Jet Aircraft Propulsion

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Use of Ramjets and Pulsejets in Aircraft Propulsion

We are going to start talking about some of the kinds of jet engines, which had actually appeared more than 60 years back in world of jet aircraft. However, for various reasons they were kind of super seeded by the gas turbine based jet engines, which we have been taking about over this lectures series. However, it is a probably right that we should have a look at some of those a jet engines, which were indeed jet engines and they actually flew along the same time when the gas turbine based jet engines first flew. And they were kind of disfavored by various reasons for various manufacturers, and aircraft builders. However, they are coming back, they have reason to have their own applications, where they could be useful even today. And we should have a look at some of them, how they function, and how they can be deployed for flying aircraft.

In some sense, these were simpler jet engines. And that is indeed one of the reasons why those jet engines appeared before the gas turbine base jet engines, because the gas turbine base jet engines as we have seen over this lecturer series or indeed rather complex machines. They do have all kinds of complex parts like compressors and turbines which make the engine extremely heavy bulky, and of course very complex to both design and analyze, and finally control during flight. Much simpler versions of jet engines appeared alongside after the World War 2 immediately are around the time of World War 2 by various manufacturers, essentially to begin with for the purpose of the war itself and latter on they were flown by various people.

And as I mentioned they were not favored in comparison to the gas turbine base jet engines, and hence they were not used for regular flights either for military or for transport aircraft purposes. However, they are indeed being looked into again for various kinds of aircraft applications by various manufacturers both in Europe as well as in USA. Now, these engines

which go by the name of pulsejets, ramjets and version of ramjet, which is known as scramjets are very simple engines. And we will have a look at these engines over the last, next two, three lectures. And we will take a good look at them and we will find that they actually do how application potential under certain circumstances in certain kinds of aircraft and those kinds of aircraft actually are looking into these engines the modern versions of them, the improved versions of them and how they can be deployed for certain aircraft flights.

So, this is what we will be doing over the next few lectures looking at ramjets, pulsejets and scramjets. How they function? What kind of aircraft they are used they have been used in the past? And what kind of aircraft they are likely to be used in future? We will look at: how they operate? We will look at: what kind of thermodynamics cycle they actually are used for? Finally, we also look at their performance and some aspects of how they are designed, over a period of next three or four lectures.

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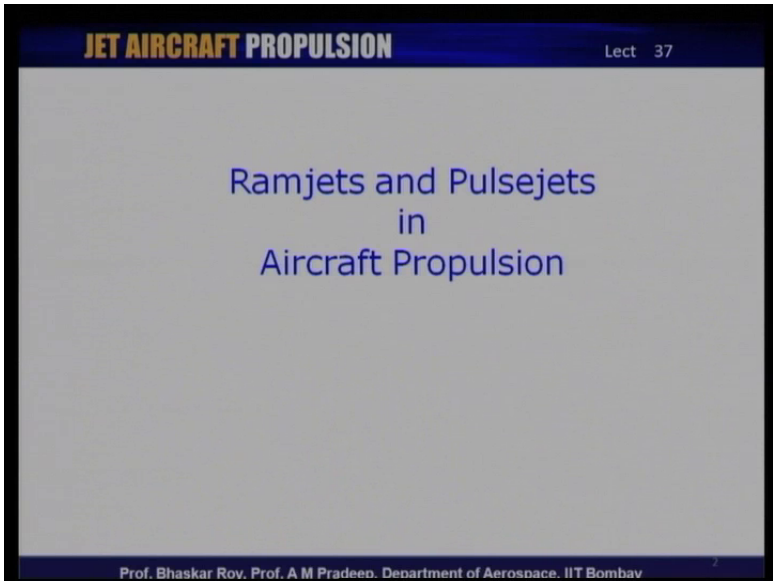

So, let us take a look at: these jet engines, which are pulsejets, ramjets and scramjets. Some of these engines, which have been as I mentioned around for more than 50, 60 years where developed essentially for the purpose of military purposes. Now of course, many of the aircraft and many of the engines, where indeed developed for military applications to begin with and even today, many of the new technologies are often used first in military aircraft,

which are indeed the more demanding kind of aircraft and hence require more demanding and more challenging kind of engines to be designed and built.

So, during World War 2 certain kinds of ramjets and pulsejets were used during the war, as war material also because as I mentioned they are very simple kind of jet engines. And at that point of time, it was a bit of surprise to the other party. And in a sense, they were; they must be considered as successful deployment of a jet engines also one must remember at that point of time the gas turbine base jet engines, which we have been talking about had not been developed so much. And as a result of, which these pulsejets and ramjets were considered to be reasonably competitive to the gas turbine based jet engines or the turbo jet engines as we call them.

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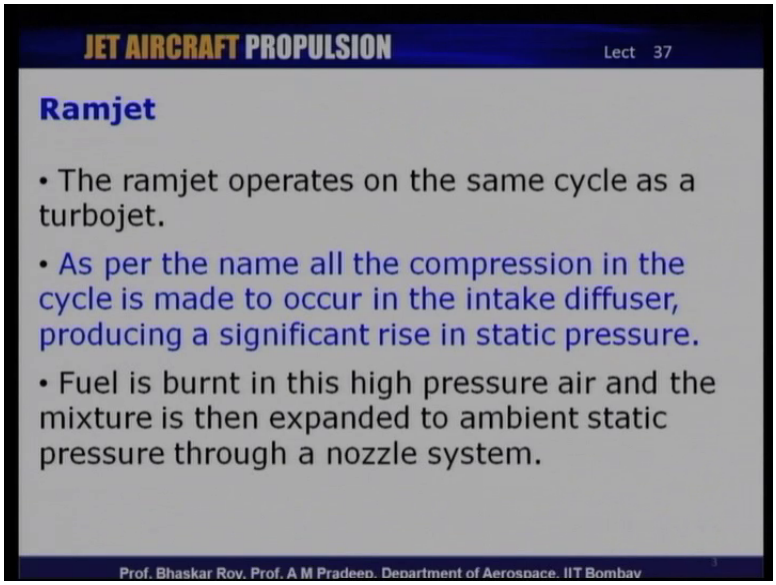

So, let us take a look at: what these ramjets and pulsejets are all about and exactly how they function to begin with all heat engines. And all jet engines have to have some kind of a thermodynamic basis in as far as they are all heat engines. Now, these ramjets operate on the same cycle as turbo jet engines and we shall be looking at this thermodynamic cycle probably in the next lecture. Now, the name ramjet engine is given with a purpose: the purpose is that the word ram, essentially refers to the fact that certain amount of air compression by the ram effect is being used here and hence the entire compression that is needed prior to the combustion is effectively done by the ram effect, which we have studied in the course of our

turbo jet engine series, lecture series. So, the entire compression is done by the ram effect and it occurs in the intake of the engine.

