Introduction to Flight
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Lecture-07.2
Gas Turbine Engine Types: Part I

This was the first Indian first gas turbine engine to be produced and interestingly the world's first turbo jet powered aircraft was from Germany called the Henkel HE178 let us have a look at the first flight test. So, in the initial testing there was a problem, as you will see there will be fire in the exhaust.

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Video: However on takeoff BMW experienced immediate failure.

Professor: There you see…

Professor: So the initial flight testing was a failure you can see the fire on the exhaust all the engines and that was very dangerous, so they had to suspend this particular flight, subsequently they made appropriate changes, they redesigned the exhaust area and then they were able to do a successful flight.

Video: Subsequent tests with other engine designs like the UMO004 A fared better in July of 1942 rental kind into the me-262 v3 prototype and declared its handling and design as extremely impressive. Steps to advance this design would have commenced rapidly…

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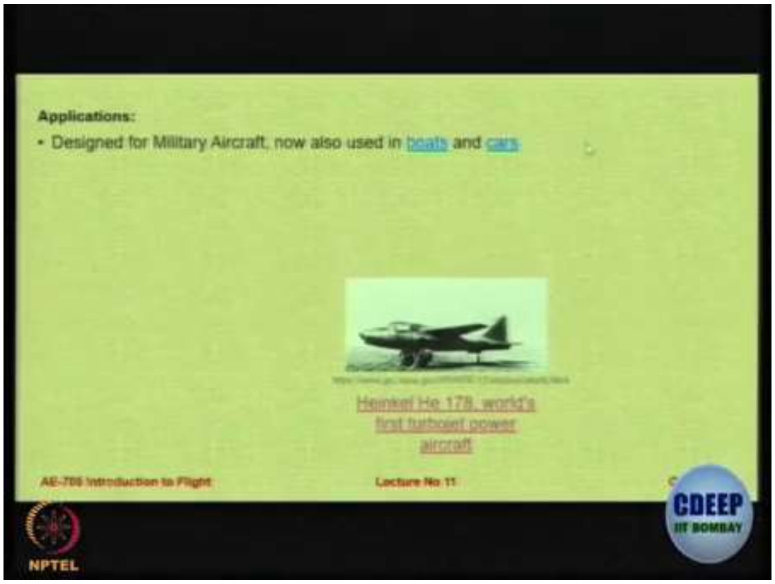

Professor: Ok what are the applications of jet engines normally used for military aircraft, but today you will be surprised to find that there are even other contraptions, even boats and cars which have this kind of an engine. Let us have a look at a turbojet engine power car.

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...the car sets off on the first of two attempts
to travel at over 700mph (1126.5km/h).


To qualify for the record, the car must
make two runs in opposing directions...
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This is the attempt to break a world record many years ago, so Rolls Royce has given 2 jet engines and the aim is to break the world record.

Video: As you see you are clear to go…

Professor: So this is a long distance video so you really cannot see what is happening but very soon you will see a close-up of the car. So in this particular vehicle there was the necessity to provide negative lift so that the car does not take off and remains touching the ground because it will not be a car if it flies, so the technical challenge was how to make it not to climb okay and very soon they broke their own record 2 weeks later they broke their own record and they went to a supersonic speed of 1228 kilometer per hour, so that is a car.

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Professor: Okay let us see a boat it does not look like a boat but actually it is a boat which is powered by a jet engine and this particular boat did not have any brakes so you see now at the end of the journey it will encounter a bridge okay just before the bridges will take a turn otherwise there is a danger that at such speeds you cannot control it is trajectory and there you see this is the bridge okay so it just took a turn before it encounter the bridge.

So jet engines are no longer the realm of only military or aircraft it can be used also on many other devices we have several cruise missiles which have jet engines. There are some advantages first advantage is extremely high exhaust speed and therefore extremely high thrust, but they also have a smaller frontal area which reduces their drag and also gives them a lower signature but the problem is they are very noisy, very-very noisy and the efficiency is bad at low speeds.

So any aircraft has to take off and land at low speeds and at that point a jet engine becomes extremely inefficient and the consumption of fuel is very high so you get low range and endurance and also the response to the throttle is not as quick as one would like to have in a case of a jet engine.

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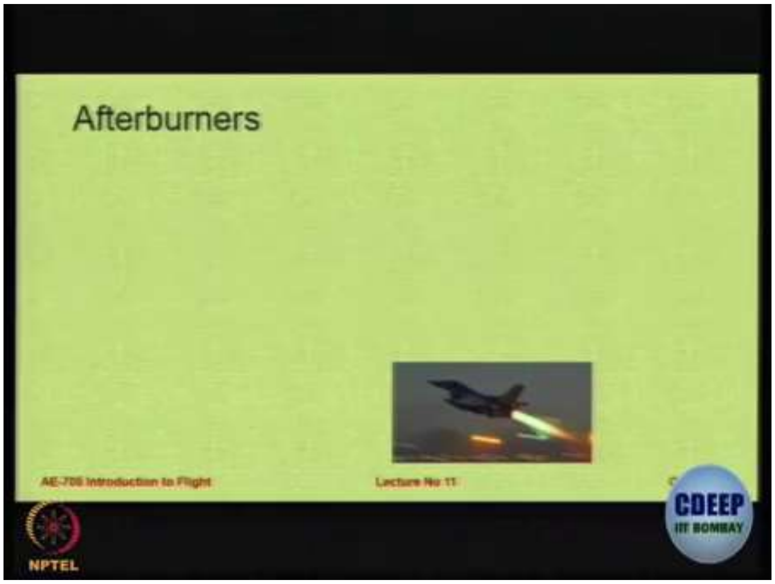

Now if you have a jet engine and if you really want to push the limits and if you want to go for higher thrust then in the exhaust of the jet engine we still have some unburnt air, unburnt oxygen so if you spray fuel in that and ignite it you can get extremely high thrust.

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Let us see an example of an F15 with an afterburner during takeoff okay. I am keeping the noise levels to the lower side. You can see the flame of the exhaust coming out just after takeoff they have stop the, they have the stop the afterburner because it is extremely-extremely fuel inefficient. It is very fuel inefficient and also it reduces the life of the engine if you do it beyond a particular amount of time so in most aircraft you have a 2 minute or a 5 minute limit to maximum afterburner so after takeoff it has to be actually used sparingly and shut down.

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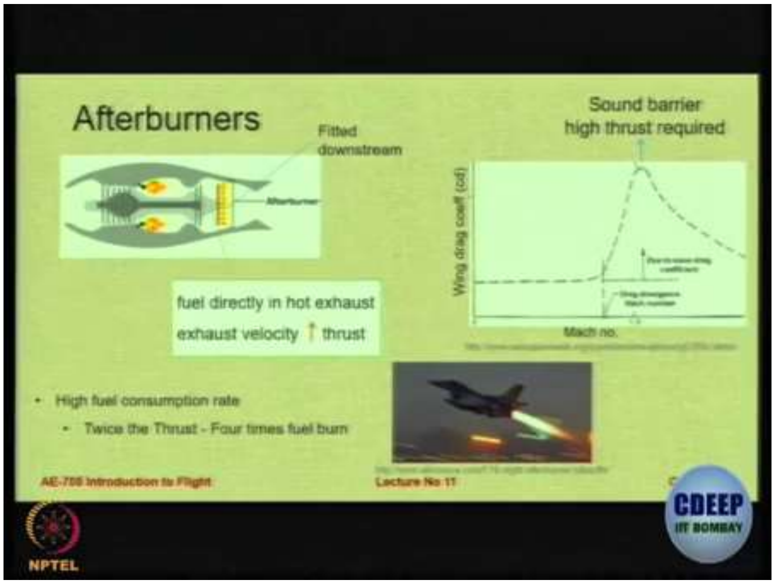

So what do we do, we basically fit downstream in the exhaust pipe of an aircraft, we fit a fuel spraying unit and directly spray the fuel in the hot exhaust. Why do we do this? Because you have seen in the last capsule that there is a sudden increasing drag as you approach the sonic Mach numbers, the so-called sonic barrier and to overcome this barrier one way is to provide excessive amount of thrust till you cross the sound barrier. So this is one way of doing it okay the problem with the afterburners is that to get twice the thrust you have to do approximately 4 times the fuel burn.

So, therefore, unless there is a requirement during combat or during takeoff and landing, so many military aircraft, for example, MIG27 it routinely takes off with afterburner because the aircraft pays around 20 tons max takeoff weight, the engines are not capable to provide the thrust needed to take off with so much of weight. So the designers have put afterburner as a routine activity but they limit the number of minutes it can be used up my right, if I remember right, it is about 2 or 3 minutes alright.

