Gas Dynamics

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Module - 18
Lecture - 45
Compressible flow facilities

Hello, everyone welcome back we stop that using delta p for generating flow and for whatever mark number, we just talked about, the basic supersonic tunnel and if it is a subsonic tunnel the only difference will be that it need not be a conversion diversion nozzle it can just be a conversion nozzle that is the main difference. Now, from there we want to go to other intermittent facilities, which may also be used for studying fleuron bodies for high mark numbers. Till now, we considered all the flow facilities they are the related to tanks storing pressure energy of the gas, either it is negative pressure or positive pressure its storing some energy in the gas and that is used for creating the flow. Now, this time there is something else which is going to give the energy to the flow.

That does not mean there is no pressure involved there is still pressure involved there is still going to be finally, the pressure is on which is going to create the shock, and that shock starting shock has to go through your tunnel for you to get the supersonic flow behind it that is supposed to happen. But, the way we created will be slightly different we will look at the other variants today. The first thing I want to do is mechanical piston drive, this is going back to the basic way of creating a shock which we discussed.

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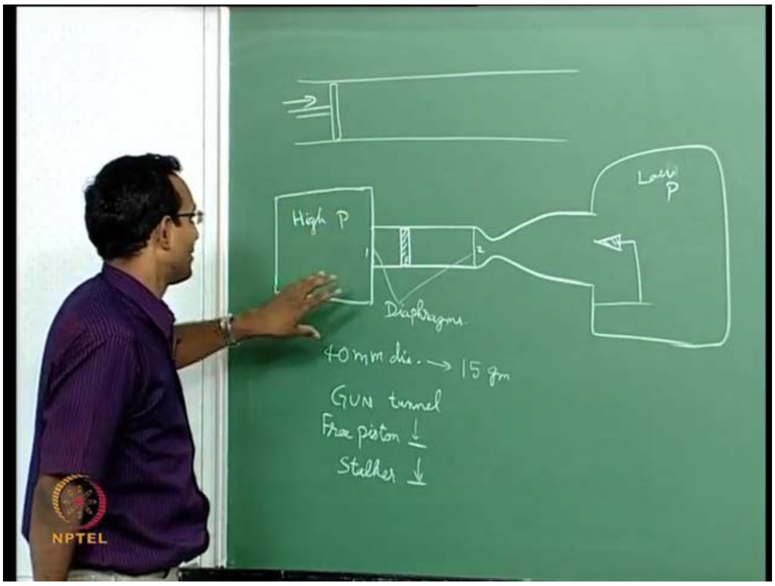

When we talked about, I have a tube and I have a piston and the piston is moving this way if it moves into the flow this is going to create a shock, that is our basic idea and want to I believe I showed you animation also on this long back. We just push this and that is going to create a shock going through and behind that there will be a flow which could be subsonic supersonic depending on the mark number of the shock, or the depending on the piston elastic the piston is going supersonic you will get supersonic. This is one way of looking at the problem, but this is not going to help create a flow facility.

So, it is going to be the flow facility which I am going to talk about, is a piston driven facility, but it still has a high pressure tank again it looks like a high pressure, low pressure ordinary wind tunnel the main difference comes here, when I put a piston inside here. I put a thin disk in a tube circular bisection and I am going to have a diaphragm here, this is a diaphragm and there is a second diaphragm here, this two are diaphragms. Now, let us think about what will happen if I break the first diaphragm let us label it 1 and 2 if I break the first diaphragm what is supposed to happen it is going to feel the pressure difference across here.

I am assuming that the pressure in here is something in between the high pressure and the low pressure in the tanks something in the middle. And when I break the diaphragm 1 somehow, I it is like a balloon and I break it and there is no more of that material sitting there, if I imagine something like that suddenly this lower pressure gas is experiencing a higher pressure gas it is a local shock tube if I think about it this is a very short length shock tube. What will happen there will be a shock created and that is going to go to the end. And now, I am going to say the end wall is not actually a fixed wall, but it is a piston, the shock will go bounce on it and come back right like any other thing immediately after it bounces back what is going to happen the pressure behind the reflected shock is so high, on one side of the piston other side is still the same original low pressure.

What is going to happen because of that the piston experiences the net force this way the delta P times the area of the piston that much force is being experienced and if I make sure that the fiction between the piston and the tube is very small that is I am calling it the free piston. If I have a free piston then, it is just going to be accelerated very fast because there is very dragged, is only force acting and there is nothing to resist it.

So that will be a good acceleration if I think about, mass being very small for the piston all the force is now converted to mostly acceleration mostly velocity kinetic energy. If I think about, that way it is a light weight piston with almost 0 friction it can never happen that there is 0 friction. So, there will be some friction if, the friction is really small and it is very light weight piston if I have such a system.

Then the piston is going to move extremely fast alright, I used this pressure difference to create a high pressure locally here, and then that piston moves very fast and because of that piston moving fast. Now, I am going to create another shock that is going to go this way, is this shock going to be stronger or was the original shock stronger. first one let us say, diaphragm one breaking that will create a shock and that reflected and it came back and the light weight piston is travelling with some velocity and that is creating a shock which one will be stronger is the question. What gives the energy to the second one? this piston movement what gives energy to the piston movement the first one which one will have more energy the first one in theory it will be the first shock that will create more then why do we use this.

I just remove this and that shock can go and hit this, then that becomes your reflected shock tunnel that you already know that is one design we already have talked about. If I have a piston there is something special that will happen now. That is why the piston is there now, this shock develops and when it reflects back when this wall starts moving there will be expansion fan going that way and killing that compression reflection back. So, eventually this piston will start getting force from this side also this high pressure will start pushing the piston also, but it got an initial momentum this way and it is moving in.

