**Gasdynamics: Fundamentals and Applications**
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**Lecture 36**
**Diffusers Intakes Inlets**

We are looking at varying area ducts and until now we have discussed about equations of varying area ducts and nozzle operation. The other kind of ducts where we find compressible flow and is having a lot of applications is the diffuser. In a nozzle flow is accelerated while in a diffuser flow is decelerated. Typical examples of diffusers are in intakes of air breathing engines or even in wind tunnels and several other such applications where flow velocity is needs to be reduced and pressure has to be recovered.

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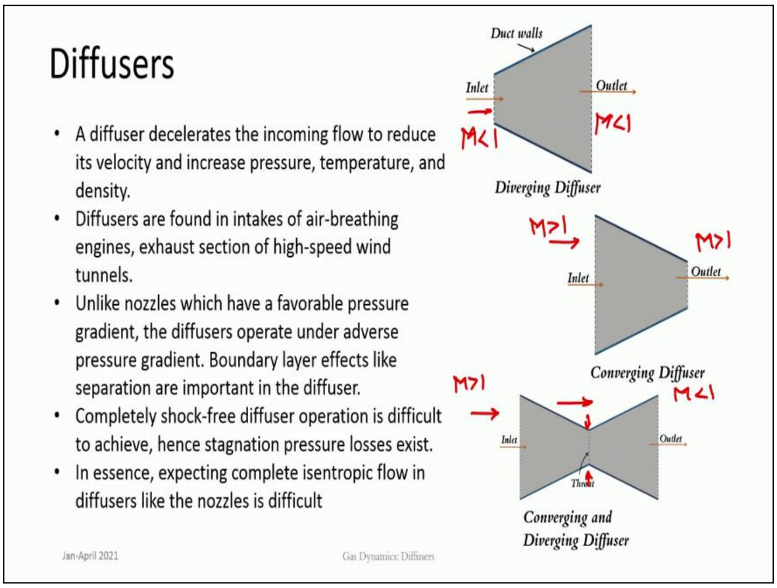


So, let us look at how these devices work. So, this is completely compressible flow. So, across the diffuser velocity decreases and pressure temperature density will increase and you have we already have discussed these differences in the kinds of diffusers it is not the shape. So, you should understand that a diverging diffuser if this acts as a diffuser then the inlet should have a Mach number less than 1 subsonic.

Then the outlet will have $Mach\, number < 1$ but at a lower Mach number. While a converging duct if it acts as a diffuser inlet will be greater than 1 and outlet will be greater than 1 but at a lower Mach number. If you want to convert a supersonic flow to subsonic values decrease it to subsonic velocities then you need a convergent divergent diffuser. So, that is the important point here.

And similar to C - D nozzles you have a minimum area here at the throat that is the throat and inlet is supersonic M is greater than 1 outlet is subsonic M is less than 1. But unlike nozzles, nozzles operate where the pressure continues to reduce. So, that kind of reducing pressure is known as favourable pressure gradient because it accelerates the flow and also in the context of viscous effect when there are boundary layers near the wall.

Then favourable pressure gradients are good because they keep the boundary layer, they do not disturb the boundary layer much. But a diffuser operates in adverse pressure gradient because pressure increases across the diffuser and this is not very good for the boundary layer. In adverse pressure gradients boundary layers have tendencies to separate from. So, when boundary layer separation happens, lot of other phenomena happen you get shocks within the ducts.

So, it is actually very difficult to achieve complete shock free diffuser operation unlike that of the nozzles. Nozzles you can achieve that but diffusers it is difficult. So, there are other reasons also why shocks are will be present inside diffusers. So, that is the way diffusers are quite different from nozzles.