And it produces significant raise in static pressure sufficient to allow the flow to go into the combustion chamber. Now, as we know in jet engines; we need to burn the fuel preferably in a high pressure and higher the pressure at which the fuel is bunt. Faster is going to be the burning process, more efficient is the burning process. Hence, this high pressure is created and then the fuel is injected into the airstream and allowed to go through the combustion process during which of course, heat is added through a working medium, which is again air and then this mixture of burnt fuel and air is a is essentially a gas now. This mixture of a burnt fuel and air, which is then expanded through a nozzle system to the atmospheric air, which is under atmospheric conditions and this expansion of course, creates the jet which helps us produce the final thrust. So, this is a in a simple way, how the ram jet is an expected to create a thrust for flying of aircraft.

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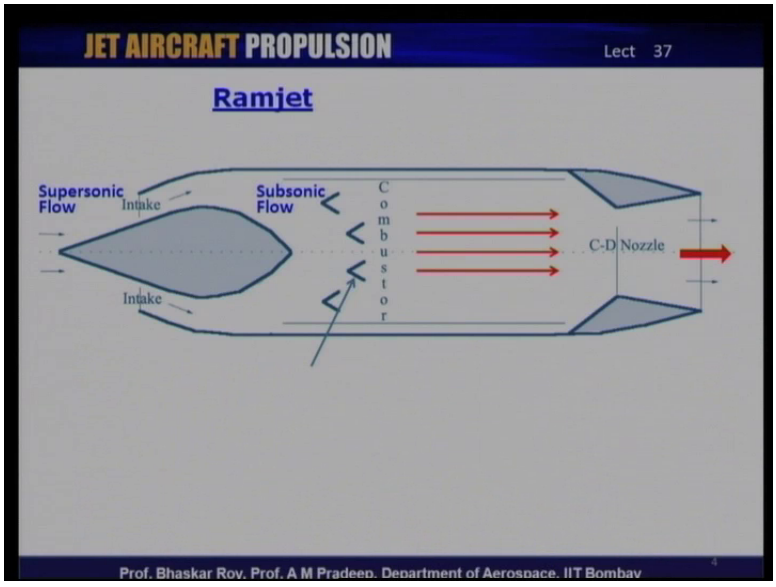

If you look at a very simple diagram of a ramjet, what it consists of is a flow coming into the engine and what we see here is that the expected flow is a supersonic flow. We shall see as; we go along and it is not it is probably appropriate to you. Now, state that a ramjet would be more useful under supersonic flight conditions and as a result of which what we have shown here that the flow is coming in with supersonic flow. However, the flow needs to be a decelerated or defuse substantially to a subsonic flow to effect the combustion process and

this combustion process is as we all know is essentially done with the help of certain flame holders, which are shown over here. This arrow shows a number of flame holders and then the combustion is a kind of held here in this zone under subsonic flow conditions.

And then the hot gas is a fed into the nozzle, which is often a convergent, divergent nozzle and then the hot jet goes out to create a jet thrust. So, this is in simple how the ramjet indeed operates. There are various facets by which the ramjet operation can be looked at. So, let us looks at: some of those various points which make the ramjet engine indeed operate.

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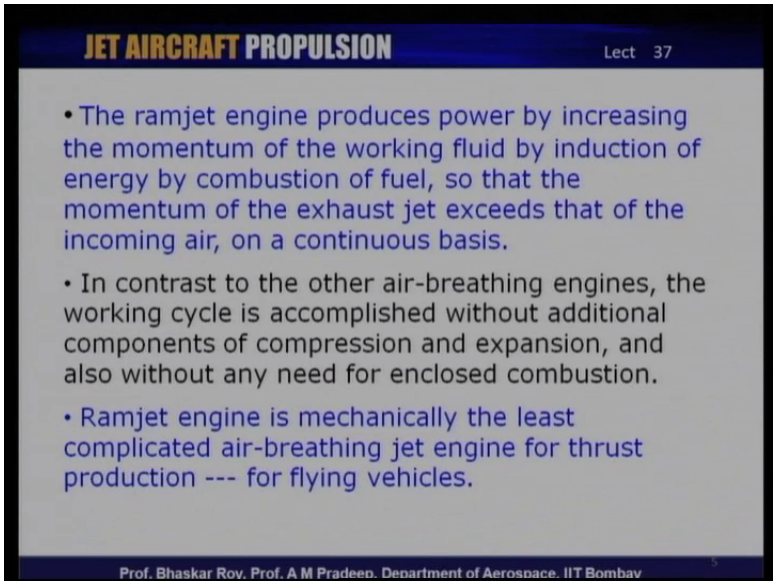

Ramjet engine like any other jet engine essentially produces a power or thrust by increasing the momentum of the working fluid; essentially by induction of energy by combustion of fuel. So, that the momentum of the exhaust jet, substantially exceeds that of the incoming air and this needs to be done on a continuous basis because of flying of an aircraft, you need to produce thrust on a continuous basis. Now, in contrast to the other kinds of air bearing engine that we have studied earlier. The working cycle or the working of the engine is accomplished without additional components of compression or expansion and that means there is no need for a compressor or a turbine in this kind of jet engine.

And it also does not require a kind of enclosed combustion, which we have seen in turbojet engines where you have can type or Can-annular type of combustion. Now, that kind of combustion is not required this combustion is entirely through the entire duck through, which the flow is flowing. It is not even annular; it is a full duct combustion process and this allows

the combustion process to be carried out over the entire duct of the ramjet engine. So, the entire process of compression expansion and combustion in ramjet engines are quite different from the other kind of turbojet or turbofan engines that we have done earlier. There is no compressor here; there is no turbine here. And the combustion process is done over the entire duct. So, it is neither can-annular nor annular and the entire duct chamber is essentially used for combustion. And thereafter as essentially a jet pipe before the entire flow is a released to the nozzle.

