Gas Dynamics
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Module - 18
Lecture - 44
Compressible Flow Facilities

Hello everyone, welcome back. We were discussing till now shock tubes, and various effects in shock tube due to the viscous effects are contact surface either in etcetera. We will come back to shock tubes today after some time. Today's class is supposed to be going towards high speed experimental facilities, and before going there. I just wanted to talk a little bit about yesterday's class. I was using some particular X versus time plot for this expansions and shocks which is uncommon in class. So, just to get used to it, I will give an exercise where, I will give you the standard bookish X versus T curves, for it in the exercise. I will also give this one as an exercise again. So that, you get comfortable with both in one short, one special exercise on that. I will give what that last class. Now, we will look at high speed wind tunnels off course, our courses only going to be dealing with compressible flows.

So, we are thinking about compressibility. So, I am going to say mock number high is good. So, I am going to think about only tunnels where mark number is more than 0.3, and I am not worrying about mark number is less than 0.3, where we will start neglecting mock number effects. We are not going to talk about those cases, here this mock number greater than 0.3. We delta within the very first few classes, we would not talk about it.

Why it is so etcetera. Now, anyways, first thing we want to decide do we needed tunnel, to do the experiment of course, we can think about taking an air craft going at supersonic speeds and then figuring out that the air craft may not with standard that is dangerous, instead we will like to do this as an experiment and then figure out that it may experience this much level of forces, and then design your structure for that kind of forces that air craft will be standard, that is the better way of doing things. So, I say it is needed. Now, when we are doing the tests there will be typically so many limitations because, we cannot imitate nature the exact way.

So, what happens is we will typically have limitations in this particular field in high speed wind, tunnels typically limitation will come from time of operation. If we think about time of operation has main parameter, I can think about tunnels, that operate continuously versus tunnels that are intermittent that is it operates, only first sometime and then it has to stop and then again I can start again and run for some more time. That kind of times that is intermittent first, we will just look at the distinction the main problem will be the power.

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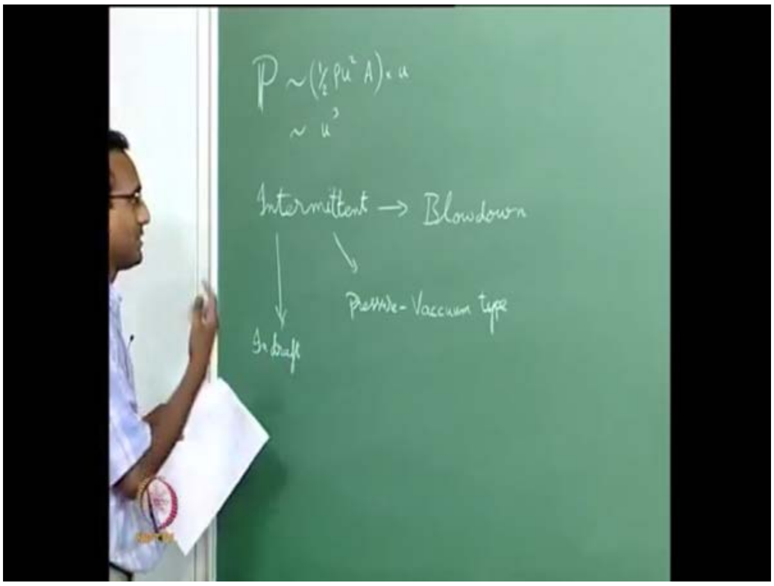

I am putting this double line P, for power. I would not use this power. So, much anyways it is going to be half of the order of half row U square times some area cross section of the test section or so. This is the kind of force required multiplied by the velocity, it is just a force times velocity kind of explanation for power, this is just order of magnitude wise it will be correct it would not be exact. I am just going to talk about this is going of the order of U power 3, if it is U power 3, and I am thinking about very high speeds, it is going to go as cubic function it is going to be enormous power.

When I go for very high velocities, the power keeps on increasing and that is the main reason power requirements for these wind tunnels will become higher, that is most of the lambs cannot supply that high level powers for long times. So, what we do is we store the power, and then we deliver it in one short, till the power is lasting after that we again start accumulating power and then deliver it again. That is the main option, if I think about continuous facilities I have to keep on giving it continuously at this power rate this is not going to be easy to deliver, this much of energy per second that is too high.

So, typically we will see only intermittent high speed wind tunnels we do not see continuous wind tunnels around of course, I have to say that there are few where government funding is so high, that they have made continuous wind tunnels they have a separate power station powering it and there are some close circuit supersonic tunnels. Where the exit flow after the test section is again re-circulated into the inlet in that kind of close circuit tunnels exist but, not very common. Common ones or most often we will always be only intermittent tunnels. Now, when I look at intermittent tunnels intermittent tunnels there are several types blow down type.