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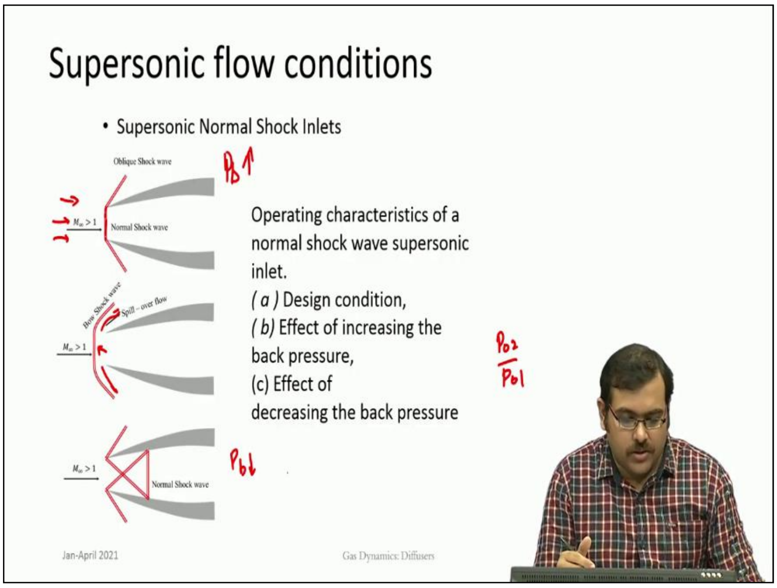


So, if you look at subsonic diffusers typical examples we take as intakes. What intakes do is they capture mass from the air surrounding air and they take the mass and push it in towards the engine. It may be a gas turbine engine or at high speeds it can be a ramjet or a scramjet engine. So, the required amount of mass flow for the engine is provided by the intake by appropriately capturing the mass as well as it reduces the velocity and so, increases pressure.

So, there is a compression involved in intakes. The compression can, happen external to the intake duct itself for example this is a constant area duct. So, it is a subsonic flow. So, there is information propagation can happen regarding pressure disturbances both ways both upstream and downstream. So, as a consequence the capture area that is the area from which mass is getting captured can change. So, that can change in a subsonic flow.

So, if in case the mass that is required by engine is smaller, then lot of mass spills over the intake. So, that is called the spillage over the lip and what this does is it causes additional drag. So, when you consider flows over intake it is not only about how much pressure recovery or diffusion you can do it also has to do how much mass flow you can capture and what should be a smallest possible drag the other one is that you also have a divergent duct.

So, incoming flow is subsonic $M < 1$ then if there is a divergent duct it will diffuse the flow that is it will $V_2 < V_1$. So, these are internal compression where compression is happening inside the duct. So, these are types of intakes now there are many aircrafts which fly supersonic also, what are those kinds of intakes what are the flow features around them.

We can still have for supersonic flows we can still have a divergent duct. But now you know that a divergent duct with an incoming supersonic flow it accelerates the supersonic flow but it is not just the duct itself we should know about the pressure ratios. In diffuser operation the pressure ratios are always high back pressures are higher. So, if you need acceleration back pressure should be low.

So, but for diffusers back pressure is high therefore it will not support a supersonic flow going in through this divergent duct. So, the way this can be sort of solved is by having a normal shock sitting right at the entry of the duct. So, when you have a normal shock then immediately flow is turned subsonic and then the further compression happens inside the duct. These are normal shock kind of intakes but when you have normal shocks you should remember that there is large entropy production.

So, the efficiency takes a hit because of normal shock but it does provide good compression. Now if the mass flow requirement is further lower it is smaller, then this normal shock is pushed away from the lip of the intake and flow spills over. So, and you have a sort of bow kind of a shock where near the intake near the lip it will be nearly normal but elsewhere can be curve.

So, if pressure is further reduced on the back side then it can allow a certain supersonic flow inside the duct. So, this kind of operations one must be now familiar with. So, many discussions of varying area ducts, so, this kind of intakes which can allow normal shocks to happen outside our normal shock kind of intakes but here you can expect large entropy rise and pressure recovery is affected because $\frac{P_{02}}{P_{01}}$ reduces across a normal shock.

