Jet Aircraft Propulsion

Prof. Bhaskar Roy
Prof. A. M. Pradeep
Department of Aerospace Engineering
Indian Institute of Technology, Bombay

Lecture No. # 27
Intakes for Power plant: Transport/Military Aircraft

Hello and welcome to lecture number twenty seven of this lecture series on jet aircraft propulsion. So, in this lecture series we have been discussing about the different components that constitute a jet aircraft engine. We have also discussed initially about some of the cycles that constitute or based on which jet aircraft engines operate. We have discussed about both the real ideal cycles as well as the real cycles. We have also discussed in detail about how we can take into account the performance of different components which constitute a jet engine.

Of course, during the time when we were discussing about the cycles we assume that these components are black boxes in the sense that we were not really concerned about what was happening within these different components. We were just calculating efficiencies, and pressure losses as the flow passes through these components. Then subsequently we have started a discussion on individual components of the jet engines. We have already discussed about the compressors, and the turbines. We have discussed about axial flow compressors and centrifugal compressors, we have also discussed about axial and radial turbines, and subsequently on combustion chambers.

Now, we are going to discuss about a few other components, which constitute the jet engine. One of the important components that will constitute any jet engine is an air intake. So, in todays lecture we are going to start some discussion on air intakes. We will have a preliminary discussion on the different types of air intakes that are used in different types of engines. And in the next lecture, which will be the next lecture that is lecture twenty eight we shall discuss the performance parameters which are associated with these air intakes.

So, today we will discuss about different types of air intakes. Air intakes used for civil aircraft as well as for military aircraft, and as we will see very soon that the air intakes can be quite different depending upon what type of engine it is to be used for. And in civil aircraft, the air intakes are usually simpler in terms of their configuration and design and geometry, whereas as the engine becomes more complicated in the sense that if it is used for a military aircraft, a combat aircraft engine would need an air intake which is little more complicated than what is used in a normal civil aircraft engine.

And so we will see some of these geometries and different types of air intakes, which are used in different applications and then subsequently we will also discuss about how we can assist the performance of the air intakes and what are the performance penalties associated with the flow through an air intake especially when it comes to a supersonic intake there are different components of losses like shock losses, besides the viscous flow losses itself. So some of these performance related issues we shall take up what is called discussion in the next class. Todays class we will just have an over view of different types of air intakes and how we can classify air intakes depending upon their application itself.

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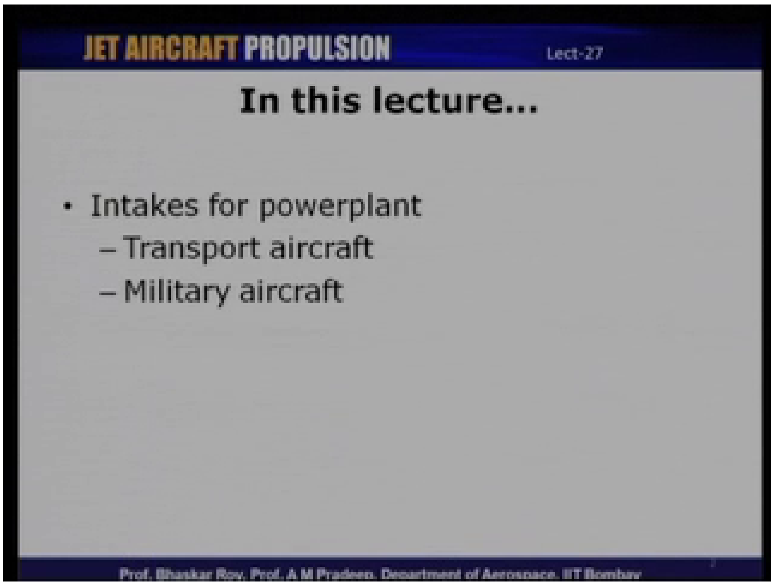

So, today’s lecture we will be primarily discussion on intakes for transport as well as for military application.

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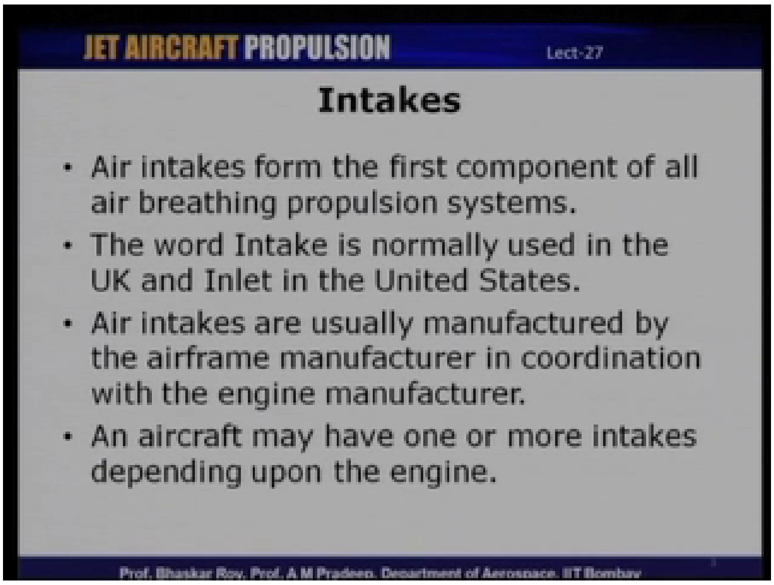

Now air intakes are probably well in fact, they are the first component that constitutes an aircraft engine as it is so aircraft engines will always begin with an air intake. Of course, the engine manufacture normally does not make the air intake itself it is usually something which the air frame manufacturer would be responsible for but of course, that will require that the engine manufacture and the air frame manufacture coordinate in the design process of the air intake. Now, this word intake is something which is usually used in the United Kingdom and in the United States it is usually referred to as inlet, they both mean the same just that they are referred to in different ways in different country.

So, intakes are some something used in UK and we will go to follow that in todays lecture as well. So, as I mentioned intake manufacturing is something which is normally taken up by the air frame manufacture the engine manufacture just supplies the engine. But of course, since the air intakes are an integral component of the engine as a whole the design and development of intake would require coordination between the engine manufacturer and the air frame manufacturer.

And so the type of intake to be used or a particular application is very much dependent or is a strong function of the application itself like if an engine is to be used in a civil aircraft as compared to what is used in military aircraft, the type of air intake would be entirely different and it is also possible that an aircraft can have multiple intakes, which something you might have observed that. Most of the transport aircraft would have multiple engines and each engine has its own intake.

In a military aircraft on the other hand the engine is not something that you can visually see from outside its usually concealed within the fuse large and there are certain types of aircraft where you have multiple inlets which are feeding into the same engine. There is one engine which is fed by a multiple intakes or you may have multiple engines which are individually fed by multiple intakes and so on. So, depending upon the type of application you might have different types of intakes, which are used in different applications.

Now what is the purpose of an air intake? The basic function of an air intake is that it is a medium or it is a duct, which basically connects the engine to the freeze stream in some way or the other. An aircraft engine as we know requires it is an air breathing engine. So, it requires air for its operation and this air is supplied to the engine through the air intake. So, air intake is basically device, which delivers the necessary quantity of air to the engine and that is not all about it.

It is also required to supply this amount of air in uniform manner in the sense that air intake also needs to provide quantity of air to the engine at the same time it also has to ensure that the quality of air, which enters the engine in terms of the flow uniformity is good that is air intake has to satisfy these two criteria and it also needs to ensure that this much amount of mass flow the required mass flow for the engine is supplied under all the operating conditions. So, an aircraft engine will operate under very extreme condition in like from takeoff where it is at very low altitude and density is very high to its cruise altitude, which is at an altitude typically around eleven kilo meters are going higher than that where the density is very low.

So, under these extreme operating conditions air intakes should still ensure that the amount of mass flow that is required for the engine operation. So, that the engine can generate the required a requisite thrust is provided at all times and that makes design of air intakes quite a challenging task especially for military aircraft where the range of operation is even more especially if it is a combat aircraft where it has to undergo very severe maneuvers and operate and sometimes even operating supersonic mach numbers if it is a supersonic aircraft. So, under these conditions for examples a supersonic intake has to not only operate in the subsonic airflow is also has to operate in supersonic mode.

