Introduction to Flight
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Lecture No. 07.1
Introduction to Propulsion

Today we start capsule number 6 and in this capsule, the first talk is going to be on propulsion systems. Our task today is to get an idea about the various types of propulsion systems that are commonly used on aircrafts and towards the end we will have a peep at the future, looking at what is in store for us. First of all to define the meaning of propulsion,

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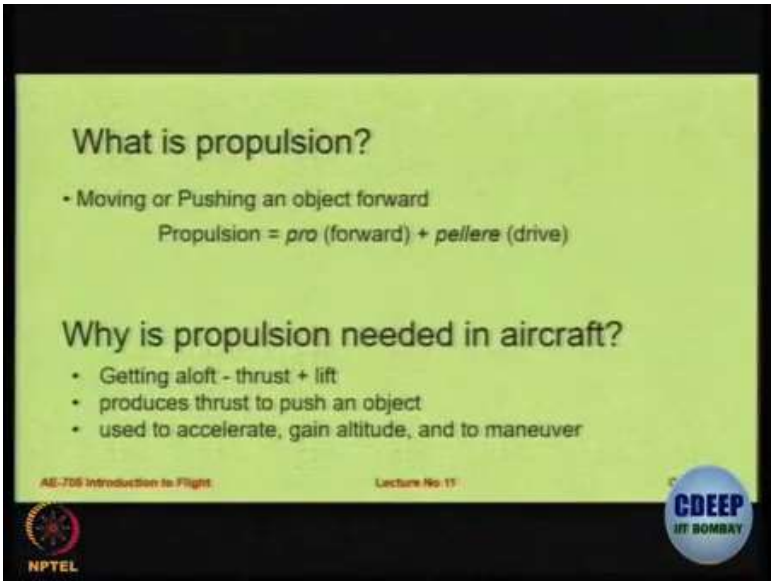

Propulsion is something that allows you to move forward by either moving an object or pushing an object. So, based on these two things, moving or pushing, there are two kinds of power plant, we call them as pushers and tractors. Pushers are those power plants which push the aircrafts forwards and tractors are those power plants which pull the aircraft behind them, okay.So why do we need it?

Because we need to generate a force that moves the aircrafts, so that we overcome the drag and also provide it with some minimum speed so that it can generate lift. Okay and then if you have extra thrust over and above what is required for the minimum operations, you can use it for gaining altitudes, manoeuvring, accelerate, etc. okay.

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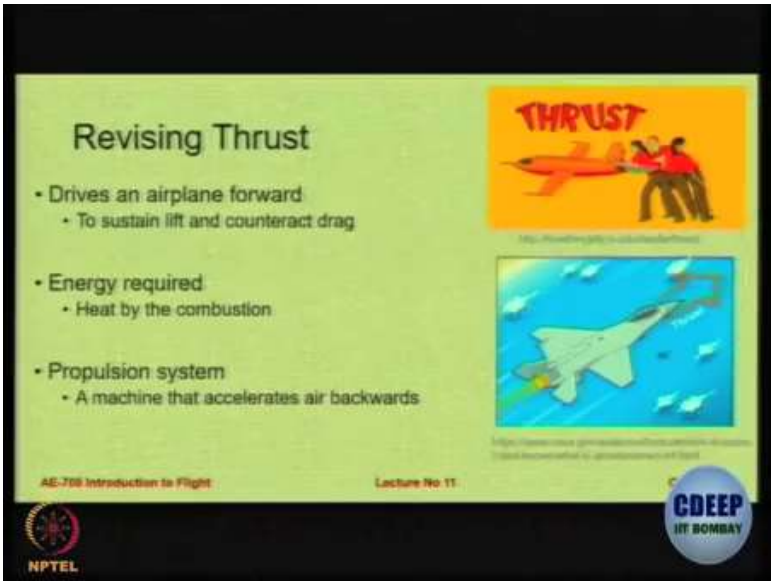

So let us just revise what we have studied in our earlier classes. We are just looking at what is thrust, okay. So, this is something that drives the airplane forward and generally the energy required to produce the propulsive force is created by combustion. So the propulsion system can be considered to be a machine or a device or a system that accelerates the air backwards and hence pushes the aircraft forward. That is the basic definition of a propulsive system.

Now there are various kinds available, there is a huge choice available and we need to look at which are the ones that are of great relevance to us. So among the lot of choices available, we will try to cover today only these types,

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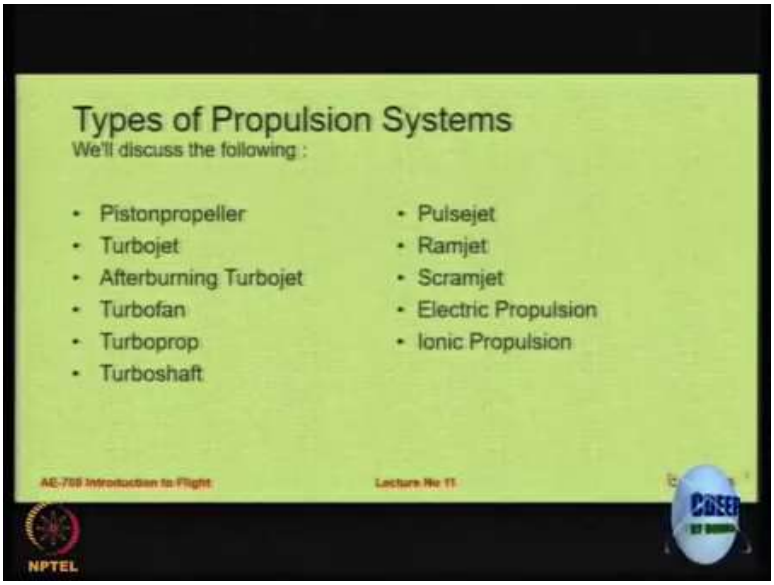

And that too, I will be able to give you just a glimpse about them. After the lecture is completed, I am going to upload some reading material which will allow you to do self-study about these systems, but in this particular sequence we are going to look at the various types of propulsion systems. Let us first have an overview about how a designer of an aircraft chooses, which propulsion system is appropriate for a particular aircraft type. So one consideration for that is given in this particular chart,

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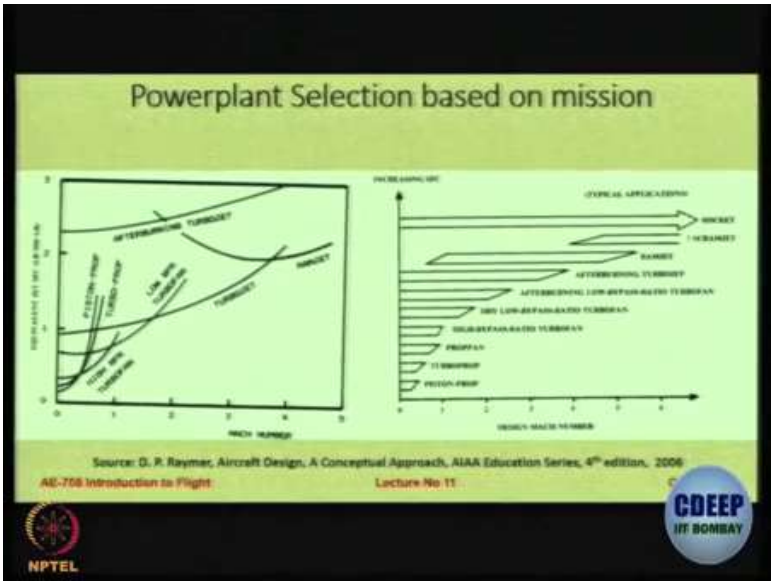

Which tells you that for various Mach number regimes or for various operating or maximum Mach number values, various propulsion systems, they have a differing value of the specific fuel consumption and we also see in this graph how they vary as the Mach number increases. Obviously for a particular Mach number at which you want to fly the aircraft, you would like to go for the propulsion system that gives you the lower SFC value. So looking at this graph, we see that for Mach numbers below 1, that is 'M' less than 1 in the x-axis, we are generally interested only in either turbofans, piston-props or turboprops.

You would not look for example for a ramjet, for that application, okay. Only when it goes beyond, you will have to look at it, correct, okay. This is another graphic that tells you, which are the Mach number ranges in which a particular power plant type is generally recommended. So there are bands. So, what you should do is, if you are designing an aircraft and you have to select a power plant, just look at the Mach number at which, in which you are operating regime falls and then choose a power plant that is suitable or applicable within that range.

For example, if your Mach number range is from 3 to 4, there is no way you can think of pistonprop, turboprop, propfan, hi-bypass, turbofans, you cannot. If it is 3 to 4, it can only be an after burning turbojet or a ramjet, okay. So, this graphic taken from the seminal book by Daniel Raymer gives us an idea on which are the ranges suitable for which power plant. So let us look at them one by one.

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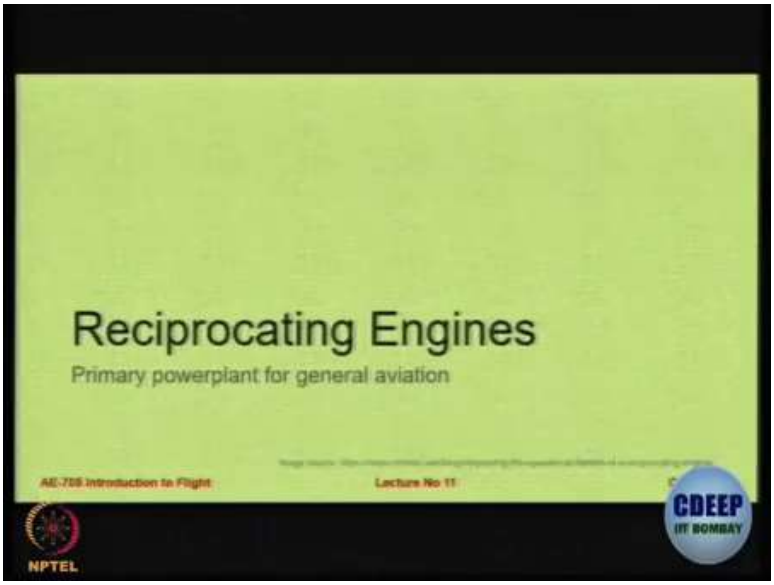

The most basic and the most fundamental aircraft engine is the reciprocating engine, also called as the IC engine, okay. And this is the primary power plant for general aviation aircraft. So can someone tell me, what do you mean by a general aviation aircraft? What is a general aviation aircraft? For which such power plants are more suitable? Anyone would like to start? No one has an idea about general aviation?