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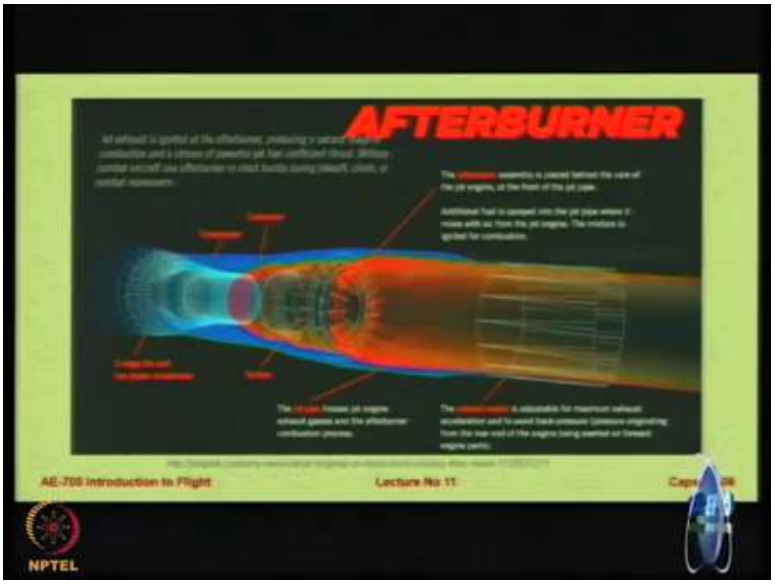

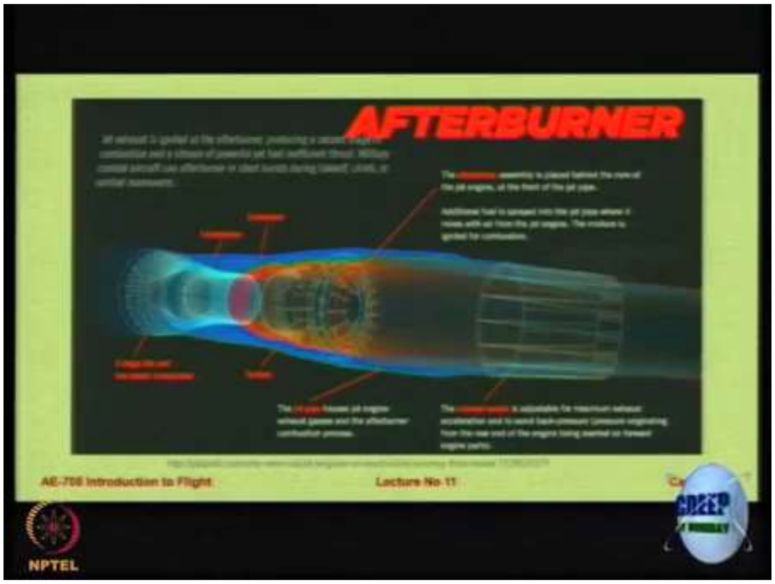

So this is how it works so in the exhaust of the engine we are spraying this fuel and that creates a huge stream of air which is ignited as you saw the flame is red or yellow or amber in color and that is how you get a huge amount of thrust. This is also called as reheat in some cases, so it is like landing gear or undercarriage; similarly, you have afterburner or heat.

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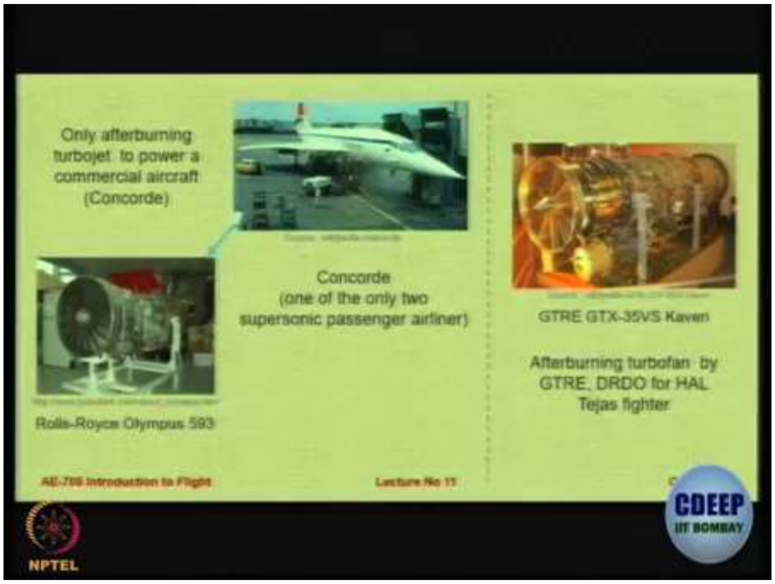

Civil transport aircraft do not have an afterburner because they are very much fuel conscious and they do not need so much thrust, the exception was the Concorde aircraft, the first aircraft, in fact, the only aircraft to have afterburner in a commercial jet and in India we have recently designed an engine for our LCA Tejas called as the Kaveri. Kaveri engine is also fitted with an afterburner because that is the requirement for the engine.

This particular system is still under development it has not yet been fully commissioned that is because engines are not very easy to design. A typical aircraft design activity may take 10 to 15 years but an engine design activity starting from zero should need approximately 25 to 30 years, so it is not very easy.

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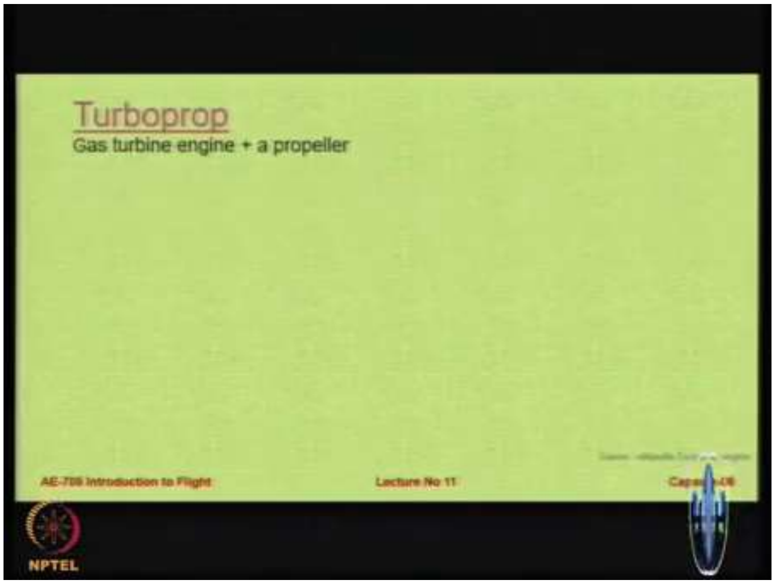

Moving on let us look at the next version of the engine above the piston prop but not working but still working with the propeller. So this is a interesting thing it is a gas turbine engine with a propeller.

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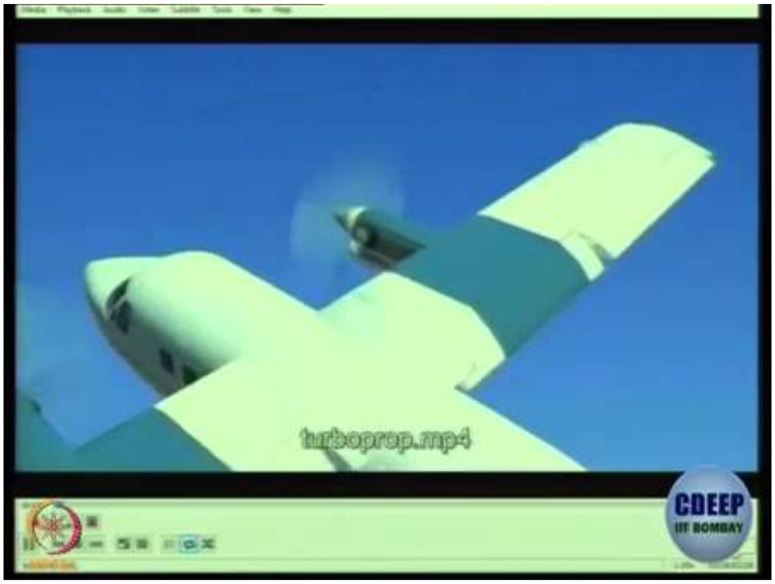