So, the ramjet engine essentially gets rid of a compressor turbine and all kinds of heavy combustion systems and hence one can say that ramjet engine is mechanically the least complicated air breathing engine for thrust production for flying of vehicles. Now, for aircraft thrust production we have gone through various versions of turbojet engine and turbofan engine. The ramjet engine, which is also a jet engine, is easily the least complicated of all kinds of air breathing engine remember. It is still an air breathing engine; it is still using air as a working medium and hence is its fundamentally still remains an air breathing jet engine for thrust production.

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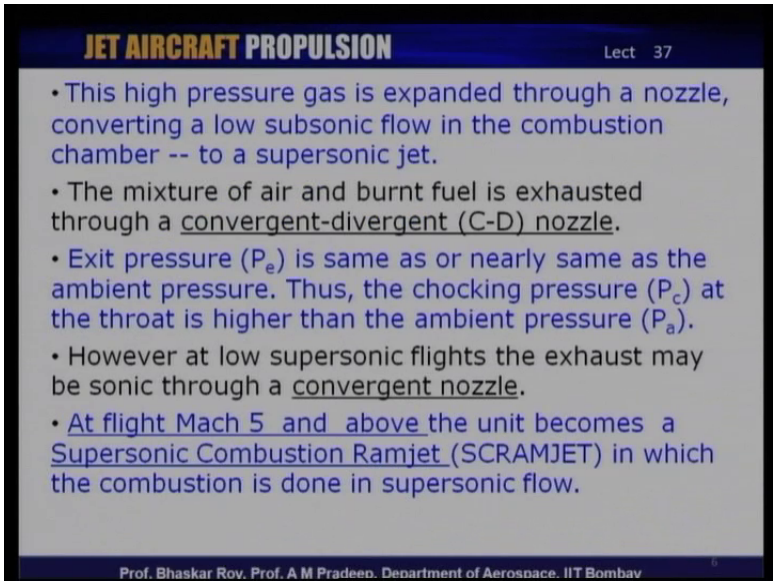

The high pressure grass which is been created through the combustion process the pressurization was done by the intake process and the combustion created the gas. Now, this high pressure, high temperature gas is now expanded through a nozzle, which essentially converts a low subsonic flow in the combustion chamber or coming from the combustion

chamber into a supersonic jet. The minimum jet speed at which it goes out is a sonic and most likely, it is going to be a supersonic. Then this mixture of air and burnt fuel that is the gas is normally exhausted through a convergent, divergent nozzles C-D nozzle. You have studied various kinds of nozzles in the nozzle chapter and the C-D nozzle. As, you remember is one of the kinds of nozzle, which allows the flow to be converted from subsonic to clear supersonic flow.

So, that is the kind of nozzle that is normally used in ramjet engines. they exit pressure at the exit face if the nozzle is likely to be of the same order as the ambient pressure of the atmospheric pressure and which means that somewhere in the nozzle in the C-D nozzle. The flow will be reached, which is ideally likely to be in the throat area and the chocking pressure, where wherever it is reached the sonic condition is reached is a somewhere near the throat. As, I mentioned is likely to be higher than the atmospheric pressure. So, the chocking pressure is quite often higher than the atmospheric pressure. However, at low supersonic flights, if the ramjet is been used for low supersonic flights.

The exhaust may be sonic, which means just sonic through a simple convergent nozzle, which is the simplest kind of ramjet engine one can think of using just a convergent nozzle. However, at Mach number very high Mach numbers at Mach number 5 and above the unit becomes essentially what is now known as supersonic combustion ramjet or scramjet in which the combustion itself has to be carried out in supersonic flow; that means, the flow in the combustion area deep inside the engine is still supersonic and the flow has not become sonic anywhere inside the jet engine. Now, that kind of an engine essentially referred to as scramjet engine and we will be studying scramjet engine in the course of this lectures.

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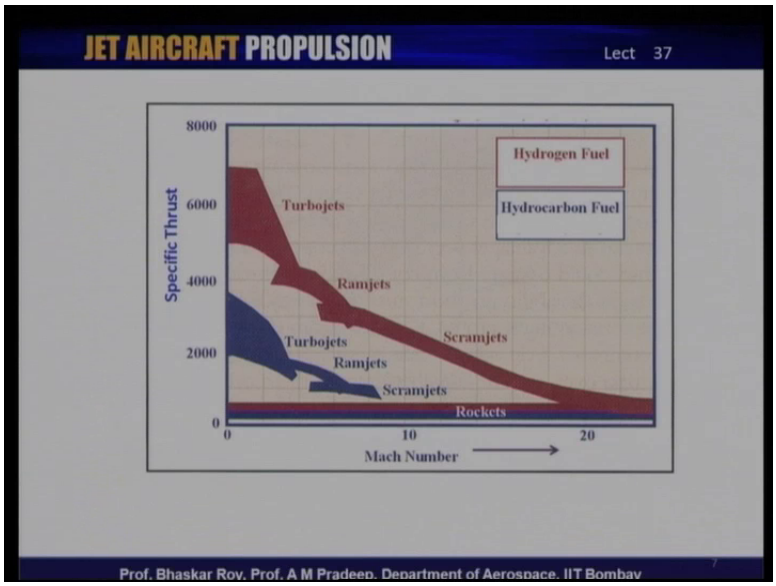

Let us take a look at: what are the certain advantages of a typical ramjet or for that matter scramjet engines for use on various kinds of aircraft. Now, as we see here; as we increase the Mach number of the flying aircraft, the typical specific thrust that is created by various kinds of jet engines, essentially show a characteristic. These characteristics are shown here with reference to two different kinds of fuel: One is the normal hydro carbon fuel that is used in all kinds of turbojet engines and the other is the hydrogen fuel which often uses hydrogen and liquid hydrogen and probably or preferably liquid oxygen. So, let us take a look at: these two kinds of fuels in case of an aircraft usage the hydrogen liquid, hydrogen will be used along with air which will essentially be the oxidizing element.

So, if we use a hydro carbon fuel the blue line here or the blue zone here shows that various kinds of turbojet engines once they are Mach number, the flight Mach number increases at flight Mach number of the order of 2.5 to 2.3 slowly their specific thrust creating capability goes down and somewhere over there the ramjets essentially, become more and more useful the turbojet thrust creating capability is going down. And the ramjet thrust creating capability is somewhat higher in the range of Mach number say from 3to 5 or 6. Above Mach number of 5 or 6 quite often you would find. scramjets essentially are more useful as the thrust creating capability of the ramjets are even lower at that kind of high very high flight Mach number and they start dipping below the scramjets and the scramjets become the better thrust creating engines at that kind of flight Mach number.