I will come back to the intermediate on later and then, I have in draft type and I have pressure vacuum type pressure vacuum type, I have these three types of intermittent tunnels. We will look at each one of them. The main idea of these tunnels is primarily I have a test section where, I am going to put some model of interest and I want to have flow, that is of a particular mark number going passed it with the particular pressure and temperature conditions for that model if that is the case.

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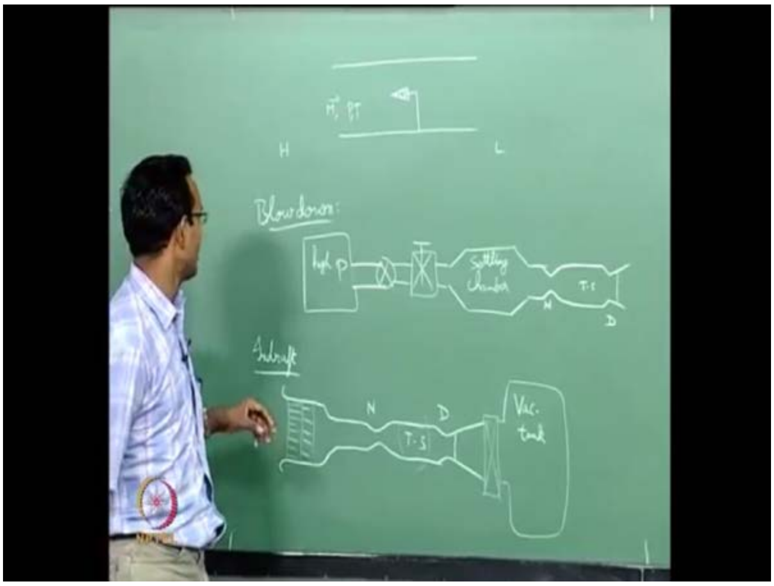

What I have to do in general? If this is my test section, I want to have a constant area duct. So that, things are simple enough nothing changes and I am going to put some model inside. Let us say, this is my model and I am holding it is somehow, we would not worry about this right. Now, we will come back to models in tunnels after this class. So, I am going to just look at this and I am going to say I need to have some particular mark number at a particular pressure and temperature going pass this. That is the main requirement of any wind tunnel. Now, I am going to say how I do this.

I need to provide a particular pressure ratio across it. So, the way I am going to think about giving a pressure ratio across this is to either basically, I need to have high pressure here and low pressure, here I can either keep this opened atmosphere and make this extremely low pressures or keep the outside as the exit has atmospheric pressure and make this pressure extremely high, compare to that all that matters is just I need to provide very high pressure difference delta.

P needed for this should be provided that is not enough, I need to have the particular area ratio such that for that mass flow rate it can achieve the correct mark number, and these are the requirements. Now, if I go look at blow down facility has a name suggest, it is just blowing out in one short and the pressure goes down and it is stops working the way it works. I have a high pressure chamber, from which I have an outlet and it has 1 on of valve and then typically it will have some control valve to control.

The pressure of the flow, that is coming out settling chamber if there is any fluctuations in pressure or velocity, all those will be less end if it is going through this 1 why that area changes. So, high that for this mass flow rate the velocity inside here will be very low, and for very low velocities turbulence does not exist.

So, it is almost laminar zed and the velocities. So, low disturbances will died on very first and after that I am going to accelerate it and take it through to my test section, with an appropriate nozzle in here, to get appropriate mark numbers. If I want a supersonic mark number then I will use a convergent, divergent mark convergent divergent nozzle, if I want only a subsonic say mark 7, mark 0.7. So, use mark 0.7, I just need a convergent duct probably I can still use a convergent divergent nozzle with appropriate pressures such that, I will get even for this subsonic conditions of the exit you know nozzle. Nozzle flow problem I do not need to discus that any more but, typically people use Seri nozzles for getting supersonic mark numbers.

After this, I just have to think about a diffuser at the end, this is going to be my test section things are not really drawn to scale. But, typically it has settling jumbler is bigger than the test section. That is how it will be diffuser can keep on going for ever it will be typically very long, I am not drawing it really long because, it just occupies the board.

So, it is something like this typically they think about exiting to atmosphere but, starting from very high pressure, I am providing the high pressure exiting to atmospheric pressure in this side that is a blow down facility, in this test section size and the mark number decides the throat and the pressure at which I operate. Will decide the mass flow rate through this and based on the mass flow rate and, the settling chamber pressure the P naught that will decide the run time of this facility, this high pressure tank will have some initial pressure say it is 100 bars and I want to operate with settling chamber pressure of 10 bars.