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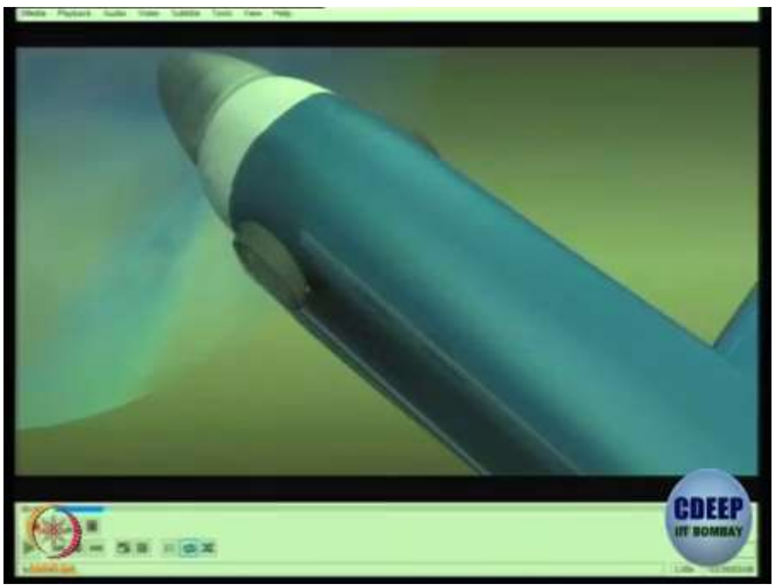
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Accessory Section
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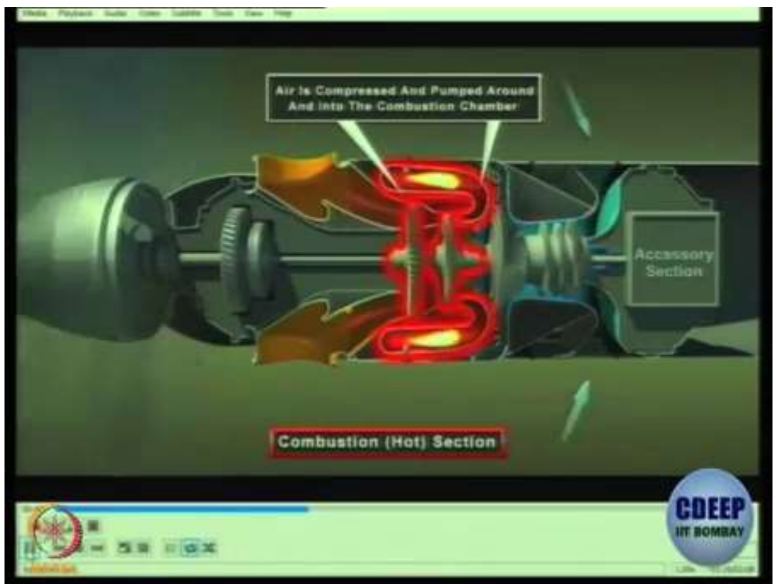
Accessory Section
Pratt & Whitney PT6A-20 Operational Air Flow


Air Is Compressed And Pumped Around And Into The Combustion Chamber
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Combustion (Hot) Section
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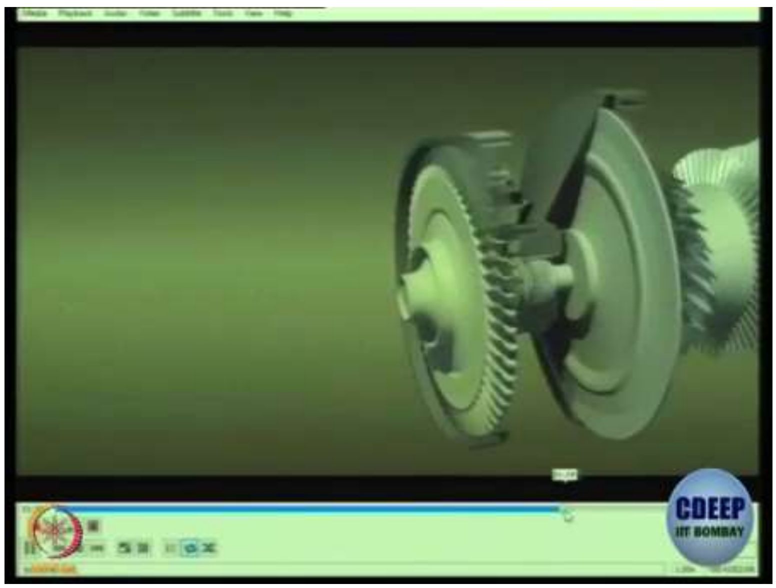
Accessory Section
Combustion (Hot) Section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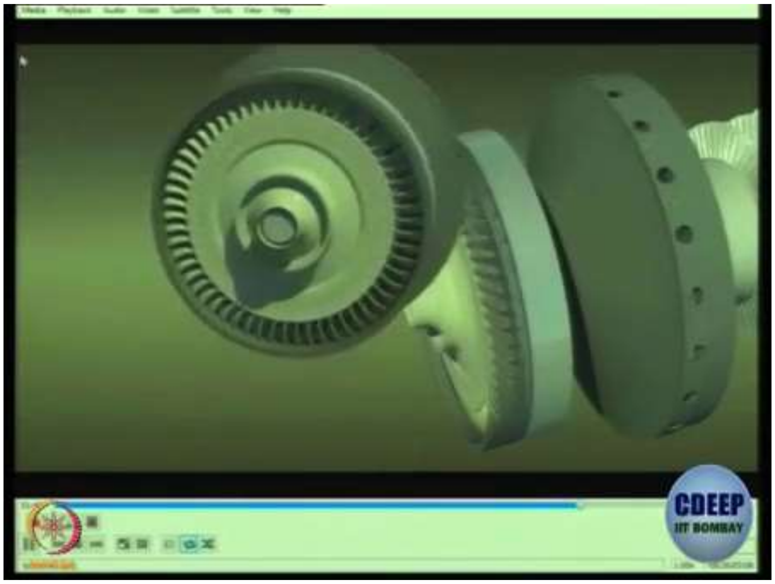

So this video will show you a breakup or a component-wise discussion but I want to just first quiz you slightly, so I am going to stop the video and ask you what is happening here okay. So you see that there is a propeller in the front and then you have on the sides 2 cuts what are these for what do you think of these for. So, let me just play the video and then I will ask you to tell me what is it for.

So you see there are some lubes there so what are they meant for, air intake all right air intake no interestingly this is the exhaust, the intake is behind so in this particular example in this particular engine you have the intake mounted behind and what you saw as an (in) and what you thought is an intake is actually the exhaust, so you see air comes in like this goes through the combustion chamber and then is exhausted out.

So the air is now sucked in by the compressor, sent forward combusted so it undergoes a 360 degree turn as it goes through the engine. So now my question is why do you think they have gone for a configuration in which the intake is mounted behind the exhaust. Now this is something I do not want you to answer right now, this is something I wanted to do the research and I am sure via the Moodle page.

Surprisingly Moodle has become very silent, I am the only 1 posting and Moodle, announcing the quizzes, announcing the exams, this is not fair. You have to now become again proactive on Moodle. So here is one opportunity for you to share your learning, tell us why in this particular engine the intake is behind and the exhaust is in the front, it is a slightly peculiar kind of an engine. So let us see it is working. It is the same thing that we saw in the other one.

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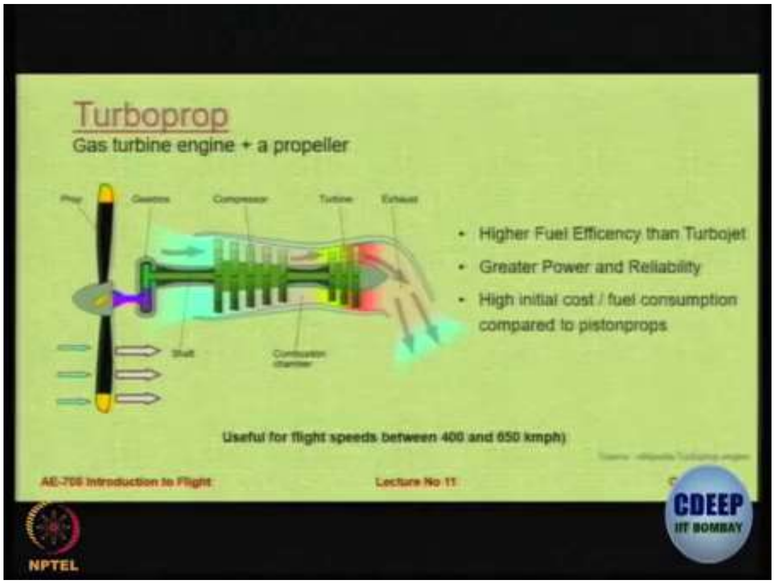

Now in this example the intake in the front so it is not that in every turboprop engine the intake is on the back, for example, you see here it is very simple, the propellers are pushing the air inside the engine then you have a compressor, turbine and exhaust, so it is not that in all cases you have it like that. What is the advantage a turboprop? A turboprop gives you much higher fuel efficiency. It also gives you higher power and reliability. But compared to piston drops this gives you higher operating cost.

So if you noticed in the graph which I showed you earlier about SFC, the piston drop line was above turboprop line for low Mach numbers but they crossed at some Mach number approximately 0.6. After 0.6 up to 0.8 or 8 or 8 5, there were props are much better than the piston props, for piston prop the consumption, the SFC shoots rapidly after a Mach number of nearly 0.4 to 0.5

So you have to be very careful you have to decide what is the Mach number range at which out a truffle operate and choose the appropriate engine so this particular engine is most suitable for flight speed between 400 to 650 kilometers per hour, so the core is turbojet okay it is the same but then what we do is on the turbine we attach a shaft and on the shaft weight as a propeller okay and then you go for providing the power okay.