So general aviation basically is non-military, non-transport, mostly used for personal purposes, mostly used by passengers who are not paying any fare but are using the aircraft for their own personal applications. Okay, that is called as general aviation. So, the aircraft that you see in the flying clubs, the aircraft that you see being used by individuals to fly for their own personal reasons, either for some official travel or for just fun and leisure, these are general aviation aircrafts. So in general, small aircraft, not for profit, not used by passengers like you and me.

So, such aircraft generally tend to be low speed, limited range, hence therefore a reciprocating engine is a very suitable engine for such power plant, for such aircraft. So in general, a reciprocating engine is very much suitable for such aircraft. So, a reciprocating engine comes to us from mechanical engineering. Essentially what it does is it converts the chemical energy present in a fuel,

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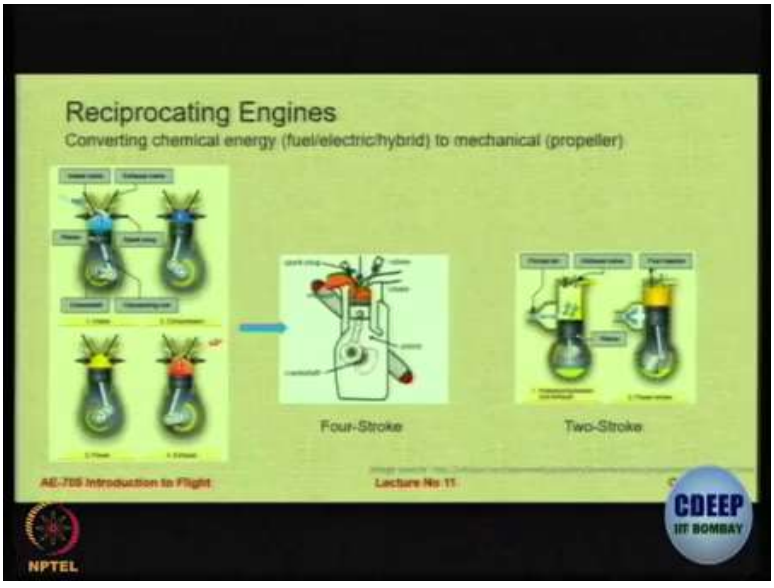

Which could be either a liquid fuel, it could be gaseous fuel and then today we also have hybrid, electric, etc. Whatever be the fuel, it has to be converted to mechanical energy through a propeller.

So, through a propeller is important. If you want to look at a internal combustion engine, okay. So, there are two basic types two stroke, four stroke, but then we also have other types called like Wankel engine, etc. Let us have a look at how this combination works.

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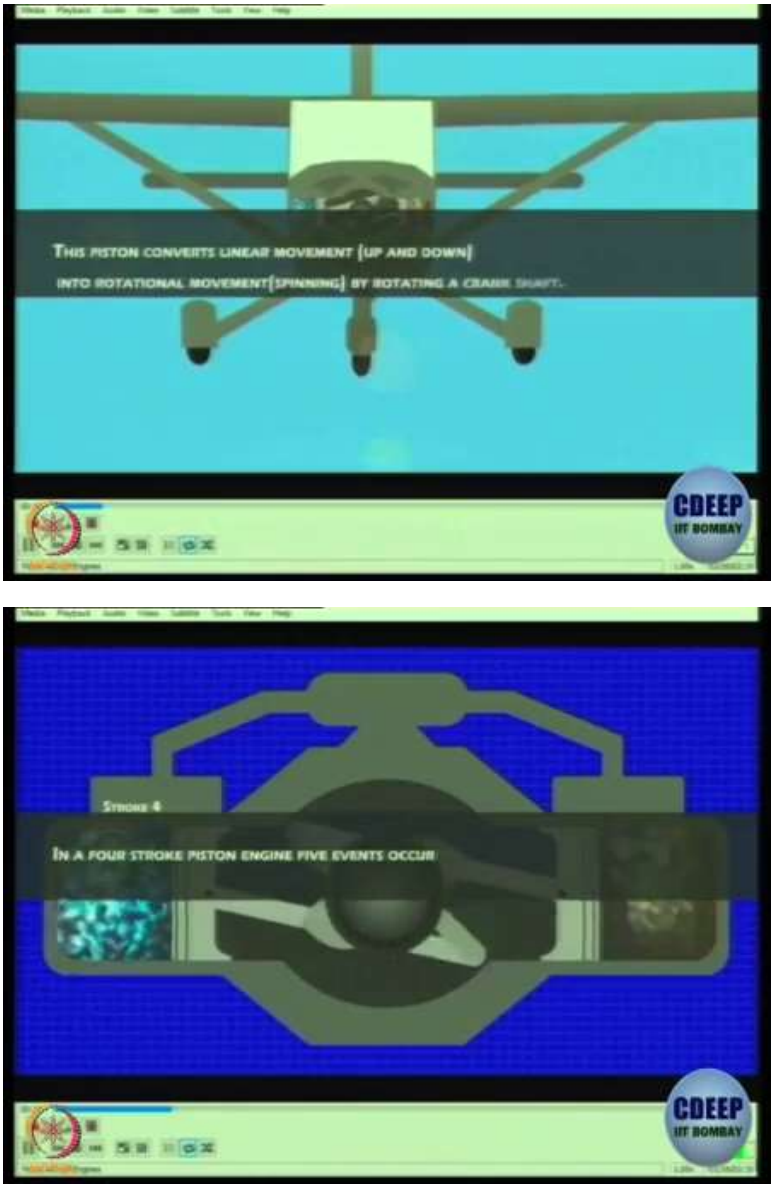

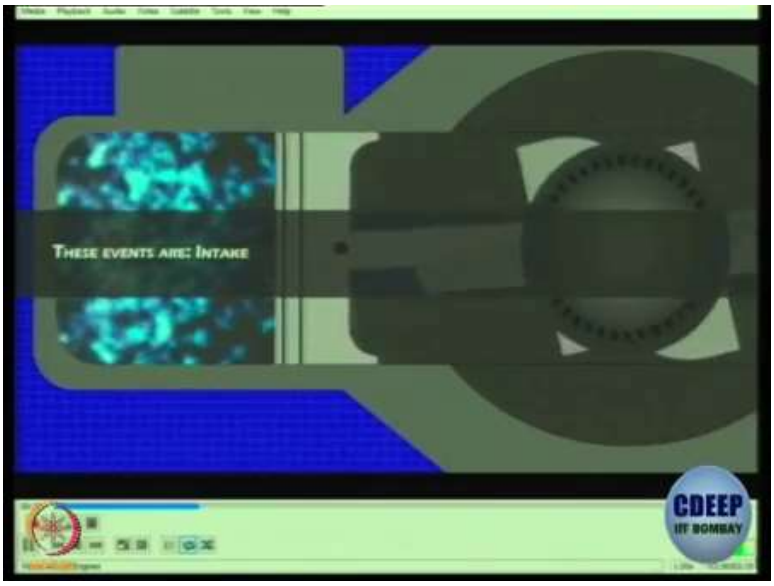
These events are: Intake
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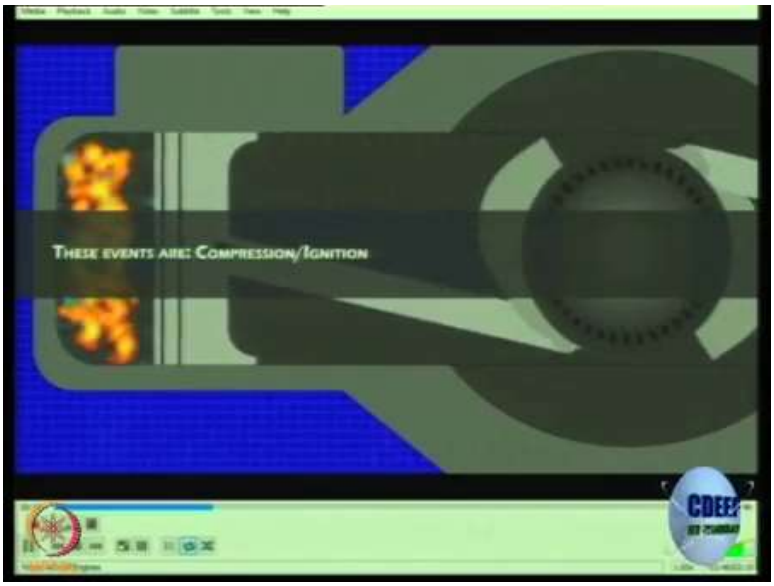
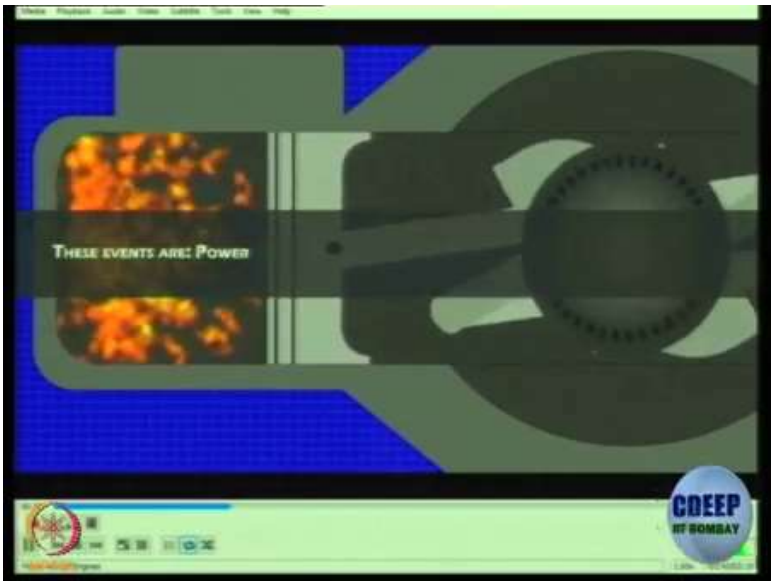

