Introduction to Aerospace Propulsion

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Module No. # 01
Lecture No. # 39
Closure of the lecture series: recap

Hello and welcome to lecture number 39 of this lecture series on Introduction to Aerospace Propulsion. After a series of lectures, we have now come towards the end of this lecture series. This is the last lecture and in this lecture series will be jointly taken by Professor Roy and me.

I will be taking the first half of this lecture and Professor Roy will continue with the second half of this lecture. Over the last several lectures, we have been discussing and interacting about different aspects of aerospace propulsion. We also had a chance to look at some of the fundamental principles behind some of these devices, basically thermodynamics of aerospace propulsion. We have spent quite a few lectures on understanding the thermodynamics and thermodynamic principles of aerospace propulsion devices.

We have discussed about some of the basic cycles involved in aerospace propulsion, basically used for aircraft propulsion. We have carried out cycle analysis; the ideal cycle analysis of these devices and also Professor Roy has been discussing about some of the aspects of piston propeller engines and elements of rocket propulsion. In today's lecture, which is the last lecture of this lecture series, we shall be discussing some of the aspects related to advanced propulsion systems. Some of those concepts, which are still a concept, but we feel that it will be used in future propulsion systems. So, let us take a look at what we are going to discuss in first half of this lecture.

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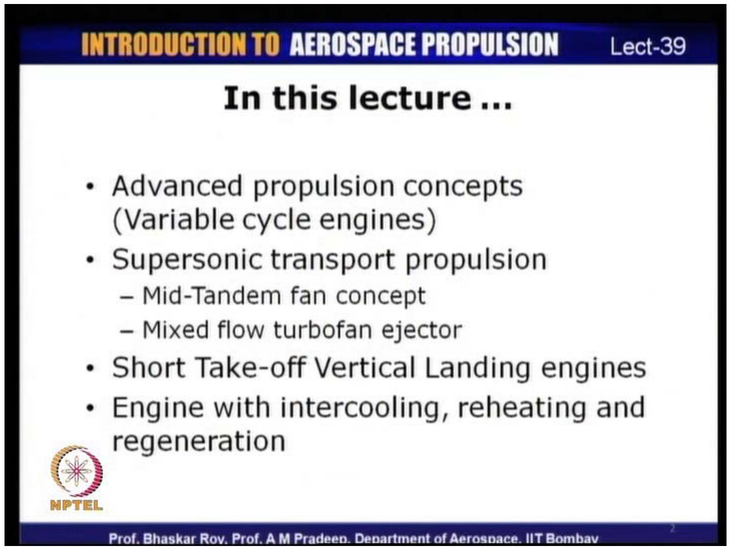

In the first half of this lecture, we shall be discussing about what are known as variable cycle engines. They are a part of the advanced propulsion concepts, air breathing propulsion concepts. We shall discuss in brief about the supersonic transport propulsion. We will discuss two concepts, which seem to be promising the mid tandem fan concept and the mixed flow turbo fan ejector concept. Subsequently, we will also discuss in brief about short take-off vertical landing engine and see what makes them different from conventional engines. Towards the end of the first half, we shall also discuss about engine with inter cooling reheating and regeneration. We had some discussion of this during the thermodynamics of the engine cycle. We will discuss little more on inter cooling reheating and regeneration.

These are some of the topics that we shall be briefly discussing. It is just what we are going to have today. It is a very introductory discussion on some of these topics. I am sure you will be able to find more reference material on these topics. Now, one of the first concepts or topics that we shall be discussing is what is known as variable cycle engine. The significance of these engines is - there are different applications of these concepts. One of the main applications that probably would use a variable cycle engine, it is the supersonic transport aircraft engine. As you are aware that we had a supersonic transport aircraft known as Concorde, which was operational for quite some time. Subsequently, due to several operational reasons, it was withdrawn and its service was stopped.

At the moment, we do not have a supersonic transport aircraft, though supersonic engines are commonly used in military engine, military aircraft. They have not been used in civil aviation or for transport. It is obvious that supersonic travel is going to substantially reduce travel time. Therefore, there is definitely a need to take a relook at supersonic transport to try and revamp the whole system altogether, but this definitely requires us to take a look at what happened really with Concorde and why is it that Concorde could not be sustained.

There are different concepts, which are being proposed. Today, we will discuss two such concepts, which probably might be used some time in the future for supersonic transport. So, in supersonic transport, the main advantage as compared to what we have now is the travel time. It can be substantially reduced and that is definitely a premium because everybody wants to travel and reach their destination as early as possible. So, supersonic transport is one of the ways of doing that. Concorde had a certain period of time during which it was operational and lot of people got the benefit of travelling at supersonic speeds and reaching their destination much earlier than what they would have, if travelled by conventional subsonic aircraft.

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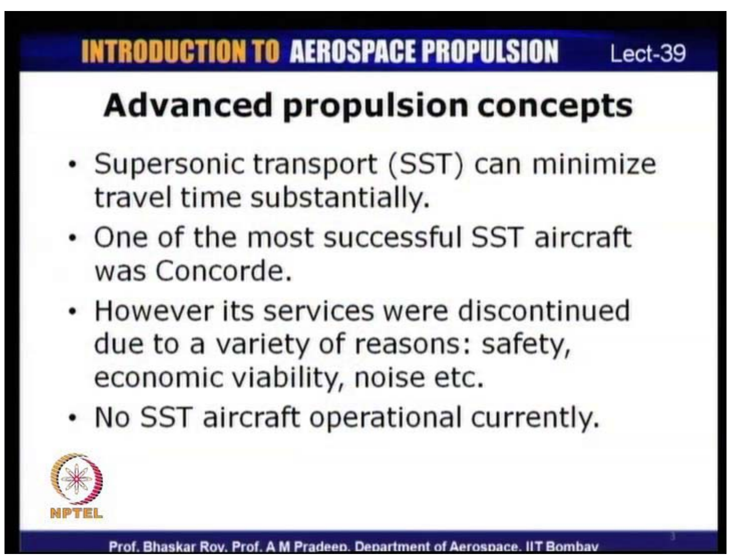

Concorde had lot of problems due to which it was discontinued. Some of them relate had to do with safety, which was an accident that took place subsequent and Concorde was discontinued. Economic viability was another issue because the cost of travelling at supersonic speed was much more than what it would be for subsonic travel and so it was not economically very viable. The third problem was related to noise and of course, there are many other issues as well, but these are three main aspects due to which supersonic transport aircraft, which was Concorde had to be discontinued. This is the reason why we did not really have a supersonic aircraft, which is currently operational. Even though supersonic aircraft is used very commonly in military engines military aircraft, they have not really been used in civil applications.

It is time that we take a relook at how we can revamp supersonic travel. What needs to be done, so that supersonic travel can again become a reality? There are few aspects that will need to be taken care of, there are key technologies, which will need to be developed for achieving supersonic travel for successfully. Though it has been demonstrated, it needs to be now done in a successful and economically viable manner.

To revisit supersonic travel or supersonic aircraft technology, there are different key challenges that need to be resolved. Some of them are basically to do with fuel economy, the engine needs to have better fuel economy because that is the key to economic viability of the engine. There needs to be increased safety because safety happens to be the key to all these technologies. The third aspect is to do with the emissions, both in terms of the pollutants and noise. These are two parameters, which keep getting stringent every few years, so it is something that such an aircraft will definitely have to meet. Emission as well as noise restrictions and norms are getting stringent every few years. So, any supersonic transport aircrafts that needs to be developed will have to keep in mind all these norms, if the concept has to be successful.