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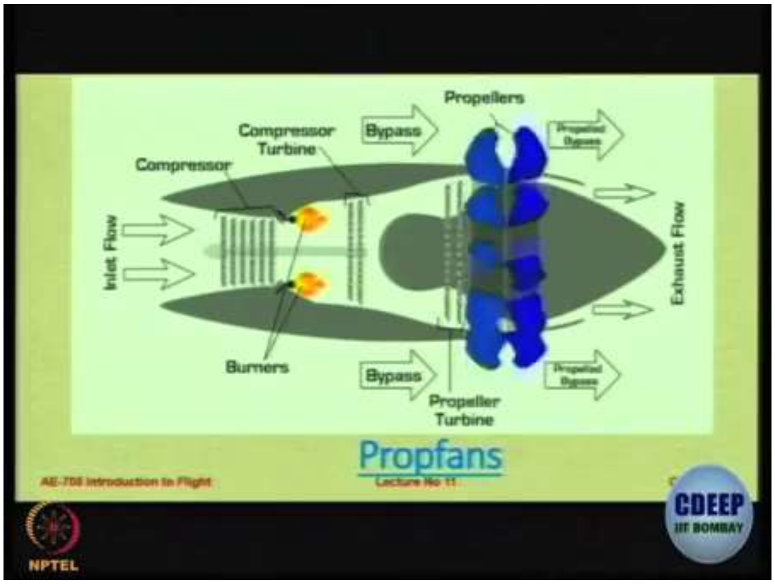

Now as turbo props became more and more popular they became more and more efficient a time came when the Mach numbers were increasing and then they increased to a point where the tips of the propeller would start having sonic flow conditions and then the efficiency would go down. So a new variant called as a props fan was thought of. This is very interesting the name comes from turboprop plus turbofan prop fan and this is a very-very efficient system; let us have a look at what is special about Prop fans.

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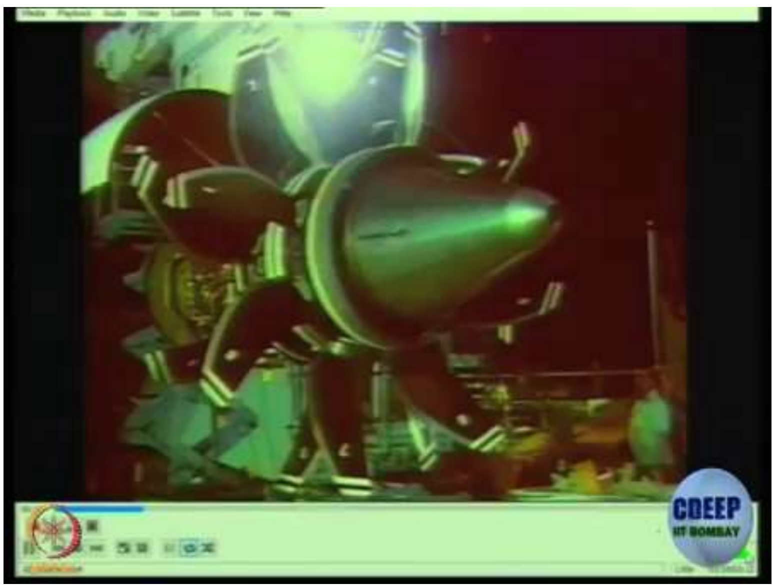
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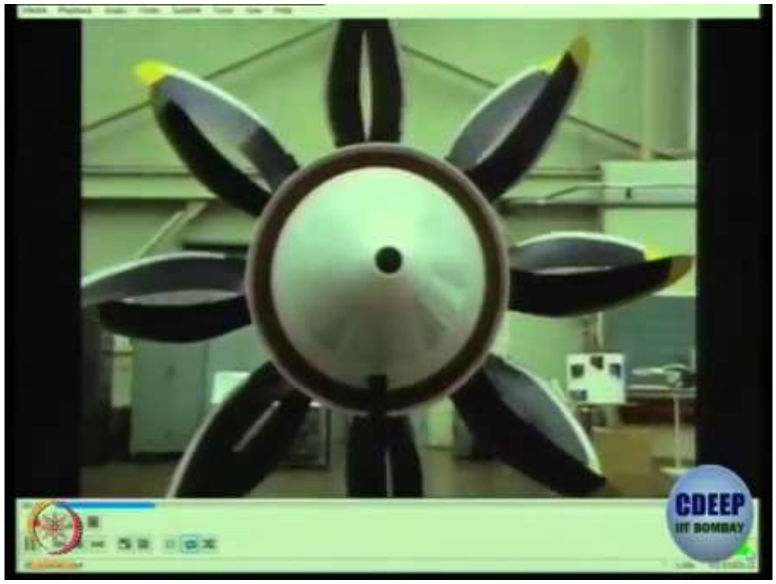
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Engines
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Video: I remember when I started working at GE back in the 80s the engines all look the same shaped like a football all that sheet metal hid the technology that laid beneath it but then came along the unducted fan born of the energy crisis this was a new fuel-efficient engine that had exposed fan blades 4 propellers counter-rotating what made this possible though was carbon fiber technology the carbon fiber fan blades were lighter and stronger and allowed you to do this unducted fan without titanium fan blades.

And it caused a sensation to when it flew, it flew across the Atlantic Ocean to England in 1988 on an md 80 to be displayed at the Farnborough airshow the concept was proven but the market conditions did not cooperate fuel prices went down the savings evaporated in the investment in the unducted fan was not justified within 2 years GE began to build the GE 90 the largest commercial jet engine in incorporating composite fan blades the composite technology allowed larger bypass ratios making the engine more fuel efficient with lower emissions the engine generated 115,000 pounds of thrust which gave it a Guinness world record for the highest thrust class commercial engine.

That accomplishment was made possible by the unducted fan the carbon fiber has proven itself in service with an incredibly reliable record that led to GE's latest engine the GE NX which powers Boeing's new 787 long-range airplane the GE NX says carbon-fiber fan blades like the GE 90 but it also has a carbon fiber fan case to go with it and you will notice that there is fewer fan blades only 18, 20 years ago we had twice as many but the carbon fiber technology is more efficient, allows us to reduce fan blades.

And has taken 400 pounds out of the engine that's almost a thousand pounds out of the aircraft and now that funny-looking unducted fan back from the 80s that didn't make it onto an airplane is now living again in the GE NX the technologies that were demonstrated then now proving their worth improving the investment bringing all the promise of lower fuel burn and lower emissions to today's modern jetliners.

Professor: So in other words prop fans were proposed as a class of engines which would be able to give us better performance at slightly higher speeds then the ones at which turbo props and turbo fans were being used, so the technology was tested and to provide the ability to give efficient flow over the blades we had to resort to such curved blades so that the local Mach number can be reduced and for that we needed the technology of composite material as shown in the video.

Unfortunately, by the time these technology matured the fuel price is reduced and therefore, the incentive for the airlines to buy new engines which were little bit more fuel-efficient, it vanished. So the unducted fan or the prop fan was not able to be present on actual commercial aircraft other than some experimental variations but the technology of creating complicated shapes on carbon fiber blades it came very handy when GE developed larger sized turbo fans for powering the modern aircraft.

So this is a one of the examples in the history of aviation where the market conditions did not cooperate the technological developments and hence a technology which was there could not be commercially utilized, but you never lose it that knowledge and expertise is available and one can always use it in the future for something else.

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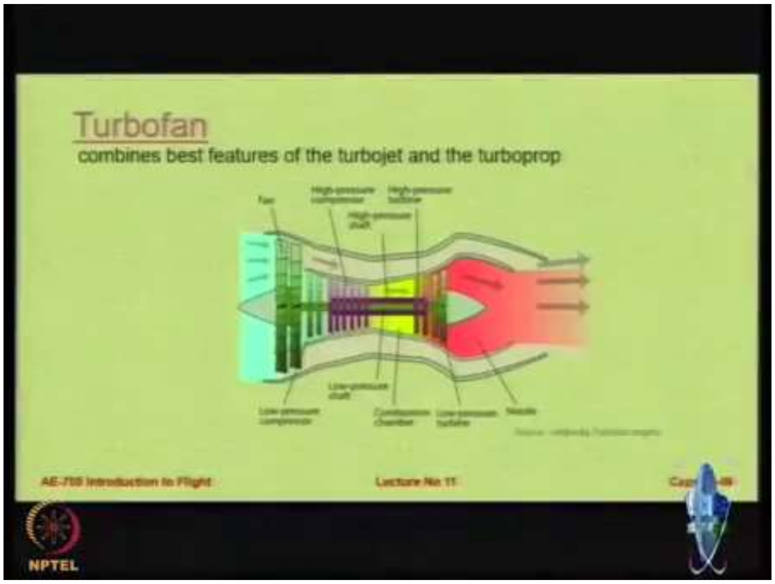

So turbofan as I told you is a combination it combines both let us see how it works.