While this is moving in, what will happen on this side there was a shock created now I will say this diaphragm is a little stronger and it can hold a little more pressure difference across what will happen it will go bounce come back, when it is coming this side the flow on here is 0 velocity, but the piston goes and attacks that shock now right. So, now, the reflected shock will be even stronger than a straight sitting wall and the shock comes and reflects on it right. So, what is going to happen?

I am accelerating the shock even faster the reflected shock is going to go even faster and if I, wait for it some 2, 3 iterations of this reflection I can create really high pressures here. But think about it, how much test time do I have? Only this much, why do I say that the piston will be moving in after sometime and that is the actual compressed this gas that I have and I finally, break this diaphragm basically if the pressure reaches such a high value that the pressure difference cannot be withstood by a diaphragm it breaks and immediately the flow is expanded through this nozzle to get whatever, mark number and temperature and pressure we want that is the overall idea.

Now, I am going to say one more special thing about this, now I can choose my test gas to be anything and I do not need to fill the whole chamber of the high pressure with that. Now, I need to fill only this chamber with it, that test gas let us say I want have a crazy test gas of xenon with iodine or something like that some crazy I do not why I chose that combination something I just chose something fluorine and xenon I guess something like that, I choose some crazy gases inside that will be very expense to fill this big high pressure chamber with it. Fluorine is a very reactive gas stupidly much more difficult to store fluorine we do not want to do that in high pressure even; instead I can fill only this region this is nominally average pressure probably closed atmospheric pressure, storing that is easier.

And I do not need to have a huge amounts of huge volumes of gas is easier that is one good thing about this tunnel. I can use special gases if it is just air I do not need all this I just use a shock tube and shock reflected tunnel is better than this problem. Now I will thing about; what should be the size of this piston? Typically people use something like 2 to 3 inches I have one information from one of the tunnels it is having a 40 mm dia and the piston weighs only 15 grams light weight disk. But, the disk should be such that it does not topple and fall down like your carom coins right, we do not want that to happen it should be still sitting there it should be thick enough that it does not go topple and fall straight I cannot make it a very thin disk it has to be having some thickness, but still light weight.

They can of course, use low density materials it is not very difficult to do. Since I am reflecting this several times across here, shock is reflected 2, 3 times I can create very high it is no more P 5 and t 5 as in a reflected shock tunnel it is probably like t 8 t 10 or whatever, some very high number it is going to reflect each time we will have to keep numbering them. Eventually, it may become t 5 will become t 7, 7 will become 9, 9 will become 11, something like that may be t 11 and p 11 can be very high and I will get very high P not and t not. In case I want to do experiments with very high P not and t not I am going to use this. And then that will capture this and I am going to start with that and go to this condition, reflected shock tunnel is not that capable of doing this because I am reflecting just once the pressure jump and the temperature jump may not be very high that is one better thing about this tunnel and the second thing is I can use some special gas and I do not need to store it for a really high values, high volumes of this.

And if you think about, after the diaphragm breaks its exactly same operation as your reflected chapter nothing new, this particular tunnel is called gun tunnel or free piston tunnel or I believe the based on somebody who first thought about it, stalker tunnel different names I believe currently people use only free piston tunnel has the name for these are various names given to it.

Now, we will go for something slightly different from this. I can think about, the same free piston facility, but high pressure being created by a combustible measure which is ignited suddenly. Right it is constant volume combustion there is a tank which has high pressure high temperature gas which is combustible and I am going to ignite it. So, it is a fixed volume tank.

So, the combustion will be constant volume process if I add heat in constant volume it is going to create even higher pressure than at constant even higher temperature and also pressure increase that situation. And eventually I will go to, high pressure high temperature gas and that can rapture that diaphragm and that can hold the whole facility. Now I am talking about, another mechanism which creates the shock. first initially last class we discussed only pressure difference crossing the flow. Now, we said a piston moving can cross the pressure difference now; I am saying combustion can cause the pressure difference I do not need to have a piston if I think about it. I can just have.

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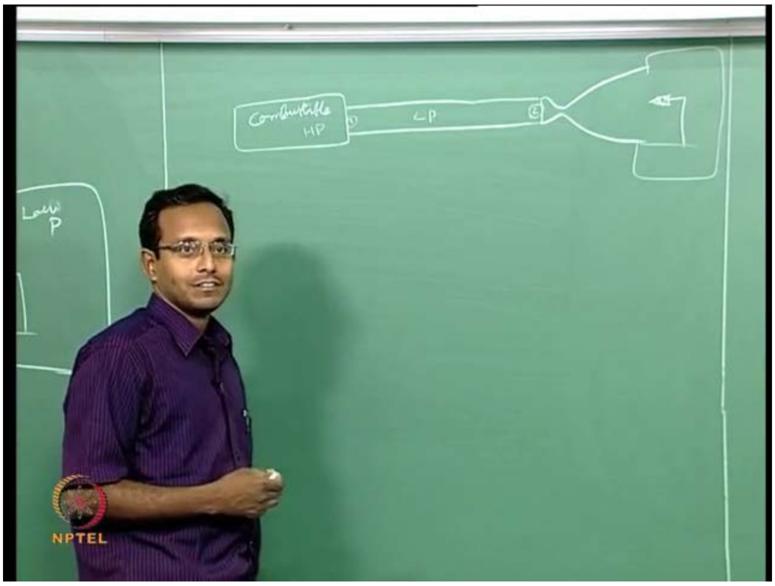

Let us, draw that picture again combustion driven reflected shock tunnels if I have a facility like this, and I have my model sitting here. If I have such a facility of course, here it should be in a vacuum tank if I have such a facility. I am going to say combustible measure combustible measure. This is your high pressure chamber, this is your low pressure chamber like regular shock tube first diaphragm, second diaphragm. This is a simplified version of reflected shock tunnel if you think about it, except for my high pressure gas is now a combustible measure which is already I had a pressure and temperature and I ignited. When I ignited suddenly the pressure becomes even higher and it raptures that they are diaphragm because of that and then that causes a shock that goes and reflects back remaining operation is same as your reflected shock tunnel. This is one way of doing it, the other way of doing it of course, is putting this driving mechanism with the free piston tunnel.