Then this can keep on supplying this pressure of 10 bar here, only up to a point where this becomes 10 bar, after that I cannot use this anymore that is where this is an intermittent facility. I have pumped in so much energy into this pressurizing this chamber I stored. So much energy P naught right pressure energy in the gas as stored. So, much of energy and finally, it is let in through this whole region P naught. I am controlling based on this valve or a regulator typically, it is a regulator in this point and from here based on the mass flow rate, if the mass flow rate is very high. So much mass is removed from here which means, the pressure will drop faster.

So, I will have a lesser run time if my mass flow rate is high. So, the test section size decides based on A by A star, here test section sides decides, the A star and P naught is something I want to said based on the pressure in the test section. I want based on mark number and pressure in the test section, I can set my P naught with this setting P naught and A star, I am going to get a particular mass flow rate.

I am going assume T naught as same as whatever is inside here, and based on that I will get my mass flow rate, that is what is deciding how fast am I depleting the pressure inside here, number of molecules going out of this. So, it becomes an intermittent facility based on that. Now, I will go for in draft tunnel immediately after this. So that you can immediately see, it has had very nice contrast. This is the other version that is I am again having the similar to this 1. There is a nozzle, here and there is a diffuser here and in the middle there is a test section.

Here again, I have a nozzle here, diffuser here and in the middle there is a test section. This whole unit is the basic supersonic tunnel. Now, how am I providing the pressure difference across this is? What matters you know, we discuss this double throat nozzle. What is really happening here is a double throat nozzle that is all it has. Basically it is a single C d nozzle, which is again having a bump here; it becomes a double throat nozzle.

We will come back to that discussion again anyways. Now, the way I am doing here, I am going to say atmospheric pressure. Here and I am going to have some grids to decrease turbulence, you would have seen such things in fluid mechanics, when we are discussing low speed tunnels typically, they have this kind of intake to decrease disturbances, outside and they will have this kind of intake very nice intake to have better intake efficiency.

So, here P naught is fixed value, which is our atmospheric pressure typically, P naught will not change much in this case here. P naught may keep on changing if my regulator is not working very well blow down facility here. P naught is decided by the regulator if my regulator is not very good and I am drawing too much of mass flow and the regulator may not keep up very well and.

So, the P naught may slowly change or it may be going up and down depending on whether it is moving continuously or in steps but, that is not the case here. P naught is a fixed value atmosphere, very difficult to change atmospheric pressure for us. It is going to be the same over the time scales of interest. The atmospheric pressure does not change at all and the main thing here is the pressure drop is given by low pressure. On the other hand I am going to have a huge vacuum pump. Which is going to evacuate this chamber finally, when I open this valve there will be suction from here into this whole thing and that creates the flow field and now you should know what matters is for this to get a shock.

Somewhere here, if I say I want supersonic flow, I do not need to have full supersonic flow all through till the tank all, I care about is the shock sits here, then the flow of where subsonic here went to choking condition here became supersonic went to slightly less supersonic and then as a shock subsonic. Here this is enough for my operation because what matters for me is only.

The test section region same thing goes here. We will never operate with fully supersonic, flow coming out we will typically have a shock somewhere here, that is the condition we will operate with and what are the advantages in disadvantages of these two, this is called a in draft tunnel because, now I am having flow from outside coming in and that is what is creating the flow field these are called in draft tunnels. Now, advantages and disadvantages vacuum tanks very safe. It is not going to explode at all its maximum pressure difference from inside to outside, is only 1 atmosphere that is a good thing about vacuum tanks.

While high pressure tanks may explode, there is a danger of this see whole thing exploding but, this is very easy to get because, most industries have high pressure tanks. So, very easy to get a high pressure tank than a vacuum tank but, of course, you can use this tank for vacuum it may not expand very well much more easy to get a high pressure tank. Why most of the industries work with high pressures? So, that is one thing we have to think about.

What decides the run time of these both tunnels, we already discuss this, and it is the mass flow rate the pressure in the tank versus. What we need and the size of the tank volume of the tank how much really the mass is present inside, if there is so much mass inside say 100 kilos of mass, and I am running it 1 kilogram per second. I can run it only for 100 seconds that is assuming, I can evacuate completely that is also not possible when it goes from 100 bars to 10 bars. I cannot use it anymore. So, I can use only 90 kilograms. So, like that is volume of this tank also matters same thing goes here. When there is so much mass flow coming here, that is going to fill this tank. Which is decreasing? The pressure is downstream. So, the delta P across is decreasing. So, eventually there will be a point where the shock moves more upstream, can happen that way that is also a possibility. Now, there is one more problem with this blow down facility where if I have really high pressures.

