Gas Dynamics
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Module - 18
Lecture - 43
Shock Tube

Hello every one, welcome back. We were dealing with what is happening inside a Shock Tube, we will continue with that we already did simple cases of pressure moment.

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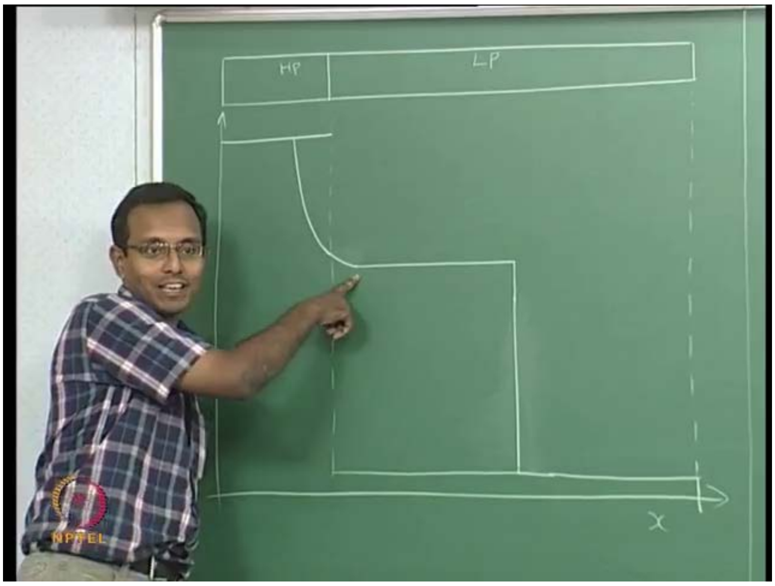

I will start with that again, pressure as a function of distance we actually plotted. And we said that the initial pressure on the low pressure section are the extremely low some value and the high pressure was really, really high. This was the initial condition and then we said at time t equal to 0, whatever was separating these 2 regions as now vanished. And because of that I am suddenly having high pressure region expose to low pressure region, and low pressure region expose to high pressure region.

So, low pressure region will send out expansion waves this way high pressure region, I will send out compression waves this way. Over all what happens is gases in the middle will move from high pressure to low pressure; that is what will happen. So, we found that there will be expansion waves, which will do something like this, I need not stop here. Ideally, it should be a vertical line, now the new system is expansion fans started going in, and so at some later time it is going to be looking like this and then it is going this something. The case I have drawn is different from what time profile I gave last time, this time profile is slightly different from the previous time.

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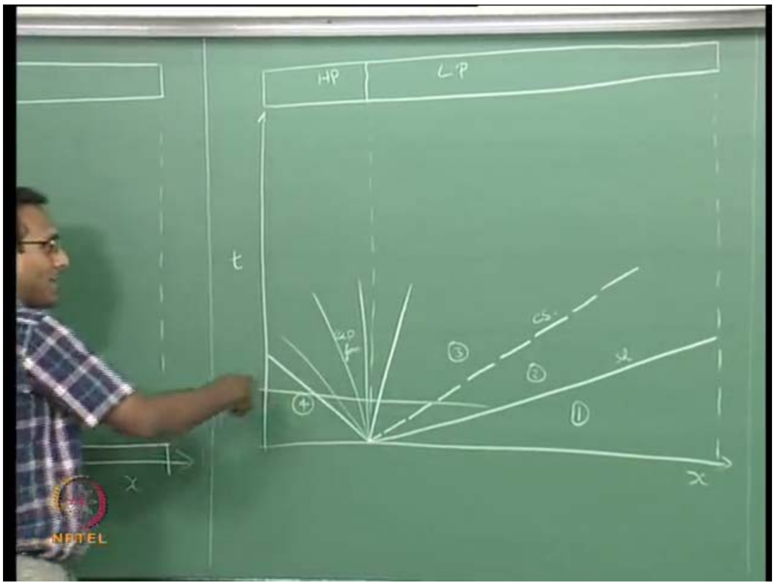

I will draw that time profile also otherwise things may go wrong for you people. So, I will be switching between these boards several times, let us assume it is constant area duct time not worried so much about that. This is again distance and this is time I have drawn it such that it looks different from the previous case, I have drawn it such that the expansion fan is going that way, this whole thing is expansion fan, why will the expansion fan go that way.