These events are: Compression/Ignition


These events are: Power
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These events are: Exhaust
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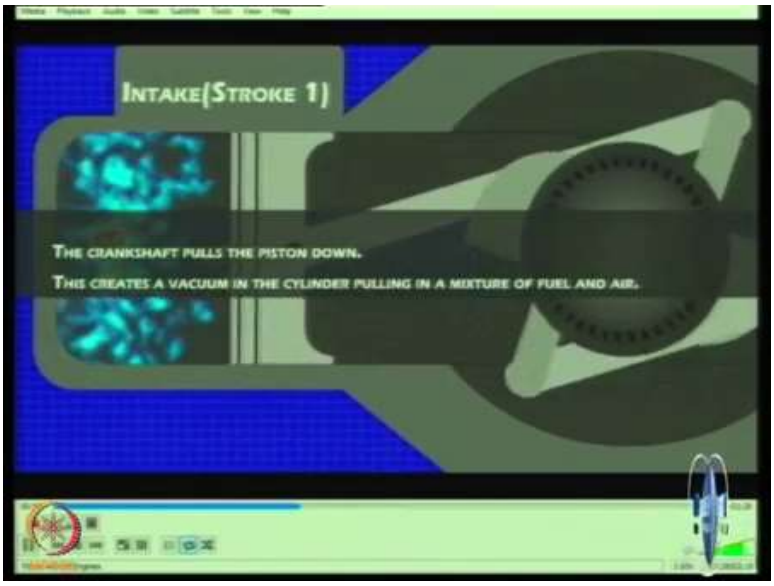
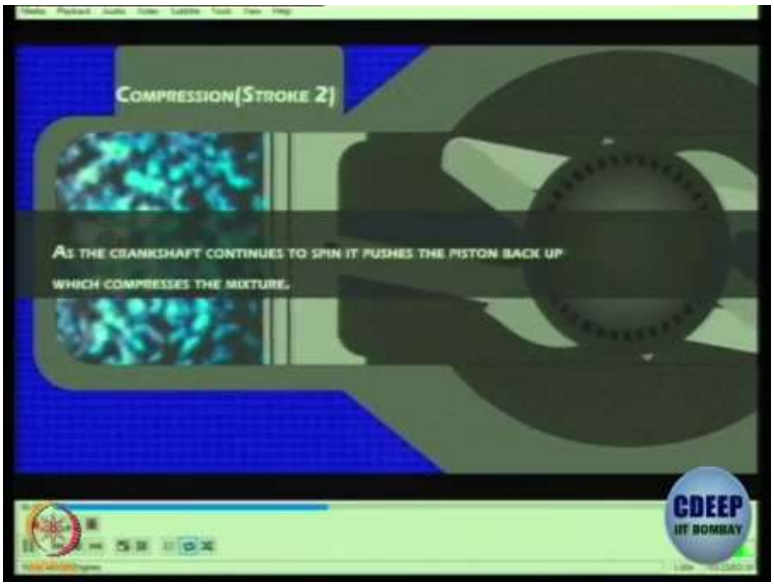

INTAKE(STROKE 1)
THE CRANKSHAFT PULLS THE PISTON DOWN.
THIS CREATES A VACUUM IN THE CYLINDER PULLING IN A MIXTURE OF FUEL AND AIR.


COMPRESSION(STROKE 2)
AS THE CRANKSHAFT CONTINUES TO SPIN IT PUSHES THE PISTON BACK UP
WHICH COMPRESSES THE MIXTURE.
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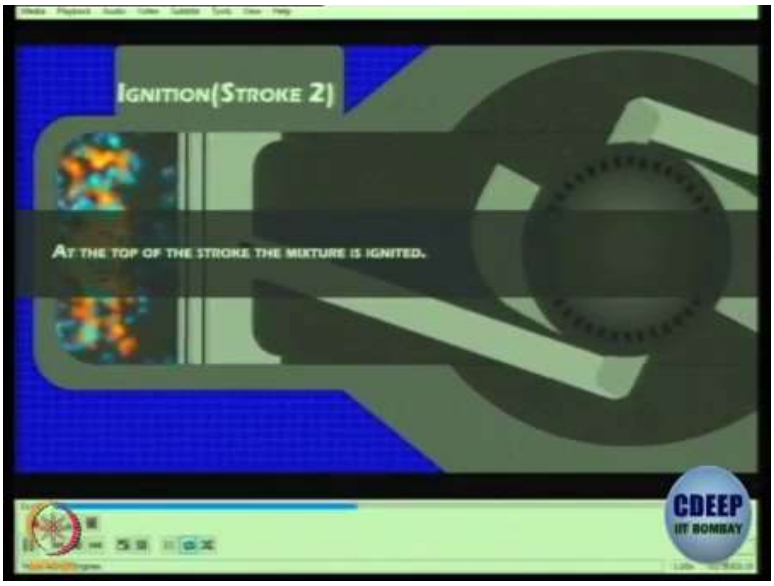
IGNITION(STROKE 2)
AT THE TOP OF THE STROKE THE MIXTURE IS IGNITED.
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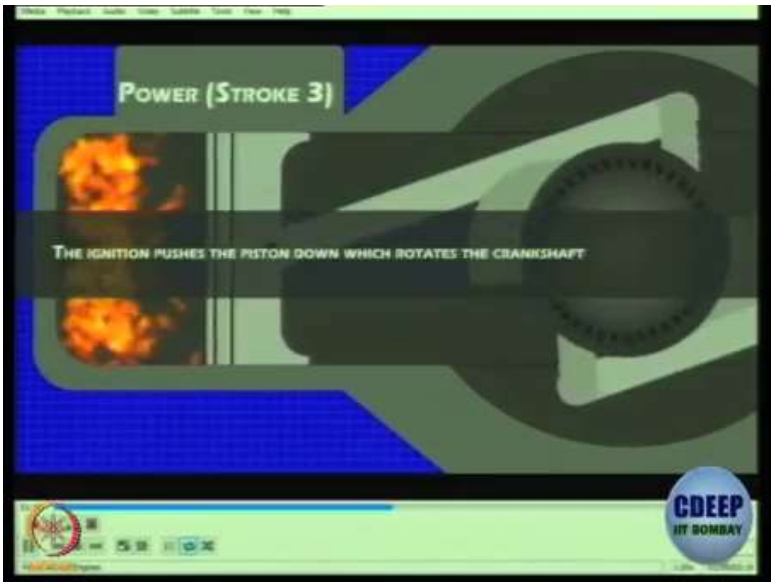
POWER (STROKE 3)
THE IGNITION PUSHES THE PISTON DOWN WHICH ROTATES THE CRANKSHAFT
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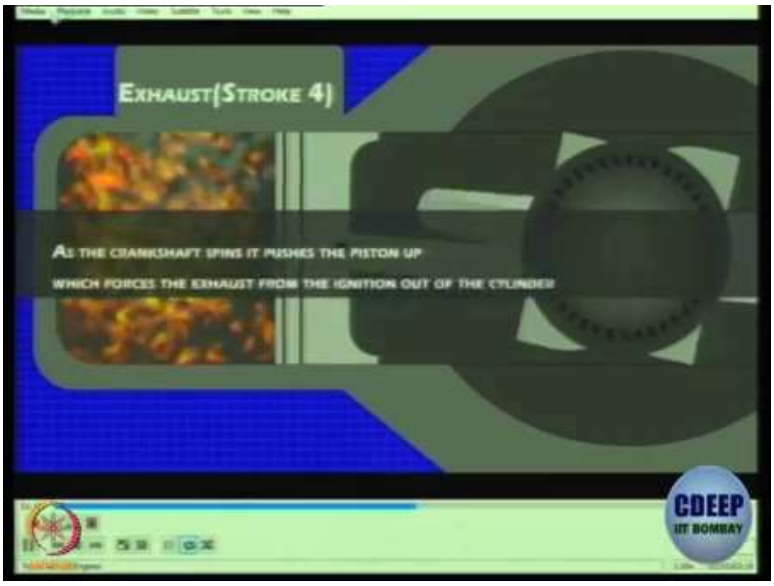

So the name itself, if it is a piston engine aircraft it uses a piston and its reciprocating motion up and down to generate power. So, here we see an example of horizontally opposed two cylinder piston engine. So, you have an intake stroke in which air is sucked in and fuel is mixed with it. Then you have a compression stroke and then and then ignition. After ignition, the gases expand and push the piston, that is a power stroke and finally the products of combustion have to be thrown out, that is the exhaust stroke. And these motions are connected or converted through a crank shaft into a rotary motion for the main shaft and that is where the power is taken up or drawn.

Okay, so each of the strokes are being explained here and the purpose of each stroke and what actually happens in this stroke is being communicated. So, I think this is something all of us know about, so we do not want to spend too much time. We have a lot of videos today to see on systems about which you actually may not know too much, okay.