So design of such intakes can be quite challenging whereas a civil aircraft on the other hand the operation is fairly limited in the sense that we know let us going to takeoff climb and reach a certain altitude and eventually it could land back to the sea level altitude and so. So the range of operation or the flight regime is quite fixed there unlike a military aircraft where it could operate under much more adverse conditions, which makes the design of supersonic intake or even a military intake little more complicated than a normal civil aircraft intake and so we will see some of these designs of different types of intakes, which have been used and which are correctly in use in many of the aircraft during the course of todays lecture.

So, air intakes will of course primary function as I mentioned this is used to capture free stream air and the in some cases also change the direction, which I will explain shortly that in some cases the intakes are curved and because the engine is located at different axial location and therefore it has to turn the flow change the direction and then supply that to the engine. But this must be with as little flow distortion or non uniformity as possible. We will quantify flow distortion in the next class how we can measure and put a number to flow distortion in the next class and the intakes also because intakes are located out of the fuse large in the case of transport aircraft and there are housed within what is known as nacelle in the engine located in nacelle.

And so the intake outer surface must also not result in excessive external drag, which again point which in will explain shortly and the most important aspect is that intake must ensure proper operation or it must supply the required mass flow rate over the entire flight regime and in some of the modern aircraft engines intake they also have noise absorbing materials to shield the engine noise from reaching the fuse large and especially in transport aircraft some of the nacelle that house the engine and that is also where the intake is molded contains noise absorbing materials, which can partially shield the engine noise from reaching the fuse large from reaching the cabin and so that is another function of course, that is not a really a function of the intake as such, but it is part of the nacelle which houses the engine and that will performs a part of the intake.

So I mentioned that the basic function of an intake is to direct air or it is suppose to capture air from free stream and deliver that air to the engine depending upon the requirements of engine that is as the pilot changes the throttle the engine would be generating different thrust depending upon the throttle settings. So, depending upon how the engine requires or what throttle settings it is to be operating under the intake is required to provide that much amount of mass flow rate to the engine, which means that if an aircraft engine has a lot of variation in its operation like a combat aircraft a normal intake which has fixed geometry may not really suffice you may require that the engine the intake geometry also needs to be variable.

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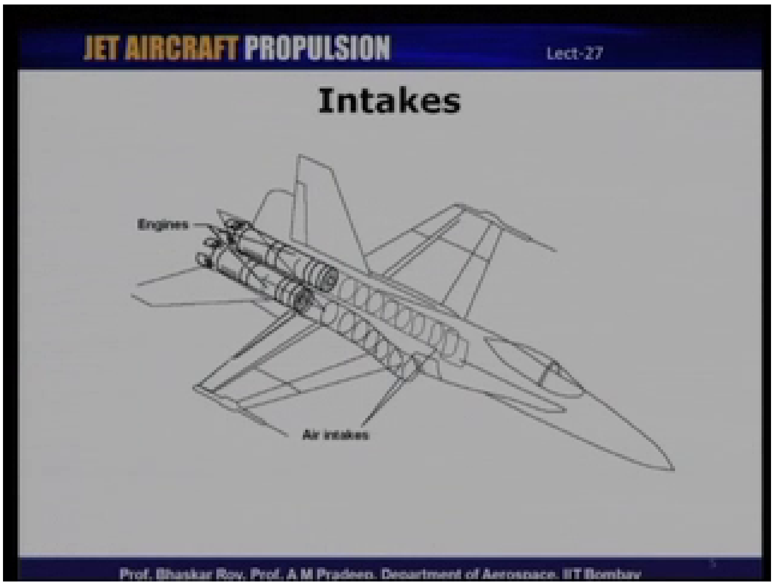

But most of the civil aircraft engines have geometries which are fixed intake geometries, which are fixed and do not change. Unless it is of course under special circumstances like in a high bypass, turbo fan there could be an intake duct which goes into the bypass duct, but that is many of the aircraft usually operate with fixed air intake geometry. But in military aircraft on the other hand or as supersonic intake for example, would usually have a variable geometry intake to ensure that this intake can operate safely under subsonic conditions as well as under supersonic conditions. And so that will necessaries that the intake has a certain variable geometry features in cooperated in its design.

So, I will show you some typical examples of air intake geometries which are which have been used and which are currently used in some of the civil as well as military aircraft engines. So, what I have here is a typical military aircraft fighter aircraft here and in this configuration that I have shown it is an aircraft which has two engines. So, these are the two engines that you can see and so immediately you can see that this configuration is very different from civil aircraft or a transport aircraft where the engines are usually exposed and you would see the engines beneath their wings usually mounted beneath their wings.

Military aircraft that is or a combat aircraft that is not the case engines are usually mounted within the fuse large. So, in this particular configuration we have two engines we also have two individual intakes or ducts which supply the air to the engines. In this case you can clearly see that the engine is located far down stream towards the tail of the aircraft it is in most of the military aircraft and the intake is supplying air from the sides of the fuse large in this particular configuration and it is delivering that air to the engine.

So, you can see that the intake duct is a curve duct in this case and this curvature also leads to additional complexities which we will discuss in the next class and so this is one configuration of an engine where in the intake the two intakes on either side of the fuse large and delivering mass flow rate to the two respective engines that would also be configurations where there is only one engine in which case these two intakes would merge and form a single duct before it enters into the engine.

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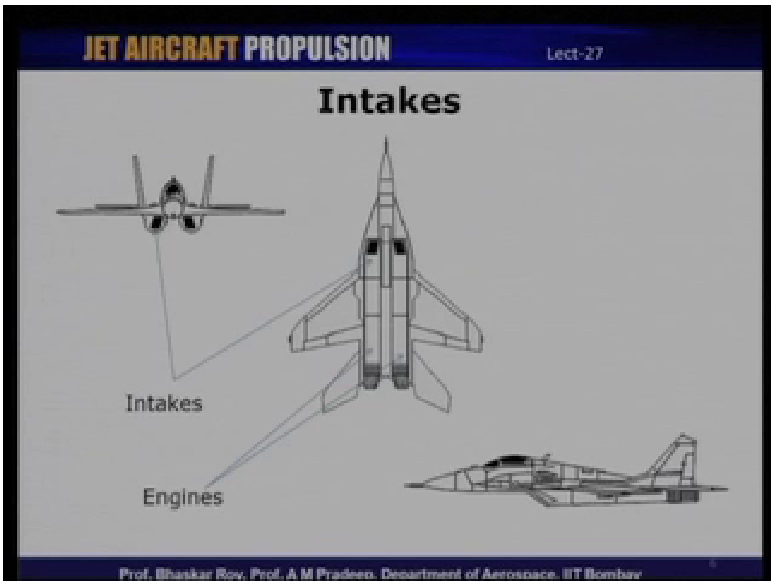

Now this is another configuration of again a military aircraft engine where in the intakes are located in a different location as compared to what it was in the previous slide. In this case previous case you can see that the on a takes are located on this slides and the engine is mounted towards the tail of the aircraft. In this case also the engines are located towards the tail but it is mounted on the underneath the aircraft fuse large and the intakes are in this case is not curved. So, the advantage of this intake that this intake has it is that it does not require any curvature as compared to the previous one. There is a straight intake in which delivers the required air to engines.

You can also see that the intakes can have different cross sectional areas. So, in this previous case the cross sectional area at the inlet was doughnut semi doughnut a kind of shape here where as in this case it is rectangular entry intake geometry at the inlet. But whatever be the inlet geometry at the engine phase at the compressor inlet the geometry has to be transitioned into a circular geometry. Because the compressor requires a circular duct and therefore, the inlet geometry is eventually converted to a circular geometry before it enters the engine phase.