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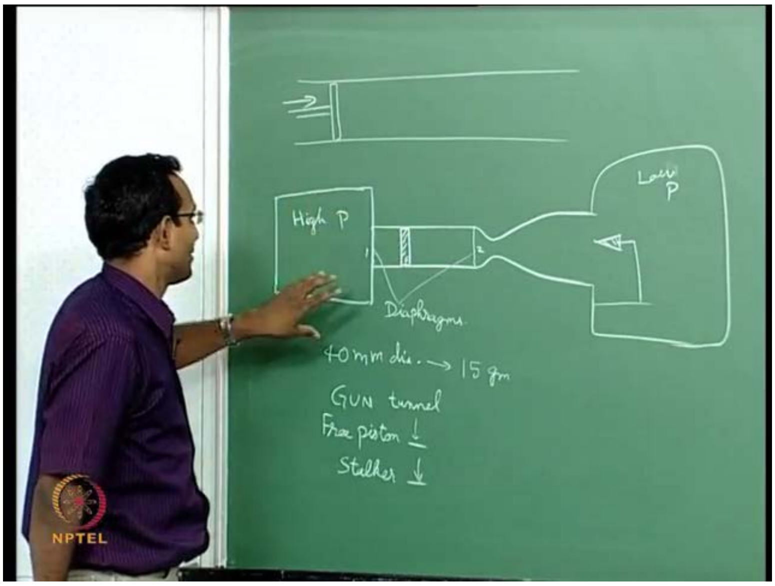

Then I go back to this picture and I will say here, I will put combustible measure. T hat will create higher pressure and temperature that will rapture the diaphragm 1 and then it is going to operate like a free piston tunnel. That is also a possibility when it will become combustion driven free piston tunnel.

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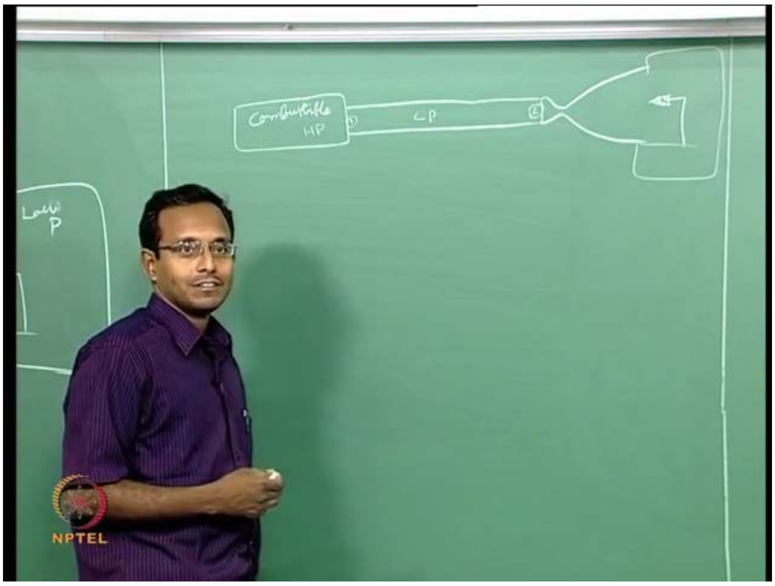

While this problem is combustion driven reflected shock tunnel. We have in our GD labatitium combustion driven reflected shock tunnel. Which I already told you, can also be modified to become shock expansion tunnel that is just something do with this nozzle alone that is easy to do. Now, if I think about what are the advantages of this? I can go for higher P not and t not of this, for the same pressurization of the gases because locally I can create even higher pressure than what I can get from tanks. If I get combustible measures in tanks that will probably be 200 bar or whatever. Now, this can be even higher if I want to create, that is an advantage here, but it is a little more complex now I have to think about and I have to start this tunnel. I have to think about have I created the correct measure is it really combustible is it at the correct pressure.

So, that the diaphragm will break will the diaphragm break braked before the ignition happens, all that details have to now to think about it. It should not break before the ignition happens, but it has to break after the ignition happens. So, the diaphragm should be calibrated better like that there are more complexities, and it is actually a bomb think about it. It is actually combustion combustible measure sitting inside a tank and I am igniting it, if something goes wrong it is a safety hazard I am actually creating a bomb inside except for its a controlled bomb. So, that it explodes only through this direction creating a shock that side that a way to look at it.