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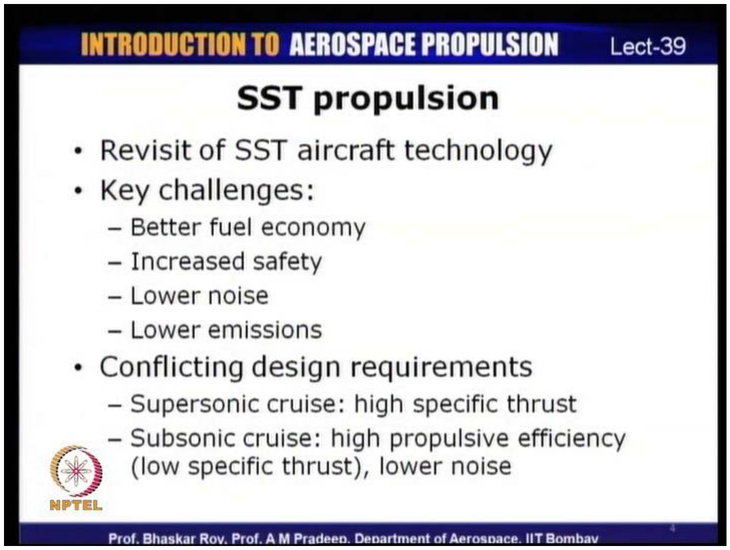

If we take a closer look at some of these requirements, we immediately see that there are conflicting design requirements, in the sense that if we look at supersonic cruise because that is what a supersonic transport aircraft needs to be doing. During supersonic cruise, there is a requirement for high specific thrust, whereas for subsonic cruise, which is what would be happening or subsonic flight during takeoff and climb to the required altitude, we are not really worried about high specific thrust, but we need a high propulsive efficiency and a lower noise. Here, we have two design requirements, which are conflicting one of them. For supersonic cruise, it needs high specific thrust, whereas for subsonic cruise, we need low specific thrust, which is basically high propulsive efficiency and lower noise.

Conventional turbojet engines can operate at supersonic speeds. It can develop high specific thrust, but they suffer from lower propulsive efficiency and higher noise. It means that if the same engine were to operate in a subsonic mach number, the second requirement for subsonic cruise is not really met. You end up having relatively lower propulsive efficiency and higher noise, which is not acceptable. So, we need to look at whether there a possibility of modifying the existing engines, either the turbojet or the turbofan engines in such a way that it can meet both these requirements.

There is a need for developing what is known as a flow multiplier device, which can basically operate an engine in two different modes that is in one mode is the supersonic cruise, where you require a high specific thrust. You basically need a lower bypass and a high jet exhaust velocity, so that you can get a high specific thrust. The second mode of operation of the same engine would be where you would like to operate the engine on a high bypass mode, so that the effective jet velocity is lower, you end up getting lower specific thrust and at the same time, it also leads to lower noise. There needs to be a certain method to convert the same engine to operate in both these different modes, so that on both modes - in supersonic flight and subsonic flight and satisfies the design requirements.

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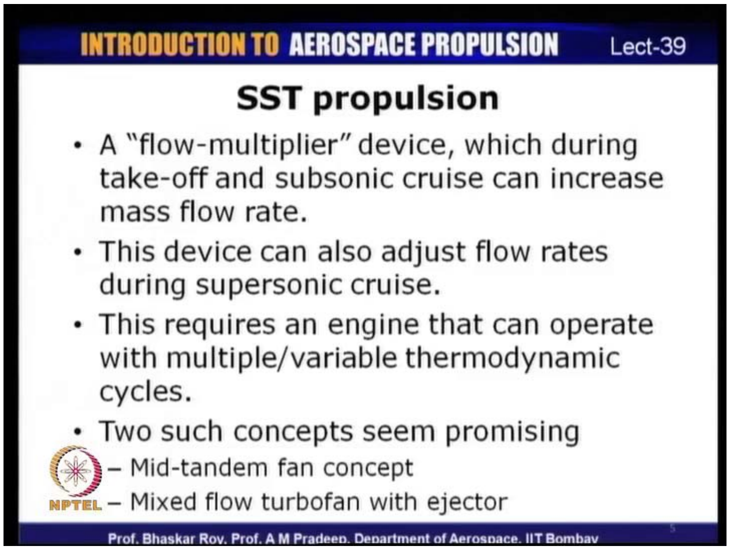

There are different concepts, which seem to have been proposed over the years. Two of these concepts seems promising and are being researched upon are - the mid tandem fan concept and the mixed flow turbofan with ejector. So, both these concepts will try to satisfy the design requirements. Basically, they try to adjust the flow rates during supersonic cruise. Therefore, the same engine operates in two different cycles. One would be an engine without bypass or a very low bypass and the other mode operates with very high bypass, which is why it is a variable cycle engine.

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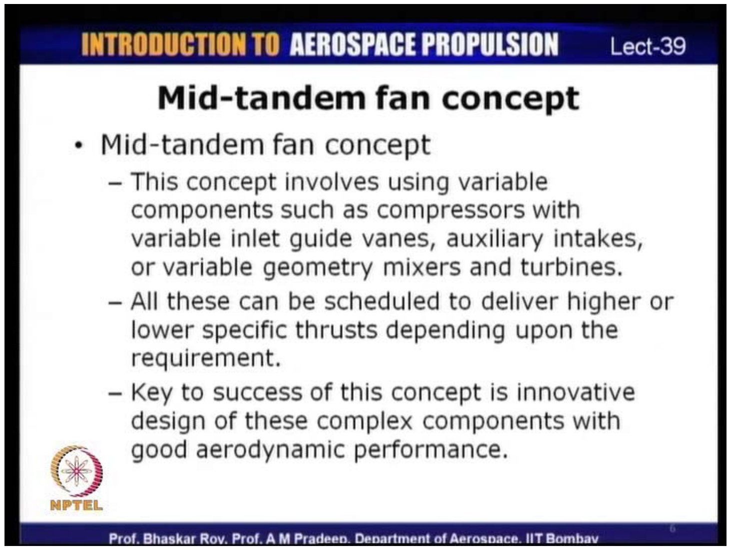

Let us take a look at the first concept that is the mid tandem fan concept. Well, this concept will require using variable components like compressors with inlet guide vanes, which are variable. It will require auxiliary intakes, variable geometry mixers and turbines and so on. There are many complexities, which are being introduced in order to operate the engine in different modes. All these complexities are basically meant to adjust the specific thrust to the required values that is for high supersonic flight.

You would need a higher specific thrust for subsonic flight and you would need a lower specific thrust. So, all these variable components are meant to enable the engine to operate in these different modes. This means that key to success of this concept would require us to design these components, which not only can be adjusted for different thrust levels, but also are aerodynamically efficient at all these different operating conditions. So, that is the key challenge for this technology.

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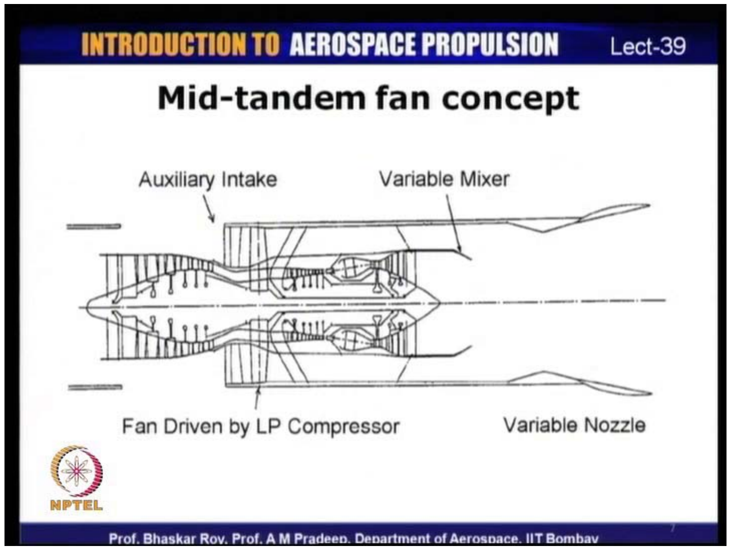

There is one schematic that I have here for you, which is explaining what this concept is all about. In this particular engine concept, what is being proposed is to install a fan, which is midway between the LP compressor and the HP compressor. This fan is of a higher bypass than the core engine, so it looks like a turbofan, but the fan is placed between the compressor stages. There is also an auxiliary intake, which can be altered to adjust the mass flow through the bypass duct.

After the turbine exhaust, you can see that there is a variable mixer and a variable nozzle. So, the variable mixer also can adjust itself according to the bypass ratio. For example, if this engine was to operate in supersonic cruise mode, then you need high specific thrust and a high jet exhaust velocity. It means that we really did not need a high bypass, so this auxiliary intake is partially closed. This means that only a small fraction of air passes through the bypass duct and majority of the air passes through the core engine. We have here an engine, which resembles a turbojet with a very small bypass. Therefore, it is possible for achieving very high values of specific thrust because the jet exhaust velocities can be quite high.