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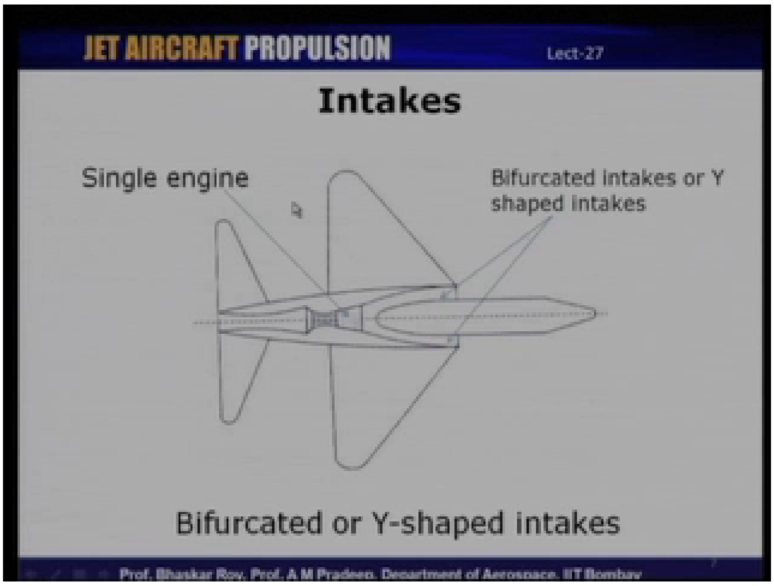

So, depending upon the application let us say I mention in that you could also have an application where there is only a single engine, which is what the case here is. There is a single engine and you have two ducts from either sides of the fuse large these are the two ducts from the sides of the fuse large which eventually merge before the duct joins the engine. So, these types of intakes are also refer to as Y shaped intakes, because there are two ducts which merge and forma a single intake. The first example I showed here are where in you have a single duct a feeding into a single engine or sometimes referred to as S shaped intakes because of its similarity to the letter S.

So, these are usually referred to as S shaped intakes these are straight intakes and these are usually referred to as Y shaped or bifurcated intakes. Now, these are intakes which are probably quite different from what you would have normally seen in a civil aircraft. In a civil aircraft the intakes are much more simpler and they are very short intakes and we will see some examples of civil intakes also little later and if you notice in when you when your problem boarding aircraft next time, we can notice that the engine is quite visible as you the at least the fan, which is the first component that you could see a of the engine is quite visible as you see from the engine from the front.

So, the duct which is just ahead of a fan or the compressor is the air intake and which is quite unlike and military aircraft that you would rarely see an engine phase when you look at the aircraft from the front and that is intentional and I will probably explain some of those details either in todays class or the next class. So, in military aircraft it is the engine faces is intentionally kept shielded from line of sight for this reasons that it has to be it has to have a lower radar cross section that is compressor phase or a engine phase, if it is exposed the radar cross section of the engine would be quite high.

Because it will reflect the radar the incoming radar signals in it will be reflected in different directions increasing the radar cross section. So, shielding the engine is one of the objectives of a military aircraft, which is not there for a civil aircraft or a transport aircraft which is why the engines it does not matter if the engines are really exposed plus the fact that in transport aircraft one would normally use a large bypass turbo fan and therefore it definitely needs that kind of mass flow, which is not possible if the engine were to be shielded and there are of course, other lot of other reasons why you cannot have an engine within a fuse large transport aircraft.

Now some of the modern military aircraft engines if you if you were to try and look at some of the geometries associated with modern combat aircraft the engines are very well shielded within the fuse large and it is the duct that you would able to see which is basically the air intake which delivers the required mass flow rate. Now in an attempt to increase or reduce the radar cross section even further some of the next generation military aircraft would most slightly have intakes, which are much more complicated than what the current generation aircraft would have and these are primarily meant to reduce the radar cross section even further, which would require that the air intake has a very complex geometry and often these geometries are known as serpentine ducts or serpentine intakes.

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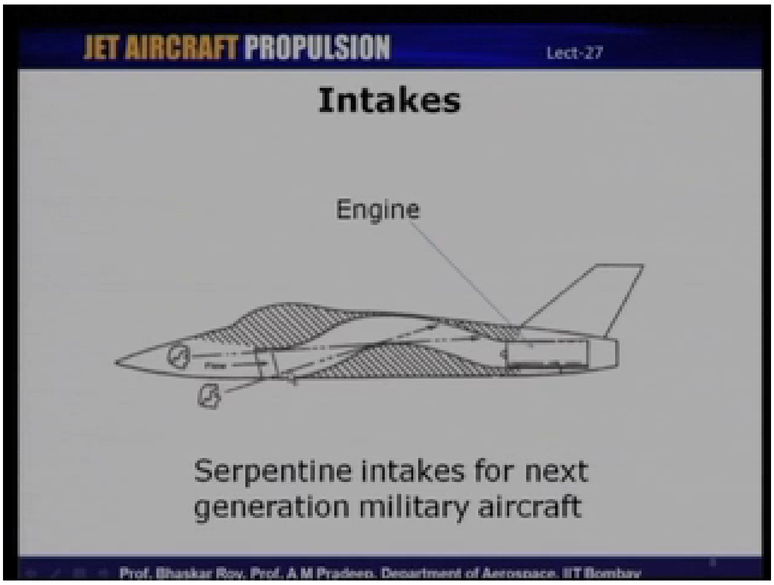

So, one such example is shown here in this schematic that I have shown probably what would see few years from now in the next generation military aircraft where the engine is of course, very well shielded within the fuse large and to reduce the radar cross section prevent any line of sight to the engine, one need to have an air intake, which probably has a very high curvature as compared to what I had shown earlier for the Y duct or the S duct. So, these are known as serpentine intakes and because of the various shape they have and it is a naturally expected that such intakes will suffer heavily from flow non uniformities by the time the flow reaches the engine.

So, currently there are lot of research studies is going on in trying to analyze this kind of geometries and try to improve these the flow through these ducts. So, that the engine phase receives a fairly uniform in flow. So, on what I have shown now have been showing all these pictures are with reference to military aircraft and I am assuming that already seen some civil aircraft intakes. I will also show you some pictures of civil aircraft intakes. But the very fact is that we the intake of normal transport aircraft is much simpler as compared to a supersonic or combat aircraft intake.

So, intakes that are used in transport aircraft normally do not have such curvatures like in the S shaped or Y shaped or the serpentine ducts. They are usually be straight and axis symmetric and circular; that means, there are no change of cross sectional area from the inlet from the entry of the inlet to the compressor fails and which is unlike a military aircraft that normally there would be a change of cross sectional and area and the geometry itself it could be rectangular or doughnut shape at the entry eventually becoming circular at the compressor phase.

So, some of the differences between military and civil aircraft intakes are primarily because of the nature of operation of these engines themselves. For example a subsonic intake would also be different from supersonic intake and that is also something we will discuss little later.

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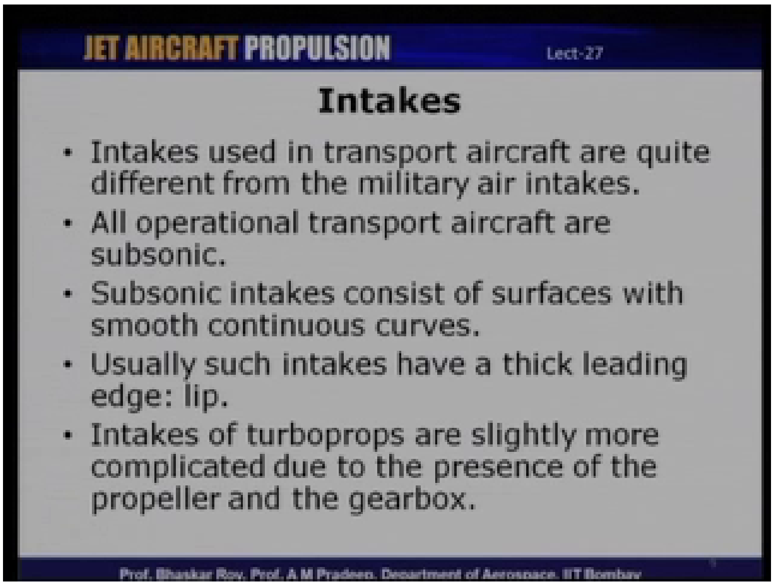

Even in a civil aircraft, the other form of civil aircraft would be the turbo prop intakes of turbo props are little more complicated than the normal turbo fan intakes. So, in since most of the transport in fact all the transport aircraft a civil aircraft that we know as of today which are operational or subsonic the intakes of most of these in aircraft are very similar in terms of their geometry and they all usually consists of smooth continuous curves which is unlike supersonic intake where you could have sharp edges.