Of course, as we know if you go to flight Mach number of 10 or above you would probably need to use rockets to create a sufficient or good thrust for flying of vehicles. On the other hand, if you use a different kind of fuel that is hydrogen fuel, liquid hydrogen using air as the oxidizing element and still air as the working medium. what we see here, that is essentially a they do create more thrust but, as we know the turbojet engines normally have not been using hydrogen as a fuel, because hydrogen is essentially a very light element and hence to carry it around you need a lot of space or lot of volume in an aircraft.

So, typically a most of the aircraft as of today do not use hydrogen fuel as of now for creation of thrust. Even though, as we can see here their specific thrust creating capability is indeed a much higher again at higher Mach number at around Mach 3 or above the ramjets essentially starts showing better thrust creating capability then the turbojets, which are now going down and the ramjets hold forth from a about Mach 3 to Mach 0.5 during, which its thrust creating capability is the best amongst all kinds of jet engines.

Above, Mach 5 or 6 the scramjets essentially become the most efficient thrust creating engine and it can hold forth for creating thrust up to almost Mach 20. So, if one is using a hydrogen fuel and one uses scramjet engine that kind of an engine with hydrogen fuel would be very good thrust creating engine or a power plant for flight of vehicles up to Mach 20 so and that is where a many of the applications are being used today for scramjet engines that new aircraft which are coming up which are called a hypersonic aircraft these are the aircraft where scramjets engines are being deployed as thrust creating engines.

So, as we see here depending on: what kind of engine you have? ; What kind of aircraft you would like to make use of on which you like to put the power plant? And at what flight Mach number they would be flying for most of the cruse. These are the considerations, which decide what kind of engine you are going to use whether you are going to use a turbojet engine; whether you are going to use a ramjet engine or whether you would like to go far a scramjet engine also. As, we can see here the hydrogen which is a light element actually indeed creates a higher specific thrust that is thrust per unit mass flow and as a result of which they indeed are a better fuels. So, far for various aircraft applications they have not been used. So, far as I mentioned because they are very light and you need a lot of fuel tank spaced to carry them around.

However, for ramjets and scramjets which are for small duration flights hydrogen fuels are very competitive and it is quite possible that hydrogen fuels would be used but, as of now the experimental and other aircraft, which are being flown with ramjets and scramjets are still using the hydrocarbon fuels. One of the reasons is the chemical kinetic sub hydrogen hydrocarbon fuel is very well established over a more that last 50 years, whereas the hydrogen fuel even though it is a cleaner fuel a chemical kinetics is still a in the process of getting established apart from the fact that it is a very light fuel.

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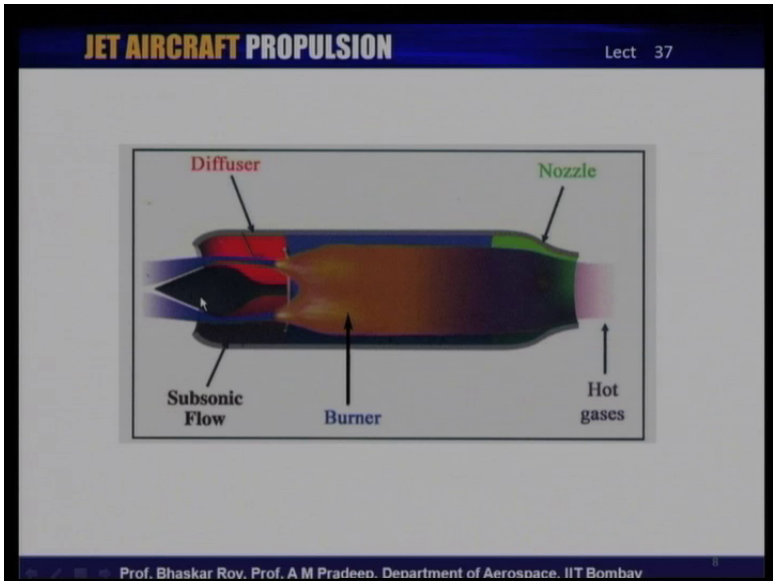

Let us take a look at a color picture of a what a ramjet would look like during its operation; it would typically have flow coming through the intake system which would typically have a spic like this central bullet, which will negotiate with the incoming flow; which is likely to be supersonic and then it undergoes supersonic diffusion and then subsonic diffusion and at the end of the diffusion process then we have the burner and through the burner the flow then is released through the nozzle in hot gasses for creation of thrust. So, this is another very simple with a little color explanation of what is likely to be happening in a typical ramjet engine.

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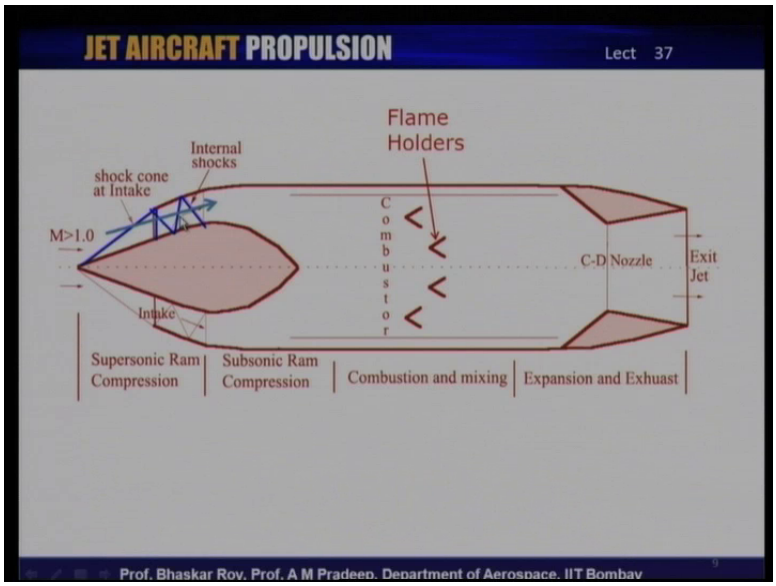

Let us take a diagrammatic schematic look at what is happening as I mentioned the flow comes through the intake system and the intake system would have a central bullet like this, which is a place they are essentially to negotiate the supersonic flow that is coming in now. As, you well know the supersonic flow the movement it hits a solid body and in this case the solid body has to have a very a sharp cone over. Here, a sharp nose which immediately creates a shock system now this shock system is what is known as the intake shock system and these parts of them are the internal shocks. It is possible that one of them would be anchored between the nose cone and the lip of the engine and the flow comes through these shocks.