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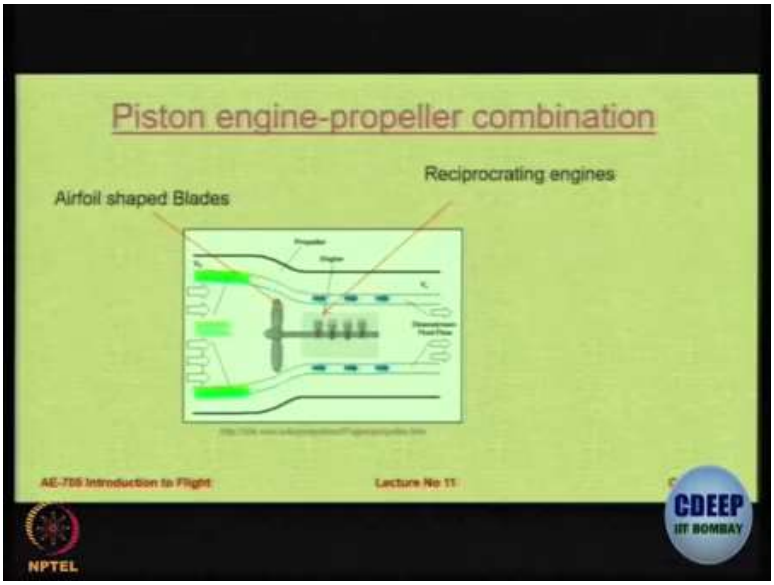

So this is the most simplest one. And the power in a in an IC engine is absorbed through a propeller, which is mounted on the shaft. So, there is something called as a shaft horse power which is the power generated at the shaft by the engine and then by mounting a suitable propeller of a suitable shape, suitable diameter and a suitable RPM, you can extract the power with some efficiency and then that power basically is converted into thrust. So the engine generates power but the piston engine propeller combination generates thrust or the force which is then used to overcome the drag, okay.

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So, let us look at a few piston engine powered aircrafts which are very popular and very famous. This particular aircraft you can see there is a for a comparison that is a man's image next to it, Is really powerful, this particular aircraft was able to fly at a speed of 528 miles per hour on a on an IC engine, okay. So it is really a very powerful example. And then here is an example of the ultimate piston powered fighter aircraft which was so much capable that it was able to fight MIG 20, MIG 15s which have jet engines, okay.

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NAVY
www.RAFALETIGRE1
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There is a very interesting video that talks about the capabilities of Hawker Sea Fury. You can see each side has a bend bendable wings. So, that the navy can use it on ships without occupying too much space. So, it is a folding wing aircraft. Right now you see it operating from a ground. The speed is high and therefore the landing gear is retractable type. Look at the wing profile and the wing shape. Because of high speed we are interested to have a profile that gives you minimum drag. Okay, so this is a very popular and very famous military aircraft, okay. So yes, in general piston power aircraft tend to be slow but there are exceptions.

Okay, let let us now move on to a technology which really transformed aviation that is the gas turbine technology, we also call them as jet engines in general, but basically they are gas turbines.

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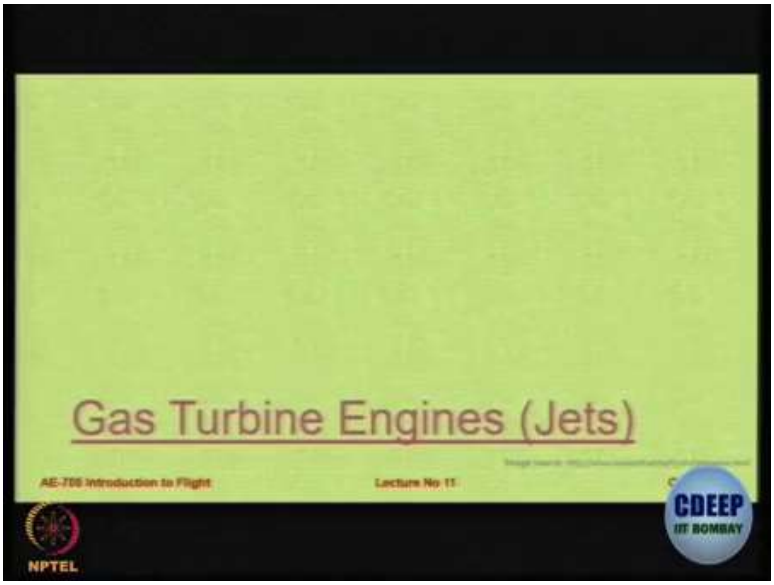

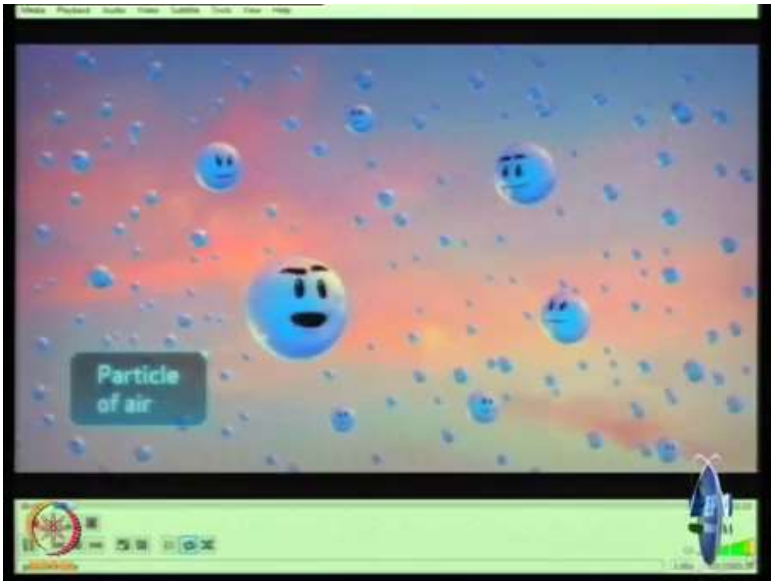


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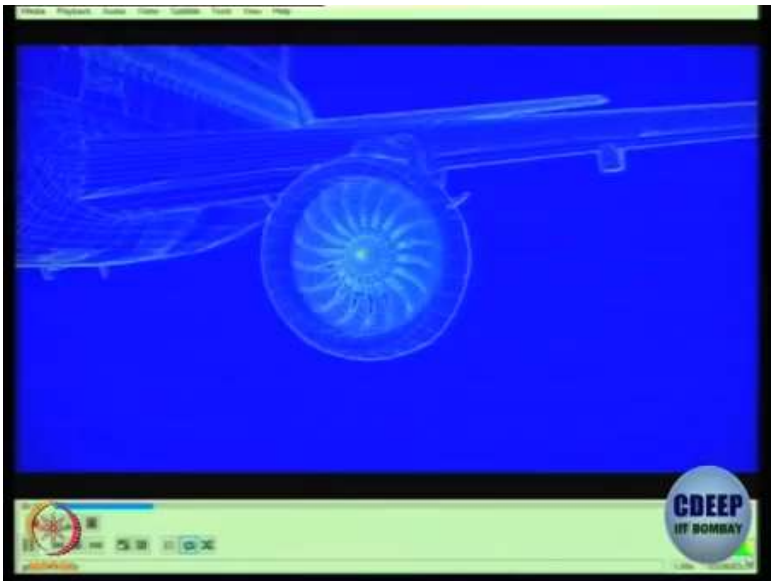
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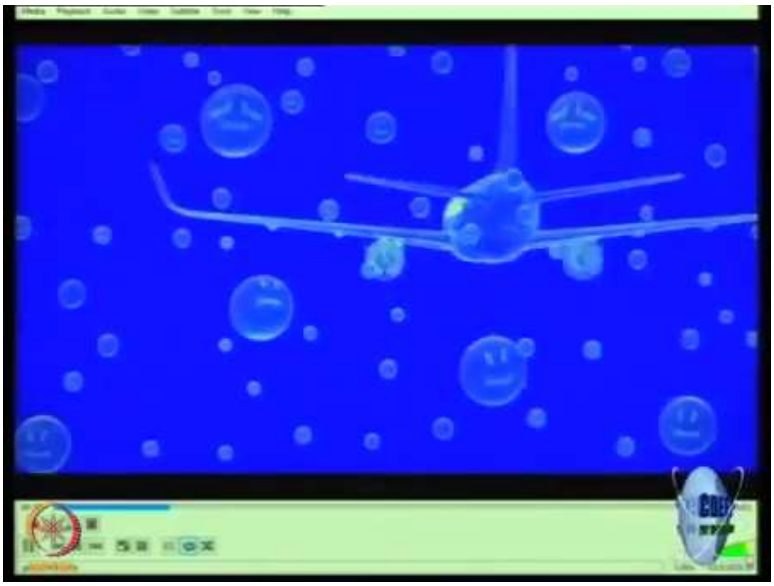