Because of the fact that supersonic intake decelerate the supersonic flow to subsonic through shocks and that is created using certain sharp edges in the intake and in subsonic intakes usually have a thick leading edge, which is known as the lip of the intake which is obviously not something that is feasible to be used in supersonic flow. Because thick leading edge can lead to the presence of a strong oblique shock or a bore shock at the head of the intake, which is not something that would be beneficial for the engine itself.

So, subsonic aircraft in intakes will obviously have a thick leading edge and in the case of turbo props the intake can be slightly more complicated. Because there is a popular and also a gear box ahead of the compressor and therefore, that makes the geometry slightly more complicated.

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So, the difference between the intakes used for civil aircraft and the military aircraft would be clear from the slide here. So, this shows a typical transport aircraft and so these are the intakes that you can see here what you see at the center is the hub of the fan. So, this part of the intake is of the engine is known is basically the intake of this particular aircraft and what you see here is the lip of the intake, which is a very thick leading edge of the intake and the entire engine is housed within what is known as nacelle. So, this is known as the nacelle of the engine that the basically the core engine is mounted within the nacelle and intakes from one part or the initial part of the nacelle itself.

So, this is the intake of civil or a transport aircraft on the other hand this is typical intake of combat aircraft and we can see that it is rectangular the two of them on either sides or the engine is mounted inside the fuse large you cannot see the engine besides the nozzle. So, probably you could be able to see the nozzle of the military engine but not the core engine as this as such. And so, that difference between this engine and this intake and the military intake is quite visible here. So, in transport aircraft the intakes are much shorter and the geometry the cross sectional changes are also quite simpler as compared to military aircraft where there could be drastic change in crosses sectional geometry itself.

In this case for example, the even ultimately it has to be circular. So, this rectangular geometry has to be slowly transient and made circular by the time it reaches the engine phase. So, because of these differences between the intakes used in subsonic flow that is subsonic intakes and supersonic intakes we will have a detailed discussion on subsonic intakes and also on supersonic intakes. So, today we will take a look at whatever different types of subsonic intakes that are possible and what are the different types of supersonic intakes that are in existence.

So, subsonic intakes are as I mentioned usually axis symmetric and the most common type of subsonic intake that are used are known as pitot type of intake. Pitot intakes are most common types of subsonic there are also used in supersonic flow but there are very rare, but commonly used in subsonic flows. So, pitot intakes are the simplest form of air intakes possible and there is axis symmetric usually axis symmetric in nature and again the different types of pitot intakes which we shall take look at. So, most of these pitot intakes are that those which are used for subsonic flows have fixed geometries so do not really have any provision for varying the intake geometry while operation in while in operation.

So, fix geometry intakes and except in some cases like in certain types of high bypass turbo fans where they have what are known as blow in doors, which are used in during certain modes of operation of the engine. But normally intakes are fixed geometry and the so in the case of subsonic intakes which are let us say use in turbo fans, which requires certain amount of variability in cooperated in them. This variable variation is required especially when the aircraft is taking of when it requires the maximum thrust which means it also lead and requires large amounts of mass flow rate as compared to when the aircraft is cruising when the thrust requirement is not that height.

So, under certain circumstances the engine might require additional mass flow and that is when the intakes may have a blow in door in which supplies little amount of additional mass flow to the bypass duct and that may lead to that could provide additional amount of mass flow rate for the engine to generate additional thrust required during takeoff. But except under these circumstances the intakes usually have fixed geometries.

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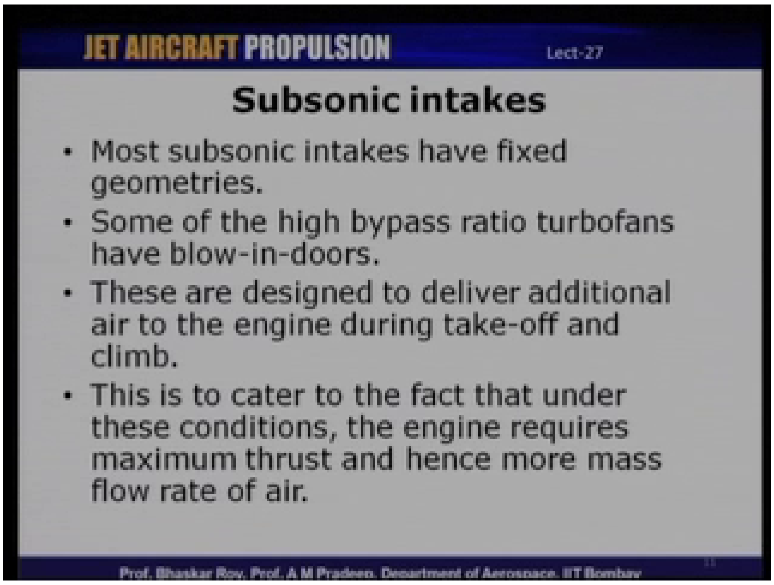

So, in the case of intakes most of the subsonic intakes as I mentioned have fixed geometric except in certain cases where we may use blow in doors used in high bypass turbo fan engines, which basically are meant to deliver additional mass flow rate to the air engine during takeoff and climb.

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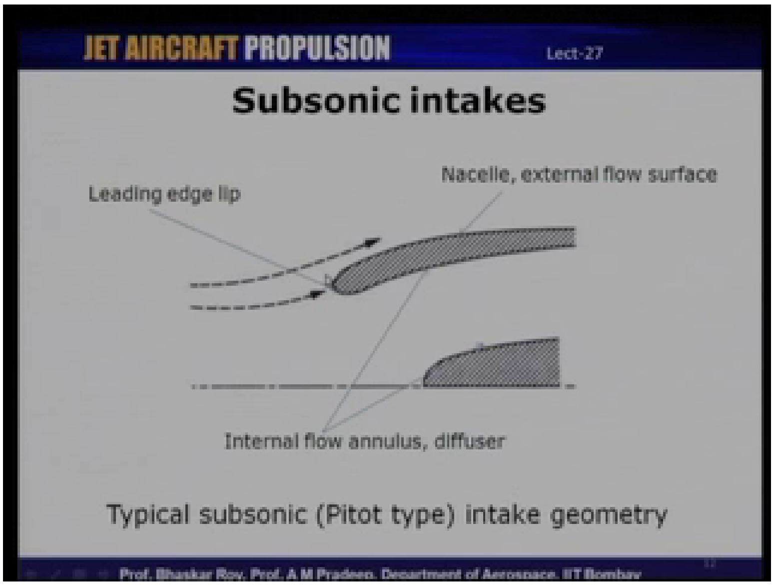

So, a typical pitot intake as I mentioned is usually axis symmetric because of the like the intake which I had shown for the transport aircraft that is axis symmetric pitot intake.

In a pitot intake geometry basically consists of the nacelle itself nacelle forms on of the in intake forms one part of the nacelle itself and within the nacelle is the engine. So, this part of what is there beneath this nacelle is the engine and what you see here is the hub of the compressor or the fan. So, the flow through this intake will constitute two parts, one is the external flow and the other part is the internal flow that is there is one part of the flow which gets split because of the presence of the intake itself.

One part of the flow moves above the intake on the nacelle that is the external flow surfaces. Other part of the flow goes into the engine itself that is the internal flow. So, typical subsonic diffuser is required to ensure that it not only produces or delivers uniform flow at the engine phase it also is required to minimize external flow drag. So, because of the presence of flow through this surface this is also certain amount of drag penalty because of this. So, the engine the intake designer the nacelle designer has also suppose to ensure that the external drag is minimized under off design operating conditions.

So, the leading edge of this nacelle which is basically the beginning of the intake is known as the lip of the intake and then there could be which something will discuss in the next class that there are different areas of this where would problems one is of course, the external flow which I mentioned that we should try to minimize the drag associated with external flow and under certain operating conditions there could also be flow separation external to the intake itself. Besides that there could be flow related problems on the intake surface or on the hub surface.

So, it could be either on this surface or in external to the intake and all this all these three are basically result of the intake of operation under various operating conditions. So, pitot intake is probably the simplest form of the subsonic intake. And there are the main reason why it is very commonly used is that the total pressure losses across a pitot intake is very less as compared to some of the other type of intake which are existing. So, pitot intake usually has very low when operating in subsonic flows had very low total pressure losses which are big advantages.