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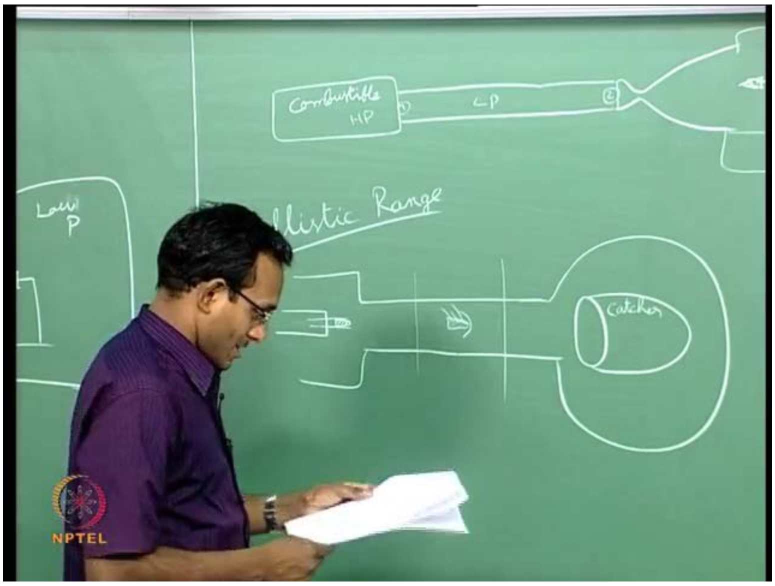

So, it of course, has some drawbacks, but it can create higher enthalpy flows it is called a high enthalpy facility also. Now of course, we go back to even earlier stages where there is much more basic way of creating floorer on the body at very high speeds what do we do? We just makes the body travel very high speeds into stagnant gas that is a best way to do it. How will I create a body or how will I make a body go at very high speeds? Shoot it.

So, what I am going to do is the next facility is called a Ballistic range. Ballistics is related to bullets, guns whatever they are all ballistics we are doing ballistics basically, what they are going to do is practically have a chamber and have a cup like a precept tattle which is soft material this is called a catcher and in here, you cannot have a cannon or a gun or something with the projectile which I want.

I will have some model typically, say I want to have a missile for body which is supposed to be travelling at mark 4 or something, and I want to test it. I will make a bullet of that shape exactly and I will have some explosives behind it, or not even explosives just have a high pressure gas behind it and have a diaphragm which raptures or lemon locally there will be a shock created and instead of a free piston it is going to be the bullet that is going to fly.

Now, the bullet is accelerated crazily and that is going to fly through this region, when it comes to this particular region now I will start taking measurements inside here. Typically if I want to think about, flow visualization ill start looking at flow visualization in this region. I will take photograph when the diaphragm when the bullet comes in here, like that if I do that then I am going to get when the bullet is here. I may get a shock around it like this, and that is our study I wanted to see what the shock pattern looks like on this body then I will look at something like this is how it is going to look if the missile for body looks more like our agniee missile. Then it will start having a lot of steps on it then it will have different patterns on it, and I want to study that that can be done with this miniature for body model with explosives behind it shoot it at the correct mark number.

Then, you get to this what are the things I need to worry about, it should not go and hit anywhere else other than go into the catcher which is probably a foam or some thermo coal kind of soft material you just take it. And then, you go cut it and take the piece from inside, next thing I need to worry about is the explosive chart just right enough to get the correct mark number at this point, and is the gas in this radius stagnant all the time or at least during my experiment is the gas stagnant. Only if the gas is stagnant then I will get the correct mark number based on flow velocity. Those are things I need to think about, and also I have to think about, am I setting the pressure and temperature at this section the test section correctly to whatever we want that is one more thing we need to think about.

The problem with our regular supersonic tunnels is when we work with our kind of P not and t not then we go to say mark 3 the pressures in the test section are not regular atmospheric pressure conditions they are lower they are probably like point 1, point 3, point 5 kind of bar values, point 5 atmospheres point 2 atmospheres that kind of pressures.

But, in these facilities I can maintain it to be atmospheric pressure already existing air around in here, and just shoot this bullet as long as the flow is very stagnant in here my experiment will be clean. Other problems could be there was once small burn or dust sitting on the target here, because of that the bullet is not going to go straight, but it is going to have ogling it may have errors like that. This was very popular long back if you go and see some old papers where they are doing this study they will be doing with ballistic experiments, where they will if you go and look at some shliren old shliren photographs they would have done shliren around a bullet you will see that the experiment was done exactly this method ballistic range experiments.

They would have done that, the good thing about here, is there is no support for the model which means there is nothing else which is going to obstruct the flow in the other cases. I have to hold the model somehow say for example, if I pick this one this is going to be sitting here, and it may obstruct my flow after sometime that is the shock goes through and then it is going to reflect back and may be its going to have some effect here. There is no such thing in this particular flow and I can calculate the exact drag on this body directly by keeping track of how fast is it travelling through this point.

If I have a set of points like this, and I just mark on this and take a video of this it will travel very fast here, as it goes because of drag its velocity is going to decrease. That directly tells me the velocity has a function of time which tells me deceleration which gives me the drag immediately that is one more information I can get out of this directly. While in the other case I have to put lot of pressure transducers on it, to get my pressure loading and I even if I do the pressure loading based drag I am missing viscous effects. Here it is absolute this is the truth, directly it is going to give me viscous effects at that pressure and temperature if the mark number is also correct then you are getting good information.

But, problem with this will be am I going to get the drag at the correct timing. So, that I will get the drag at that particular instant of course, you can you could do some analytical work to get to the point where I need, so much energy in this explosive. So, that I will get to that point can be done not very difficult people have work done this already. But, if I think about say I want to measure pressure somewhere inside there is no way of measuring pressure on this body currently of course, now a days we have modern instruments people go back and do this now radiometry is there. So, what I have to do is go put a sensor with battery and etcetera inside it is going to send information through electromagnetic waves out like radio waves we are going to send it out and even collect it. That is the next thing people are again using this now days.

Because it is now, having a new use for it people can use it this way also, but if I want to think about repeating the experiment. Experiment can never be repeated, I cannot do the same thing again and again the next time when I shoot the bullet even if it is the same bullet and it is not damaged by the catcher if the shape does not change at all, even then when I put it back and fire it the next time may be the explosives not exploding the exact same pressure may be slightly less or slightly more whatever.