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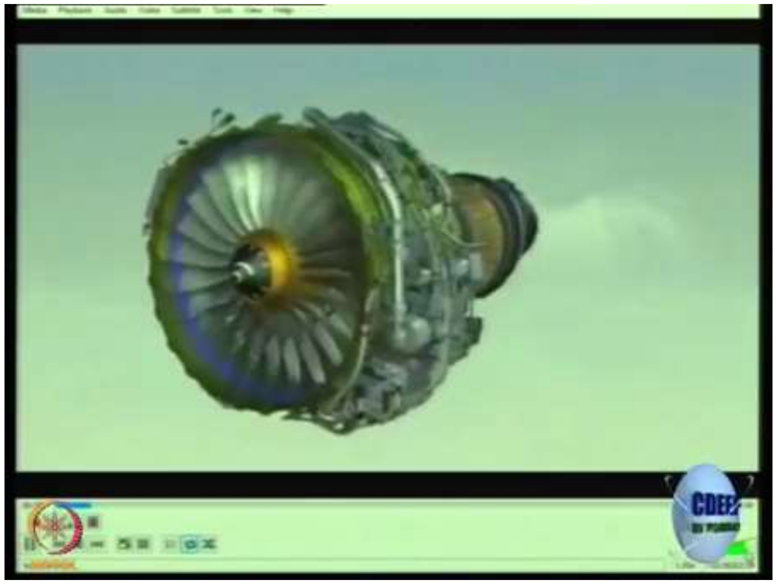