Because a total pressure loss in the intake can eventually lead to loss of thrust. So, total pressure loss is something that one would like to minimize and that something which is inherently present in pitot type of intakes.

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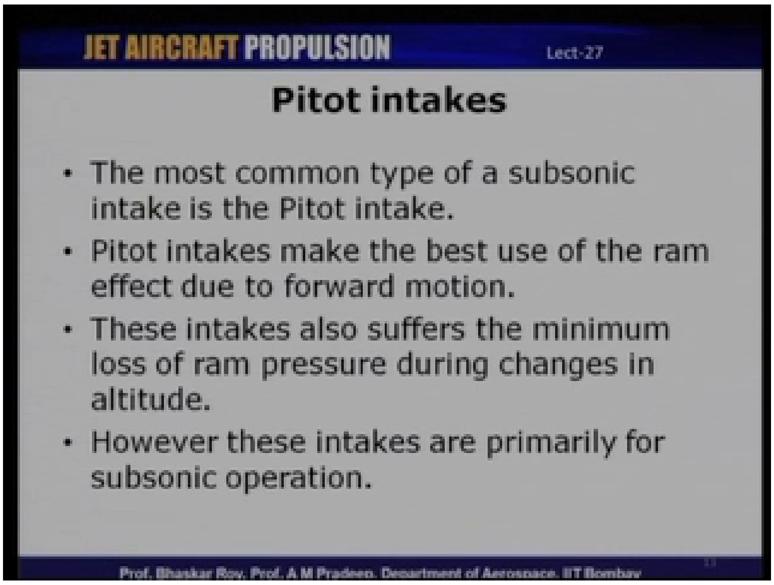

So, that is one main advantage. But the main advantage associated with the pitot intake is that it makes the best use of the ram effect due to forward motion as compared to many other types of intakes which are existent. So, pitot intakes are able to benefit from the fact that because of the very geometry. There are able to make the best use of the ram effect as the engine moves forward there is a ram effect for the incoming air. So, pitot intakes are able to make the best use of that with minimal pressure loss and that is probably the most important advantage, besides the fact that it is much simpler in geometry as compared to other types of intakes.

So, we will discuss in some detailed about what are the difference types of pitot intakes that are existence and what are their characteristics features of these difference types of pitot intakes. So, as I mentions pitot intakes are commonly used because they can use the ram effect due to the forward motion and they suffer minimum loss in ram pressure especially in changes in all when the engine is operating under different altitude conditions.

But of course, these intakes like the one which had shown earlier are meant primarily for subsonic operation and because for an efficient operation of these intakes it requires that the leading edge is smooth and it consist or constitutes a certain curvature which is not something that would be desirable for a supersonic flow, which is why these type of intakes are used primarily in subsonic flows.

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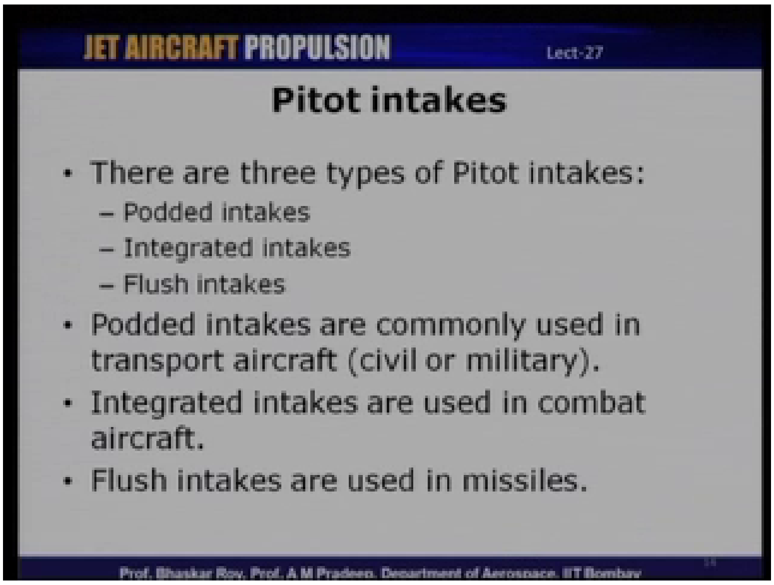

So, there are different types of pitot intakes. There are basically three types or which are commonly used. The probably the most common type of pitot intakes are known as boarded intakes, which is normally used in transport aircraft like the one which the picture I had show earlier for a transport aircraft that is a boarded intakes. Then we have integrated intakes and flush intakes and boarded intakes are usually used in transport aircraft both civil as well as military. Even in civil even in military aircraft there are certain types of military aircrafts which are used for transport of military equipment.

So those types of engines are normally the ones which would which use a boarded intake and because the thrust requirement in such engines you would not really want to operate at supersonic speed. Subsonic speed with a high bypass turbo fan is probably the ideal engine for such aircraft and so such an aircraft a boarded intake which is a pitot type of intake is the best solution for these intakes. Other types of intakes are known as integrated intakes.

Integrated intakes are those which form part of that is they divert air from the fuse large into the engine, which is located probably within the fuse large itself and something which would be used in some of the military aircraft the combat aircraft and the third type of pitot intake are known as submerged intakes and these are used normally in missile. Especially if the missile is to be launched from a canister then the geometric advantages of submerged intakes used. So, submerged intakes may be used in missile type of applications or so these three types of intakes are the most commonly used types of pitot intake. So, let us take a look at what these three intakes look like.

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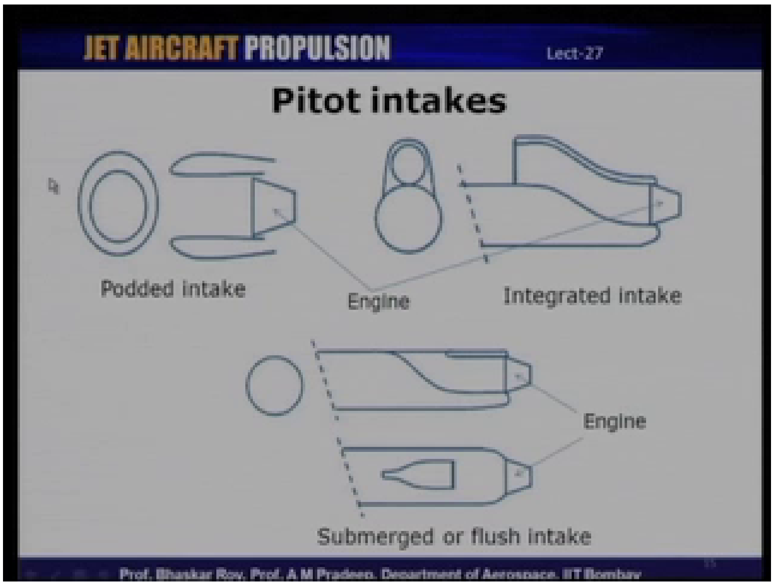

So, the first one that is showed here is a boarded intake, the one which is used in most of the civil aircraft and some of the military transport aircraft and boarded intake as we can see consists of an nacelle within which the engine is housed and there is a thick leading edge and this is a lip of the intake and the this is where the engine begins. So, this engine is housed within the nacelle and you can see that this is an axis symmetric type of and an intake. The other type of an intake pitot intake is the integrated intake.

So, this is shown here this is an integrated intake where in the engine is mounted here and it is not in the same axis as where the intake is beginning, which is why it is called an integrated intake. Because it part of the intake a region is partly within the fuse large itself and so the engine has intake has to divert flow from the sides of the fuse large into the engine through a ducting. So, integrated intakes would normally require a duct and so as soon there are associated problems like I mentioned this is typical S shaped duct and there could be issues with flow separation and flow non uniformity at the engine phase because of their very geometry.

And the third type of pitot intake are known as the flesh intake or the submerged intake where in the engine is well within the fuse large itself and you would not want any part of the intake to be protruding out of the fuse large surface and these are type engine and these are the intake types which are used commonly in missiles. So, as you can see from the side view you do not see any protrusion from the fuse large which is not the case in either of these cases where either here or in this case the intake is very much visible and so in advantages main advantage of this type of an intake is that if they the missile for example, is launched from a canister then it is necessary that there is nothing else which is nothing else is protruding out of the fuse large itself.