If the same engine was to operate in subsonic mode, then the intake can be opened fully enabling more mass flow to pass through the bypass duct. Therefore, this engine now operates like more or less like the conventional turbofan engine with a high bypass and therefore, the effective jet exhaust velocity is lower, the specific thrust is lowered and you also end up getting lower noise. This is one of the means of achieving these conflicting design requirements for supersonic and subsonic flight by adjusting the auxiliary intake and also the other components. It means that simply by adjusting the intake alone will not suffice; one would also need to adjust the mixer and the compressive guide winds and so on, so that the performance can be matched. That is why the whole concept requires a very clever design of these different turbo machine components.

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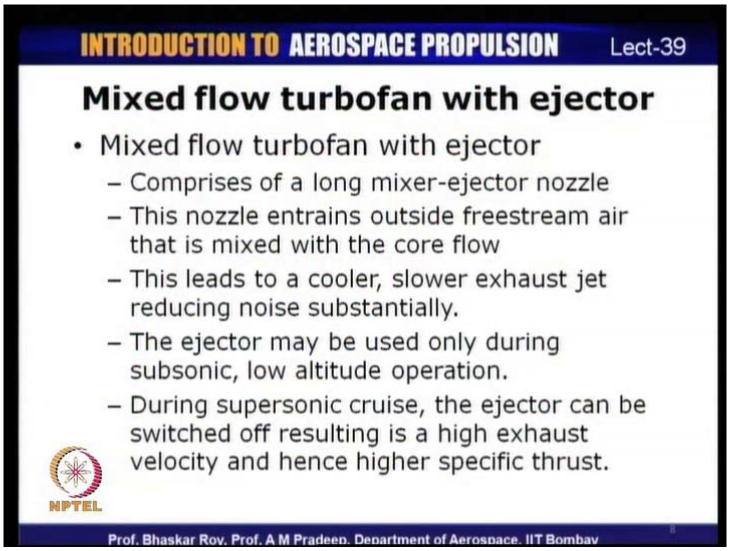

The second concept that is being looked upon is what is known as a mixed flow turbofan with ejector. It basically comprises of a long mixer ejector nozzle. This nozzle would entrain outside free stream air and it is mixed with the core flow leading to basically a cooler and slower exhaust jet. It reduces noise substantially and also the specific thrust. Obviously, it means that this ejector is required only during subsonic or low altitude operation when the aircraft is operating in a supersonic cruise the ejector can actually be switched off resulting in a high jet exhaust velocity and therefore, higher specific thrust.

This second concept is simpler to what we discussed for the first one because here, we do not really have complicated turbo machine mechanisms. All it requires is a longer jet pipe, which is integrated with the nozzle and also has a provision for entraining ambient air. As you entrain ambient air and mix it with the core stream, it reduces the jet exhaust velocities, noise and specific thrust. So, this is the mode in which it would operate during subsonic flight or during a supersonic flight. The ejector can be switched off and it operates like a pure turbojet with a very high jet exhaust velocity and a specific thrust.

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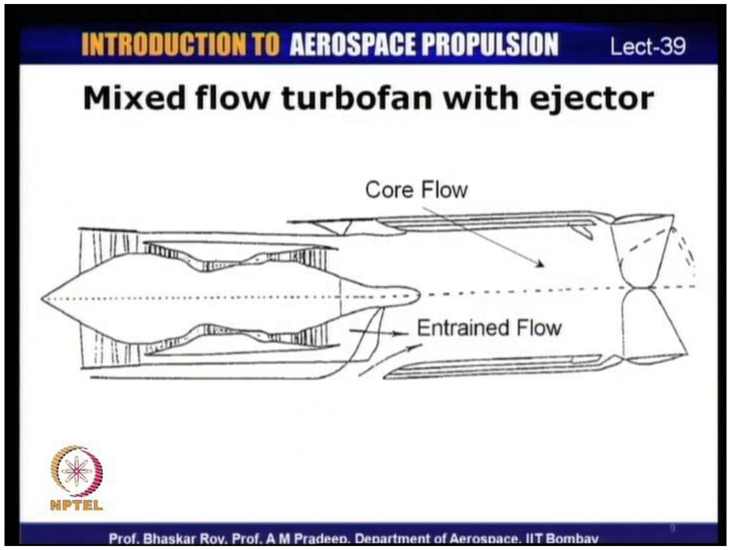

One schematic of this concept is shown in the engine that you see. It basically resembles a turbojet engine, so the initial part of this engine is exactly a turbojet. What has been proposed is to put a duct around this that is after the turbine exhaust, it has a longer duct before the nozzle. Depending upon the operating requirements, the ejector can either be switched on or off leading to entrained flow. This entrained flow from the surroundings will mix with the core flow and the jet exhaust velocities can be altered. Therefore, this engine can operate in different modes as required. So, this is a mixed flow turbofan with an ejector, which is also another contender for supersonic transport aircraft.

An analysis of these two concepts has shown that the first one that we have discussed was a tandem fan concept. It seems to be in terms of performance; better than the second one, but in terms of geometric complexity, the second concept is simpler because it does not require too many complicated turbo machine geometries involved. So, these are two different concepts which are being looked at. There are several other concepts that have been proposed for supersonic transport. It needs to be seen where these will eventually make it in actual proto type.

The other application that I mentioned was one would need to look at such variable cycle engines, it is the short and take-off vertical landing or the short take-off and landing or vertical take-off and landing. These are different modes of operation of an engine, which are being proposed. Some of them are actually being flown and that is another application, where a variable cycle concept will be required that is if the aircraft needs to take off with a very short runway length and land vertically, which is what is known as short take-off and vertical landing. The engine needs to again operate under two different modes depending upon the operating condition.

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In a short take-off and vertical landing, engine or aircraft would need a relatively low bypass at high flight speed and high bypass at lower flight speed, basically close to ground. What is done is that the thrust is vectored depending upon the mode of operation of the aircraft that is if the aircraft has to takeoff during a short runway length, the aircraft does not really have that required speed, so that the wings can generate enough lift. The nozzles can be vectored downwards to support the weight of the aircraft and so it is basically partly by adjusting the nozzle exhaust. During different modes of operation like supersonic cruise, one would need to operate the aircraft with a higher specific thrust. Therefore, the engine will need to be operated in different modes like what we discussed for supersonic transport.

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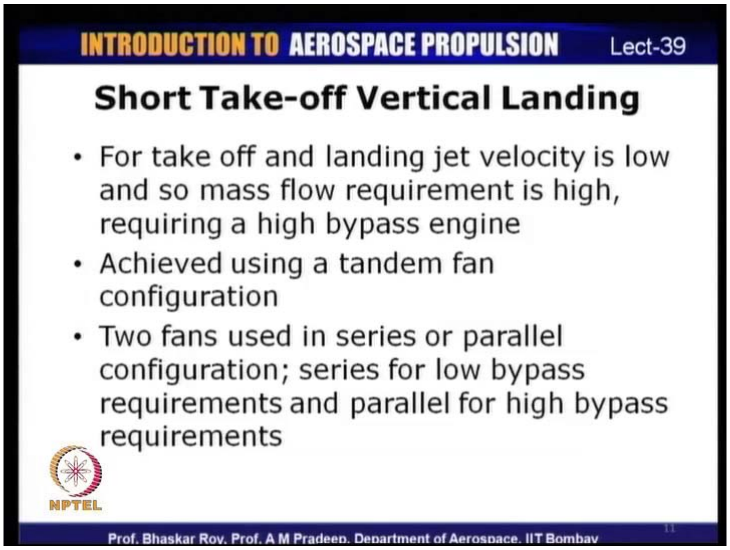

There are different concepts, which are being proposed like a tandem fan concept very similar to what we had discussed. We could have two fans, which are either used in series or parallel depending upon the application or design requirement. If the fans are operating in series, then the whole flow passes through the front fan and the second fan. It operates more or less like a turbo fan engine with two fans. Therefore, it has a higher core exhaust velocity and therefore, higher specific thrust. In a parallel fan configuration, the flow from the first fan is vectored downwards and the second fan takes air through the auxiliary intakes giving a higher bypass, which is what is required for low altitude subsonic flights