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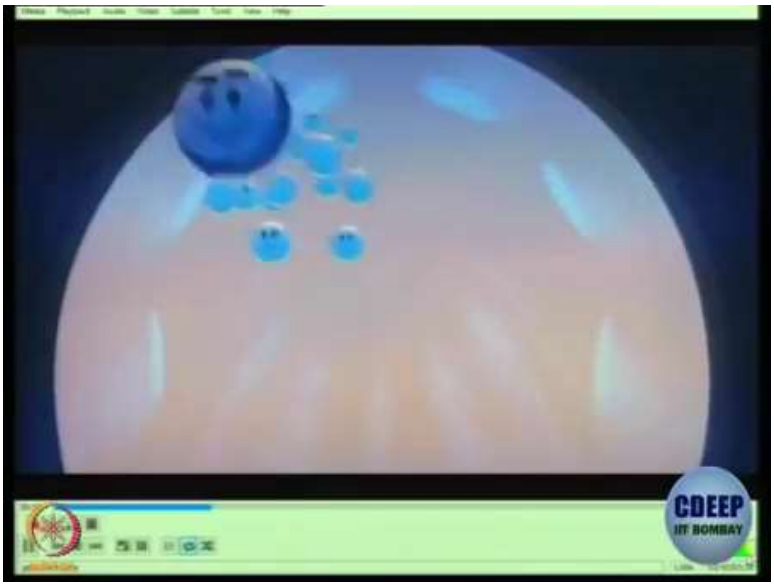
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3-D woven
carbon fiber
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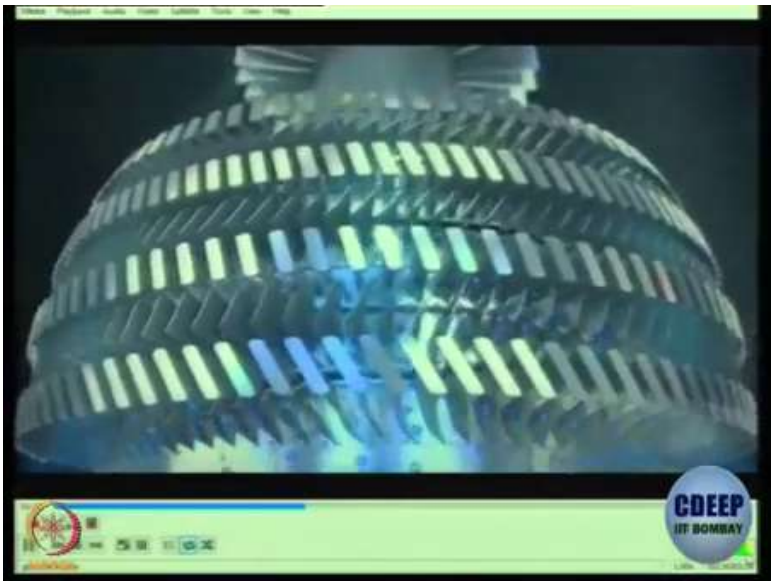
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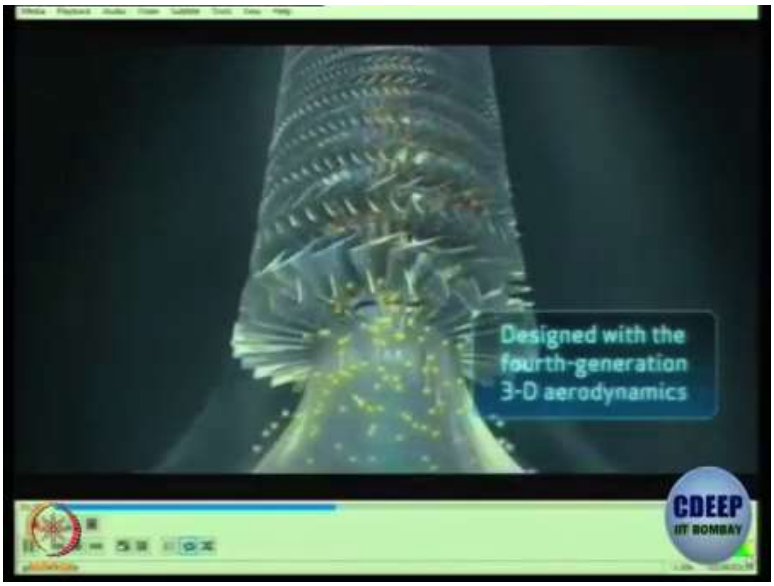
Designed with the
fourth-generation
3-D aerodynamics
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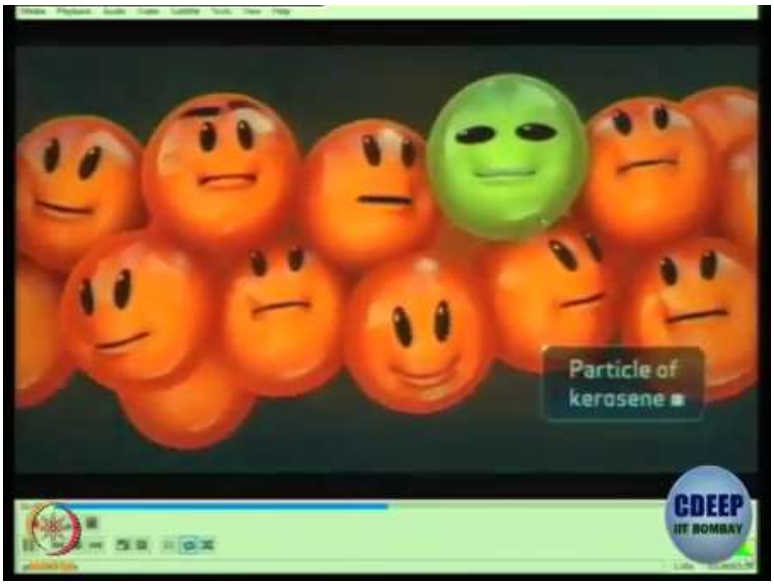
Particle of
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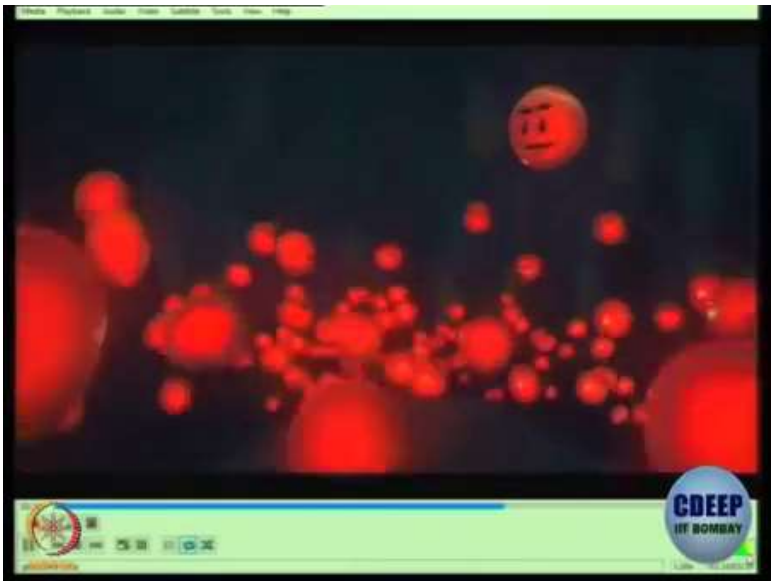
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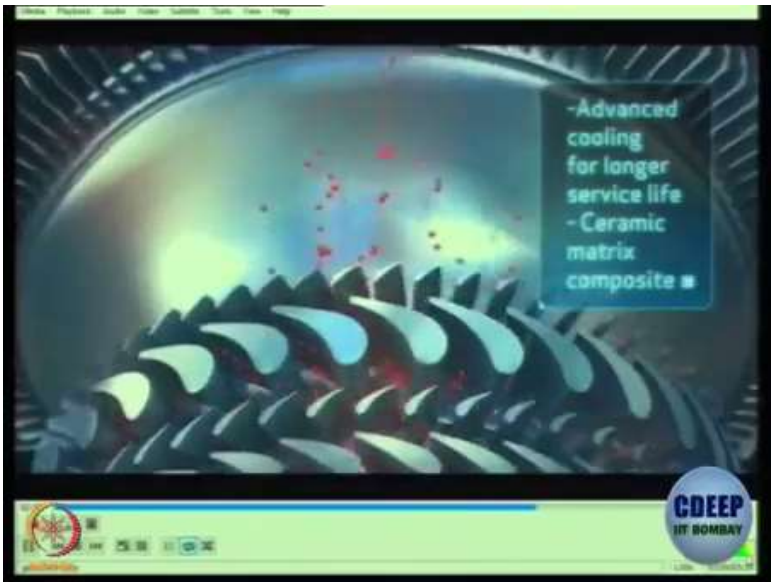
-Advanced cooling for longer service life
- Ceramic matrix composite
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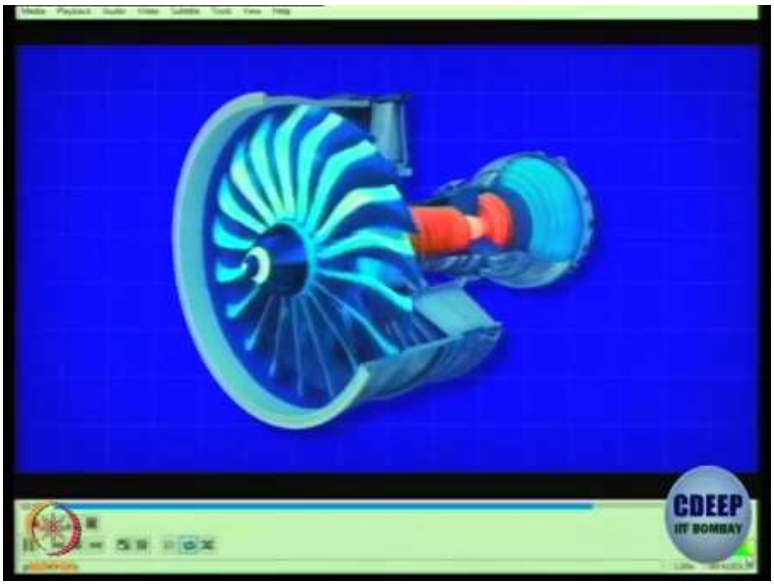

Video: Hear that voice? What is it? Just another narrow body aircraft. Hey! My atoms are shaking, strange, it sounds far but I bet my last proton that beast is much closer than you think. Hold on people it is a leap powered aircraft, a leap into the unknown! What on earth is a leap? Something you should have seen before, everybody get ready we are going in. Someone please tell me what just happened! Sure, the engine makes the plane move forward, thrust is produce by air being pulled in by the fan blades, then this air is injected at greater speed through the exhaust, creating the required pushing force.