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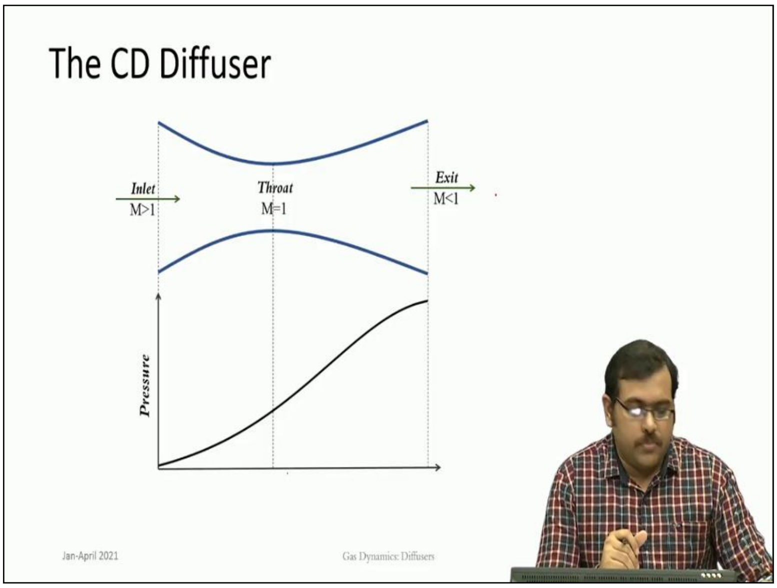


Now if you want much better pressure recovery than normal shock intakes then you should one will always consider convergent divergent diffusers which can convert a subsonic flow sorry a supersonic flow it is a diffuser supersonic flow to a subsonic flow. Entry is Mach number > 1 and exit is Mach number < 1. Now if we follow the same principles that we did for nozzles then at minimum area Mach number should be equal to one.

So, this is the ideal operating condition for a C-D diffuser without any shocks inside the duct converting these supersonic flows to subsonic flow. But we also know about various problems in the varying area ducts that is not just the area ratio you need to know about pressure ratios also. So, similar to the operation of nozzles these diffusers also have operation characteristics according to the pressure ratio across this C-D duct. But even more important than that is what is known as the diffuser starting problem the problem.

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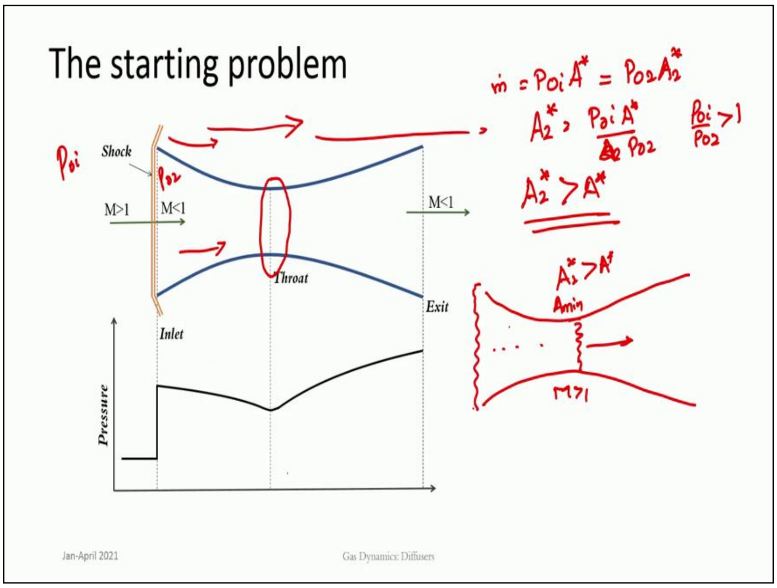


The problem of diffuser starting is just like you had nozzle starting that is you started providing a certain pressure ratio that if it was $P_0$ was constant and then you reduced back pressure and you saw various flow regimes happen in the nozzle. Here in the diffuser also you will have such starting issues. But here the problem is that the inlet flow or the intake flow that is coming into the intake is supersonic it is not that with the nozzle.

Nozzle the incoming flow was subsonic it allowed information propagation to happen both upstream and downstream. But for a diffuser this is not possible because incoming flow is supersonic. The supersonic flow will not know before it enters the duct that there is a minimum area available. So, and Mach number can become one at that point. So, this information is not transferred upstream in a supersonic flow.