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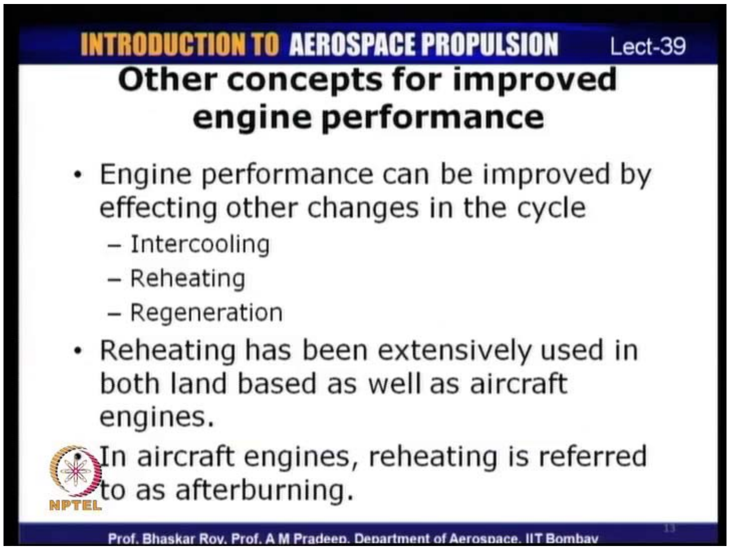

Besides the short take off and vertical landing, there are other concepts, which some of them that we have already discussed during Brayton cycle with modifications that is inter cooling, reheating, regeneration and so on. Out of these three, the reheating is one, which is very commonly used, especially in military aircraft engines. We refer to reheating as afterburning in such engines that is afterburning is when, turbine exhaust has enough air present, where you can inject additional fuel and raise the temperature to much higher levels than the turbine inlet temperature. Therefore, gain additional thrust is commonly used in supersonic military aircraft, where the engine has to be accelerated to supersonic speeds and also cruise at supersonic speeds, whereas other concepts like inter cooling and reheating or regeneration are not necessarily being used in aircraft engines.

In some form, they are used in land based or in marine applications. The basic reason why they are not used in aircraft engines is the associated increase in weight and complexity. The benefits that we get out of using inter cooling or regeneration is not higher than the penalty that is needed to pay for increasing weight and its complexity.

Reheating is one thing, which has been commonly used because it does not really require any additional complexities. It is just a tail pipe that is attached to the turbine exhaust before the nozzle. In aircraft engines, reheating is usually referred to as afterburning. They are used in land-based engines for power generation, where you have different stages of turbine with reheating in between the aircraft engines. In military aircraft engines, it is used at the exit of the turbine.

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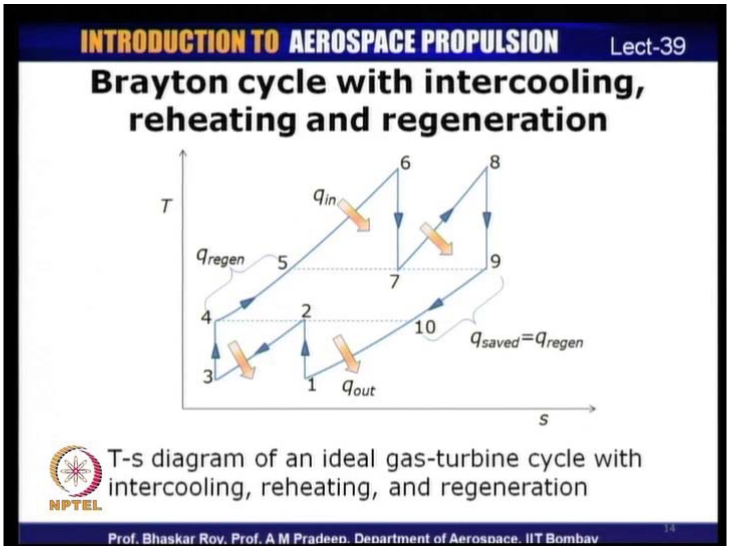

This is one cycle diagram and if you recall, we had discussed this during our discussion on Brayton cycle, where we have inter cooling between the compression stages. After we split the compression stages into different stages, we remove air and remove heat from the system. Therefore, we achieve inter cooling and reheating. We split the expansion from the turbine into multiple stages and add heat during the intermediate stages. Regeneration happens when we transfer or store heat during one part of the cycle and transfer it back to the cycle during another part of the cycle.

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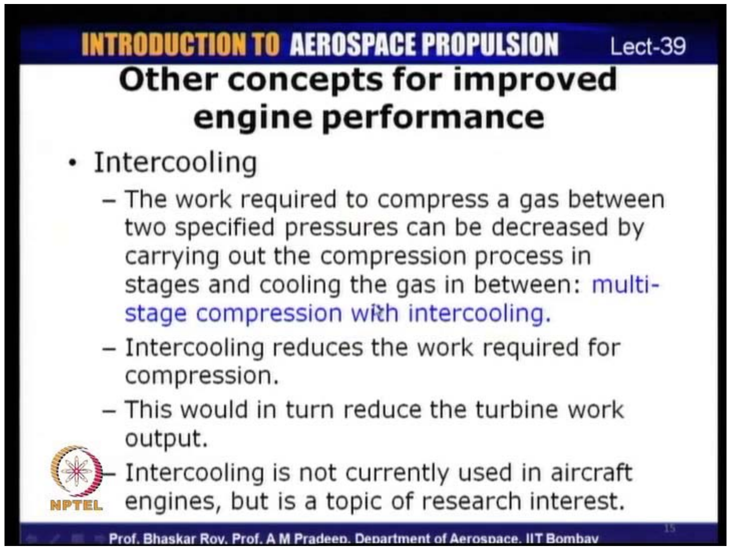

Inter cooling basically reduces the work required for compression and in turn, it reduces the turbine work as well. As I mentioned inter cooling, it is not really being used in aircraft engines as of now, but it is a topic of extensive research interest. There are lot of performance benefits that one can gain by employing inter cooling. Therefore, there is lot of research currently being undertaken on trying to use inter cooling or apply inter cooling between compression stages in an aircraft engine application.

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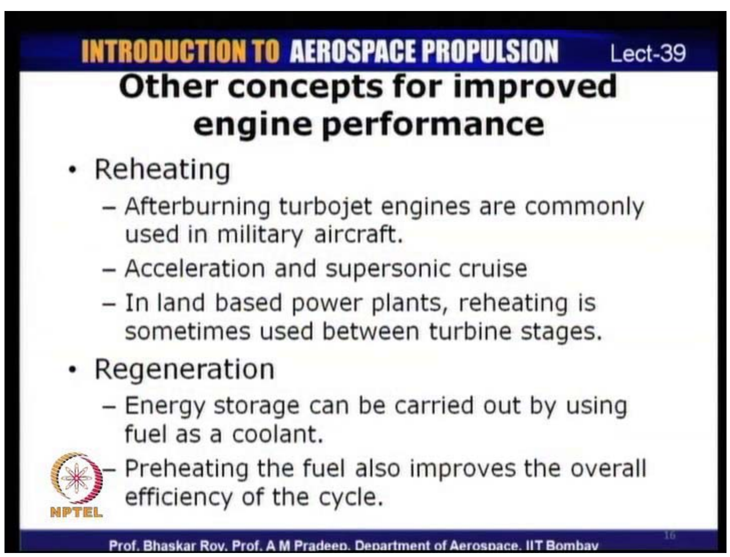

Reheating on the other hand has been used for a long time in both land based as well as in aircraft engines. Reheating is something that is already been used and its benefits are being already seen. The third aspect that one would like to use is regeneration, where energy storage can be done in the case of aircraft engine. Fuel can be used as a coolant and you can preheat the fuel by cooling some of the other components. Therefore, regeneration in some form can be implemented by using fuel as regenerating fluid.

These are some of the concepts, which probably likes inter cooling and regeneration. It can probably find applications in the future aircraft applications, besides the other concepts like what we discussed for supersonic transport and also for short take off vertical landing and other such engines. So, these are some of the simple concepts that we might get to see in future - air breathing propulsion systems. There would be many more concepts and such concepts will be discussed in the remainder of this lecture. Professor Roy will now discuss about some of the other concepts, which are being actively pursued and would probably be employed in future aircraft propulsion system. So, I will now handover professor Roy to take up the rest of the last lecture on introduction to aerospace propulsion.