It so happens that the velocity induced is more than the speed of sound that is going this way, in to this gas. That is why the final way was sitting out, there this is a special case it is a much higher pressure difference will cause this. Since, I have drawn that picture I am going for this, and then I will tell you what it will be if it is other way. If it is regular cases I would not have any expansion fans going this side. If it is very high pressure difference then the velocity induced is much more than the speed of sound there.

So, it may push the way of this direction that may also happen, this is all expansion fans and I am going to have a contact surface. Thus going to be moving like this and a shock which induced all this motions in the low pressure section going to move like this. This is my shock, this is my contact surface and this is my expansion fan and we are again going to label 1 2 3 and 4. Notice that we do not label anything inside the expansion fan we will label only 3 or 4 nothing in the middle. Thus the only thing will do we will keep it like this n. So, we are considering this particular case and I have picked that time somewhere like this, this particular time is what I am plotting the pressure for that is why I am having some such curve.

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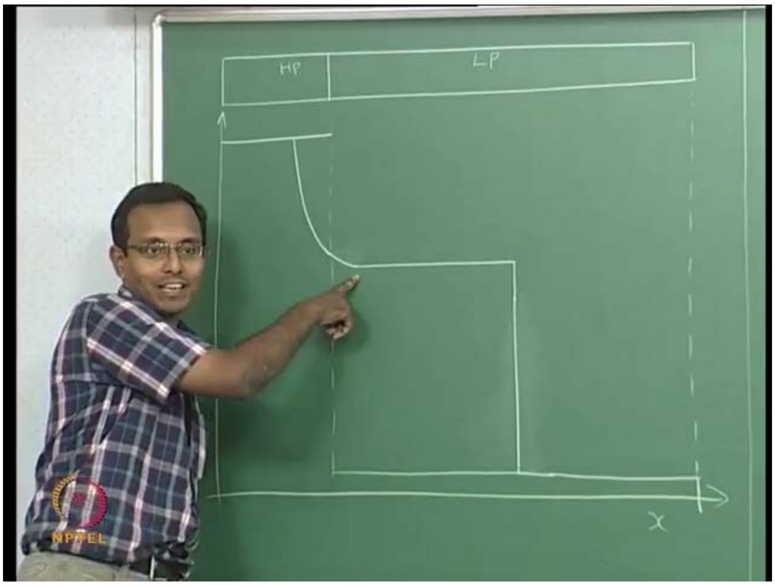

Now, we will go back and look at it at higher time, where the shock is just barely reach the other end. We will pick such a case if that is the case expansion fan would have gone reasonably inside. If I look at this particular picture and correlate exactly for that go back here and I am going to say when the shock reaches that end.

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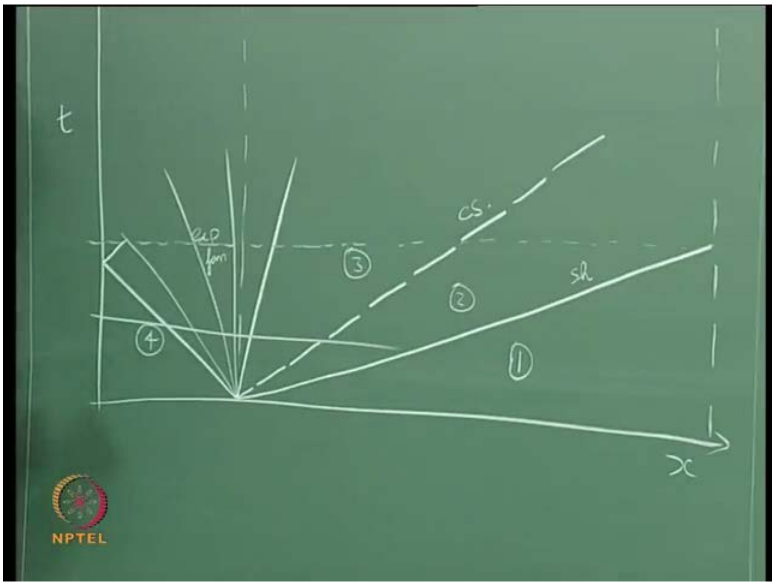

That is the time line I am looking at if I look at it this expansion wave already reached the end, but some other expansion wave did not reach. So, I am somewhere in the middle of the expansion fan while part of the expansion waves will return back. That is what I am going to have in here let us first not worry about what is returning back.