So, I am may have some variation if I was expecting some particular drag at this point now, the same drag may happen a little earlier or little later. It is not going to be exact repeatability, but you can work around it if you know what is going to happen you can think about it, but you have to now think about it. In the other experiments model is fixed. So, when I say repeat if I check the pressures are same not number as the same and I can repeat the whole thing that is easier for us that a little difficult in this particular facility. Now, there is one more special facility till now we talked about; energy for the flows given by stored pressure moving piston combustion and this explore some ballistic range is also either stored pressure or combustion one of these two. Now we will give one more electrical heating.

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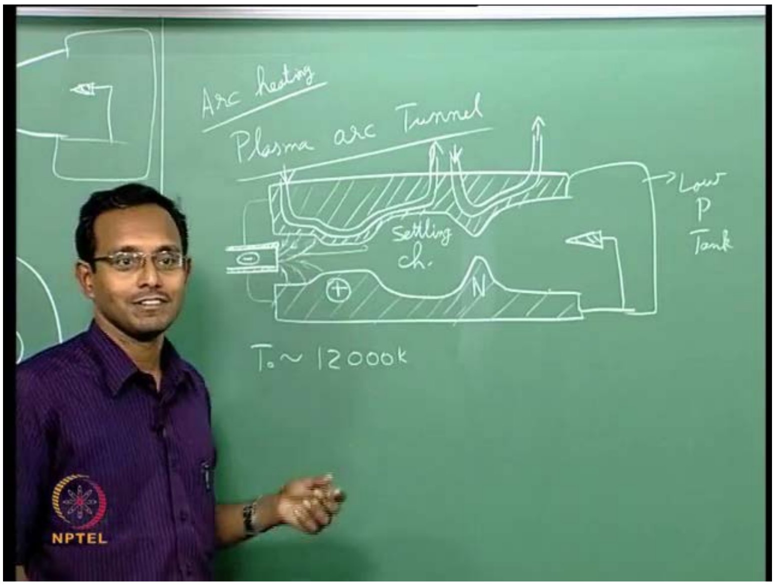

It is not simple electrical heating; it is Arc heating. So, it is actually called as Plasma arc Tunnel previous thing is called ballistic range. So, it looks like this actually throat should be tight some seedy nozzle. And I will have a model sitting somewhere like this. Now, I will draw the remaining portion of this, do not finish this i will come back and draw something, but I will just tell you, the principle basically I am going to have say an axisymetric body here, and it is going to be considered as a positive electrode it is not completely blocked positive electrode it is going to have a straight hole through the centre this positive electrode this negative electrode. And now, I am going to say the negative electrode is shielded on the sides with some insulated material. So, that only the front portion is going to send the electrode electric field. If that is the case, electric field will typically go like this. Actually I am drawing the arrows the other way arrows go from positive to negative typically something like this.

So, what I am doing is I am concentrating all the electric field lines here, it is going to create lot of electric field strength which immediately breaks down to gas, through ions and the electrons and that immediately going to cause lot of energy dumping into the gas. Why a ion is the gases, which means I gave some energy into the gas to knock out the electron from the molecules of the gas. That is one way of dumping energy other way dumping energy is those ions now, going to be moving electrons ions neutral molecules everything is going to be moving because of high temperature and now I am going to say they predominantly are going to go this way. Now, if I say actually I am not allowing it to go out anywhere it is going to be closed on this side.

So, it is going to go only this side now I will say, it is settling chamber here, and this is my nozzle and after the nozzle I immediately have a model and this is my low pressure tank. I have this particular system let us think about something like this, simple enough supersonic facility I am not having a diffuser in this case. I have something like this is my flow facility. Now, I have to think about one special thing because of Arc heating this electrode gets too hot. So, now, I need to have cooling tubes through this. Now, I am going to have some coolant in and coolant out. I do not want to say the coolant is water really it need not to be water. In fact, most likely it is not water because of high voltage, some coolant in and some coolant out and that is going to be cooling.

This whole block of course, I should put the same coolant on this side and I am just going to put hatch instead, you know that there is coolant of the whole block and its axisymmetric block. This is going to be your facility, what I am doing is essentially creating some kind of high pressure high temperature zone locally and that is going to be your source overall that is going to go to the settling chamber become a little more uniform flow and then it is going to go through this throat and get out through this direction.

If, I have create dump enough energy into this region and created very high pressures and temperature then, this can be used as a source for my flow field and I should set my low pressure really low enough that my Pb by P not for my nozzle works in favour of creating a supersonic flow in here. So, I have to set my pressure appropriately to get the required flow. Typically in this I can create T naughts of the order of 12000k quite high, the drawback will be its not going to be a neutral gas that is going to come out it may have some ions and electrons in it. Which means my gamma value will not be simple. Now gamma value will be changing, if my there are molecules that are becoming ions then I am going to have gammas that gamma getting lower. Gamma will get lower which means, I am getting more compressible I am going to have more compressible gas plasma sitting inside that will start happening.

And how much is the operation time for this, it again comes down to very low right why is it very low? I have dumped so, much electrical energy from somewhere it was stored and saved huge capacitor somewhere and only till the capacitor gets discharged I can do this job and then again I have to wait for charging the capacitor, and then again fire it once. That is all I can do with this facility. So, the time of running depends on the size of the capacitor and the size of the wires I am using etcetera.

Since, it is high current setup typically people use argon with this, argon is a noble gas which is easily ionisable and it is reasonably available in our atmosphere. So, people use its very easily ionisable noble gas simple enough to work with. But, 1.66 gamma is no more 1.66 for this it is going to be lesser than that. I cannot tell the value it depends a lot on what is the exact current going through and how much is the ionisation efficiency etcetera, but gamma will not be 1.66 it will be slightly less than that.