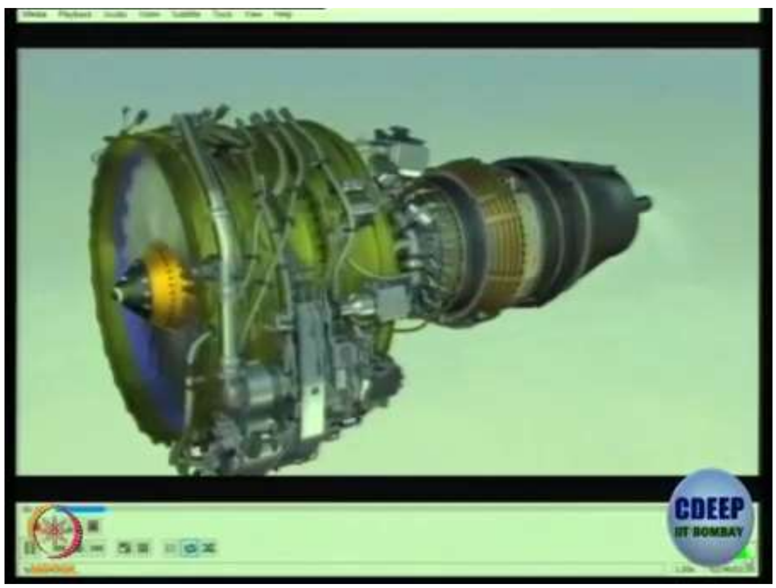
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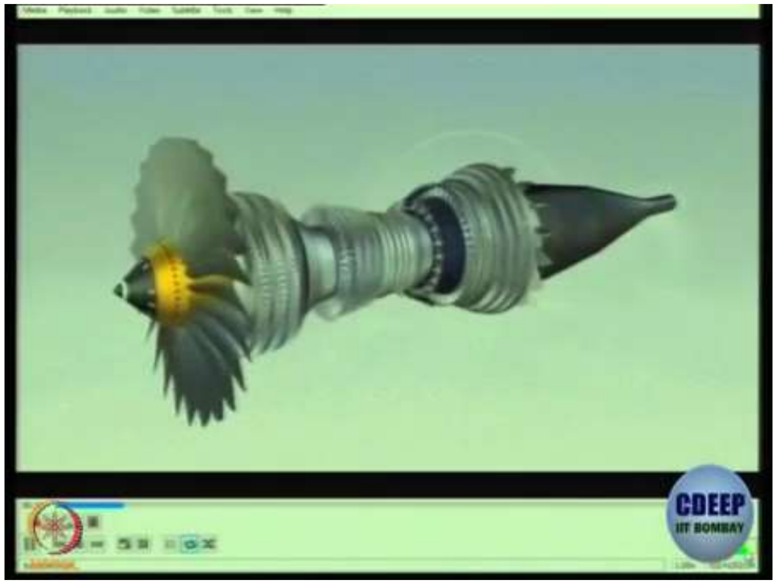
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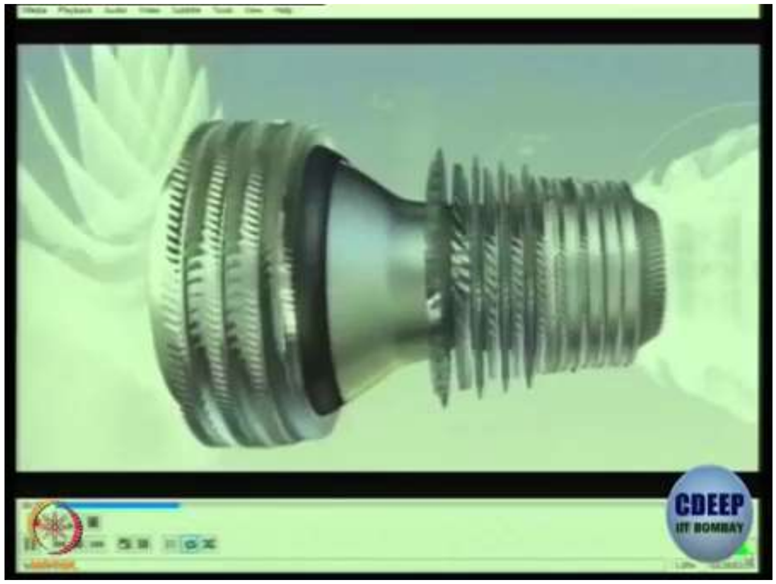
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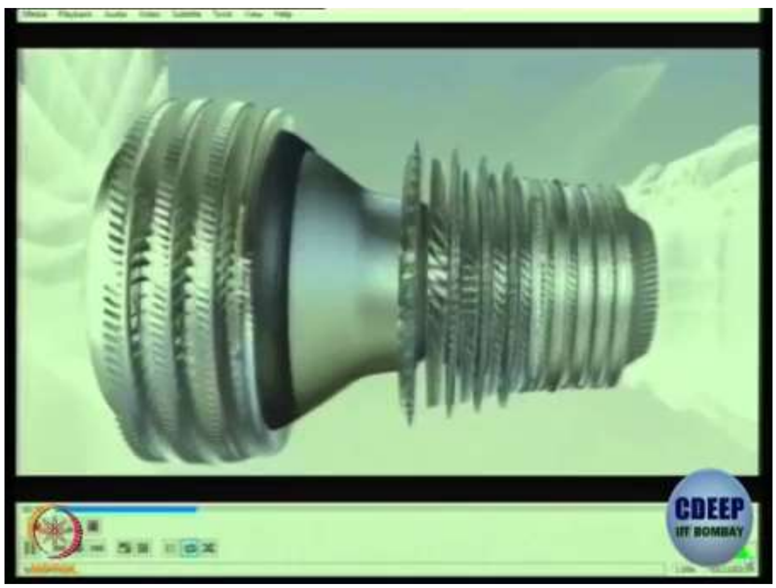
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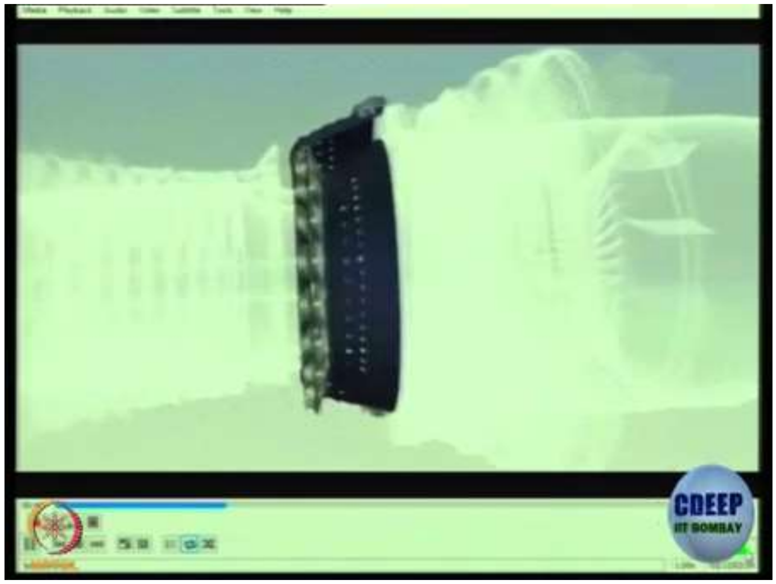
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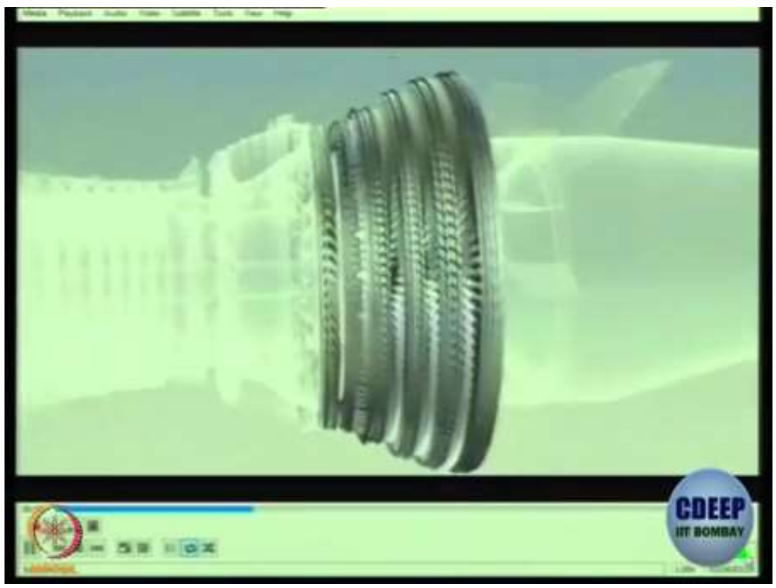
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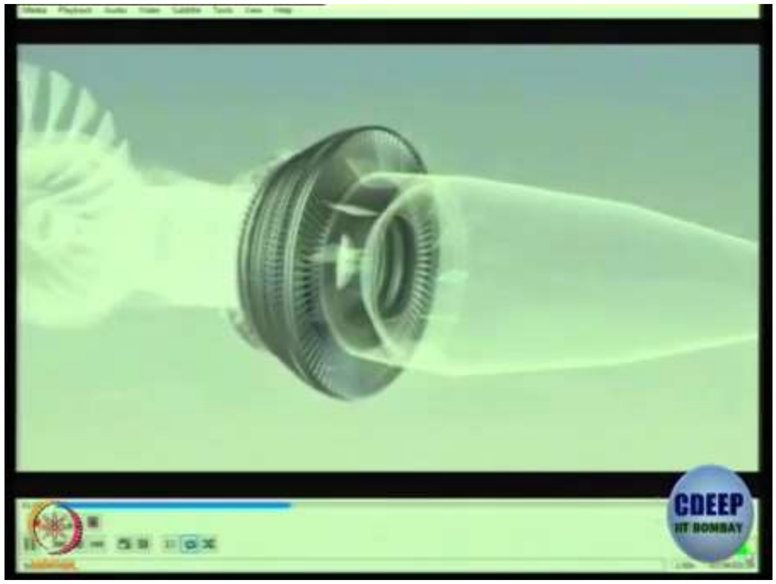
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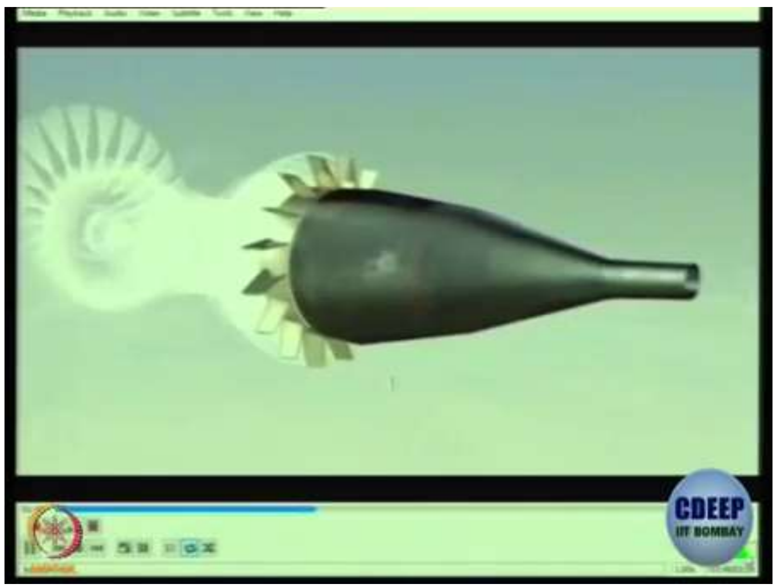
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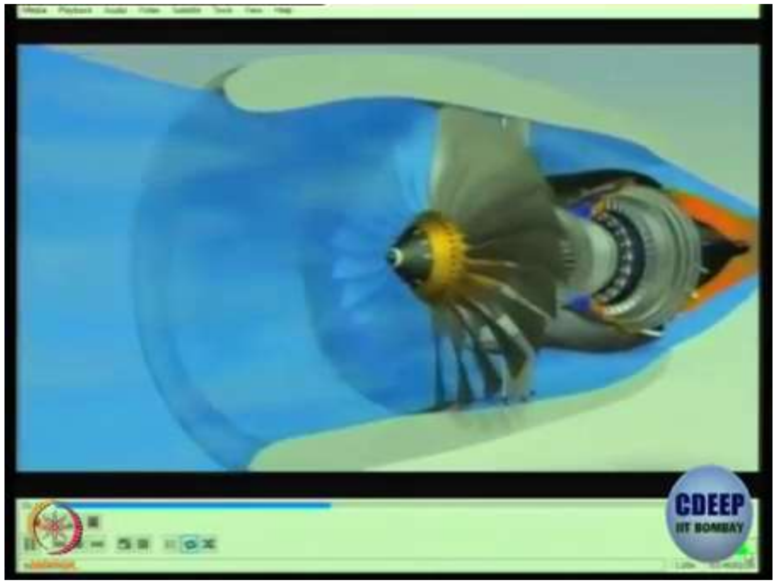