So that, I will get lot of run time, I am going to have the problem of if; I have a mass flow rate going through this there is a depletion of mass here. So, the gas here is going to expand when it is expanding. What is going to happen, getting colder, it is going to take up heat from here inside into this point. So, it is not really sitting at particular condition, it has to start cooling things that is one way of looking at it. So, my valves and the tubes are all going to be little colder this called the joules.

Thomson effect I believe. So that, it will sort happening that is one thing and if the pipes are very small and size you will have more effect of it. I have a case where I had icing on top of my stainless steel tubes. My data was all wrong because, my T naught what I assumed was room temperature but, that is not the case if there is icing on top of the tubes. So, you should careful about that also in there. If you look at cost wise which is easier cost wise it is. So, happens that blow down facilities are easier and that is why most common supersonic tunnels are blow down facilities. This one it looks like it is very simple but, vacuum pumps are not very cheap and to maintain this pressure you have to have really good vacuum.

So that, you will have flow for long enough time that is the next thing. Now, if I look at the pressure vacuum type supersonic tunnels. Actually I just have to say high speed tunnels nozzle can be anything still right need not be supersonically. What I am going to do is I am going to put a high pressure tank, for the high pressure here and low pressure tank, the vacuum tank for this side. So, this immediately tells me that, I am going to have much higher capacity for this flow to happen typically. What they do is, I can set very high pressure difference across here, that the mark number that I want to experience will be higher typically they use pressure vacuum tunnel for mark numbers above 5 or so, that will look like this.

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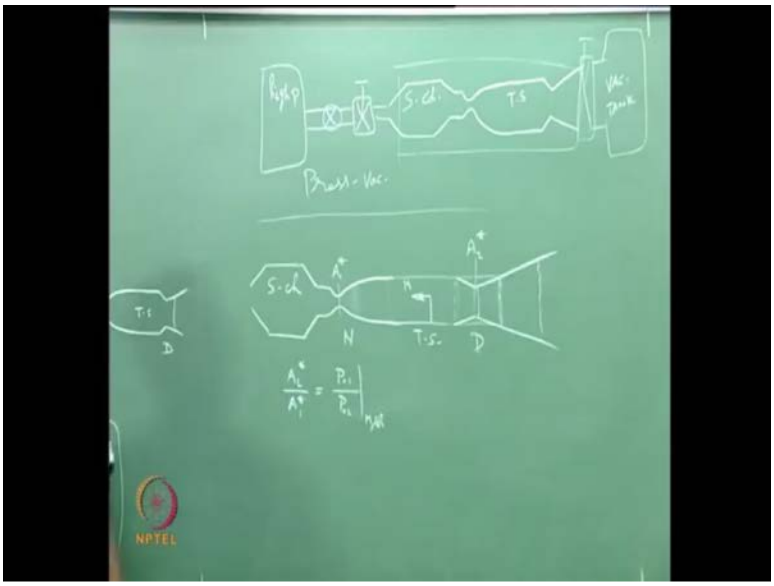

I have a high pressure tank, I have similar design. I have a regulator, I have a settling chamber, and then I have my nozzle which is going to produce whatever flow I will typically draw it a bigger size test section for this. The A by A star bigger to emphasis that is much higher mock number condition and everything else is similar. I am going tons have another system with control here and then a vacuum tank. I will have a vacuum tank on this side.

So, if we think about this is going to have both the positives and negatives of each of the previous ones, we discussed that is going to be special case in here. Now, I need to have a high pressure tank and a vacuum tank. So, I need to have a vacuum pump which is again I expansive and this is safety hazard all that together that is the bad points, Good points. Now, I can set very high pressure and the upstream side and very low pressure, on the low downstream side and eventually.

I will get lot higher capacity possible those are the advantages and disadvantages of these systems. Here if you want to, really no disturbances in your P naught values, you should go for in draft tunnels, which is a little more expensive that is 1 special case otherwise you can think about blow down facilities. Which are quick and easy to make and one more thing If I use high pressure tank to supply my air, which I am pumping into this for use inside this flow may have some oil vapors from the compressor, your hair may smell different if you go smell it, you ever see the facility then that could be a problem.