This is a principle of Newton's law, for every action there is an equal and opposite reaction. So how is this possible? Geno soles, come with me to the bypass. Extreme sports freaks, with me,

move at the compressors, combustor and turbines. The leap is a high bypass ratio engine which means that a large amount of air bypasses the core of the engine to be injected directly into the exhaust stream. The fan acts like a propeller, its curved rotating blades accelerates the air flow into the engine.

Lighter composite materials provide better efficiency and resistance. Here come the compressors, get ready, things are gonna heat up. Feel that? It is the low pressure compressor squeezing us. Now, the high pressure compressors, you are gonna feel the difference. Ultra efficient compressors deliver optimum air pressure and temperature conditions for combustion. It is rising up now, let us get toasted. Gentlemen meet your kerosene counterparts. These guys are gonaa light up your day.

Already, we usually mingle inside. Not anymore. I thought there would be more of you. Normally yes, but in this engine fewer of us are needed. This little kerosene particle is right. The leap engine burns less fuel than former engines. In addition, the fuel nozzles mix fuel and air before they enter the combustor, creating a homogenous mixture that minimizes the peak temperature during combustion. This technology significantly reduces emissions. Okay, let us go. The combustion chamber, this is the heart of the engine, where energy is created through combustion of fuel and compressed air.

Are you ready? Here comes the final blast. What a boost. Where are we now? Turbines, let us transfer our energy to them. This is the last extreme stage before we join the soft team. Enjoy. Advanced materials and aerodynamics make the turbines much more efficient and durable. The pressure and speed of the high gas provide the force needed to turn the turbines and the shaft, which in turn drives the compressor and fan. Come on guys do not hang around we alone are responsible for 90% of the thrust from this baby.

Here come those adrenaline junkies. So, how was it? Fast, hot and fantastic. What a trip. Are you kidding me? It was us in the primary flow that did most of the job. Not exactly kid, it is teamwork, we definitely need each other. We provided the energy to drive the engine and they provided most of the thrust to make the aircraft move forward. Hey boss, sounds like we are in luck today. You said it, it is game on again boys. Let us go.

Professor: So this video was related to one of the latest jet engines called as the leap. We will see about it towards the end. It is just a way how they work, okay. So, we saw that there is something called as the core air and then there is something called as a bypass air. But before we go to the details of a gas turbine let us first look at the most basic gas turbine which was the first to be invented called as a turbojet engine. So, the word turbojet is a combination of turbine and jet.

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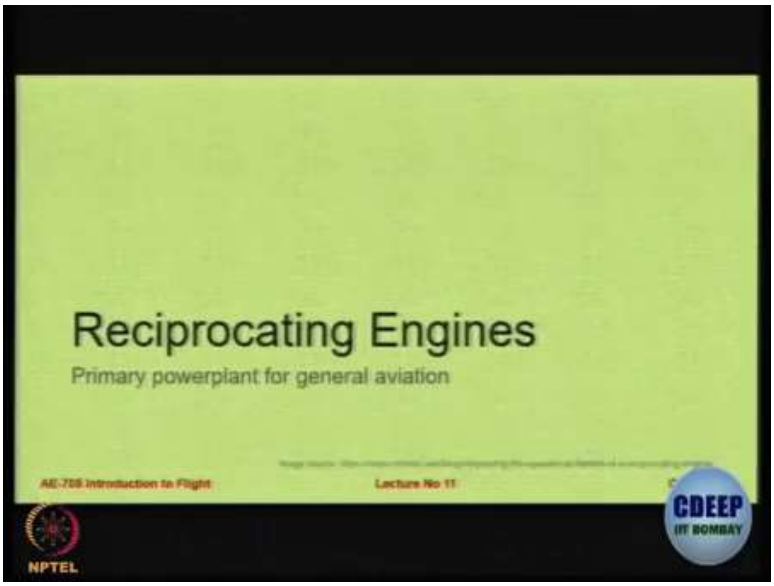