In the process of flowing through the shocks, the flow gets diffused. Finally, through one normal shock the flow finally, becomes a subsonic flow and then the rest of the diffuser essentially is a subsonic diffusion process before it comes into the combustion zone, where as you can see the flame holders are placed there. And the flame holding process is similar to what we have done in the combustion chapter earlier that the flame needs to be stabilized and essentially to be held do to say in one place anchored in this place. So, that the combustion process is done under a controlled situation. Once this combustion is completed, the hot gas is then released to this nozzle, which as I mentioned.

Now, as sufficient pressure through this compression or ram compression process it has developed a sufficient pressure and it has now been infused with sufficient amount of

combustion or heat released. So, that at the face of the nozzle intake face of the nozzle it has very high pressure and very high temperature and with this high temperature pressure. When, it is released to the nozzle; it produces high velocity jet. So, the expansion and exhaust is normally through a C-D nozzle and as we have done before to have a C-D nozzle, you must have sufficient pressure and temperature to begin with to make full use of a C-D nozzle. So, this is how a ramjet engine actually operates, it has various components that intake, which needs to be designed very accurately for the particular flight Mach number at which it is likely to be flown; at which the aircraft is likely to be deployed and this would indeed a decide the shape and size of this central bullet cone.

The angle at which this nose cone is to be created will decide of course, the shock that is created and those shocks will decide essentially the rate of supersonic diffusion that takes place and of course, the final aerodynamic efficiency of this intake system. If the supersonic flow and the nose cone geometry are not in a consonance with each other; if they are not matched to each other, the shock system that will be created will be highly loss making shock system and as a result the intake efficiency very low and that will of course, indeed ha tell on the overall jet engine efficiency, the ramjet engine efficiency and the efficiency would be lower. So, we need to create an intake system which is uniquely designed for that particular flight Mach number at which this ramjet engine is likely to be flown with the aircraft.

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This is a the German V-2 Bomber in which ramjet engine was a utilized and as you can see here, it is a very simple aircraft in which the flow came in right from the nose and indeed this was not a supersonic aircraft; it was actually a subsonic aircraft.

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A more modern ramjet power supersonic aircraft which is being designed, shows that you do have this nose cone at the front or sharp nose cone, which essentially negotiate the supersonic flow the shape of the aircraft tells you that it is a blended body wing body aircraft which is typically designed for high Mach number; that means, the Mach number of this aircraft is likely to be above Mach 3 and hence the shape of the aircraft is typically a blended body shape and the ramjets which are a being shown here sort of a corresponds to the kind of ramjet that we have been discussing and at the back over here there is a weapon that is been deployed over here.

So, this is the kind of a ramjet power supersonic aircraft that people are thinking of where it will be flying somewhere around Mach 3 or Mach 4 over a certain distance and is most likely to be for military applications.

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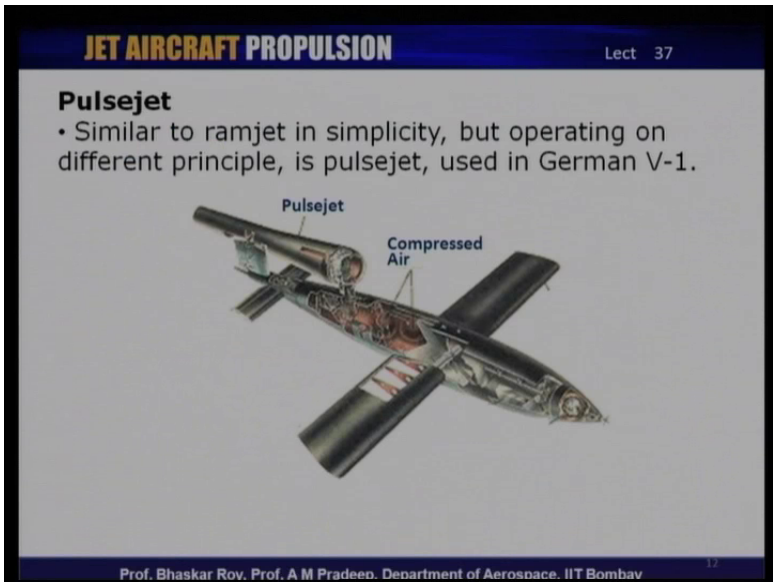

Let us take a look at what kind of pulsejets engines, which people have used before and how do they function. Now pulsejets, in a sense are similar to ramjet engine in simplicity in the sense there is again no compressor; there is no turbine and there is no enclosed combustion chamber. Again, we have a open combustion chamber and this kind of engine was used again by the Germans during world war you know V-2, V-1 aircraft, which use the pulsejet you can see here the pulsejet engine is a mounted over here and it uses compressed air source for initiating the engine, which we will discuss in a few minutes and this is the shape of the German V-1.

So, this is also has been use during the world war by the Germans and we shall see latter on what kind of use they are likely to be if they are to be used in a modern aircraft.

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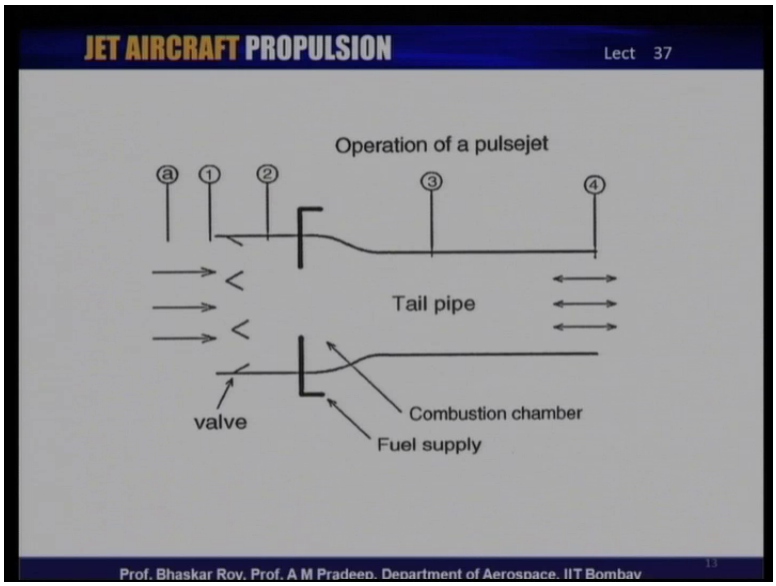

Let us take a look at how the pulsejet engines indeed operate. As I mentioned it is again a very simple kind of a jet engine, in so far as it is still a jet engine. It is using air as working medium. So, the air comes in from the front, and it goes through set of valves through which the air is allowed to come in intermediately not on a continuous basis. So, as the name suggest it operates in pulses, and the thrust is created in pulses. So, the air is allowed to come in to the jet engine intermediately, and once it is been allowed to enter soon thereafter, there is a chamber over here at which the air is a at a very low velocity or more or less still.