So, the supersonic flow can never know about it suppose this diffuser was completely closed and then suddenly it is open to supersonic flow then immediately at the inlet of the diffuser there would appear a normal shock because until that point there would be no information propagation upstream. So, only after the normal shock once the flow becomes subsonic then information can transfer within the duct.

So, within the diffuser but then what is the problem if the flow has become subsonic and the shock is standing right at the entry of the duct what is the problem at this particular point.

The problem is that ultimately we want an operation where it is completely smooth that you do not have any shocks for that this shock has to go into the diffuser and be thrown out of it. So, but if you go back and look at this particular case when $M = 1$ at the throat and we have a particular $P_0$ for the exit for the internal entry at the inlet.

And this is then $P^*$ then and a particular $A^*$ is known for this then we know that $P_{0i}$ multiplied by $A^*$ multiplied by a constant is mass flow rate $\dot{m}$. Now this is the mass flow rate that this diffuser can allow. But if a normal shock stands right at the entry of the intake then if it has to support the same mass flow rate then the area should be something different.

So, if it has to support the same mass flow rate $\dot{m}$ and $P_{0i}$ that is at this point but this is at $P_{02}$ after the shock. So, the area that was supposed to be there was $A^*$ in the ideal operation but after the shock it is $P_{02}A_2^*$ what is $A_2^*$? $A_2^* = \frac{P_{01}A_1^*}{P_{02}}$ and $\frac{P_{01}}{P_{02}} > 1$ P 0 2 is smaller that means $A_2^* > A_1^*$.

So, this is the key idea that if you if the shock has to be pushed through the diffuser then the minimum area that the diffuser should have is much larger than the ideal operation of the of the diffuser. So, this is for an ideal operation if this area ratio is provided for the diffuser entry then the shock that stands at the inlet of the diffuser will never be able to pass through the diffuser. So, in order to sustain that mass flow rate, so, as a consequence diffuser designs are dictated by this starting problem.

So, not only the these points about area ratio you should also provide the correct pressure ratios also as we have decided but i have discussed but important point is for C-D diffusers convergent diversion diffusers or supersonic diffusers. The main design approach or approach towards operation of diffusers is the problem of normal shock standing at the entry to the diffuser and causing the diffuser to unstart that particular process is known as unstart.

And if there is no normal shock at the intake at the entry of the inlet then supersonic flow exists all through the convergent portion and at the exit you can have Mach number which is less than 1 subsonic. But now the minimum area is not according to the Mach 1 principle because area is now larger $A_2^* > A_1^*$. So, as a consequence even at area minimum Mach number will be greater than 1.

In order to get subsonic flows you should have a shock. So, a shock will exist in diffuser operation this shock will generally exist in the divergent portion of the diffuser. So, that after the; shock you can have diffusion by subsonic to subsonic velocities. The shock will not stand in a steady flow it will not stand anywhere in the convergent duct. So, if the pressure ratios are changed beyond this value then the shock will come and sit at the intake of the diffuser this is known as unstart.

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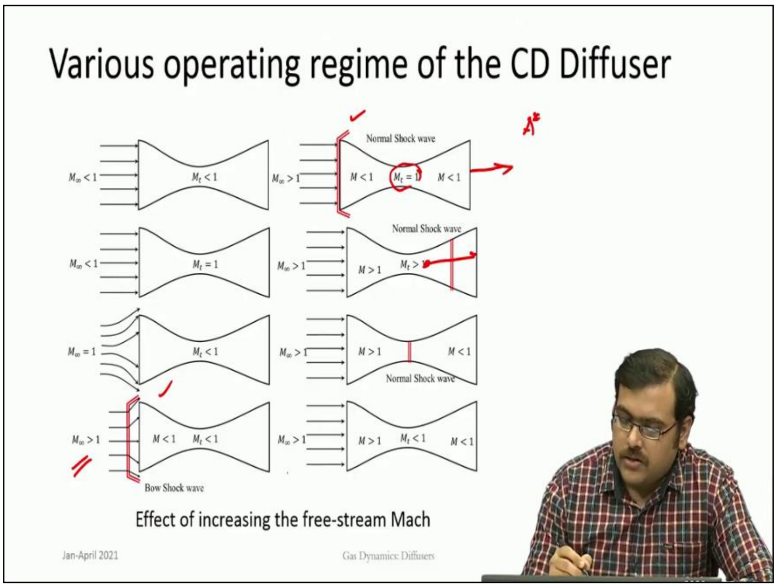