Flesh intake are submerged intakes can ensure that this is possible. But of course, there are performance penalties associated with this because of the very fact that the flow has to curve substantially or has to take a substantial curve before entering the engine the performance of these intakes are usually very poor as compared to the boarded intake or even compared to the integrated intake. But and therefore, that is the reason why there used only under certain special circumstances especially for missiles applications and so on. Now in boarded intakes the frictional losses as I mentioned are not very significant as compared to some of the other types of intakes.

The performance of these intakes is subject to the flow behavior internal as well as external to the intake itself. So, there could be possibility of flow separation not only within the intake, but also from the nacelle and leading to external drag increase in external drag. But leaving that aside the performance of boarded intakes are usually better and frictional losses minimal, but of course, these are meant purely for subsonic flows and as the engine if the engine were operating supersonic flow these intakes are not going to perform efficiently at all and therefore, in the case of boarded intakes the presence of separation of course, will affect the performance of all types of intakes.

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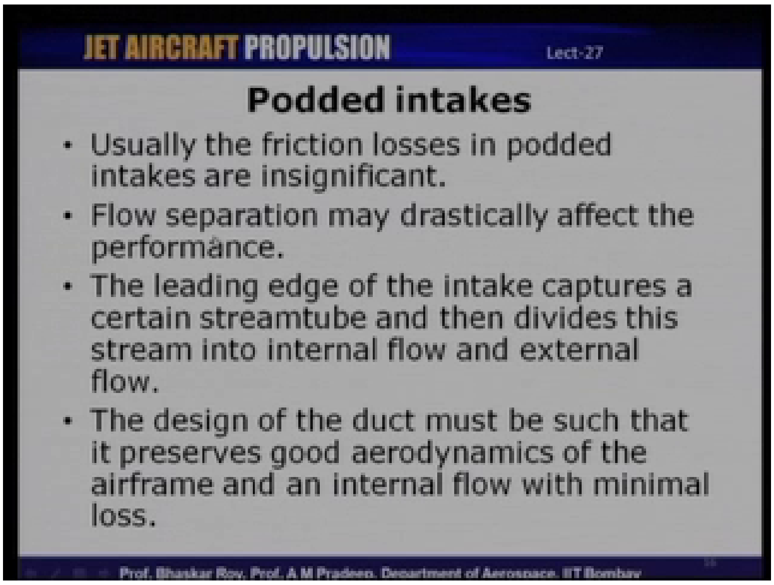

But, if there is a separation within the surface of the boarded intake, then it will drastically affect the performance. And in the case of whatever be the geometry whether it is a boarded or flesh or integrated intake, the duct design also plays a significant role besides just the leading edge of the intake. The design of the duct should be such that it preserve the good aerodynamics of the air frame. At the same time it also provides reasonably good flow at the engine phase with minimal pressure loss, because pressure loss will directly affect the thrust developed by the engine.

And therefore, the intake and the ducting associated with the intake must ensure that not only preserve the good aerodynamic flow outside the intake or on the outer surface at the same time it also gives a fairly uniform flow to the engine for proper operation of the engine. Because they have already discussed about occurrence of surge and stall in an axial compressor, and these can be initiated if the incoming flow to the compressor is not uniform.

That is if the incoming flow from the output of the intake has large non uniformities then those non uniformities will enter into the compressor and the presence of these non uniformities may initiate the occurrence of rotating stall and may be even surge and that is something obviously, we would as engine designers one would like to avoid therefore, the intake is necessary is suppose to provide or minimize the presence of these non uniformities as the flow exits the intake and goes into the compressor.

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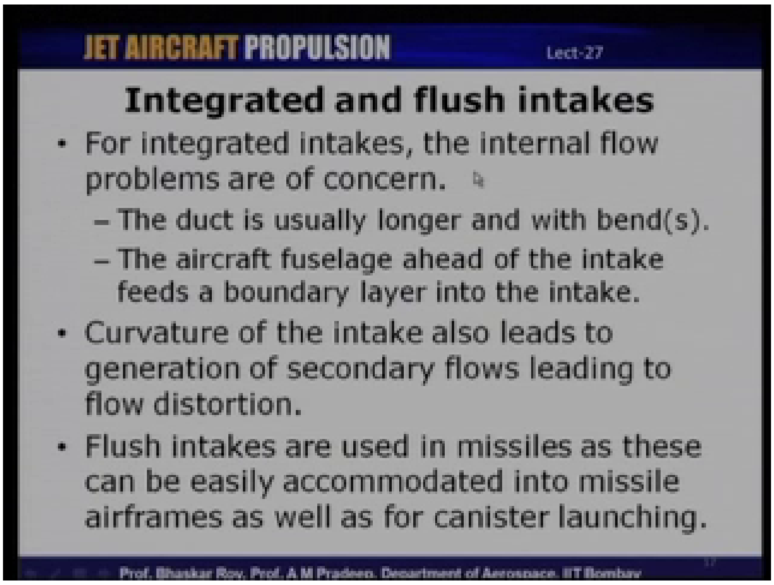

Now, the other two types of intakes are discussed the integrated intake and the flesh intake. In integrated intake we have more concerned about the internal flow problems and as compared to boarded intakes where we are concerned more of the external aerodynamics than the internal. Integrated intakes basically we have most lightly would have duct, which is longer and with the presence or occurrence of bent one or more bents and besides this the intake usually gets its air from the fuse large surface, which means that if there is a boundary there developing on the fuse large that boundary layer might feed into the intake and therefore, the intake into entry itself would have non uniform flow which might get amplified by the time the flows leaves the intake.

So, let me just go back to that picture I was showing. In this integrated intake as you can see the intake is almost adjacent to the fuse large itself. Therefore, if there is a boundary development on the fuse large that would enter into the intake and that means, that the inlet the entry of intake itself has a non uniform flow and therefore, as the flow proceeds or progresses through the intake the non uniformities may get amplified because of the presence of these curvatures and by the time the flow exceeds the intake the flow is likely to have a high levels of non uniformities.

So, that is these are two limitations one is the fact that there is a longer duct here, which means frictional losses would be larger than boarded intakes. At the same time there are possibilities that the inlet entry of the entry flow to the intake itself has non uniformities. So, curvature of the duct in this case may lead to generation of secondary flows etcetera, which can cause even more in few distortion to the compressor. In the case of flesh intakes also the same problem exists as in the case of integrated intakes.

But here the problem is even more compounded because of the fact that the curvature is much higher then what you see in an integrated intake. Therefore, the flow in this case takes an almost ninety degree turn, which means that the flow entering the engine is lightly to be highly non uniform. Therefore, depending upon the type of geometry of the intake that you have the simplest being the boarded intake then we have integrated and this submerged intake. The flow quality that leaves the intake and enters the compressor phase is lightly to be significantly effected as a result of these non uniformities.

So, it is one these are one of some of challenges that an intake designer would have to keep in mind, even though we are dealing with simpler components as compared to compressors or turbines, which are formal complicated by themselves. Here we have simpler components, but even then the outcome of the design is lightly to affect the engine substantially depending upon how the design was conceived. So, a design of these intakes even though they are subsonic needs to keep in mind the presence or the lightly hold of occurrence of these flow issues, which might substantially affect the performance of the engine.

So, we were discussing about so far discussing about subsonic intakes in general. But some of these intake geometries may also be extended to supersonic flows. But of course, they are not the optimum type of intakes which could be used in supersonic flows. pitot intake are also used in supersonic flows, but they are not very commonly used because of the fact that the total pressure losses in pitot intakes when operated in supersonic flow are usually on the higher side. So, there are different types of supersonic intakes that are that have been designed and developed. So, let us take a look at whatever different types of supersonic intakes and what is it that makes supersonic intakes much more complicated than subsonic intakes.