We are looking back and looking forward. We will look at what we have discussed over the course of this lecture series and then look forward to what is in store for us in years to come in the field of aerospace propulsion. We have seen that all the propulsion units that are used for various aviation crafts are basically heat engines. Hence, they are fundamentally governed by the various concepts of thermodynamics and various concepts of gas dynamics. As a result of which, if you need to make fundamental change in the way the engines work, you need to go back to the fundamental thermodynamics and fundamental gas dynamics to affect those changes.

Now, many of the changes that have happened over a period of last 100 years is basically dependent on various thermodynamic concepts. Those concepts would need to be converted to technology, where technology is available at that movement of time and the state of art of the technology is available to the engine designer at that moment of time. so, quite often, thermodynamic concepts are available for quite some time before they are converted to an useful technology.

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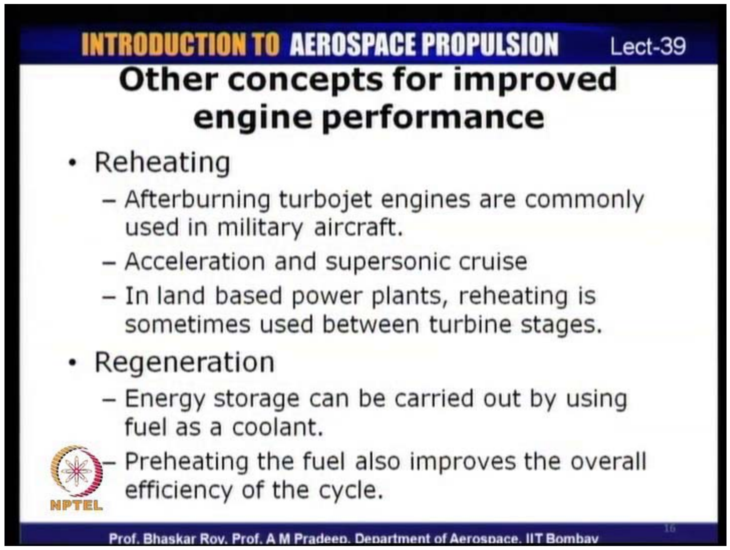

Now, this is something which is known to us for a long time, many of the engine that have been devised essentially came out of the various concepts that fundamental thermodynamics had thrown to us quite some time back. Let us take a look at some of these concepts that are in store for us in future. We shall see how these concepts are born out of fundamental understanding of how these propulsion units work; the fundamental thermodynamics or the fundamental concepts of basic aircraft and rocket propulsion that we have been talking about over the course of these lectures series.

Now, we know that a heat engine is normally used in aircraft have higher efficiency. If you have higher pressure ratio, it directly translates to higher thermal efficiency. The kind of engines that have been used over the years have tried to enhance this pressure ratio more and more by using various technology that is available. At various points of time, there are limits within which these engine need to be created or configured. So, there are technological limits within which the engines would need to be configured. The concept that if you get higher pressure ratio, you get better thermal efficiency. Everybody wants engines with high thermal efficiency, so you try to push the technology to accommodate higher and higher pressure ratio.

We will have a look at what are the other concepts that contribute to better efficiency in terms of utility value of aircraft engine and the rocket engine and how the fundamental concepts contribute to development of some of these engines. As far as the piston engines are concerned, which we discussed in the course of this lecture series they were actually powering their craft for 50 years before the jet engines came in. They continued to power many of the aircraft that are flying around the world, especially the small aircraft. They are still competitive; they are still quite good in that particular range of application. The point is everybody wants to have even better engine and everybody wants to have more efficient engine.

If you take a piston engine, it is pretty much known that if you have higher pressure ratio, you can get more and more thermal efficiency out of those engines. The problem is that if you go for higher pressure ratio, you end up having engines that are very heavy because to withstand that high pressure inside the cylinder, the engines need to be made stronger and should be made of thicker material. Hence, they become heavy and nonviable for aircraft application.

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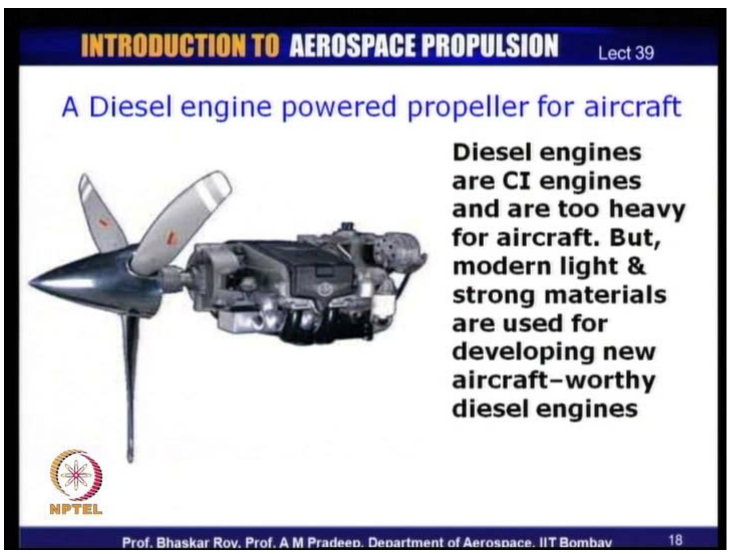

One of the candidates, which have been around for a long time and has never been considered very seriously is the diesel engine or more specifically the compression ignition engine CI engine. Fundamentally, the CI engine is heavier and as a result of which, it was never considered very seriously for aircraft application, however in the recent years, the CI engines have again been considered. One of the reasons the CI engines are being considered is because the CI engines can now be made of modern light and strong material. It can withstand the high pressure that are created inside the cylinder and as a result of that you can use the CI engines and hence, the diesel engines. Now, these are known to be thermally more efficient devices than the normal aviation kerosene or aviation fuel that are used in normal piston engines of aircraft usage.

If these are technologically possible, the CI engines would provide better fuel efficiency and that is always a sought after thing, when it comes to aircraft application because you need to carry less amount of fuel with you. Now, this is one kind of engine that is being developed. If the new materials that are new alloys that are being created; the titanium alloys or the various kinds of aluminum alloys. If they are strong enough to withstand the high pressure that is inside a CI engine, they become a very good candidate for application in aircraft and the thrust is to be created by the propeller. Propellers have been around for the more than 100 years. So, hooking up a propeller with a diesel engine is something, which people are working at. It looks entirely possible that in years to come, we may have these kinds of engine powering aircraft propellers and flying them with greater efficiency.

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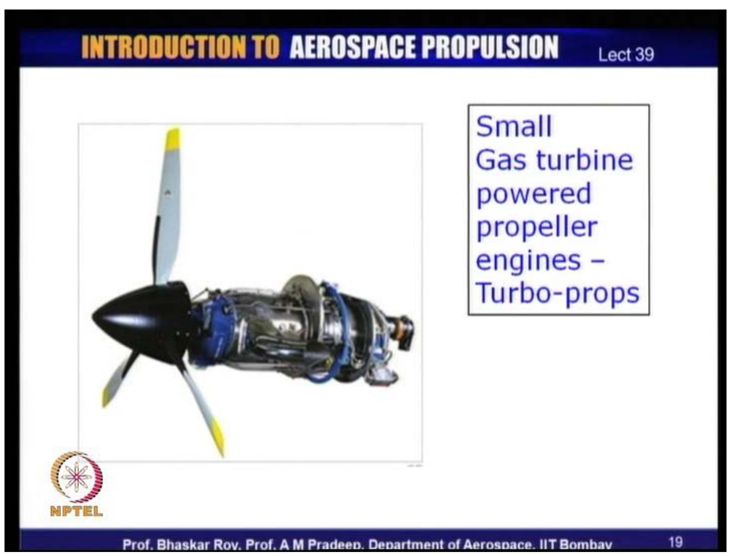

The other thing that is looking up is the small gas turbine engines, which are basically used for jet engine powering propellers to create thrust. Over the years, what had happened was gas turbine engines became smaller and smaller and they lost out in efficiency. Very small components of gas turbine engine do not promise to have same kind of aerodynamic or gas dynamic efficiency as the larger ones. As a result of which, for a long time small gas turbines, which are not considered very efficient devices. Even the piston engines were considered more efficient than small gas turbine engines.