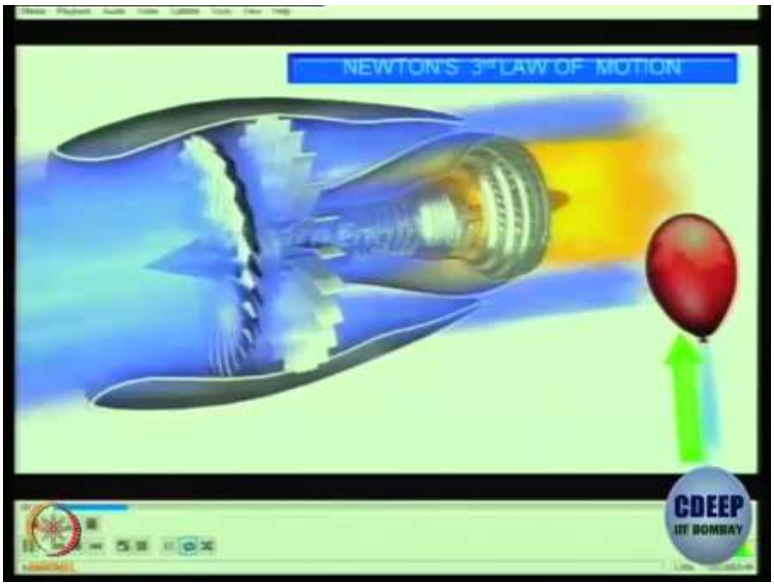

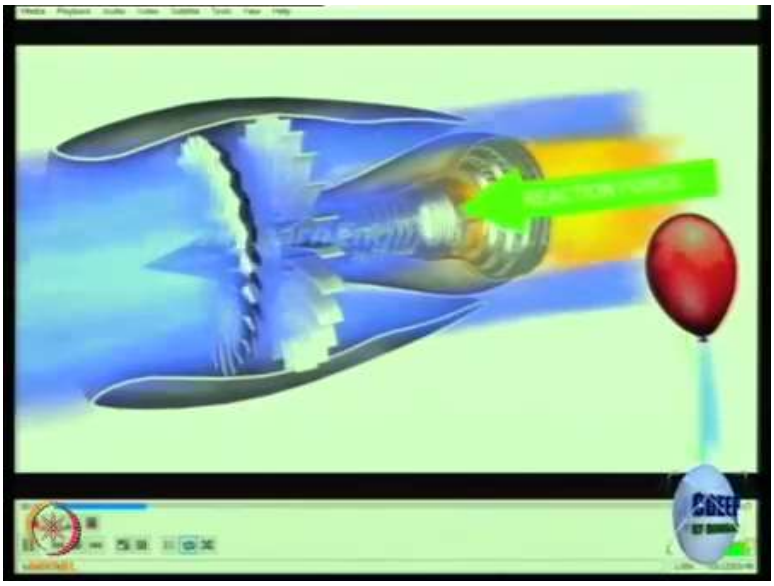

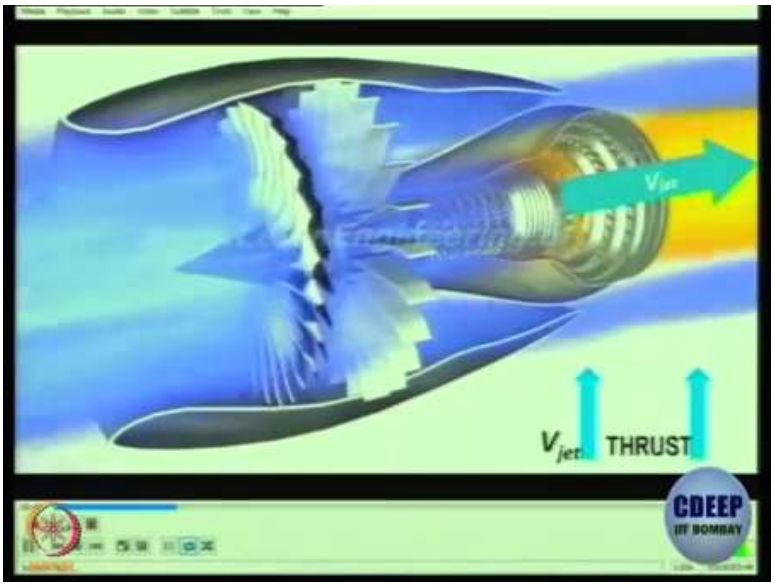
V_{jet}
V_{jet} THRUST
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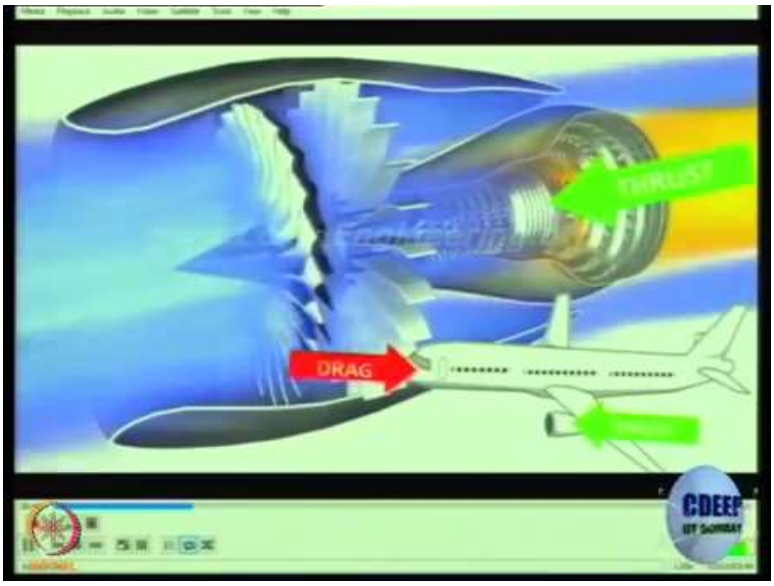
THRUST
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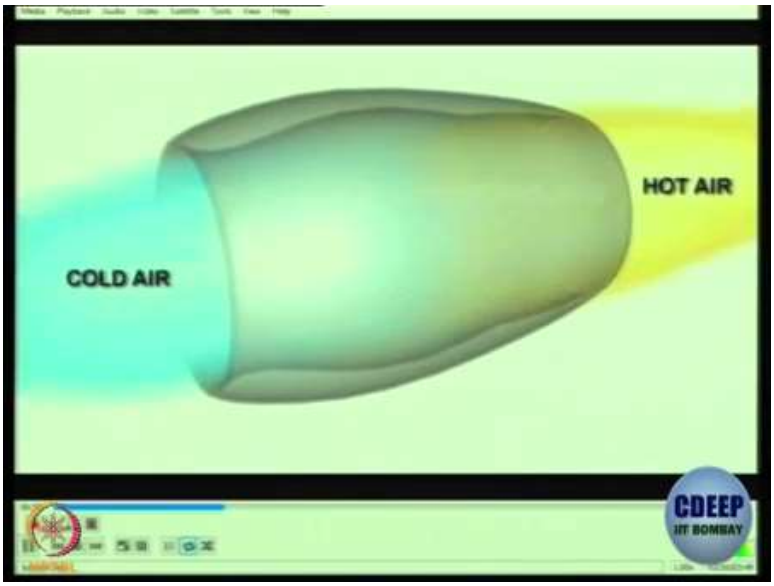
HOT AIR
COLD AIR
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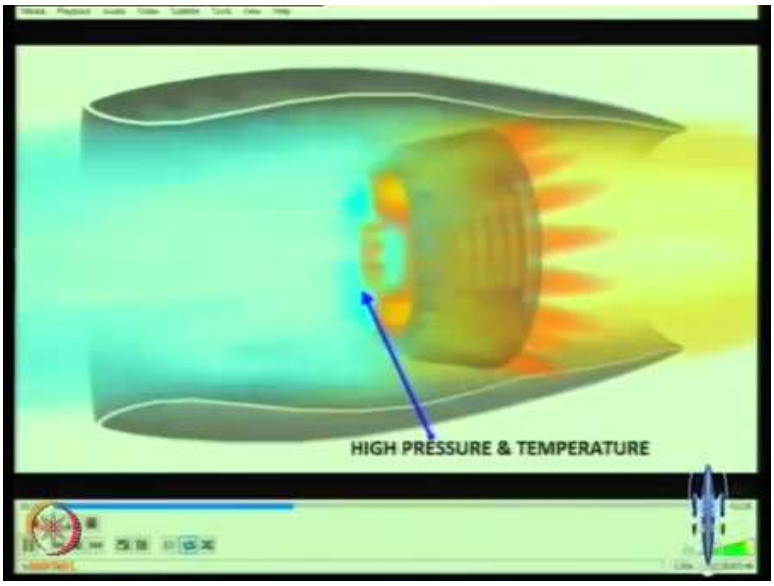
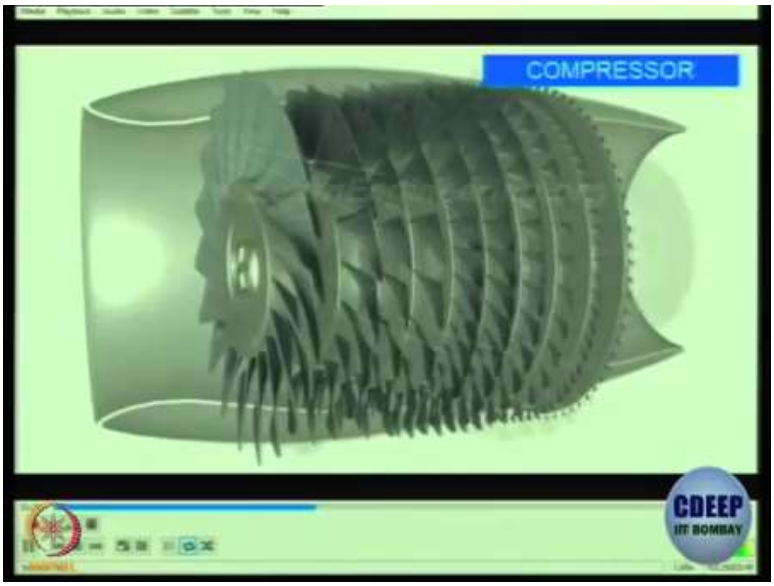
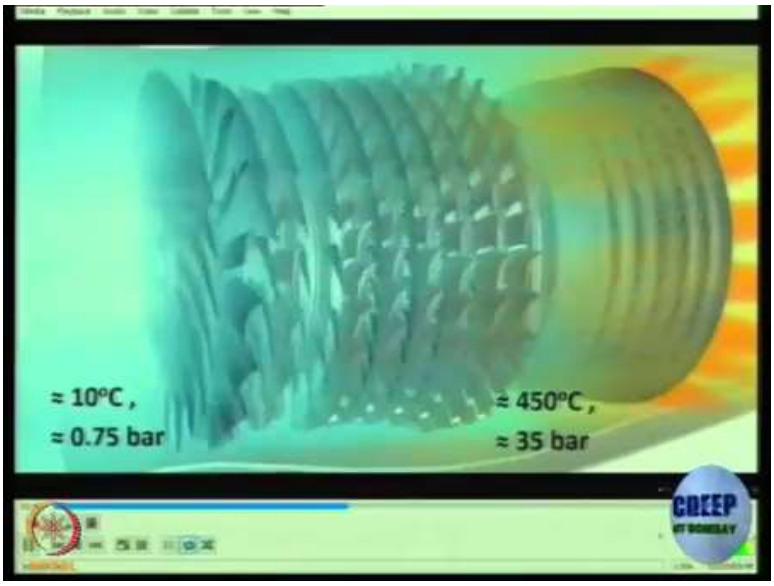
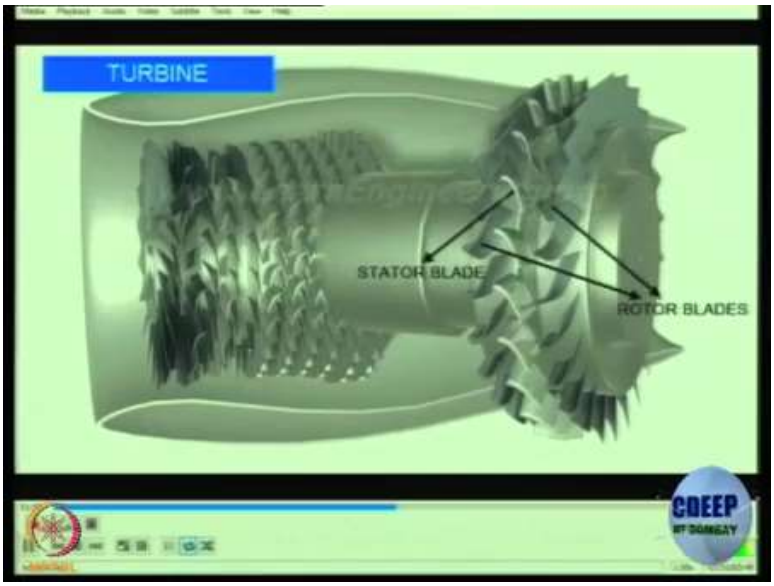
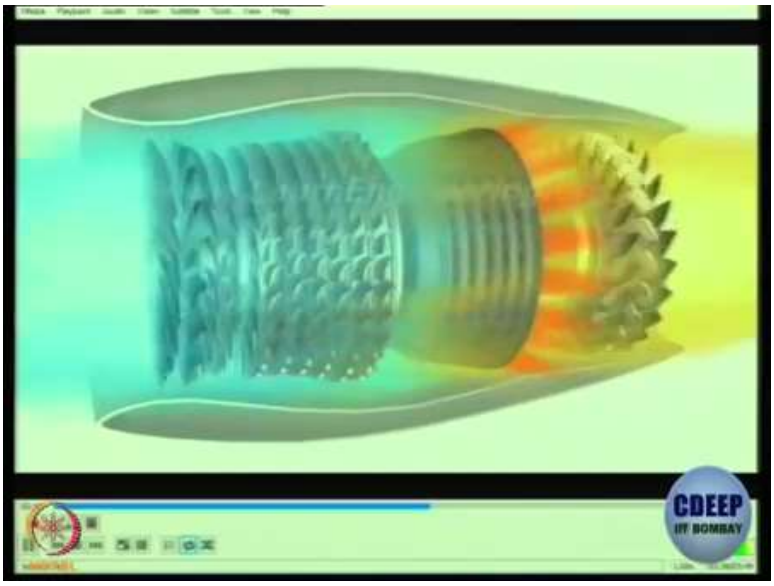
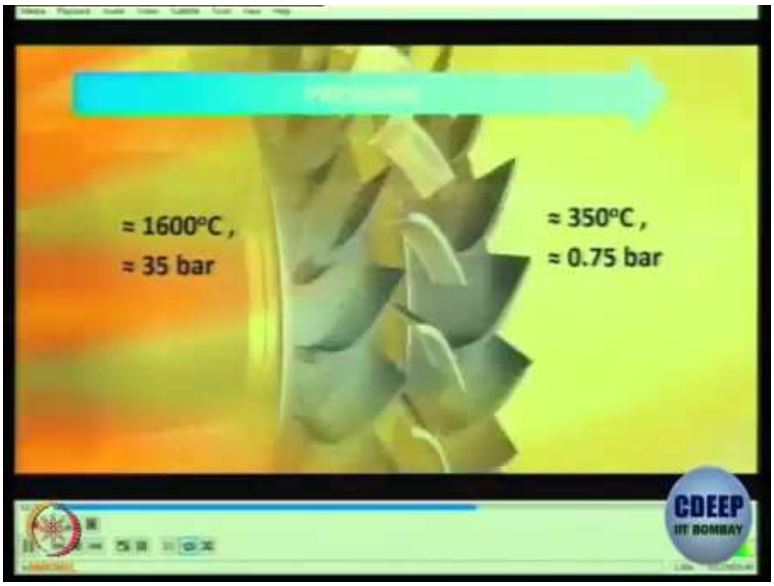