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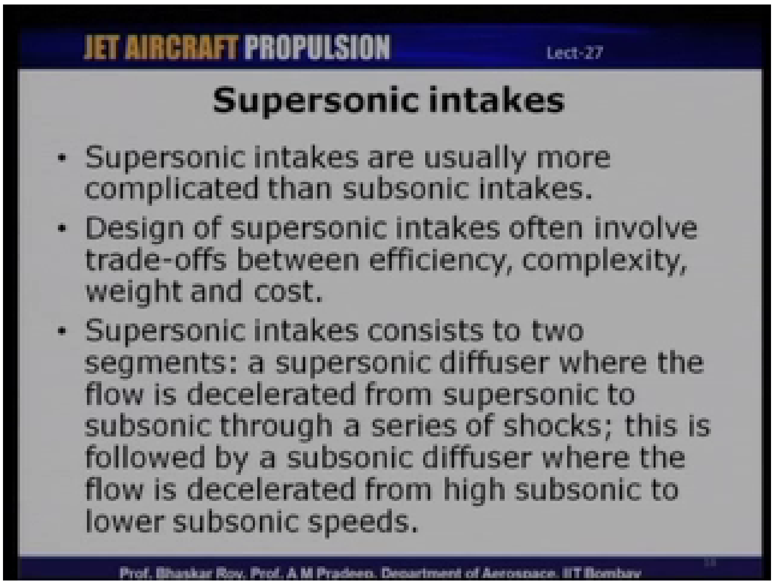

So, supersonic intakes are usually it is a fact that supersonic intakes are usually more complicated than subsonic intakes and the design of these intakes usually involve tradeoff between efficiency complexity weight and cost and the that is something that the designer would have to eventually optimize and try to develop a design which will involve some sort of tradeoff between all these parameters. And supersonic intakes will usually consist of two components of or two segments.

One is the supersonic diffuser where the flow is decelerated from supersonic flow to subsonic flow through a series of shocks and then this is followed by a subsonic diffuser where the flow is decelerated from high subsonic to a subsonic flow, which is permissible for the compressor phase usually around mach 0.4 or 0.5. So, is the aircraft is let us say the operating at supersonic mach number of let us say mach two the supersonic diffuser decelerates the flow from mach to all the way to subsonic flow let us say around 0.8,0.9 or so.

The second part of the diffuser or the intake that is the subsonic diffuser further decelerate the flow from high subsonic to around mach number 0.4 or 0.5 which is what is required for the operation of the compressor. So, supersonic diffuser will constitute these two components, the other complexity is that supersonic diffusers will also need to operate at subsonic speeds. Because aircraft has to take off and reach a certain altitude and Mach number before which it can accelerate at supersonic speed, which means that the aircraft has to operate at all these speeds all the way up to supersonic speeds.

Therefore, the intake must ensure that the necessary mass flow rate that the required quality supply to engine under all these operating conditions, which makes the design of these intakes quite a challenging task. So, let us take a look at whatever different reasons which make the operation of supersonic intake much more complicated than subsonic intakes.

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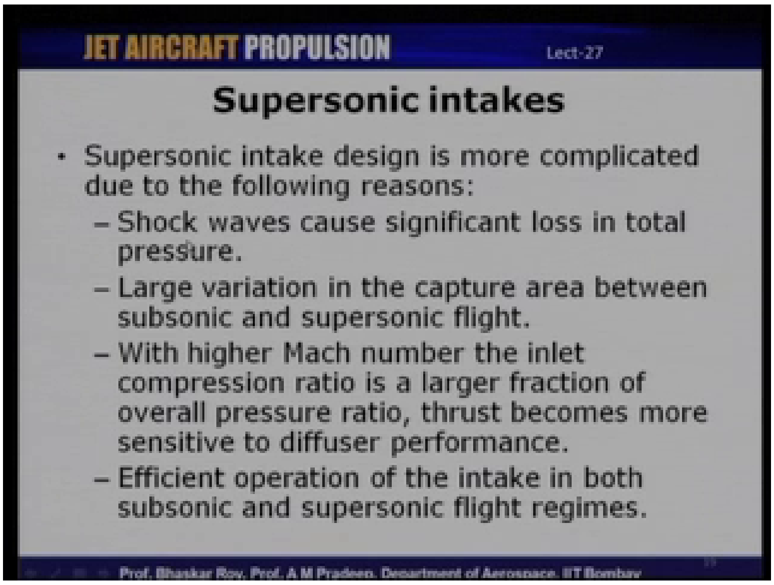

Now one of the major concerns on or issues that affect the performance of the supersonic intakes is the presence of shock waves which is obviously, something that is repaired because deceleration from the supersonic to subsonic is possible through shock waves only. So, you definitely need shock waves for deceleration, but these shock waves also cause significant loss in total pressure and it is one of the challenges to try to minimize this total pressure loss. The other challenge is the large variation in the capture area between subsonic and supersonic flight.

That is capture area refers to the area in the free stream the imaginary in the free stream, which is actually delivering the required mass flow to the engine and the as the engine operates from subsonic to supersonic flow the area variation of this capture area is substantial as compared to subsonic intakes where the variations of area is not that height. Now the other issue with these intakes is that if the engine is operating at high Mach number then the pressure ratio that across the intake is quite high and that will form a large fraction of the overall pressure ratio.

So, the intake pressure ratio at higher ratio at higher Mach number will form a substantial part of the overall performance pressure ratio of the engine, which means that the thrust developed by the engine will become very sensitive to the flow through the intake itself or the performance of the intake. Because thrust is a function of overall pressure ratio and now this overall pressure ratio has a significant amount from on account of the intake itself. So, the thrust developed will strong function of the intake performance and the last important aspect of this is that efficient operation of these intakes in both subsonic and supersonic flight region that is obviously, a very significant task.

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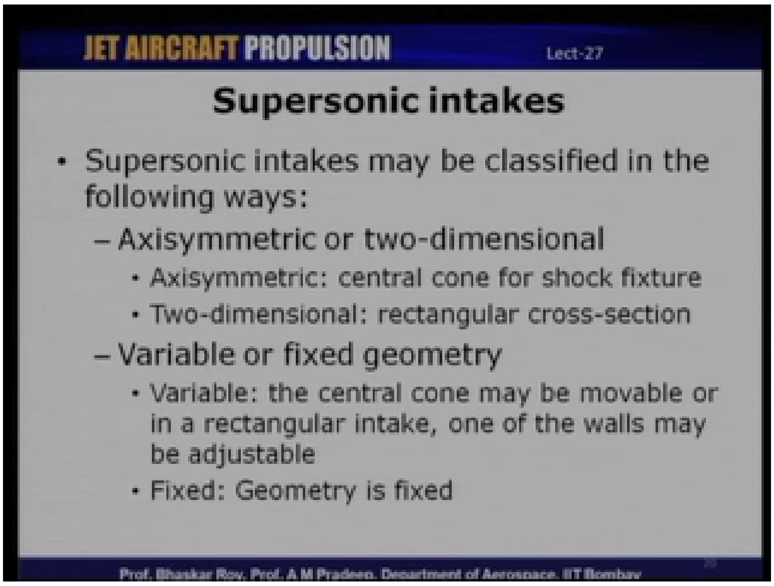

Now let us take a look at what are the different types of supersonic intakes you can classify supersonic intakes in different ways. One way of classifying it is axis symmetric or two-dimensional. Axis symmetric intakes are usually involved the presence of the central core and spike which is basically meant for fixing the shock location. Two-dimensional intakes are rectangular cross section I have already shown you some examples of the two-dimensional intakes or an engines which use two-dimensional geometry are rectangular cross section.

Other type of classification is variable or fixed in variable geometry if it is axis symmetric the central core the movable or it rectangular type of intake one of the walls of the intake may be adjustable depending upon their requirement and of course, you could have geometry which is fixed something which is usually not preferred type of intake.

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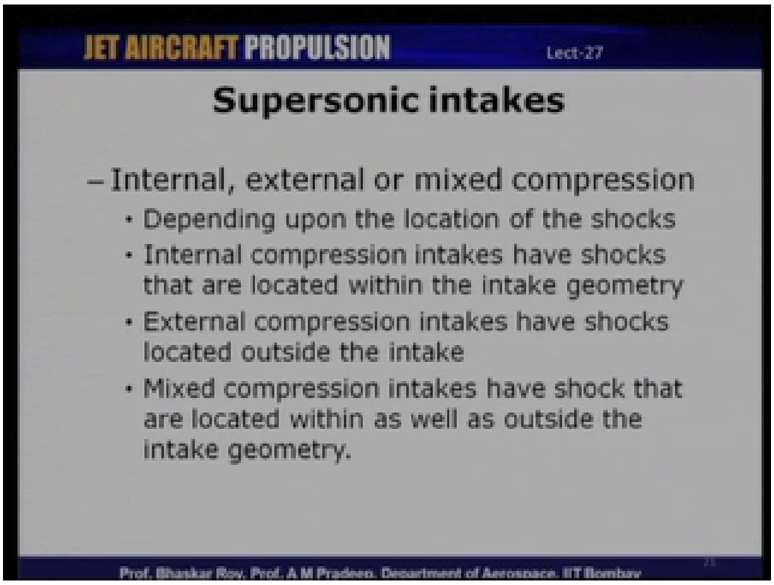

The other type of classification is depending upon the location of the shock itself, it could be either internal compression, could be external compression or a mixed compression intake. In internal compression intakes the shock are located within the intake geometry itself that is you have shocks, which are inside the intake geometry which cause deceleration supersonic to subsonic and then the subsonic diffuser which decelerates high subsonic to low subsonic.