If I have in draft facility, that is not a problem because, now I am taking fresh air from atmosphere around. Now, the next thing we want to talk about, as operation of supersonic facility. Now, I want to worry about, what is giving the pressure difference. I will just look at the basic supersonic facility that is up to here settling chamber to the diffuser alone. How I said the pressures difference across, there I would not talk about anymore this is your pressure vacuum facility, actually I already wrote it pressure vacuum facility. Now, I want to look at only the basic supersonic facility. Which is I have some settling chamber some there I am having a nozzle followed by a straight section.

Which is my test section, this is my nozzle and after that I am having a diffuser and somehow I am setting pressure difference across this we know how to set it we have three different ways of doing this and if I want to think about putting a model inside. I am going to put some model inside and hold it somehow we will come to what models can be inside etcetera, some other class what we have to talk about A 1 star and A 2 star and let us say, I want some particular mock number in the test section M.

So, we already discuss the problem of A C D nozzle with another bump in the nozzle where we said that, if I want this not to choked I need to have a conditions such that this mass flow rate coming out through this, which is choked must be able to go through this one and I said that the area should be more than a critical value. We said that A 2 star by A 1 star the critical value is equal to P naught 1 by P naught 2, for that mock number shock, this was our condition we came and we said that if the area is more than this value, then it will not choke then it is safer.

So, typically if you are designing a supersonic tunnel. Now, you have to think about this area more than this particular value. This is the minimum area that is possible do not ever keep the minimum value because, in this analysis we did not take in to account P naught drop due to friction. If you have long test section your friction effect will be much more typically to avoid this problem. What they do is they make this nozzle, such that it is almost flat parallel towards the end and they put the model in here itself, then the nozzle itself nozzle. N point itself becomes your test section that is also people do for decreasing cost. People do that but, a more clear experiment should be when I have this straight section, where I want to make sure the mock number is constant, everywhere that is better but, my assumption is not true if I say friction is not here, friction is present if I take into account friction present, What should I do as I go here, I am going to have P naught laws. So, my mock number will go towards M equal to 1, If I started with M equal to 3 here, say nozzle is M equal to 3, it may end up with M equal to 2 at the end if my nozzle is too long in that situation.

What should you do, since it is supersonic flow I will use area divergence, I will make my valves expand a little more. So that, my mock number from here to here will be constant that is a next special case and you can exactly calculate how much should be the area divergence. So, it is for that particular mock number for the particular friction factor F and the hydraulic diameter B for your test section etcetera. You can calculate and put that value and you can measure the mark number and it will be almost the constant whatever you expect that is possible. Now, I have to talk about starting of this tunnel how does the tunnel start I am going to apply P naught and I am going to apply A P B.

We will apply it, such that we know that the flow will start very nicely. So, we will go through look at our nozzle flow problem again. What will we say as P naught increases, keeping P B constant they going to have fully subsonic flow all though initially and this is the smallest area point. So, this is the first point which gets choked, after that it will be choked. Then subsonic fully after some time there will be a shock that forms which people called the starting shock. It forms somewhere as in it starts from then throat and keeps moving downstream as I increase my P naught, if I keep doing this the shock keeps on moving, more and more downstream go to this point.

Next and this will be gone and eventually we will go pass your test section, and it will go sit here, if I increase my P naught some more from here. It has to go to a higher area than this. So, the next higher area is sitting fast this point. So, I just shock may go there which is higher than this particular level and from there, if I keep on increasing P naught it may go and sit even further downstream, that is also going to happen. Now, if I think about tunnel starting this is the actual process I just went through a full starting of tunnel when the shock cross my model immediately.

I have supersonic flow, here why can I just keep my shock sitting here, if there is any perturbations it will jump in, I do not want that situation. So, we will push it to the other side where it is extremely stable in the divergent section. We already talked about this shock is stable in the divergent section.

So, it will be typically we will put the shock in the divergent section and we will leave it. Now, if I think about how much energy am I wasting on this, am I efficient enough if I put my shock here mostly likely no, because I am having much more higher P naught than what is required for minimum operation for minimum operation all I need is may be the shock should have gone from here to here but, think about it I have given much more than that which means, I am wasting more energy where is the energy going finally, it is going as a higher velocity z at the exit. I am wasting the energy in the form of kinetic energy of the gas. So, I do not want that to happen what will I do, next I will decrease my P naught may be I will come here and that is efficient enough yes but, now I see if I decrease my P naught further the shock is not going to jump to the test section. This still sit here because the area can be even lesser it is still in the divergent portion of the diffuser. So, what will happen this is your diffuser writes I did mark it the second nozzle is your diffuser.