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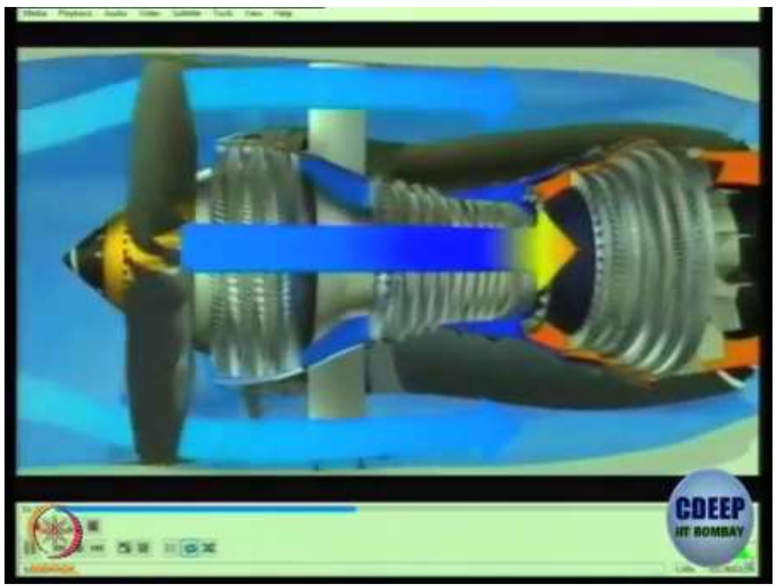
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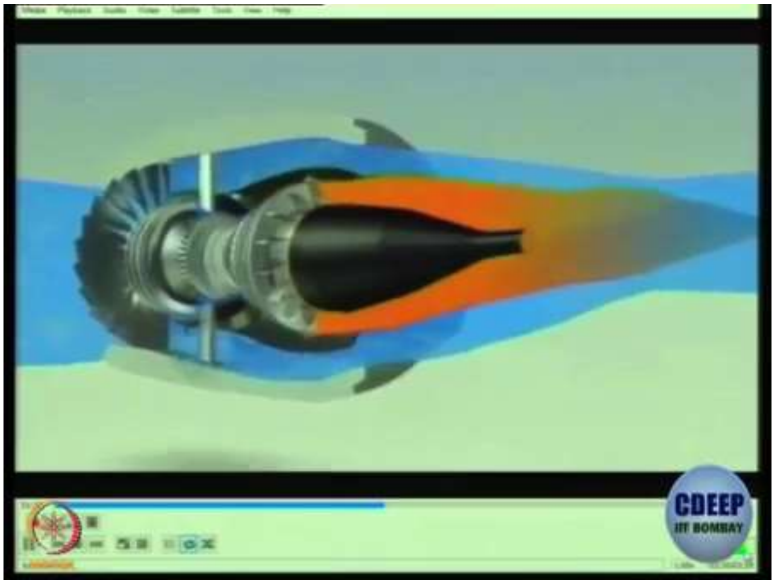
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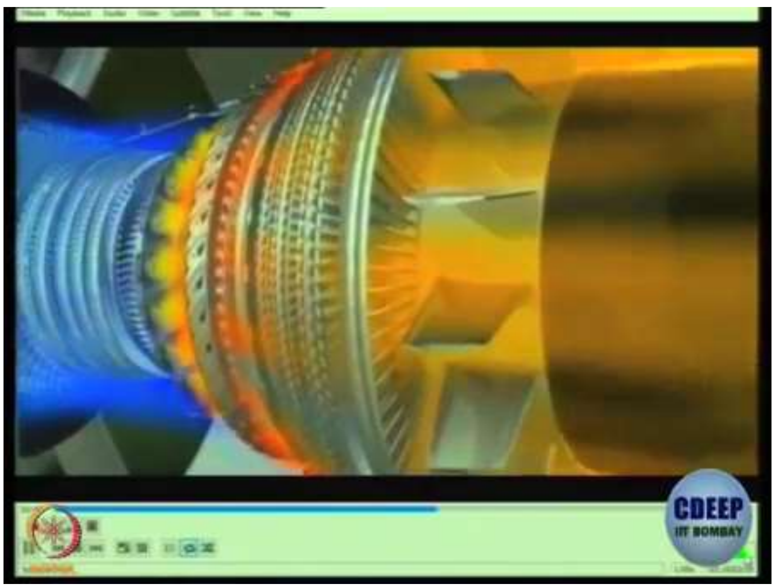
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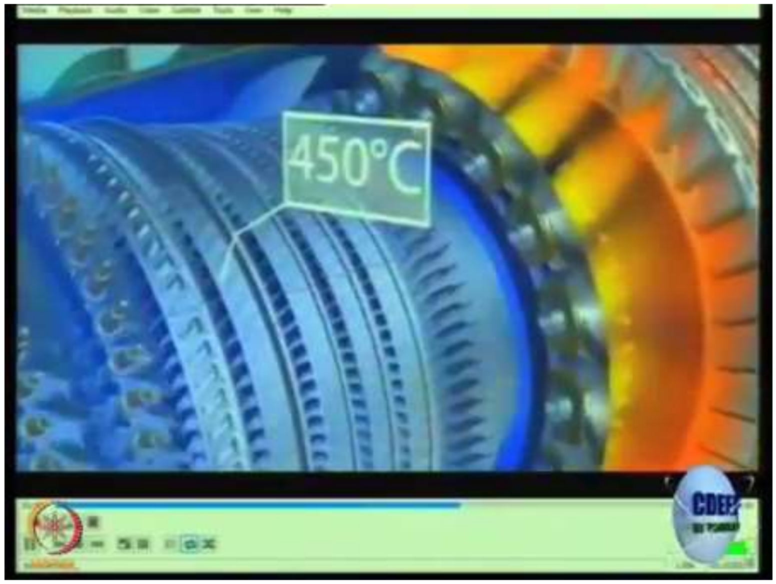
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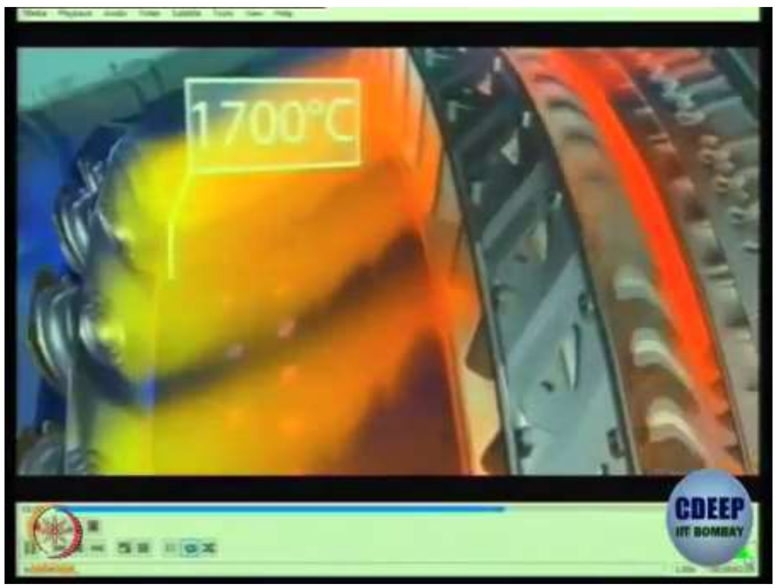
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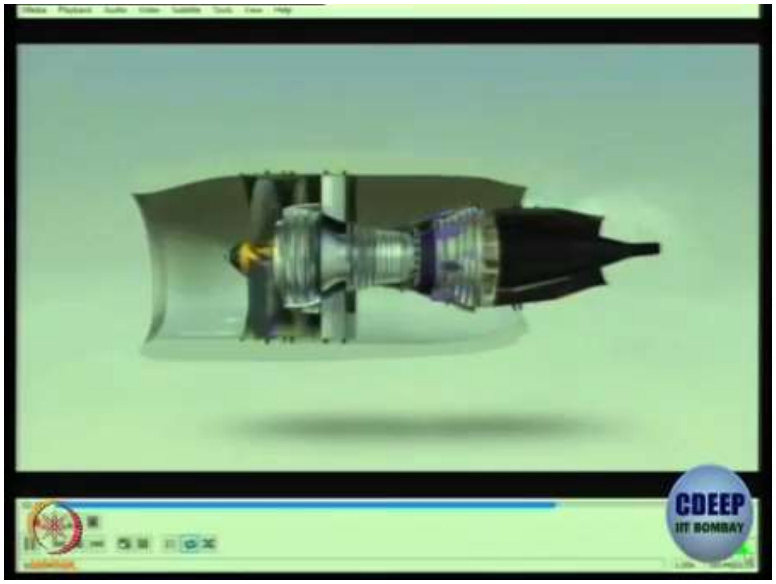
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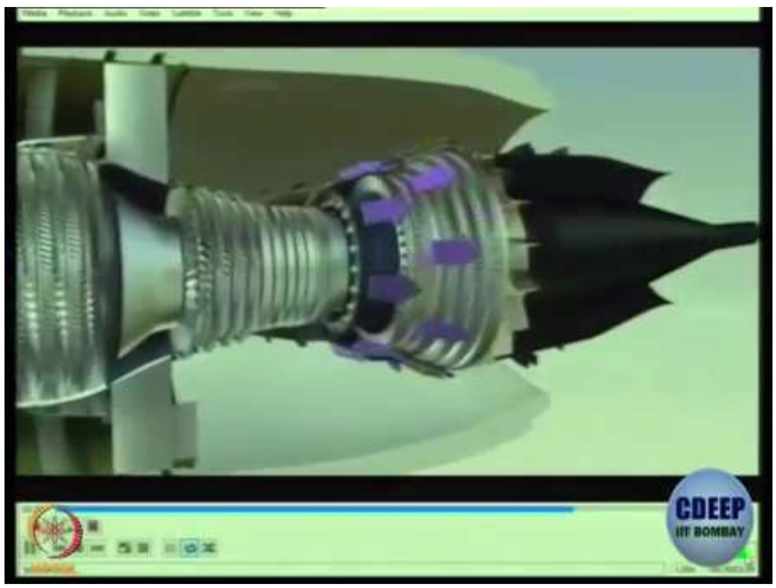
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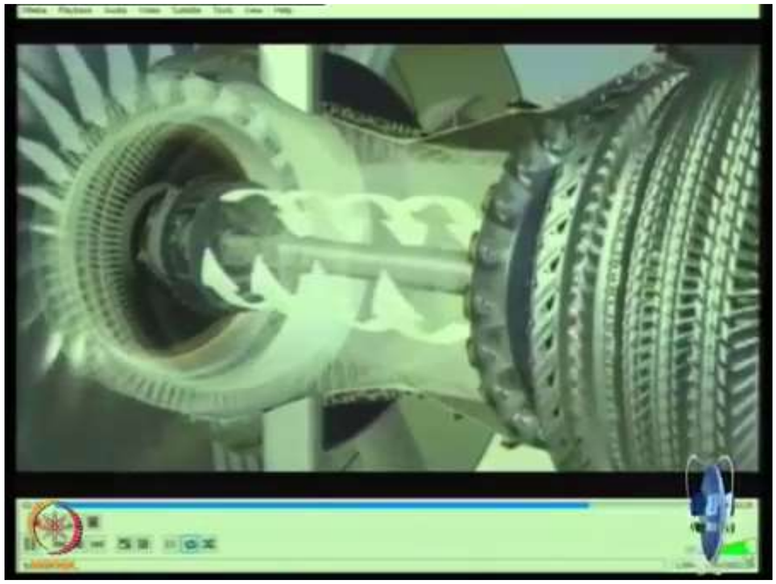