And when this valve closes this chamber essentially has a more or less still air in which the fuel is burnt and the combustion takes place. So, this is the combustion chamber which the combustion takes place more or less in still air. And then this combusted gas is released through the long tail pipe, and then released through a nozzle; there is indeed going to be a nozzle system over here for creating the jet.

So, the pulsejet engine operates under situations where the flow is allowed in intermediately at pluses and as we shall see as we go round that in the early days pulse is used to be of the order of 50 pulses per second. The modern pulse jet engines have been going much higher than that of the order of few hundred pluses are possible. There are mechanical imitations of creation of the pulses and this mechanical imitation of the pulses essentially is been pushed to higher limits over the modern pulse jet engine development. Some of these developments are being done in the modern era to bring the pulsejet engine to the modern aircraft flying

experience and as I mentioned the pulsejet was indeed used 60 years back during the world war.

So, these are the various kinds of development that are taking place. Let us take a look at: how this pulsejet engines actually function. The air is drawn into a system through which the through a set of valves. As, I mentioned and these valves operate intermediately and then fuel is sprayed into the combustion chamber now, the fuel spray we have done in the combustion chapter it tells you very clearly that the fuel spray to be atomized they have to evaporated they have to be mixed. So, al, that phenomenon or phenomena of combustion that we have studied in the combustion chamber chapter are indeed valid also for ramjets and pulsejet do the combustion would have to be carried out more or less the same way that we have done in the combustion chamber, combustion chapter earlier.

So, once the combustion occurs it is an enclosed chamber now unlike even ramjet. So, in that enclosed chamber, once the combustion occurs the pressure builds up. Now, normal thermodynamics will tell you that once you have increase of temperature in an enclosed space any volume of air or gas will also undergo change of or increase of pressure in a flowing fluid. In a ramjet or in turbojet engines that does not happen, because it is a continuously flowing fluid but, in a pulse jet engine what has been done is something very similar to that is done in piston engine. That the air is captured in a volume and in this volume the fuel is sprayed and the fuel spray is allowed to burn and the combustion takes place and in the process not only the temperature, but the pressure also goes up.

So, the process of increase of temperature and pressure now occur in an enclosed volume and essentially it is more or less like a mini explosion and during this process as I mentioned the pressure goes to a very high volume values. Now, this high pressure high temperature gas can be released through the jet pipe and through the nozzle to create your thrust. So, one can see here that slight details of the operation of the pulsejet are different from that of the ramjet. Now, one of the major different that comes out is that of creation of thrust. You are not using flowing fluid which means that a pulsejet engine can help an aircraft to take off from ground, which a ramjet engine cannot.

A ramjet engine works on ram effect now once you need to create a ram effect it is necessary that you have a certain velocity of the flow coming into the intake which create sufficient ram effect or pressurization and as we know higher the pressurization better is the combustion. Of

course, indeed better is the jet creation. In a pulsejet there is no ram effect that it is not necessary to have a ram compression for creation of pulse jet thrust. The flows allowed coming into the combustion chamber and then effectively it is entrapped in the volume of the combustion chamber by closing the valves. Once the valves are closed there is no way air is going to go back anywhere and hence you have a entrapped air and the combustion is carried out into this captive air volume inside the combustion chamber.

This allows that the engine can be used on an aircraft even for takeoff, because during takeoff as you know the ram effect would be very small. Hence, typically a ramjet engine cannot be used for taking of a when it is mounted on an air craft. Now, this is a problem with a ramjet engine that it is a very poor engine for aircraft takeoff. this problem is solved if you are using a pulsejet, which can be used for takeoff purposes but on the other hand the problem is that pulsejet engine may not be a very good engine when one once to use it for high Mach number flights. Because the flow indeed would be coming into the valves at very high pressure at very high flight Mach number there would be some kind of a ram effect and then the operation of the valve would become mechanically a more and more difficult as the pressure in front of the valve is going to be higher and higher, operating the valve in a certain controlled manner would indeed become more and more difficult.

So, as we can see now the pulsejet engine is more useful under low flight Mach number conditions where as ramjet engine is typically more useful under high flight Mach number conditions. Typically at flight Mach number which are supersonic and as we have seen they are actually competitive at high Mach numbers above Mach 3, where the pulsejet engines are useful at low Mach numbers where they can be deployed for creation of jet thrust.

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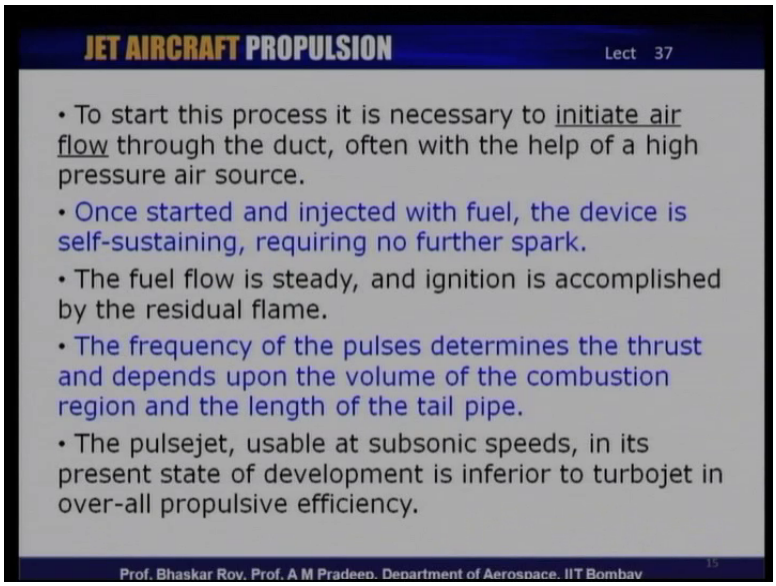

So, let us take a look at a little more details about how the pulse jet engines operate. To start the pulsejet engine, it is necessary to initiate air flow through the duct often with the help of a high pressure air source. Now, this is what is necessary to be done, because the pulsejet engine does not come in with a ram effect. It does not come in with a high pressure and to initiate the flow through the duct; it is often necessary to create a flow, because there is no flow to begin with.