So, I can make it operate which shock somewhere here just downstream of my second throat, if I keep it operating here still the shock is sitting in the divergent section. There is small perturbation nothing will happen, it will not jump in, it will still there it is stable enough there it stays there if I give a huge perturbation off course, it is going to jump in and immediately it will go and sit with some other area similar to that which will happen probably somewhere here. If I give a huge disturbance it is going to jump here. Now, I have to increase my P naught very high. So that, it goes pushes the shock all the way back to this point till that I am I have to operate. Now, they will think about some safe operation point where it will never jump into the test section. So, they will tell that the minimum needed is this value P naught, I will operate say ten P S I above it. Something like they will operates slightly more pressure than that. So that, they are having a safety margin side this is typically the way a supersonic tunnel works, they will keep it such that the shock starts and goes that side if you are not worried about too much of run time we would not worry about bringing it back, because while you are thinking about bringing it back and closing a valve you are wasting so much of mass flow rate. Now, your run time become even lesser if I want to worry about run time being long enough then I will do this quickly.

I will go the section from here, the shock from here jumps out of test section into the diffuser divergent and I will pull it back to just before I just downstream of throat and I will keep it there. Now, I will run it at most efficient situation for how much ever time possible should I always worry about, this particular thing not always why by the time I adjust this, if all my mass flow rate is gone from the tank. It is useless to do this adjustment instead I will get some time without adjusting, that is the typically the trade of people used and I have seen tunnels where there is no second throat also where they just put a straight section and a divergent portion I have seen tunnels like that also, where I am not really worried about efficiency. I am just going to push the shock into there and take data inside this is the actually an extended nozzle, if we think about it just A C D nozzle just a straight portion in the C D nozzle and then a divergent portion again. That is all I am having even that will work, I have a straight section where I know my mark number is going to be constant and I will use my model in there that is could enough in fact, in our g d lab and i i t m we have one such facility for mark two where we do not use the second throat in there all the time.

Now, if I think about delta t of running if I have a second throat then my P naught will be lesser if I bring my shock to this point P naught will be lesser and my run time increases why my mass flow rate is decided by the P naught and my mass flow rate is less. I am not evacuating all the molecules from my original high pressure tank. So, I will get run time a little longer or if it is in draft tunnel, I am not going to fill that downstream vacuum tank with lot of molecules if mass flow rate is lesser. So, I get higher run time. So, typically you have to think about mass flow rate really but, people really talk about P naught and area of the test section and the mark number actually if you think about all that. It just comes down to M dot inside here, M dot and the tanks supply pressure and the tank volume those are the primary variables for our run time. Now, we will go back to our shock tubes again this is one way of creating high energy flows.

Next we will go for I will just draw the end of the shock tube.

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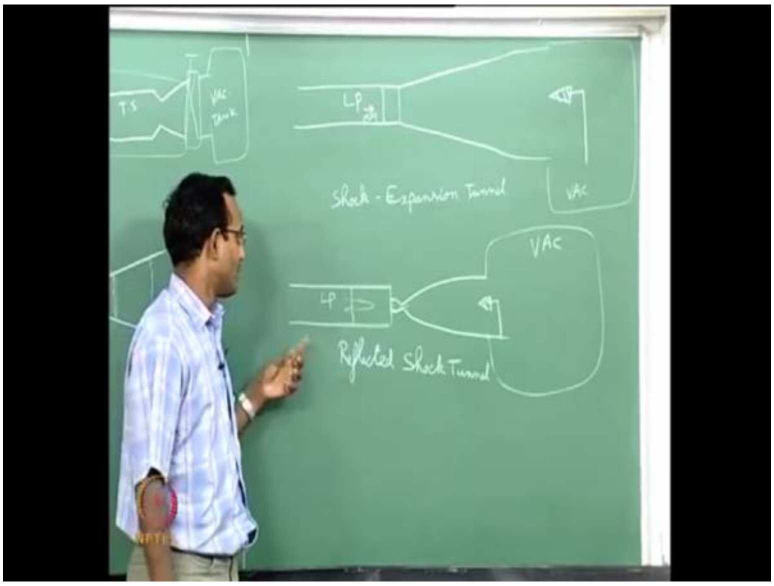

This is just the low pressure section of my shock tube, we know that if I extend that side I will have a high pressure section diaphragm from and the low pressure section everything whatever we did last class. Now, we know that in a shock tube when a shock is coming this way behind it. The flow is typically supersonic of course, I can make it subsonic also when the pressure difference P 4 by P 1 is not very high, then it may be subsonic flow also behind it but, typically we will have a case where it is supersonic flow behind the shock, then when the shock is coming here, flow behind it has M greater than 1 and all these flows having exactly the same mark number neglecting viscosity, neglecting friction, we discuss that last time in it, if I have such a situation.