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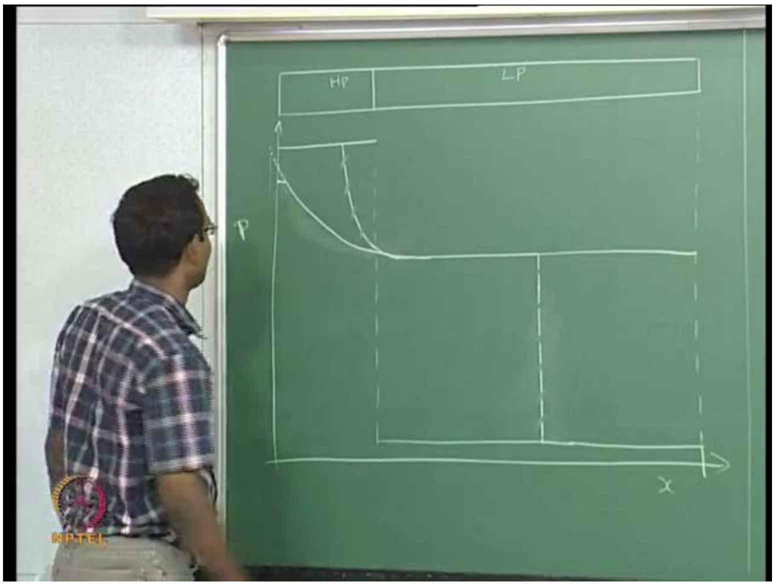

I will just say that the curve is going to look like this, I am drawing some imaginary curve right now. I will come back to it and I am going to say the curve is going to go like this by the way the pressure should be the same. So, I have to change my curve a little bit, it is going to go reach the same pressure p 3 and p 2, and then this has gone a long distance straight and the shock has just reach that point. That is what I am considering the shock has just reach their, ideally I should be erasing this line.

Let us say I would not erase anything right now, we will keep it like this may be I will make this one the old curve. So, this is my current curve now I am going to say I will look at this detail, if the tube was little longer this will be the curve and pressure. But, now since these expansions cannot happen there, there is no more high pressure gas there, these waves will hold back and decrease the pressure on this, which means that much pressure drop should be taken by these.

That thickness of wave that thickness of the gas should take this much pressure drop on this portion. So, it will look more like this, it will be doing something like this. I do not want to say what curve it is? it is going to be something like this, this is what will be the situation after sometime. Over all what does happen the pressure from this height, this high value has come down to some other value at the corner and it is going down from there also further. When, these waves come in further it is still going to keep on decreasing the number, I do not want to say it is a straight horizontal line. It is not it need not be it can be slightly up going, slightly down whatever any of those. I just want to say it is going to do something like this and I have reached all the way to the end. What happens next?

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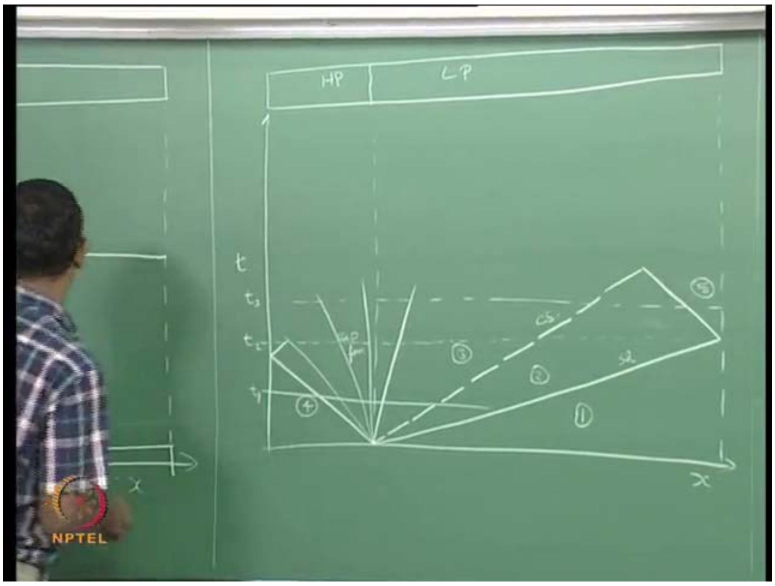

I will go back to this what where shock as has just reached this corner and we know we did this as a reflection of a shock wave at the end of the wall. So, you know it is going to reflect back out of this side we did that problem already, that is why I spent more time there, I do not need to spent that time here. I will just tell that shock will reflect back and we can easily find the mark number of the shock, and so since I know the temperature t 2 I can find this speed of the shock wave also.