HIGH PRESSURE & TEMPERATURE

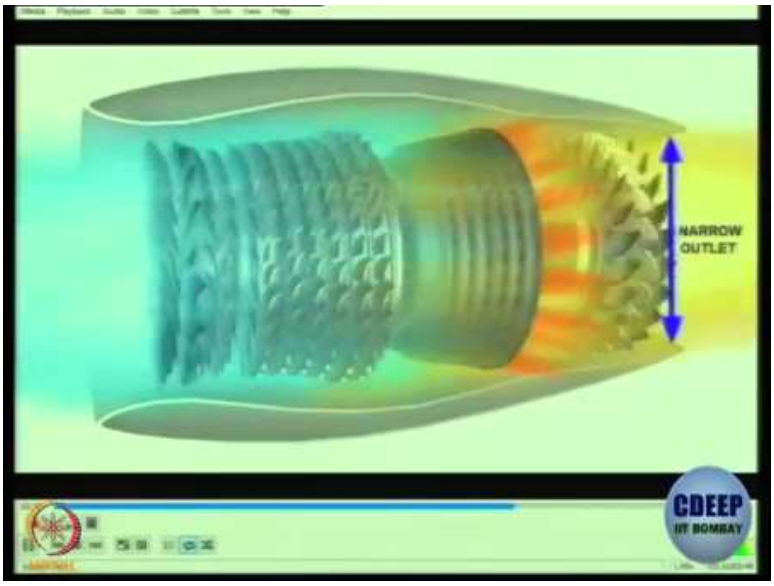

COMPRESSOR
CDEEP
IIT BOMBAY

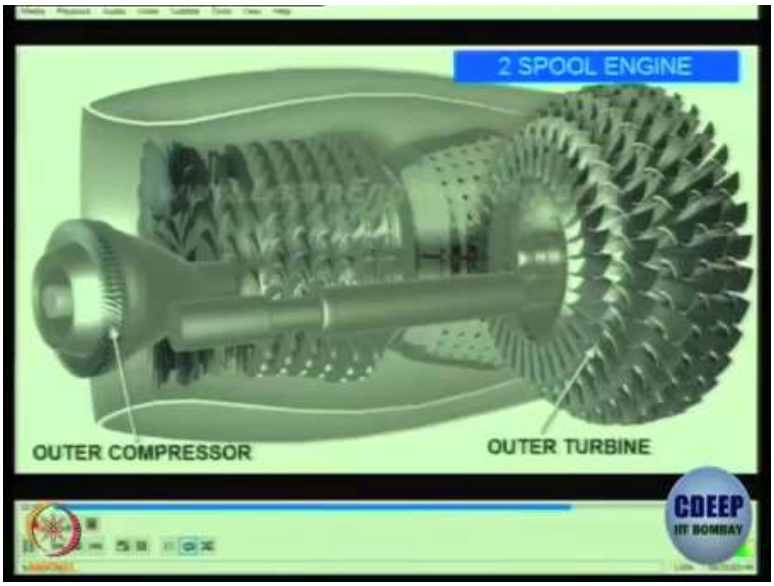

≈ 10°C ,
≈ 0.75 bar
≈ 450°C ,
≈ 35 bar

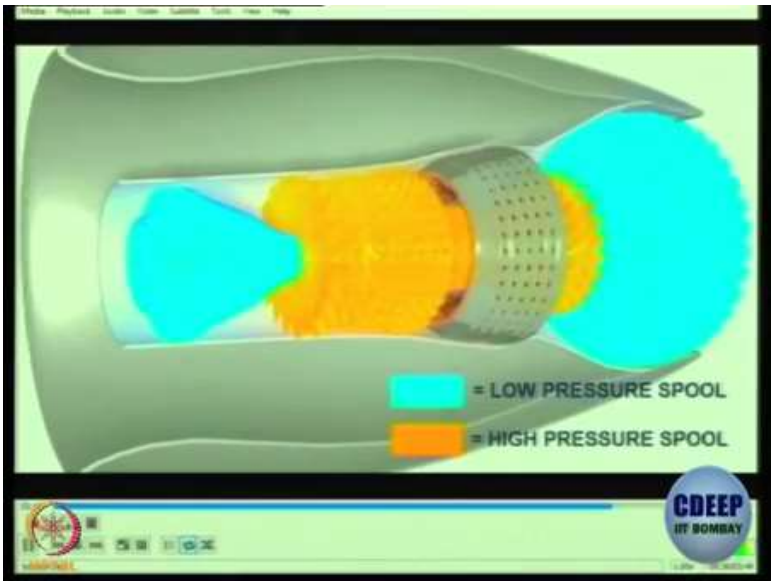

TURBINE
STATOR BLADE
ROTOR BLADES

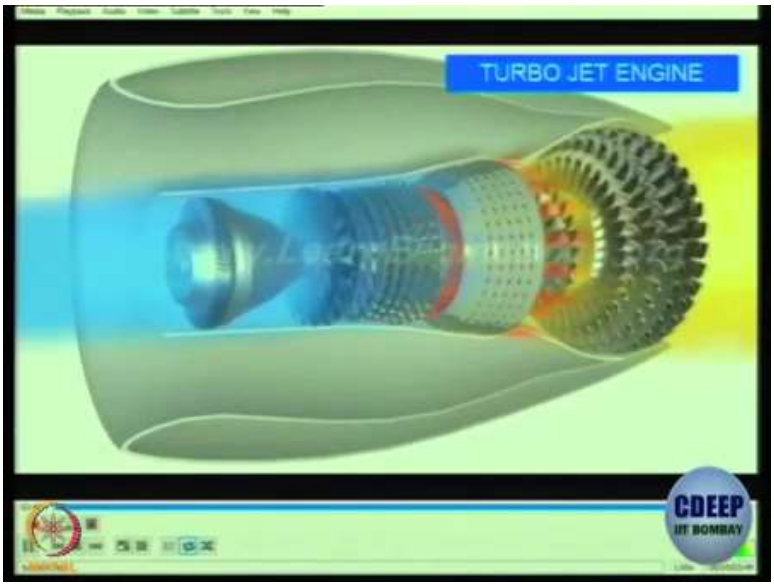

CDEEP
IIT BOMBAY


≈ 1600°C ,
≈ 35 bar
≈ 350°C ,
≈ 0.75 bar
CDEEP
IIT BOMBAY


NARROW
OUTLET
CDEEP
IIT BOMBAY


2 SPOOL ENGINE
OUTER COMPRESSOR
OUTER TURBINE
CDEEP
IIT BOMBAY





Video: In this video we will explain the technology behind the jet engine in a logical step by step manner. A jet engine keeps an aircraft moving forward using a very simple principle, the same that makes an air filled balloon move. Yes, Newton's third law of motion just like the reaction force produced by the air moves the balloon, the reaction force produced by the high speed jet at the tail of the jet engine makes it move forward. So, the working of jet engine is all about producing a high speed jet at the exit. The higher the speed of the jet, the greater the thrust force. The thrust force makes an aircraft move forward.

Such high speed exhaust is achieved by a combination of techniques. If you can heat the incoming air to a high temperature it will expand tremendously and will create the high velocity jet. For this

purpose, a combustion chamber is used. An atomized form of the fuel is burst in the combustion chamber. Effective combustion requires air to be at moderately high temperature and pressure. To bring the air to this condition a set of compressor stages are used.

The rotating blades of the compressor add energy to the fluid and its temperature and pressure rise to a level suitable to sustain combustion. The compressor receives the energy for the rotation from a turbine which is placed right after the combustion chamber. The compressor and turbine are attached to the same shaft. A high energy fluid that leaves the chamber makes the turbine blades turn. You can see that the turbine blades have a special airfoil shape which creates lift force and make them turn.

As the turbine absorbs energy from the fluid, its pressure drops. Through these steps we have achieved our objective, a really hot and high speed air emitted from the exit of the engine. The engine case becomes narrower towards the outlet which results in even greater jet velocity. In short, the synchronized operation of the compressor, combustion chamber and turbine makes the aircraft move forward. Modern aircrafts use a slightly improved compressor-turbine arrangement called a two spool.

Here, two independent turbine-compressor stages are used. The shaft of the outer compressor-turbine passes concentrically through the inner one. The outer turbine is subjected to a low energy fluid and relatively of a low speed than the inner turbine. Low pressure blades are longer. This low speed helps to reduce centrifugal stress induced at the root, thus improving the blade's life. Some modern aircrafts even use a three spool engine. The engine we have discussed so far is more specifically called as turbo jet engine. Turbo jet engines tend to produce high levels of noise….

Professor: Okay, so just to sum up what has been said, to generate thrust using Newton's third law, we need to create a force and then the reaction acting on that force will give you the forward thrust. In other words, we need to create a jet of air moving behind at a high speed. Higher the speed, higher the thrust available. To produce that, we need a combustion chamber in which we spray fuel. The fuel is atomized so that it can mix nicely with the air and ahead of the combustion chamber, we need to put some systems such that the air at the entry of the combustion chamber is ready for combustion.

By ready I mean at the right temperature and the right pressure. This is done by putting a compressor in the front. There are various types of compressors centrifugal, axial, etc. Whatever be the case, the job of the compressor is to take the intake air and give it a high pressure and a high temperature, making it ready for combustion and the combustion chamber basically is a place where fuel and appropriate amount of air at the right conditions are ignited and then they are thrown out.

While they are thrown out, we put a turbine there which extracts the power. So one part of the turbine will drive the compressor and the other part of the turbine can actually give you, if any extra power is needed, okay. So that is the simple explanation of the working of a classical turbo jet engine.