And one more thing, I am jumping myself out of this course content currently if I say that this plasma high pressure, high temperature plasma that coming through this nozzle once it goes to supersonic flow the pressure and temperature becomes lesser at those conditions the plasma cannot exist as plasma and it has to recombine to form neutral molecules neutral atoms in this case if it is argon. If, that is the case then because of this recombination the gamma of the gas will change the molecular weight of the gas will change average molecular weight of the gas will change because of all these I will have variation in a along this direction variation and gamma along this direction.

So, my flow is little more complex now, this enters the regime high temperature gas dynamics. Now, I have to know little more than whatever we talked about, in our simple gas dynamics course. We need to talk more about, high temperature gas dynamics why my temperatures are pretty high I need to think about this of course, when I am going to mark for the temperature is going to be much lower, it is not going to be 12000 it probably is going to be 2000 also, where I cannot have ions sitting by itself will become recombine to neutral atoms. And one more drawback of this Arc heating mechanisms is basically the electrodes will get eroded with time. Because, there are electrons going and bum boding into the positive ions positive electrode and ions coming and bum boding into the negative electrode, because of this whole thing I am going to have erosion of or spattering they call it spattering of the electrodes will start happening this is all bad for the electrode.

Eventually, I have to change the electrode the whole setup will become a waste within some many runs I do not know how many it is depends on the electrodes. And now, we will think about something much more if I want to make something fly at really high mark numbers. What else can I do? I can put it in front of a rocket, put in front of a rocket and fire it that is one more way of making this kind of experiments, but if I think about that I cannot do flow visualization on that I cannot be carrying my cameras along with the rocket to some extent I can, but I cannot do really perpendicular to the flow kind of direction. Rocket powered you can think about, I have not seen much experiments where they do like this.

But, we hear a lot about people testing out engines using rocket powered systems. Ramjets and Scramjets when they first tested what they did was they put a rocket behind it and they fired it up. So, that it reaches good enough mark numbers and after that the engines start working at that point the rocket falls off they have done something like this. So, that I can tell that I can just connect a rocket behind it and that itself will start becoming use full for it. I am accelerating really high power what am I using here chemical power? Chemical energy it is propellant burning creating thrust and that is causing the whole model to be going very high, drawback of this it has to withstand the launching G values initially of course, you should anyway design for if it is high mark number have to design for the flow forces more than that now, I have to think about G values.

That is one more thing I have to think about accelerating with the rocket. Of course, you should know it is extremely expensive it is not simple typically only big rocket launching agencies like NASA or. In fact, TYOS are also planning something like this I believe. So, some such things only those kinds of people can do this cannot be an institution like IITS or anything that cannot do this, it is much bigger scale than this. And you have to also think about safety of people below, it cannot be that the rocket that detaches from there and comes and falls on somebody’s head. So, you have to think about that safety also typically it has to be flown over some safe sea area where they have already cleared out allthe fisherman and other ships around there, only that area they will fire things that is true for any rocket launch anywhere for us.

So, you have to think about that also, but the good thing about this experiment is, it is really done in actual air in which I want to fly the engine say they are Scramjet. If I, want fly this Scramjet in some particular condition I will take the rocket till it goes there and fire it there that is the best thing you can do. So, people can work with that also one more such an experiment possibility is re-entry problems re-entry models I will take something with my rocket send it up into the orbit like, our space re entry experiment SRE. We can make it go for 1 or 2 orbits full circles and then when it comes next time you de orbit and start coming in. Now, I am really studying re-entry problem.

Now, I can put special sensors on that at different locations and actually study the heat transfer of course, first time I should over design, but later with the sensors I can find out exactly. How much is the heat transfer? And what could be the pressure distribution? What could be the temperature distribution? etcetera and now, I can check my whatever insulation tiles for example, you can test those things that is a good thing about re-entry based facilities, not much has been used in this mode anywhere in the world because it is much more expensive than rocket launch expenses.

Now, I have to think about going all the way out of the space out of the earth atmosphere and then coming back into it, much more expensive research I have not seen many people who are doing this, may be NASA has done it once or twice India has done it once or twice and that is it I think may be Europe also somebody would have done it once or twice I do not know about Japan or Russia right now. I know Russia has a very huge continuous running supersonic facility which is really huge where we test our Scramjet engine that is also there. So, some such things are present somewhere. Anyways so, the next thing is transonic tunnel here till now, we did only supersonic tunnel.

Now, we will go look at transonic tunnel there is some special considerations you need to worry about, when it is transonic tunnel. So, I will give you one small bit about supersonic tunnel and I will come back to it. If I, think about any supersonic tunnel.

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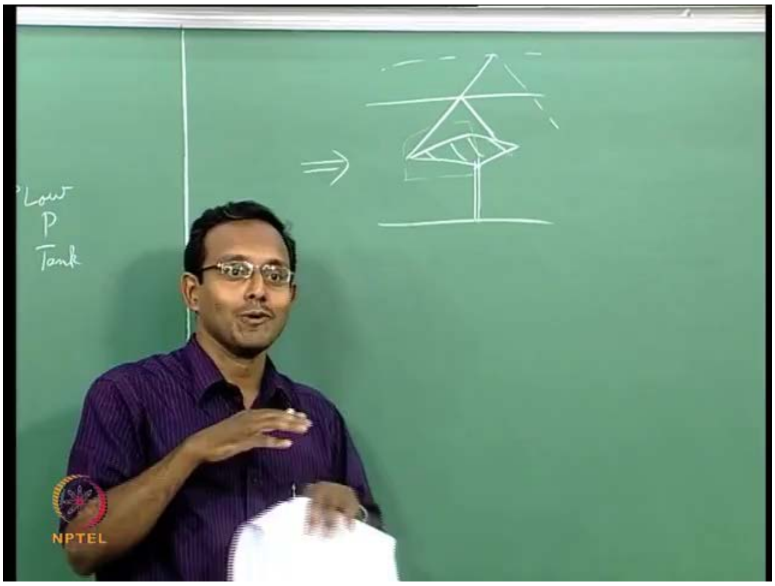