Now, if I put small diaphragm here, actually not small diaphragm I will put a thin diaphragm here which can hold low pressure difference across this but, not the shock post shock pressure and what will happen when the shock reaches here immediately diaphragm experiences fluids pressure difference across here and diaphragm ruptures typically people use thin plastic sheets, there we use thin plastic sheet, once side is very high pressure, other side very low pressure. It just gives up it cannot stands there it will be like a balloon busting and immediately downstream operates, if I put a divergent duct what will happen I have flow behind a M greater than 1 and I am putting a divergent duct. I can expand the flow further to even higher mark numbers and typically.

If I curve it, such that it becomes parallel for some time I can put my model here and say that. Now, my flow experience by this is going to be that high mark number based on the area ratio you guys know how to calculate this already. So, you can find that mark number here and that particular mark number will be flow situation here for all this to happen of course, you still have to think about what should be, the pressure here it should be low enough if you do not have low enough pressure things are not going to happen right. So, typically what they do is in this kind of a facility they will have the model in a vacuum tank and the end of the shock tube. Now, going to have a expansion nozzle expanding nozzle. So, this whole flow facility now together is called a shock expansion tunnel. Basically, it is a shock tube and now the flow behind the shock is the expanded further to get to whatever mark number you want typically they use this kind of facilities for really high mark numbers something like hypo sonic flows seven, we have a hypo sonic flow facility.

Where you can go all the up to twenty five mark of course, it just depends on what area ratio I use beyond some point. I would not believe the data because it may become non-continue then I have to think about it. I can make a nozzle for hundred also mark number but, at that point the pressures are so low that it may be become non-continue. Then I have to worry about is my data really value we would not worry about that right, this is one particular facility shock expansion tunnel is basically at the end of the shock tube. I do not have a solid wall but, I have thin membrane which will break when the shock comes and reaches there and of course, for it not to break initially I should had the same low pressure at this side. So that, the pressure across the diaphragm is 0, there is no difference across the diaphragm that is what we should have. Now, I will draw one more case, this is again the low pressure section of the shock tube high pressure section is somewhere to the left and this time I do something different I have a small hole in the end wall and put a c d nozzle from there and again.

I put a membrane here and again I maintain two different pressures similar to the other one, where it was just expansion here. It is what I call it that convergent and divergent in here. So, I have a shock that is coming here. Now, I design this diaphragm a little stronger I am going to say it will not break for the post shock pressure here but, it will break for the reflected shock.

Post shock pressure the P 5 it will break, I will put it a little stronger. So that, it would not break for P 2 and this value but, it will break for P 5 and this value. So, the shock comes this way and then it goes back and the shock goes back reflect it that pressure is too high for this and. So, what I have essentially done is created a very high pressure, very high temperature gas stagnant gas here. We discuss this at the end of shock tube which stagnant gas, compressed gas and essentially there is a nozzle, C D nozzle basically it is like our test section any supersonic flow I have created the high pressure here and I am setting a low pressure based on a vacuum tank on the other side and basically I have a flow inside, this is my vacuum tank. My model will be sitting somewhere here something like this model will be sitting inside here. Basically, I am now provide high pressure and low pressure for the flow to happen similar principle has everything else just that the high pressure and low pressure high pressure is created by the shock tube that is only special thing here, low pressure is till the vacuum tank. Now, what is a main drawback of this facility compared to the other one which we used high pressure tanks what is that pressure in this one.

Pressure can change, that is not the main thing I think why did you say pressure will change, because of the shock I want to come to back after some time the pressure changes because the shock may reflected the contact surface and come back or expansion may come back after reflection at the contact surface because of this your run time comes down that is the main difference in intermittent facility is with pressure tanks. The run times will be the order of few seconds, few tens of seconds probably or facilities are operating up to twenty seconds or twenty five seconds around here.

The times will be the order of few micro seconds or few hundreds of micro seconds, maximum one millisecond or so that kind of times. It is extremely small times and what decides these times of the run for shock tube for run times here. It is not related to the mass flow rate through this nozzle anymore because after some time I do not experience was same P naught and T naught. So, it has nothing to do with mass flow rate anymore of course,, there is a special case where the mass flow rate is so high that this gas is depleted that may happen that is not the most important thing typically it will be the pressure and temperature P 5, T 5 here. It may not be the same anymore, after sometime the reflected shock will interact to the contact surface and come back as a shock or expansion and disturb this gas again that is typically the case. So, if I have to think about if I want to think about the run time.