Over the years, because of the advancement in manufacturing technology, in the fabrication technology, the material science and metallurgy, it is now possible to create very small gas turbine engines. They are also competitive, in terms of overall thermal efficiency. Now, this makes another candidate for small aircraft, for powering the propellers and creating thrust for small aircraft. So, small gas turbine engines are becoming more and more competitive. We will see that more and more gas turbine engines would be used. One of the reasons the gas turbine engines would be considered a good candidate, if they can be made in small sizes is because gas turbine engine is intrinsically fundamentally a more efficient heat engine. That is the reason why people are still looking at gas turbine engine; a small one, which can power aircraft power planes.

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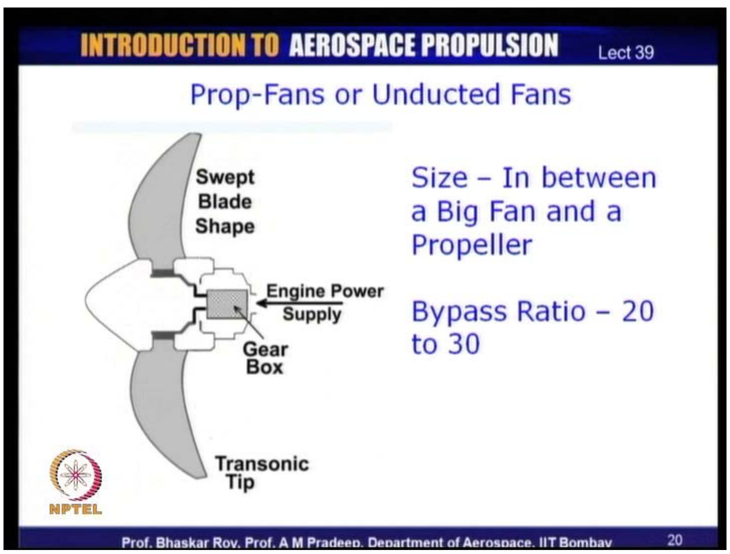

The other device, which we have touched upon is the prop fans, which we have introduced once, let us look at it little more closely. We have seen that fuel efficiency of an aircraft is enhanced, if you introduce bypass devices. Once the bypass is introduced, the specific fuel consumption is vastly improved. This is a known fact for more than half a century and that is the reason, why we have so many turbofan engines.

If you stretch that concept a little more and introduced prop fans, they are indeed devices that are somewhere in between a fan and a propeller. If you consider propeller, where the entire mass flow bypasses the engine and creates thrust. Prop fan is something in between, where a very large amount of mass is activated by the prop fan. If you talk in terms of bypass ratio, we are talking in terms of bypass ratio of the order of 20 or 30. You see the normal bypass ratios of the big fan engines that we see today, which powers the commercial aircraft like jumbo aircraft. All have a bypass ratio of the order of 5 or 6, even the modern airbus or the modern Boeing aircraft 777. They have engines with bypass ratios of the order of 6 to 7 and of course, people are talking about bypass ratios of turbo fans of the order of 9 to 10.

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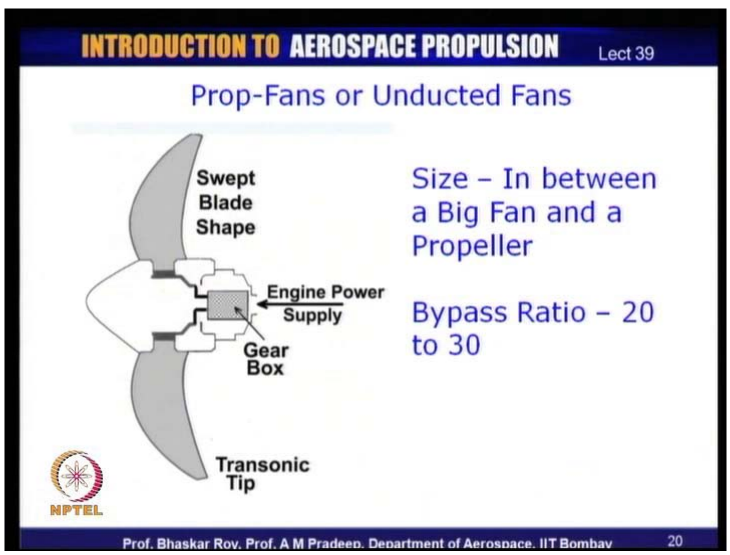

Now, we are looking at these prop fans, where the bypass ratios are indeed of the order of 20 to 30. The fuel efficiency that occurs out of this high bypass ratio is very high ultra-high bypass ratio is huge and this is being developed for quite some time. Now, you can see the shapes that have been developed and some of these have been around for 10 15 years. These are becoming more and more efficient, the designers are working on them are getting more and more exotic shapes to create more efficiency.

The fundamental fact that the very high bypass ratio gives a very high fuel efficiency. It is the biggest attraction and that attraction is what has kept them alive. Now, it looks entirely feasible that in very short while, we shall see these prop fans operative and fly aircraft, especially the subsonic civil aircraft. All over the world, they are extremely efficient devices. As I said, it is more efficient than the big fan engines that you see today. Flying around is simply a matter of time, before these prop fans take over flying the big aircraft.

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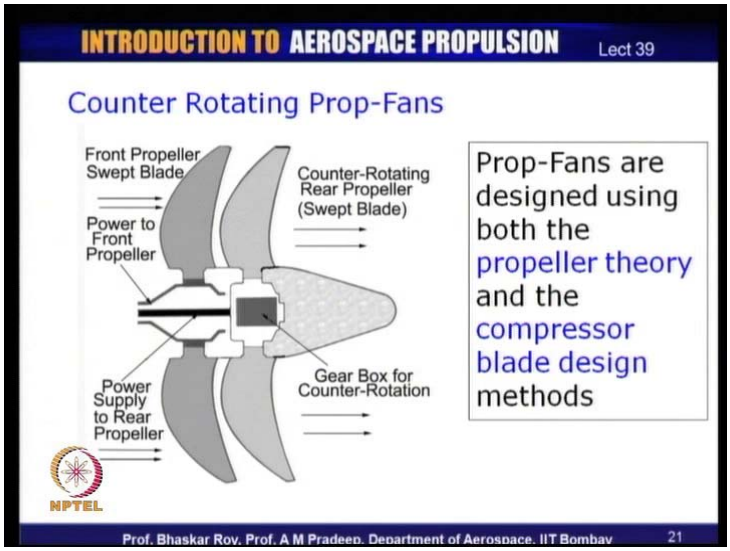

One version of prop fan is being developed very seriously. It is known as counter rotating prop fan and we had a glimpse of it once. Let us take a closer look again. in this configuration, you have two prop fans, which is the front one and the one, which is the rear prop fan rotating in opposite direction. There is a technological device, by which the counter rotation is affected.

The two prop fans are driven by something like a big gas turbine engine and the shaft that comes out has a gearbox creates the opposite rotation of the rear fan. As a result of this, you have two prop fans rotating together creating thrust. Now, this prop fan compared to the earlier prop fan would have much more thrust making it capable. It retains the efficiency of a prop fan and nearly doubles it by creating more mass flow and more thrust making capability. It retains the huge fuel efficiency that occurs due to the very high bypass ratio that it can create.

This kind of counter rotating prop fans are indeed on the anvil and is very likely that over a period of next few years, we shall see many of them flying around the world powering very large aircraft. The design of these prop fans are indeed created using a combination of propeller theory, which we have done in the course of our lecture. The compressor blade design methods have been around for close to 50 years. So, many of these theories that we are talking about or have talked about in the course of our lectures are combined together to create these prop fans and the counter rotating prop fans.

You have the theory, you have the fundamental concept that high bypass ratio gives you better fuel efficiency and as a result of which, you can create better thrust making devices. Now, one of the issues or problems of these prop fans have been the noise. They make a lot of noise and some of the noise is indeed aerodynamic noise. The aerodynamic designers of these prop fans are now working on these machines or these blade shapes to reduce the noise and conform to the present noise regulations, so that the huge fuel efficiency can actually be made use of in actual operation. Noise is one of the issues that need to be sorted out and once that is sorted out, we shall see many of these prop fans flying around the world.