So, you can look at the various possible operating regimes of the convergent divergent diffuser we are talking about cases where you have incoming flow as supersonic Mach numbers. These are the cases where there is normal shocks standing at the entry to the diffuser. The limiting case is that there is a normal shock at the entry to the diffuser and there is at the throat Mach number will become equal to one.

So, this is a limiting case. If further changes are made the shock can move and be pushed out of this particular point. So the shock can move within the variable converge divergent portion of the diffuser. So, since we always provide areas greater than the $A^*$ for the entry Mach number in diffusers in order to achieve starting. So, in order to achieve subsonic flow you will always have shocks within the diffuser.

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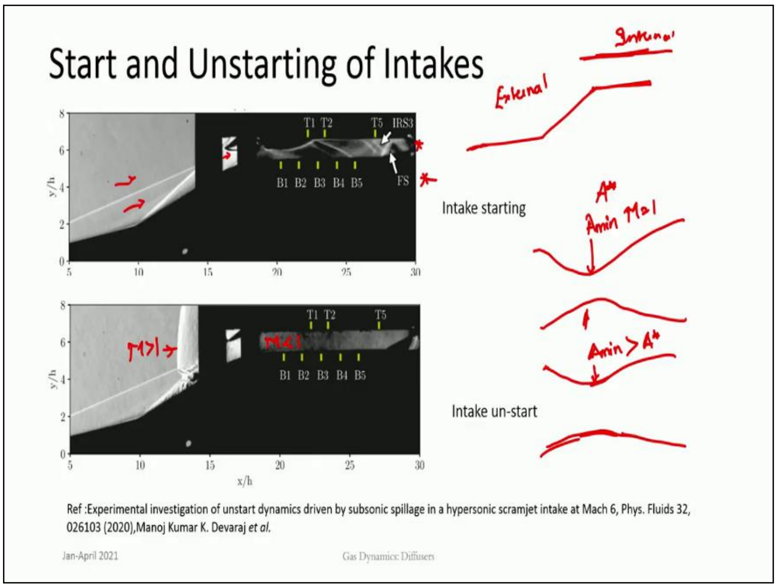


So, this is the highlight of diffuser operation and here I have shown a particular case which we had looked at in the laboratory in wind tunnels. So, here there is a intake diffuser for supersonic flow and this kind of a diffuser is having 2 kinds of compression there are compression ramps on the outside and before there is a final internal compression. So, it has both external compression and internal compression.

So, these kinds of intakes are called mixed compression intakes. Now when it is com operating completely in the started condition this is the case you have supersonic flow all through this is supersonic. And the evidence of supersonic is the presence of these shock waves shock waves or oblique waves are present only in supersonic flows and everywhere you see there are oblique waves they are for supersonic flows.

We control the back pressure by changing things at the end by using a flap and increase back pressure beyond a certain point a certain back pressure. This flow is no longer able to produce a started flow and it pushes all the shocks out and you have a near normal shock that is standing out of the intake. So, here you see that Mach number is greater than 1 here but here Mach number is less than 1.

So, this is an unstarted intake. So, in diffusers when we look at diffusers the major problem is starting off diffusers and diffusers are always designed. So, that they can be started, so, even though in ideal conditions we expect that the minimum Mach number should be 1 $A_{minimum}$ Mach number should be a 1. But in order to ensure that the diffuser starts in any condition we have to provide for a larger area.

So, this is for ideal operation I would say $A^*$ and this is $A_{minimum} > A^*$. So, that diffuser starts. So now having known this let us understand these principles another application of these nozzles and diffusers is in design of experimental test facilities which we will see in the next class, thank you.