If I want to think about the run time of this particular shock tunnel this is actually shock expansion tunnel, this is actually a reflected shock tunnel, if I have to think about run time of reflected shock tunnel and or a shock expansion tunnel. How will I increase this first thing I can do is tailoring of the shock, tailoring of the contact surface from the reflected shock. I can do that, second thing is I can make the if I tailored then the only thing that disturbs it to decrease the delta t will be the expansion way, that goes all the way to the other corner in the high pressure section and comes back right we did that last class. So, when it comes back it will come back if the length is very short. The length is very long my tube my whole shock tube is really long.

Then I will have that much longer run times but, even then I am not going to have few seconds or so it will still be in milliseconds only. It will never be going to seconds of time or run times I have seen photos of long shock tubes you can also see on the lab. So, everything is available lab there are big research facility is where these shock tunnels will run half kilometers or so filing that kind of thing it is possible to make something where you will get much higher run time probably few milliseconds, may be milliseconds also that kind of. So, length of the low pressures section to high pressure section, those also matter, those are all important parameters.

If I want to do the test in a particular gas, then what matters is how much time the contact surface is going to take to common reach. This corner once the contact of surface comes and reaches this point it is no more, the same gas that is flowing through this. It will be something different. So that also cuts down my run time, lets one more thing I have to worry about if I have special gases, that I am trusted need not always be the case as of. Now, we have discussed so many high flow rate facilities, high mark number facilities, which are like blow down facilities. I told there could be at the close circuit facility for supersonic flow but, I did not discuss that really we have blow down facility in draft facility, pressure vacuum facility and then we said shock based facilities, reflected shock tunnel or a shock expansion tunnel we will discuss in the other way. These are different facilities that are possible people use all of these in fact in g d lab. we have the same shock tube but, it can have this nozzle at the end of it or it can have this nozzle at the end of it going to the same tank, vacuum tank and that will change the what type of tunnel it is either it is shock expansion tunnel or a reflected shock tunnel just decide the based on that and of course, you have to use the appropriate diaphragms for this. The diaphragm used for this is just a thin cellophane sheet and this one is two layers of cellophane tape that is a kind of thing we need to use just a little thicker.

Why it breaks for higher pressure typically whatever packing tape we use that kind of tapes are good enough for this as a diaphragm the next set of things that we have to discuss or not pressure based. Of course, whatever we discussed here this and shock tubes based wind tunnels, they are all pressure difference giving energy for the flow.

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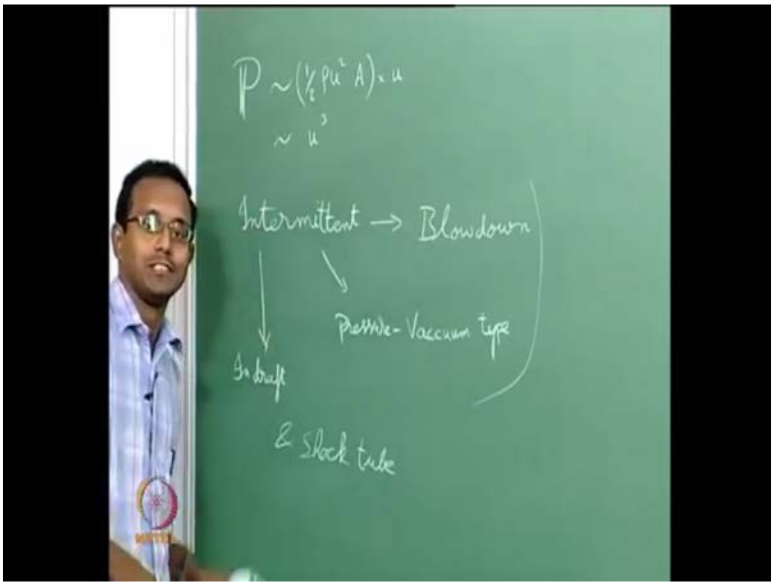

There are other facilities where it can be a mechanical piston giving driving the flow that is one possibility giving energy to the flow or it can be comb us and driven or it can be electrical heating driven but, of course, eventually it is all going to create the pressure difference across the nozzle for the flow to happen how am I creating the pressure difference is. The main change here blow down facility, I create a high pressure tank and the atmospheric pressure in a draft tunnel. I am going to say atmospheric pressure and the vacuum tank here, it is high pressure and vacuum tank in shock tube I am creating that high pressure high temperature gas that is being used here. The next set of things, we need to discuss, we will have pistons moving and combustion driven and electrical heating driven I do not think I have time to start any of those. So, I will stop for today any other questions you have see you people next class.