actually fixed to the engine. So these are various kinds of arrangements that have been used over the years. Almost all the arrangements are still in use, for example, these are the ones you are likely to see in small aircrafts. These upper 2 you are more likely to see in small aircrafts which probably fly 2 people or not more than 4 people, whereas the lower one you would see powering aircraft which flies may be 6 people or 8 people and radial engine which accommodates more cylinders which mean more power, more typically be used for aircraft which flies more people, something like 10 12 people in 1 aircraft. Then we look at the various kinds of jet propulsion devices as 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 and this was a Heinkelaa jet powered aircraft which flew for the first time with a jet engine. So it’s recorded as the first aircraft to fly with a jet engine or by what is also known as Heinkel engine. However Heinkel engine is not the first recorded jet engine. That credit goes to, is given now to Frank Whittle, even though historically it’s pretty much understood that the creation of Heinkel engine by Von Ohain and that by Frank Whittle in England Von Ohain in Germany were were going on simultaneously ,independent of each other and they came up with 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 –ah-- he patented. You can see here that he had all his concepts in place. It was based on a thermodynamic concept of a cycle in and, it is a heat engine, so it’s supposed to conform to a known cycle and he already had the idea that what kind of cycle he would use. These are the details of the engine in which he used a a actual compressor used a centrifugal compressor which then a supplied the air to the combustion chamber which drove an axial flow turbine which in turn drives the compressors and then you have the jet over here which are exit nozzle, which is supposed to finally go out in the 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. The kind of a a aircraft power plant that we have today, there are many of them, a we have just seen that the early 50 years most of the aircraft were flown with what is known as piston props that means piston engine powering propellers. Now as soon as the jet engines came in, one of the variety that immediately sprang up was what is known as what we today know as turbo props. That means these were the jet engines but they were powering the propellers that is the jet thrust that was available was not the main thrust making device but it’s a propeller which creates a main thrust. However immediately thereafter the actual pure jet engines started coming and this is the thrust characteristic of these 3 basic kind of engines which are in operation even today. And as you can see here as the flight mach number increases from 0 to let’s say 0.75which are still subsonic flights. The effectivity of the turbo props or the piston props or the propellers start going down and somewhere around mach 0.5 the effectivity of the propellers have gone down to the level that the turbojets 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 imminent immediately after the world war 2 a, 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 a 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 flight even today at lower flight 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 a pure jet engine or a turbojet engine to power your aircraft. If one stretches a little more aa with the use of what is known as propulsive efficiency, which is actually a measure of the end usage of available energy for final thrust creation. It is not same as thermal efficiency or the overall efficiency of an engine as determined from, from the thermodynamics. This is the propulsive efficiency that is how much of energy that is available at the end of the engine aa 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 of the 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 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 ok. And then if you look at the jet engines and it’s variants the turbofan engines they start rising, and from flight mach number 0.5 onwards they become competitive. The modern variant of the propeller which is some kind of aa mix between propeller and fan is called prop fan. And this prop fan extends the propeller utility a little more upto say mach 0.75 or 0.8 and makes keeps it in a competitive market after which again turbofans and the turbojets would need to be used to power the aircrafts. So these are pretty much known today than if you have pure propeller your effectivity or efficiency would start going down very fast, a 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 there after inevitably it’s efficiency would start going down. And one of the reasons the propellers suffer from the efficiency defect is because the flow over propeller, we have seen they are made of airfoils, the flow over airfoils do become supersonic. The airfoil that is used in propeller scan not 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 of them in years to come. Some of the supersonic flow is being accommodated, a low supersonic flow has been accommodated but even today a high supersonic or clear supersonic flows can not be accommodated through the rotating propellers and as a result of which the efficiency drops starts appearing and hence you would need to use variety of jet engine either pure jet or turbojet to power your aircraft. The use of prop fans on a also called prop jets extend the use of the propellers to high mach numbers and this extension has been possible by redesign the propellers with new kind of airfoils. When you go to the propeller chapter we will have a look at those airfoils what allows them to negotiate higher mach numbers as they are flowing over the propeller blades 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 2 and 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. Let’s take a quick look at the fundamental issues that we are bothered with here. The thrust generation as we have seen is by using the newton second law and this creates the thrust which is finally aa equated to the a a mass of air and the acceleration. We can now rewrite rewrite that as mass flow and change of velocity and this is the mass flow that we have. Now this mass flow 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 a 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 in momentum is what the propellers do. So 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. So the propellers and the jet engines operate on same principal but they use the air mass in different ways. This is the typical modern propeller, it has large propeller as you can see here the propeller body is much larger than the engine body ok. So it is actually geared to use a large amount of air mass. On the other hand a modern prop fan as I mentioned and we shall study this later afterwards uses a propeller which is mounted the rear of the engine and you can see here 2 propellers. You can see here the propellers very big compared to the size of the engine. 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 finally we have a net change of momentum which finally creates the thrust that makes an aircraft fly. And we shall cover the modern jet engines, -- various kinds of jet engines in the next class.