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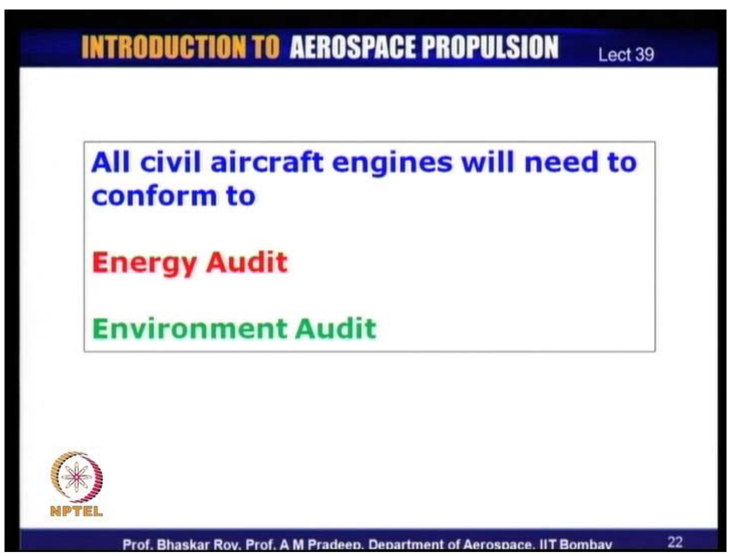

So, the issues the modern engines would have to deal at this stage of its concept and then at the stage of its technological feasibility study, finally making it the two concepts. They are - one is the energy audit, how much energy the entire engine is making use of to create that amount of thrust? The thermal efficiency comes into picture; the entire energy usage of the fuel and other devices that power the aircraft would have to be taken into account. Hence all aircraft propulsive devices would have to conform to very stringent energy audit from now onwards to be competitive in the market, to be useful in the market for the operators to make reasonable economic profit out of it.

The other conformity that is strongly required is the environmental audit. The environment audit that needs to be done is again to conform to the modern regulations, environmental laws that have been put in place all over the world. Noise is one of the issues that most of the aircraft engines over the years were indeed extremely noisy. Much of the noise have now been reduced to a very low level, probably some more needs to be done. Some of these noisy elements including the jet or including the fan and the big fans or the prop fans would have to be considerably redesigned to conform to the new noise regulations.

The jet engines that are used would have to conform to pollution regulations. More and more stringent pollution regulations are coming and have already been put in place. These have to be conformed and unless they are conforming to these energy audit and the environmental regulations in future, these engines would not even be certificated. They would not even get a certificate to be operated and hence, the new engines born out of the concept that we have talked about it may be thermodynamic concept. It may be due to the bypass engines or any other concept. When the technology is finally applied, one would need to conform to energy audit and one would need to conform to environmental audit, otherwise these engines would not be allowed to be flown and they would not be certificated at all.

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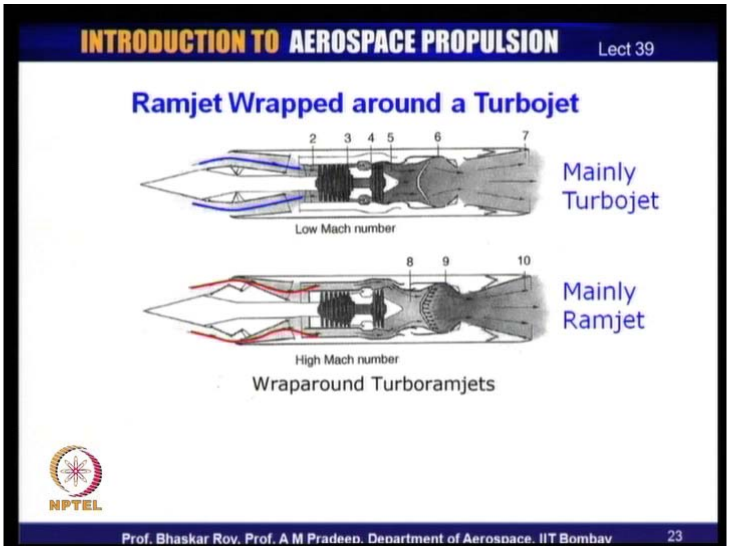

Let us look at the some of the more complicated engines that people are now looking at very closely. Some of them may have applications, which are not necessarily civil applications. These may have applications, which are probably military applications. One of the concepts is we have talked about the ramjet engine, which takes an ordinary craft or a missile to hypersonic speeds. Essentially, the point is that ramjets do not operate at low speeds and hence, you cannot take off a craft with the help of a ramjet. So, the concept is that if you combine a turbojet with a ramjet, the turbojet will help it take off to some high altitude and some high Mach number. From there onwards, the ramjet would take over and take it to hypersonic speeds.

These are concepts that people are working on. It is simply referred to as a wraparound turbo ramjet, where a ramjet is essentially wrapped around a turbojet. So, the outer annulus is essentially ramjet and the inner core is a normal turbojet. When the aircraft is taking off, it mainly works in turbojet mode and during takeoff and climbing to very high altitude it works in turbojet mode. Once it has gone to very high altitude and very high Mach number around Mach 3, then the ramjet takes over and takes it to even higher Mach number like Mach 6 or Mach 7.

It is a combination of turbojet and ramjet. This allows the craft to takeoff from ground and even come back to the ground, while landing at the same time going all the way to hypersonic speeds and while flying at extremely high altitude above the earth’s surface.

This is one concept that people are working on, which will allow craft to go hypersonic from takeoff to hypersonic and then back to landing.

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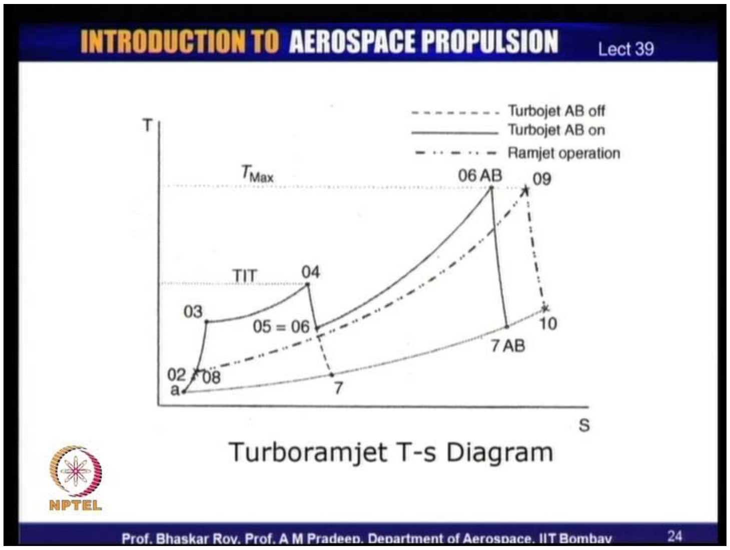

This is a thermodynamic concept, on which the turbo ramjet is being conceived. You have done the cycles and there are possibilities, which we can look into. You have the normal cycle over here, which is the turbojet cycle. You can have the after burner, which will take it to Mach 3. You can operate it without after burner at low altitude and low Mach numbers, then put the after burner, which is a reheat engine. Take it to Mach number 3 and from there onwards, you have the ramjet engine, which takes over and operates it at hypersonic speeds.

It is basically a variable cycle engine, where during the flight itself, it changes from turbojet without afterburner, then turbojet with afterburner and then a ramjet engine. So, it is a kind of convertible engine and one can say, it allows the craft to takeoff, climb, go hypersonic, come back and land.

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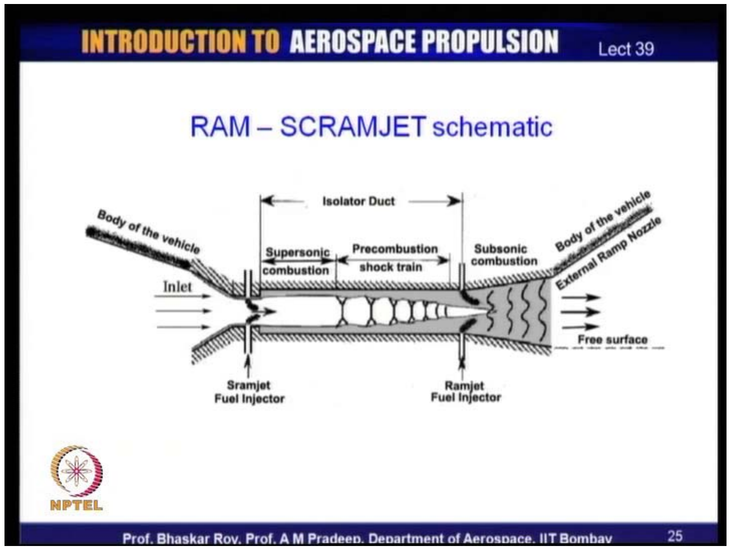

This is another concept, which allows people to fly very high supersonic to hypersonic. Let us say from low hypersonic to high hypersonic, at low hypersonic flight conditions, a ramjet engine is known to be quite useful and very good. It provides thrust, whereas once you think in terms of high hypersonic that is Mach 8 or above, one would have to think in terms of scramjet engine. Now, scramjet engine is something we have done before and this is a concept, where you have a ram and scram together in one engine. In this part, the combustion is done sub sonically and part of the combustion is done supersonically allowing the craft to operate both under low hypersonic as well as under high hypersonic conditions. So, one can operate reasonably and efficiently under a wide range of hypersonic flight Mach numbers.