Let us say, this is my test section wall and I have a model like this, I will use a different model for this time. If I have a longer model like this and somehow I am holding it let us say I am holding it something somewhere. Now, because of the flow let us say, I have a shock like this what will happen to this shock now, it is going to comeback reflected. Now, this shock is going to interfere with our model that could cause trouble that is one thing you have to think about when your designing model for a supersonic facility this could cause trouble.

Now, this is not going to be there in your real flow experiments where there is no wall around it. So, your model should be such that if the shock that is going from the leading edge should not be reflecting back on to the model. That is one more thing you have to worry about of course, if you are interested only in the front portion it will still work. Why flow supersonic thinks downstream will not affect upstream assuming I am thinking only steady state problems. I keep mentioning this steady state is very important there. So, this is the bad thing about this model. If this is the case then I have, to either move the wall more and have the wall reflect the shocks away far down stream. That is one way of doing it, that is typically not possible just because I made a bigger model I cannot go and redesign my whole tunnel.

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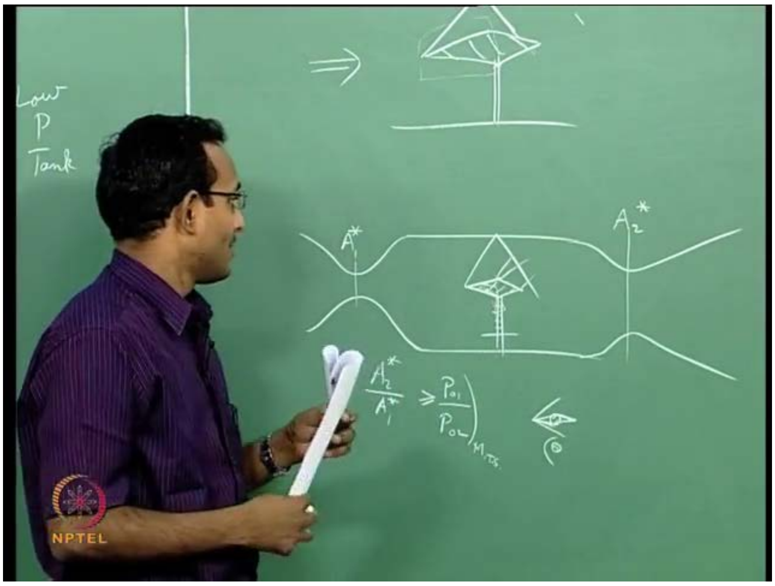

So, what you people do typically will be having the same tunnel, but decrease the model size. Such that now, the shock that is reflected is going to go out of it will not go and interact with it. Now I can go and study expansion fan shock whatever, I believe we discussed this problem already floorer on external floorer on bodies we have already discussed this. There is one thing we need to think about, other thing we need to think about is you know typical supersonic tunnels have a nozzle and diffuser and we said this is A 1 star this is A 2 star, and we said that A 2 star should be minimum some value. If not, the flow will not start the tunnel will not start we said what will happen the shock that comes here will never go pass this direction we said that. So, for that condition it is A 2 star by A 1 star must be greater than or equal to P 01 by P 02, at mark number of test section for that shock cut that mark number at the test section that is what this means.

So if you think about this, now I will think about special case this model is going to be actually blocking the flow right, this flow cannot go through the model there which means now the actual flow available area available for the model flow area available for the flow is only between this wall and this model and between the wall and this model. If that is the case then now, I have to think about the area decrease because I introduced a model in my test section if the net area available for the flow if it is less than this A 2 star then that becomes your throat second throat even though you have 1 more throat downstream. This becomes your second throat and the shock will never cross this if A 2 star by A 1 star is such that it is not greater than or equal to this.

So your model has a limitation both and length and in total cross section area total frontal cross section area in both ways there is limitation on your model. One more thing, it is not just the model it is also the holder included holder is also blocking the flow. Now, if I have to think about I have pressure transducers on this and there are wires going through, and the wires are just wrapped around this let us say, with some kind of tape even that total cross section matters typically what they do is they put this holder as a tube and take all the wires through it may not be all is as possible most of the time they do this all those things matter. And typically the holders are not cylindrical rods as in subsonic flows they are not going to have a cross section of a circle like this, they will typically have some kind of fairing around it.

So, that it looks sharp enough why a blunt body is going to have a more shock while a sharp body with small enough angle will have a attach doubly shock which will cause much lesser P naught loss what matters downstream of the model is what is the net P naught that this gas has. So, that now I can think about what is the mass flow rate through this throat, not just this single first shock thing is the basic staring condition this is the basic starting condition.

Now, because of all these extra shocks present the P naught 2 will be even lesser this even lesser think about this, ratio will be even bigger. So, my A 2 star by A 1 star should be even higher if I have more resistances to the flow. So, that to minimize that again I have to have small model small holders everything small of course, now there will be a point where we will say structurally it is not stable if it is too small. If I have, very thin rod trying to hold the huge model it is not going happen. So, there has to be some compromise somewhere this is one more thing we need to think about. Now, that we have done this we can go back to transonic tunnel. Transonic tunnel mainly I am thinking about, a tunnel where mark number is of the order of 1 anywhere between 0.8 or 0.9 to 1.1 or 1.15 that kind of mark numbers that is what is called as transonic region where any small participation matters so, will redraw the whole thing.