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Let us take a quick look at: how the pulse jet you know the flow here is entrapped there is no flow and to initiate the flow from the combustion chamber from high pressure; high temperature zone through the tail pipe; through the nozzle; through the hand out to the jet requires a flow to be established.

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That is why in the German V-1 engine or V-1 an aircraft we see here a compressed air source which is carried inside the aircraft and this compressed air is then supplied into the jet engine and fed into the pulsejet engine behind the valves to initiate the flow.

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So, pulse jet engine requires that airflow supply high pressure airflow supply for in initiation of the flow. So, that is one of the needs it does not need a compressor nut it does not have a ram effect something else is required in terms of a high pressure air source to establish or initiate the airflow once it is initiated it can be sustained on its own but, the initiation requires a compressed air source. Now, once it is started and injected with a fuel the entire device is essentially self sustaining, you do not need the compressed airflow air source on a continuous basis and there is no need for sparking of the fuel also on a regular basis like it is done in piston engines; like all other jet engine that we have studied earlier. The flame is continuous and self sustaining it does not need a sparking or a initiation or ignition again and again.

So, the fuel flow if it is held steady, the ignition is a continuous and is accomplished by the flame which sustains itself on a continuous basis. The frequency of the pulse is determines the thrust or the average thrust that is created by the engine and essentially depends upon the volume of the combustion region and the length of the jet tail pipe.

So, the volume of the combustion chamber has to be calculated and designed and built accordingly to the amount of thrust that needs to be created. Now, pulsejet essentially as I mentioned useable at subsonic speeds essentially is a not a very fuel efficient device and a not really in terms of efficiency competitive to the various kinds of turbojet engines or turbofan engines that we have studied. Hence, essentially there is no thought of using pulsejet engines for regular powering of aircraft, because they are not really a fuel efficient in terms of their usage.

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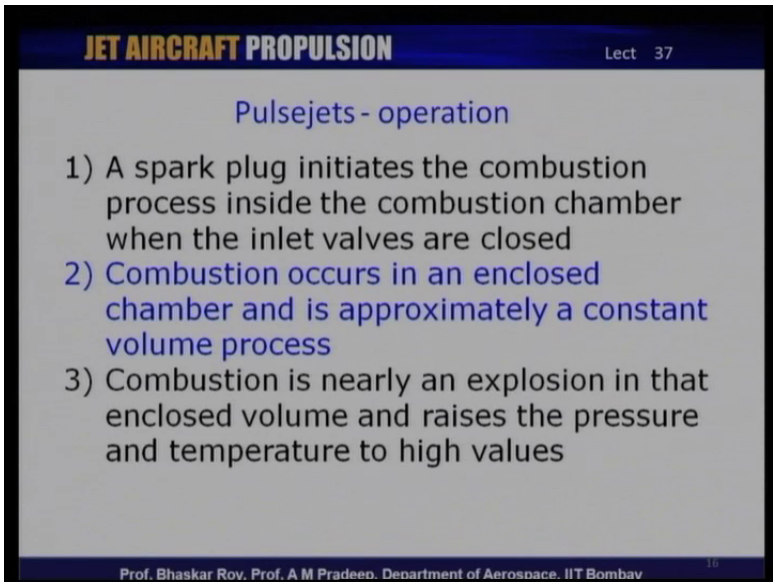

Let us take a look at: the steps by which pulsejet engine is indeed operated you need a spark plug to initiate the combustion process once the valve is closed. So, there has to be synchronization between the closer of the valve and the initiation of the spark plug this needs to be done in a synchronous manner right in the beginning of the initiation of the engine. The combustion occurs in an enclosed chamber and is approximately a constant volume process now this is in contrast to the fact that in all other jet engines including ramjet engines the combustion is in a constant pressure process. So, in a flowing fluid the combustion is essentially a designed and carried out in a constant pressure process.

So, the thermodynamic process that is deployed there is constant pressure in pulsejet it is back to constant volume which is what the piston engines often use the icy engines use for hundred years now. Now, the combustion phenomenon as I was trying to explain a little while earlier is essentially a nearly an explosion in the sense that the volume in the enclosed volume it raises the pressure and temperature to very high volumes since it is an enclosed volume as soon as the temperature is raised as per the gas loss the pressure would immediately be raised to high values one needs to make a calculation of what are the values they would be indeed attaining and as a result as a consequence of that the jet would be created.

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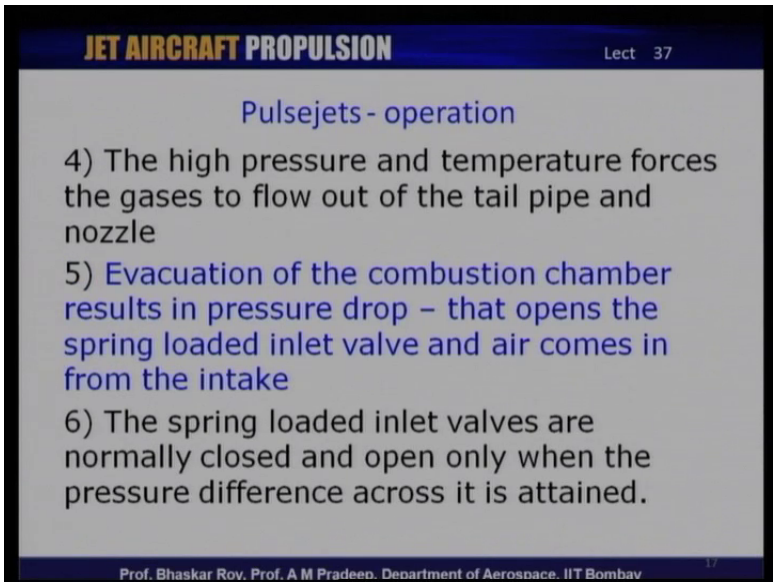

The high pressure and temperature then forces the flow through the gas to the tail pipe and the nozzle and as I mentioned before this needs to be initiated in the right in the beginning with the help of compressed air source. in case the pulse jet, goes out of operation or for some reason gets extinguished during flight it can be started all over again but, you need the compressed air source all over again to initiate the process of the flow through the pulsejet engines without which this flow may not be established through the tail pipe and through the nozzle.