And you will get some such curve typically, it is actually a straight line need not be called as a curve it is a straight line, because it is single velocity single math number, single temperature it is going to be 1 number. So, it comes up to here and this region typically is called the 5, region 5. If I drew a line here, and I want to find for this time what is happening? We will go back and draw the pressure curves again I will label these t 1t 2 now we are at t 3.

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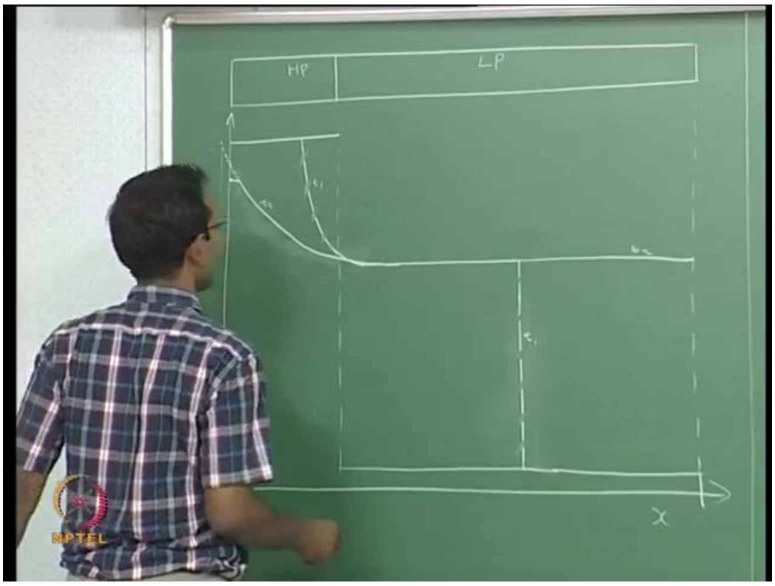

We have drawn this for a t 1, this is for t 2 and now we want t 3, third curve, now again I have to figure out what I will do with the lines I will use dotted lines for t 3. After that it becomes more complex I would not go more than this, so we will just stop there. For t 3 it is easier to start from the right side.

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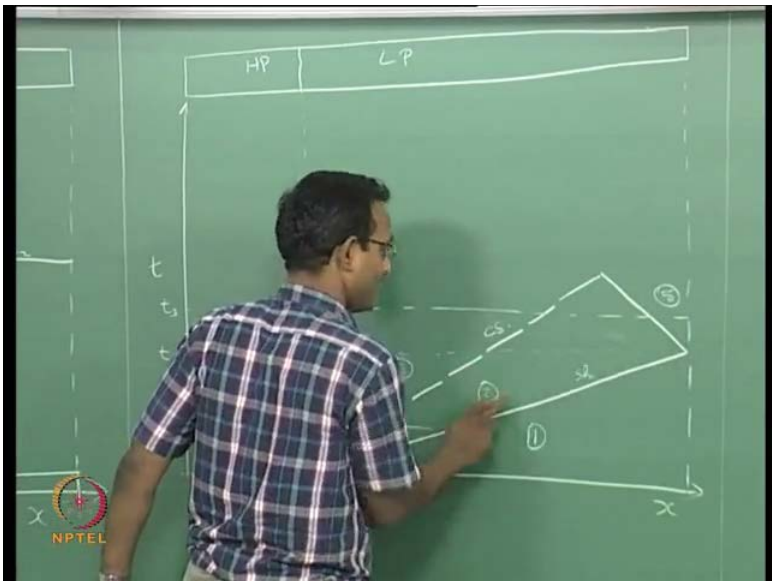

So, I know that the right side from this corner, it has gone through 2 shocks, the gas at the corner. First was process by 1 shock immediately process by the other shock and there are 2 shocks processed. So, the pressure will be higher than this p 2 value right, this is my p 2 value equal to p 3 any way.