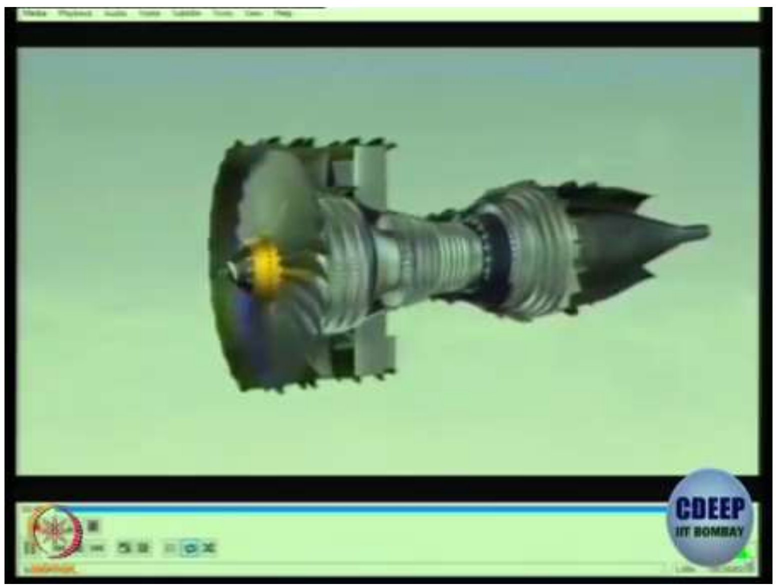

Video: To make an aircraft move forwards we need a pushing force or thrust which we create by making the air accelerate between the front and the back of the engine this is basically giving by the large fan at the front of the engine through which air passes at a high rate these are the various components of the CFM56-7B.

The fan which is a large diameter propeller, the low and high pressure compressors with 12 stages which step-by-step increase the pressure of the air as it flows through them, the combustion chamber in which jet fuel is mixed with air and burned, the high and low pressure turbines in which the pressure of the hot gas is reduced as they drive the compressors and fan there are five turbine stages 1 high pressure and 4 low pressure and finally the exhaust assembly.

The CFM56-7B is a high bypass ratio engine the primary flow passes through the combustor while the secondary flow passes only through the fan 80 percent of the engine airflow accelerated by the fan is directed into the bypass duct and provides 80 percent of the engines thrusts. The primary flow passes in succession through the compressors, the combustor and the turbines.

Before being ejected real words through the exhaust assembly the air is compressed in the low and high pressure compressors and it is temperature can reach 450 degrees Celsius after which it enters the combustor where fuel is injected and ignited burning the mixture of fuel and air brings the temperature up to 1700 degrees Celsius. Finally the accumulated energy is extracted in the five turbine stages immediately after the combustion section the pressure of the air drops as it passes through the turbines and makes them spin.

And the turbines whose shafts ride within 1 another concentrically in turn drive the fan and the 2 compressors the air is then expelled through the primary duct joining the air from the fan stream. A turbofan is therefore a flow cycle engine; air is compressed then heated by burning fuel after which it is passes through the turbines which drive the compressors and the fan.

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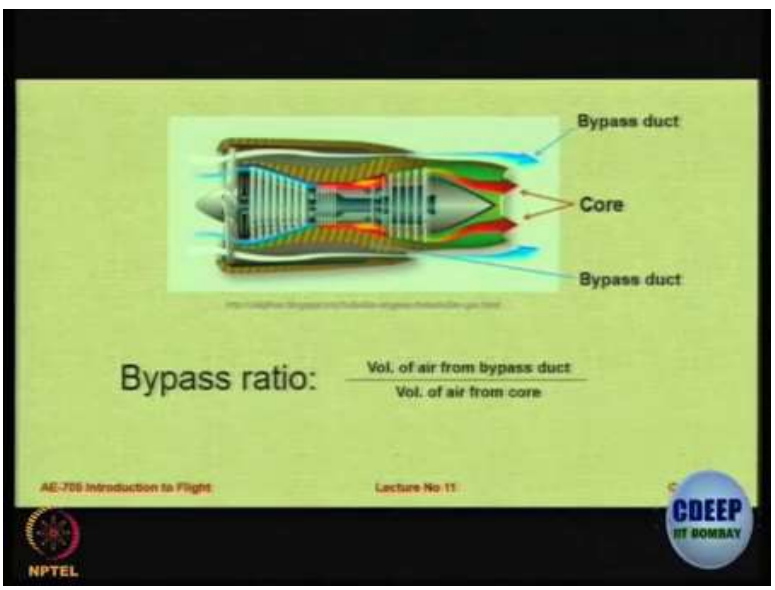

Professor: Alright, so there was a mention in this video about a term called a bypass ratio. The video said that 80 percent of the air goes in the outer duct and the remaining 20 percent passes through the central engine which is compressed, ignited, exhausted. I also said that around 80 percent of the thrust comes from the bypass air, so this is very interesting, you are working chemically and mechanically on 20 percent of the air but it is the remaining 80 percent which is just being bypassed that gives you the maximum thrust, so there is a term called as a bypass ratio

So there is a bypass duct outside there is a core duct inside and the bypass ratio is a ratio between the volume of air that goes in the bypass to the volume of air that goes in the core and higher the bypass ratio more is the fuel efficiency, lesser is the noise level but unfortunately lesser is also the thrust produced. So, if you really want very high thrust and if you are not worried too much about noise, fuel consumption, then go for turbo jet but if you are fuel conscious, your thrust requirements are reasonable or manageable and if you are also concerned about the noise then you have to go for a bypass turbofans.

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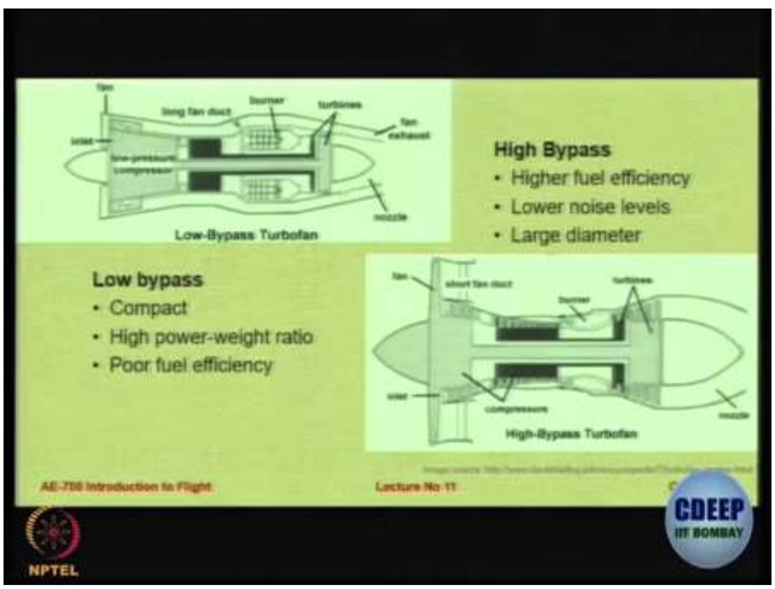

So in the low-bypass turbofan you have a very compact engine small dia, you have a high power-to-weight ratio but very poor fuel efficiency. In the high-bypass turbofan engine you have higher fuel efficiency, lower noise levels but the diameter is large, especially because of the fan in the front, in fact, the fan becomes the limiting, the diameter of the fan becomes the limiting on the size of the engine so these engines tend to be very large in size and hence you can use them for transport which do not fly supersonic or at very high speeds. So you choose low B P R or high B P R depending on your requirement. Yes?

Student: Are we doing any any operational bypass so that it reaches the maximum thrust.

Professor: No, that is a beauty, that is a beauty. We are not doing any mechanical work on the bypass air, we are simply collecting air at low speed and making it go through a duct but this air mixes with the high speed exhaust of the core air and that is what gives you a higher reaction, remember the thrust depends on the jet velocity.

So it also depends upon the mass flow it is actually $\dot{m}V$ or to be more precise it is $\dot{m}(V_j - V_a)$, so V_a is the input velocity which is a number that depends upon your cruising speed, V_j is the jet velocity, so if you use a turbo jet you can get very high V_j but $\dot{m}$, the mass flow is not so high. In a bypass high bypass engine what we do is we reduce the V_j slightly but we add more of $\dot{m}$ so you get the thrust from m dot component.

$\dot{m}$ is a bigger contributor to thrust compared to the V_j and the moment you reduce V_j then you have a better fuel efficiency, better propulsive efficiency and lower noise level, so this is very interesting that you do not do any mechanical work on the bypass air but you do have a mass flow which gets mixed with the air coming out from the jet and that is how you create the requirement okay. Does it answer your question? Thanks.