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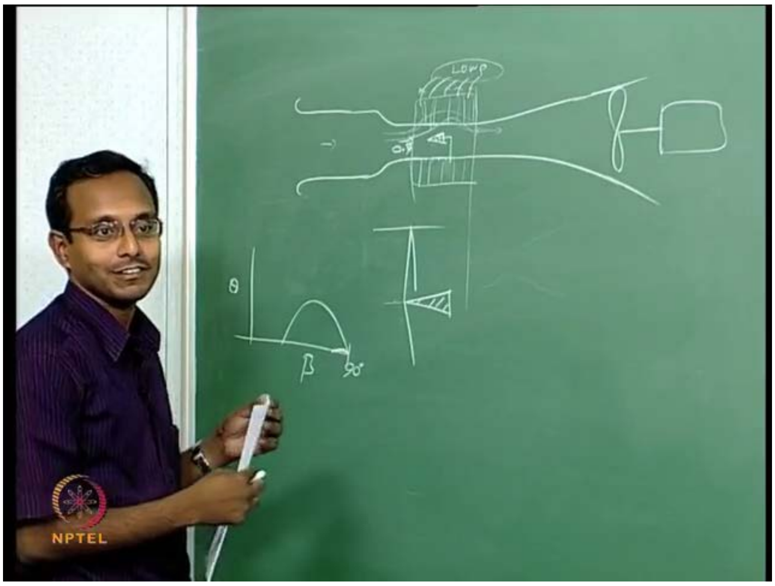

The tunnel looks somewhat like a in draft tunnel I am drawing one of the facilities possible, and in this case what I am thinking about is it is transonic. Which means my model should be sitting at the throat of a nozzle right because at the throat of the nozzle only you get m equal to 1. So, I have to put a model at the throat of the nozzle. And now, you know why I talked about the other thing if I put a model there the area at the throat of the nozzle is only the area available for the flow around here. So, the actual throat is somewhere at this location if I think inverse it if I think viscous was can be even ahead of it. We said viscous effects will have boundary liar growth because of that there is going to be a equivalent thinking about wall can be shifted a little more inside and this wall will be shifted a little more outside. So, overall area available can be shrunk even more, that can also happen anywhere.

So, I am just thinking about some particular flow facility where let us say, somehow I create the pressure experiments. Say ill put a fan and a motor I will cause suction here, in the diffuser section I create suction and that is going to start the flow from here, p naught is the atmospheric it is in draft tunnel. Another way of creating in draft facility for low mark numbers I can just use a fan up to 0.6 also I think you can use in draft just a fan. But above that, I need to go for actual vacuum pumps and storing this particular facility if it is a fan is can be continuous it can be operating for a long time. That is a good thing about this facility.

So, I have drawn this particular case for you, and of course, the model needs a support so this is your test section region which actually happens to be near the throat of the model itself throat of the nozzle itself overall it looks like 1 c d nozzle. Now say, I have to think about, what are all the problems that can happen first thing is of course, blockage because there is a model sitting in this region. So, my mass flow rate is going to be already lesser or, the fan has to take that extra load to keep the same pressure drop. Mass flow rate is a lesser is a nicer way of looking at things if I think about, my flow having I am thinking about mark number 0.9 I want to do the experiment if I think about, mark number 0.9 here then it is going to have chocking right any small area change if you go look at a by a star for mark 0.9 it is going to be close to 1 already and if I change the area much more and suddenly there will be chocking in the middle.

And now, that flow cannot go through because it is choked and I am still changing area what will happen that flow never happens it resets everything then says this point is n equal to 1 and the mark number is naught 0.9, but lesser. It resets everything decreases the mass flow rate upstream, there will be accumulation if you think about from the point of view of rely flow of enough flow we discussed if the chocking happens earlier or I extend the length decrease the area more similar to extending length in fan of flow we can discuss I am going to say resistance is more there will be compression waves coming.

Changing the flow speeds in front of it. I wanted mark 9.9 here, but I might get only 0.85 unless I do some more things. What they do is they will put holes on the side and keep this region at slightly lower pressure than what is in that section. So, that I will bleed out some mass flow if I bleed out some mass flow now I can make sure that the incoming flow is 0.9 because not all the flow has to go through this because that is having a chocking condition, but this is not want to send out some mass field. Now, I have to think about all these extra situations this is to take care of geometric choking. Next thing is shock reflection now, think of a edge even if it is very thin for mark 1 or 1.05 shock is going to be like this right. How do we know this? We have our theta beta m curve for very low mark numbers beta was very close to 90 only when it is mark 2 it was getting more inside otherwise it is only here, beta was almost close to 90 all the shock is almost normal shock.

Now what should be my model size for this, there is a wall here it will go and hit back and come back straight. Now, my model should be inside this itself cannot be anything bigger that could be a problem with this facility. So, to avoid this what people do is go and put the holes there and then put compartments and connect them all to 1 big low pressure facility if I, connect to something like this and have individual valves in between they are opened amounts different amounts if I have something like this then I can allow for air that wants to go out through this and come back out through this, something like this.

It is as if the wall is not really there the flow will go out and comeback that is what it feels like something like that can happen. This is called correction in the transonic facility and we have one such facility which is self correcting transonic tunnel in our ITMGD lab. The next only thing left is low density facility I will just spend 5 minutes on that next class and then we will move to how to design models etcetera and go to pressure measurements and temperature measurements.