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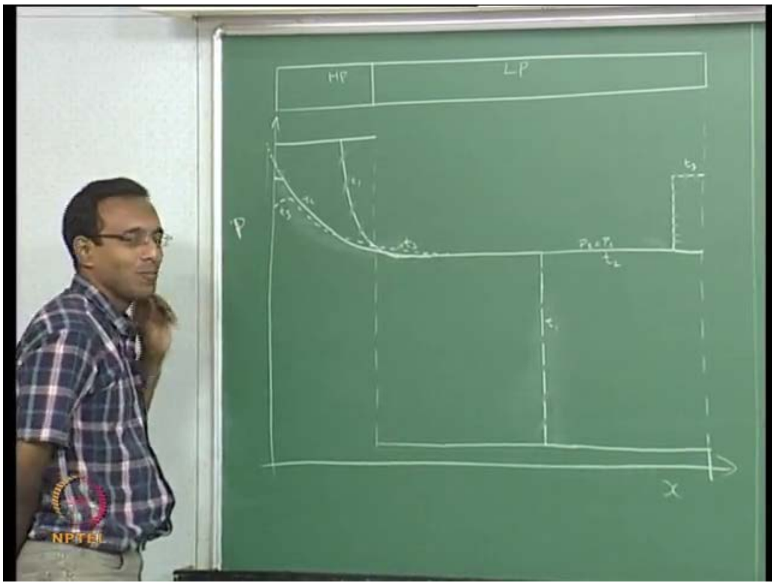

Now, I am going to say pressure is higher at this point, it cannot be very high compare to that going to be somewhat high. Some reasonably high pressure, and then up to some distance there is that shock and then it draws back to 0, not 0 it draws back to p 2 value. I will write this label t 2 below, this is my t 3 and then it follows the t 2 curve, for sometime till where it is going to go all the way till expansion wave.

Now, of course, expansion wave has travelled a little more inside this direction. So, the pressure will start increasing from there itself, it is going to be somewhere from here, and I will start using dotted lines or small dash lines for this. It is going to go through something like this and since the expansion wave is a reflecting and coming back I will draw curve something like this after that. It would have turned back now definitely, after some more distance it will be lower here than the middle it is going to lower back.

So, now, we will start seeing because of this what will happen, the flow does not always go from here to this direction, suddenly the flow wants to go back this way because high pressure here and low pressure here. that is the induced velocity which makes the fluid stop near the other wall, previously expansion wave from here came and told everybody go that side. But, that information reached here at the end, now no more people can go that side because there is a wall.

So, what will this wall do everybody come back this way, that information is going to go that side expansion waves from here that side. So, that is going to be inducing pressure higher there and lower here. So, people will start coming back that is high pressure and low pressure gas wants to go from high pressure to low pressure. It starts to turn this direction, that will start happening here.

So, now, I have a new curve I will make this also small dash lines. So, that I am somewhat consistent. So, it is going to be going through this same t 2 curve and then it is going to rise up from here, I will draw this as t 3 this particular curve is t 3. So, this is going to be my pressure distribution inside my duct at some other time t 3. If I go little more things will become more complex.

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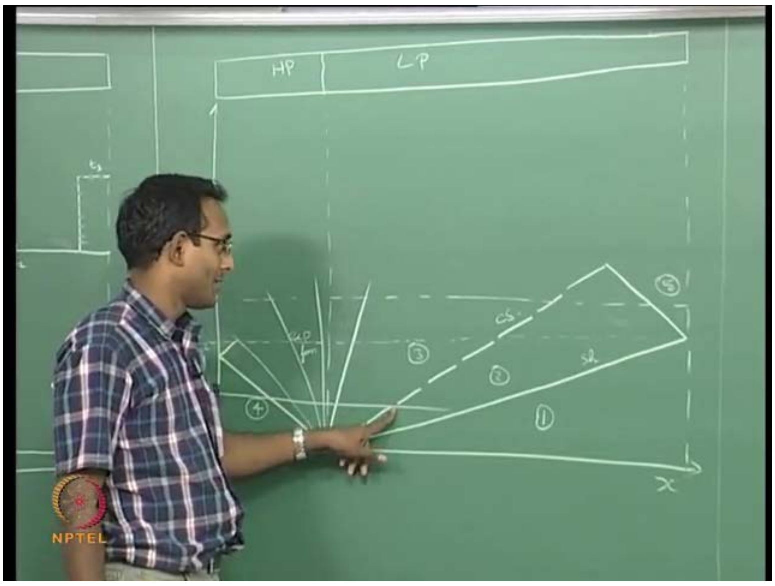