External compression intakes have shock, which are located outside the intake geometry and mixed compression have shocks some of the shocks located outside and some of the shocks, which are located inside the intake geometry. So, these are three different types of classification of intake geometry is supersonic intakes it could either have axis symmetric two-dimensional or fixed or variable or internal external mixed compression there could be intakes which have which could of course, fall in all these classification separately as well.

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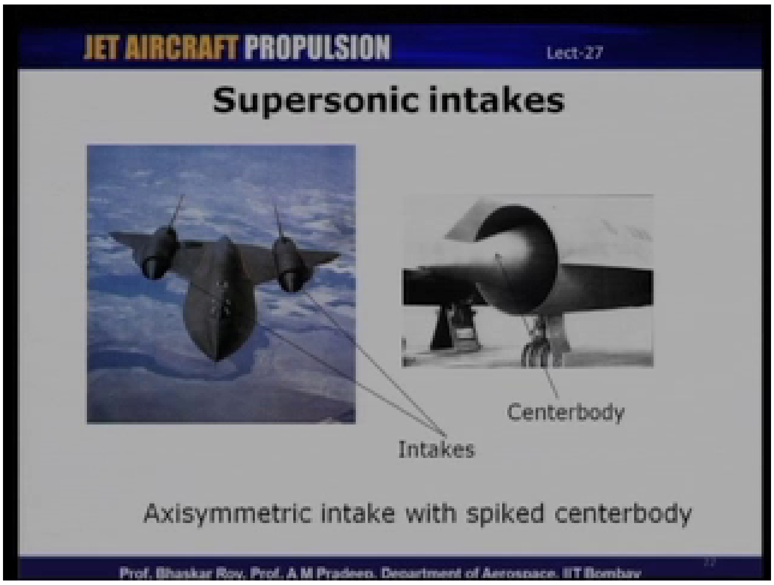

Let us take a look at some examples of these intakes. Here we have an axis symmetric intake. This is an aircraft which was operational and probably the seventies this was known as s r seventy one it could operate at high supersonic Mach number of a mach around mach three or so, so this aircraft had two engines with axis symmetric intakes. So, these are axis symmetric intakes which are supersonic and you can see there is a center body or a spike and this fixes the location of the shocks and most of the time the center body are the spike location is variable so that you can change location of the shocks depending upon the operation itself. So, this is one example of an axis symmetric intake with the spiked center body.

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This is two-dimensional intake this is this was only civil aircraft which could cruise at supersonic mach number and this was Concorde and the operation of this was abundant a few years ago and so these this aircraft had four engines, which all of them used at two-dimensional intakes what you can see here with these are the openings of the intakes these intakes are straight and these are rectangular in and in geometry. But these geometry these are not fixed geometry these are variable geometries as compared to some of the in fact most of the modern day subsonic aircraft intakes which are fixed intakes Concorde had intakes which were variable because it had to take of its subsonic speed and climb and reach the decided altitude before it could cruise at or accelerate to supersonic speeds.

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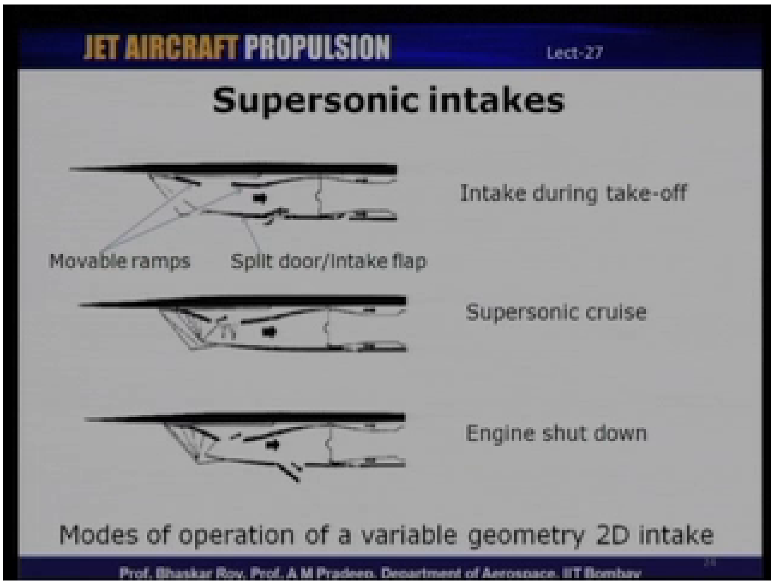

So, the intakes are required to have variable geometry. So, in this case there were movable ram as we can see one of the surfaces of the intake was movable and so depending upon the operation of the intake operation of the engine these rams were moved. So, that the engine could either operate in during takeoff at the subsonic flow and when it was operating in supersonic flow these doors were closed and so you can see that geometry has changed from what it was during takeoff to cruse to engine shut down or during stopping of the engine.

So, these are three different modes of operation of the same engine which is possible because of the fact that the intake has some provision for changing its geometry for itself the variable geometry to the intake. So, this is the intake of Concorde which was operational till a few years ago that only transport supersonic transport aircraft which was operational and you can also see that that required the use of variable geometry intake. So that can operate under different operating condition from low subsonic to supersonic cruise and during land.

So, we have just discussed the different types of intakes the subsonic intakes and the supersonic intakes in brief in todays class. We had an over view of different types of intakes and in the next class we will probably continue this in some more types of at least the internal compression, mixed compression, external compression intake. I shall show you a geometries which or intakes which use these geometries. We will also try to understand the performance parameter used in these different types of intakes the subsonic and supersonic intakes.

We will also look at some of the issues related to supersonic intakes which are known as starting of supersonic intake we will also understand try to understand what is meant by starting of supersonic intake. So, these are the some of the topic which we shall take up in for discussion in the next class.

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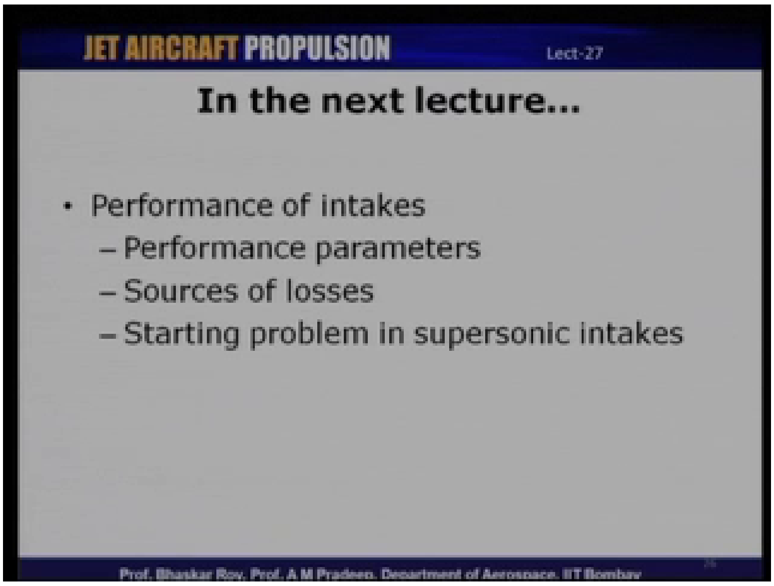

So, in the next class we will be talking about performance parameters associated with intakes sources of losses of intake basically the frictional losses and the shock losses. And also we will have some discussion on what is meant by starting problem in supersonic intakes typically in the pitot type of supersonic intakes. So, we will take up some of these topics for discussion during our next lecture.