So, this compressed air source, which you have, is a required essentially to initiate the flow but, it is required essentially to reinitiate. In case the pulsejet engine gets extinguished for some reason or the other. The evacuation of the combustion chamber results in a pressure drop as we can well imagine that the indeed as soon as the pressure is dropped it opens up the spring loaded valves the valves which I mentioned and showed earlier a spring loaded they open up which means as soon as the pressure across the valves drop below a certain value the valves open up. It allows the air to come in and fill up the combustion chamber all over again.

So, this is the process that is going on intermediately in pulses and that is what creating the pulsejet the spring loaded valves are normally closed and opened only when the pressure difference is attained. This pressure difference and the opening and the closing of the spring loaded valve has to be accurately determined by calculation and hence this is a tie up between aero thermodynamic calculation and the mechanical design of the spring loaded valves that

needs to be done extremely accurately for the pulsejet engine to be operated in a continuous basis for creation of thrust.

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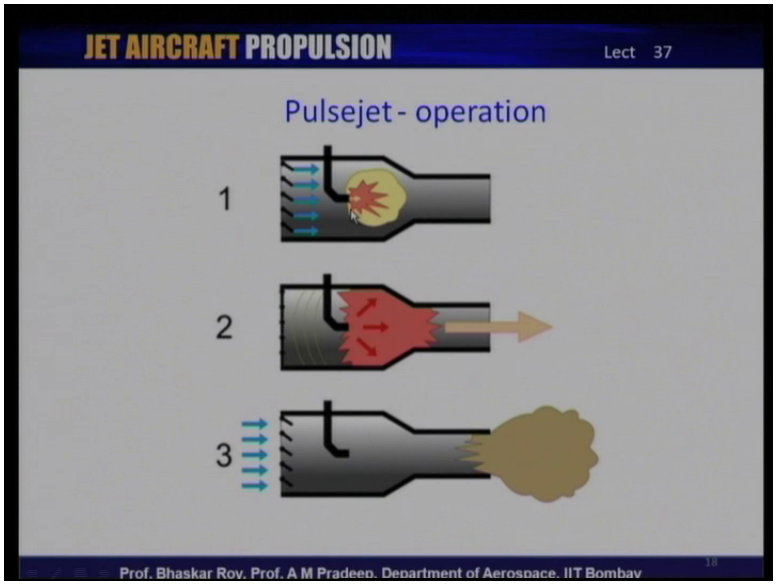

Let us take a look at a picture of how the pulsejet engines indeed operate the flow comes in through the valves. It goes into the combustion chamber combustion is a initiated and hence as we mentioned a small, a mini explosion occurs increase in temperature pressure, then this hot jet gas is a release through a tail pipe and it comes out as a jet through the nozzle. As soon as this gas has been released from the combustion chamber the pressure here falls; as soon as the pressure falls these valves open and the fresh air comes in again. So, this is the cycle by which the pulsejet indeed operate continuous or intermediate rather exit of the hot jet and entry of the cold air; coming in from the front.

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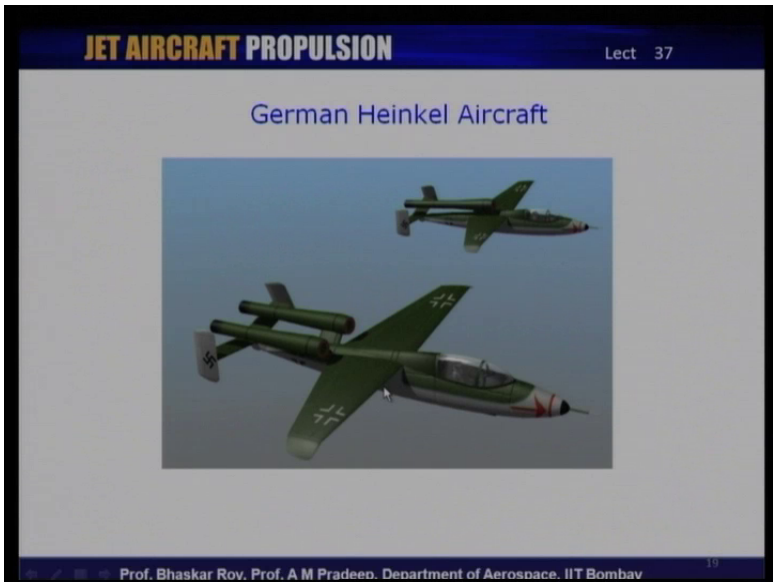

This is the kind of a German Heinkel aircraft, which use the pulse jet engine during the world war. They used it quite successfully for flying of the aircraft it was indeed a very successful a deployment of pulsejet engine for an aircraft flight.

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This is a modern pulsejet powered aircraft more of an artists impression rather than a real aircraft flying. As you can see here it is a modern aircraft which is a likely to go subsonic or even supersonic and as you can see here it is an it is indeed a military aircraft. In which the

pulsejets; two pulsejets are deployed on the top of the aircraft and they are powering this aircraft which has a front mini wing and the enlarge wing with all kinds of control surfaces.

So, this is a possible pulsejet application of a pulsejet engines in modern aircraft likely to be military application. So, we have gone through various kinds of pulsejets and ramjets and have seen that they can be used an in modern aircraft, if we want to most likely they are likely to be used in military applications for certain military kind of aircraft whereas, as one can well imagine the pulsejet engines and the ramjet engines are much lighter. They are much lighter than the various versions of turbojets or turbofan that we have studied there is no compressor, there is not turbine, there is no heavy combustion chamber either. So it is so much lighter and that itself is a very attraction preposition even if their fuel efficiency is much lower than that of the various kinds of turbojets under turbofans that we have seen.

So, the lightness of the engines make them extremely attractive preposition for some of the modern aircraft usages, and that is what some of the people are thinking that they could be used for modern military aircraft applications, special aircraft applications. We have an a quite seen the applications as yet or it is possible that with improved design some of those applications can be seen in near future. We will continue with are discussion on ramjets, and we shall latter on go into discussion with reference to scramjets over the next few lectures. So, we will continue our discussion on ramjets, and then scramjets over the few next few lectures series.