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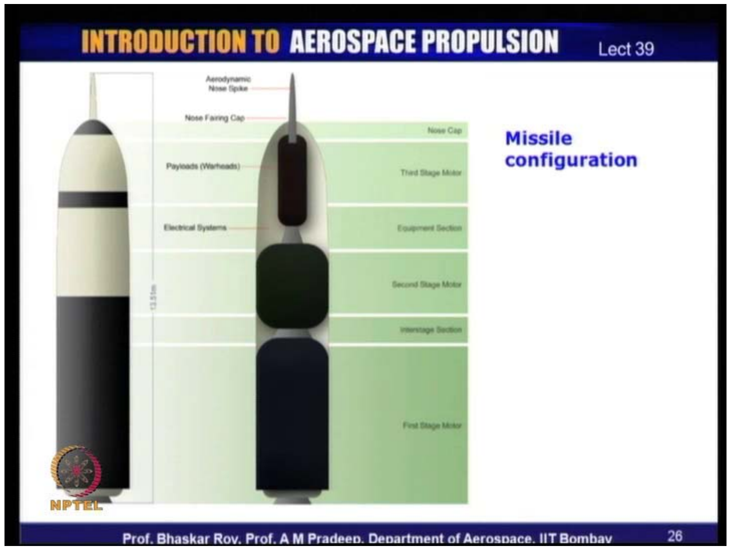

These are devices, which take craft to very high Mach numbers to hypersonic Mach numbers. This is a missile configuration and finally this missile is going to fly supersonic. So, if you look at the nose of the missile, you will find a supersonic spike over there and that has been created essentially because some part of the missile flight is going to be indeed supersonic and during which, this nose over here will indeed create shocks. Nose is then created to negotiate those shocks to create minimum drag and fly the missile efficiently through those supersonic flight conditions.

As far as the propulsion device is concerned, you can see there are essentially three stages- the big first stage over here and then the nozzle, which is shown over there and then you have the second stage the nozzle, which is seen over here. You have the third stage and the nozzle, which is seen over there. So, this is a very simple way of trying to show how a missile can actually be powered by a three stage propulsive device. Many of these missiles depending on their flight range, depending on their mission quite often have combinations of various kinds of propellants. We may have a combination of solid propellant, first stage liquid propellant in second stage and may be solid propellant in third stage.

So, a combination of solids and liquids are often used in multistage rockets, so that they are optimally utilized. You have an optimal thrust making capability at various stages. As you are probably aware that in such rocket flights, once the first stage is used up, the entire first stage is indeed ejected and it falls off. Similarly, once the second stage is used up, it actually falls away. Only the third stage, then flies the main payload, which in military applications could be warhead to its destination and a little before, it reaches the destination. The third stage also falls away, so these rockets stages are essentially ejectable and they get ejected at various stages in a very planned manner. This plan is done by the designer and he designs very accurately at what point of time, the first stage or the second stage or the third stage would falloff.

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These are designs, which are created and it depends on the missile. As I said, you could have a single stage missile, you could have a two stage missile or you could have three stage missiles. Some of the intercontinental ballistic missiles may even be four stage missiles. Some of the missiles do indeed use hypersonic, go to hypersonic flights and they often use ramjets or scramjets for their missile powering.

Missiles are often powered by rocket, but in some cases, the missiles may be powered by ram or scramjet engines, especially when they have long cruise going over hundreds or may be even thousands of kilometers.

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We have discussed some of the rockets. We may look into the future of what we are moving into. You are all aware that in India, we have already launched Chandrayan, which is our first step towards going to moon. Some first launch has already been successfully done. We have already retrieved some material, the experience has been applauded by all over the world and it is a successful experience.

Now, this particular Chandrayan - I was launched by PSLV. It is known as PSLV or Polar Satellite Launch Vehicle and that rocket was used to launch the Chandrayan - I. It is a four-stage combination of solid and liquid propulsion systems. The first stage is the one of largest solid fuel rocket booster. It is indeed one of the largest solid fuel rocket boosters in the world and this has been used for launching Chandrayan – I.

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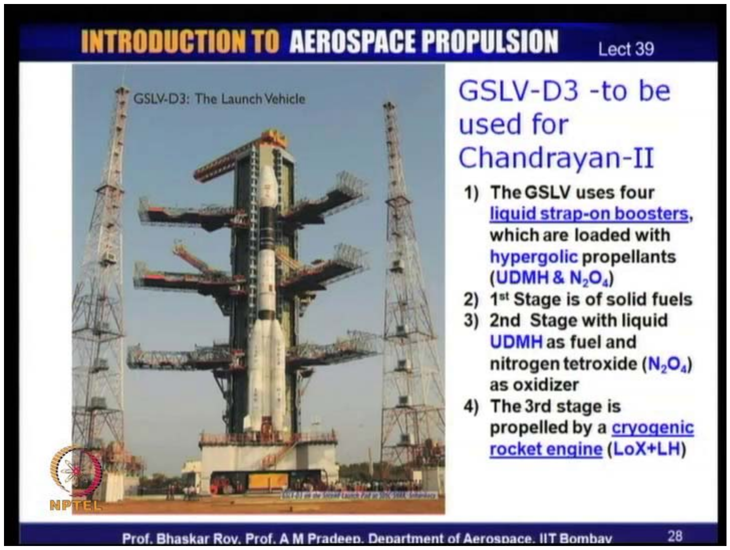

So, it is a combination of solid and liquid propulsion system. What we are looking into is Chandrayan – II. It will be launched with the help of GSLV, which is Geosynchronous Satellite Launch Vehicle and this uses a more complicated and a more involved rocket propulsion system. It has four liquid straps on boosters. If you look at the picture here, you will see these boosters, which are wrapped around the main core of the rocket. There are four of them; you can see two of them on this side. So, there are four of them. These are liquid propellant rockets and they use hypergolic propellants, which are essentially the propellants. They come into contact with each other and they immediately ignite. So, you do not need a igniter to ignite them. The moment they come into contact with each other, they get ignited or the combustion process starts.

The propellants in use are UDMH, which is Unidirectional Dimethyl Hydrazine and nitrogen tetroxide. So, these are hypergolic propellants and they have been used in these liquid strap-on boosters, which you see around here that are on the outer side of the main rocket core. The first stage is again three stage, the first stage is of solid fuel, which is just inside here. So, outside, we have the four liquid boosters and inside, we have the first stage, which is a solid fuel rocket.

The second stage is a liquid of UDMH and nitrogen tetroxide, which is a second stage and then you have the third stage, which is a cryogenic rocket. We have talked about this a little and this uses liquid oxygen and liquid hydrogen. This is a new technology, which has been used in India comparatively. This is going to be used in the GSLV- D3, which will power Chandrayan – II, which we are hoping that it will take some Indian to moon. So, this is the technology that we are looking for the future. It is a much matured technology, a combination of liquid and solid propellants being used and cryogenic rockets propulsion are being used to power our flight to moon.

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This is a coverage that we have done in this course, covering some ground on aircraft propulsion and a little ground on rocket propulsion. It tries to bring you the fundamental concepts that are required in making of these crafts and how the crafts are developing over the years and what we can look for the few years to come. I would very strongly urge you to read books, not just to look at the internet websites, but look at the books because that is where you get the depth of the material and that is where you get the theories that actually conform to the various things that we have discussed.

The theories are indeed used for making these various kinds of engines. I hope, we have been able to bring to you some of the fundamental concepts and I hope it enthuses you to read more books and more material, so that you get more and more knowledgeable about how aerospace propulsion work.