Now, let us look at this contact surface here it is very nice to track it. So, I am saying contact surface that is the contact between the high pressure gas, original high pressure gas and original low pressure gas. Say, the left gas and the right gas will label it contact between the left gas and the right gas is somewhere here at this point, after sometime it is here which means the right side gas is now only form here to here. It is getting compressed and it is only from here to here, at even for that time it is only from here to here. It is getting more compressed and it is sitting only inside that region, why is it getting compressed? The high pressures section is pushing the low pressure section in to the corner, that is what it is happening.

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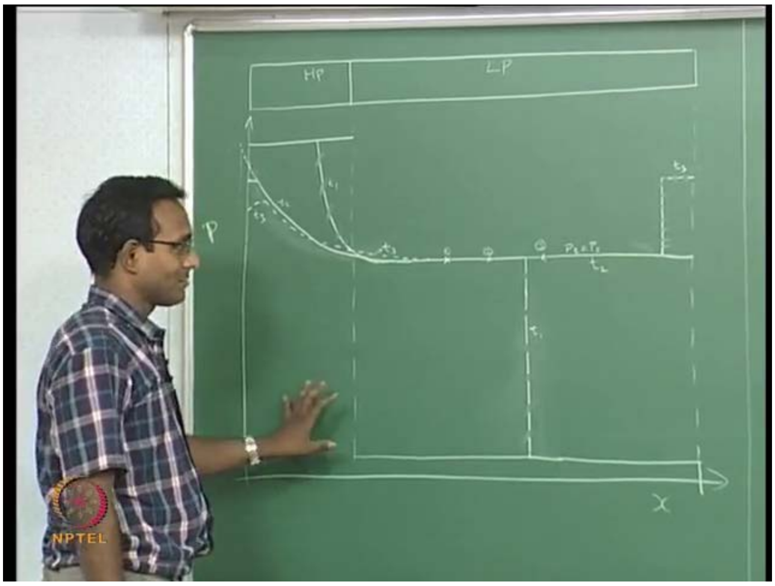

So, if I put a x mark wherever there was this contact surface, it is going to be something like here for 1, somewhere here for 2, somewhere here for 3. t 1, t 2, t 3 three particular conditions the contact surface is slowly moving to that direction. That is what I am seeing in here, this is all nice I want to now look at temperature as a function of x will keep this curve will keep this plot. Now, I will go to the next board and I draw temperature as a function of x again another shock tube is nice to draw.

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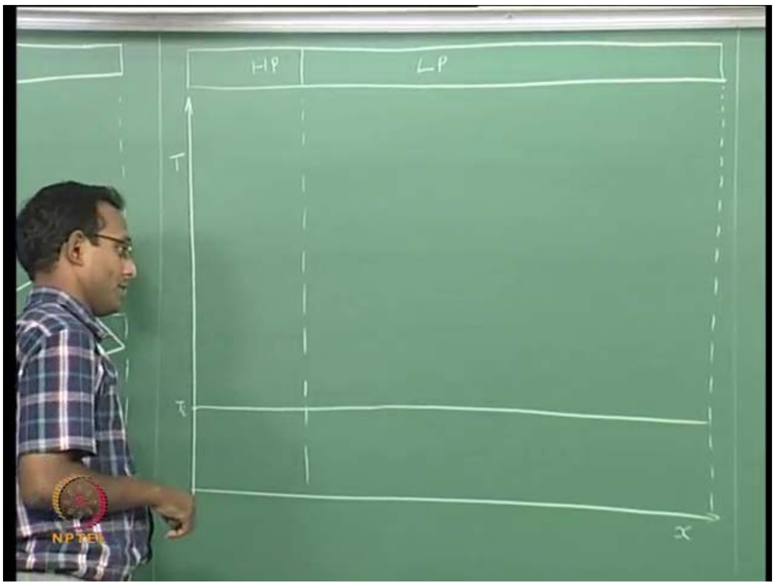

Again let us assume it is constant area, constant cross section, it is I am not drawing straight line for that long distances. Now, it is temperature distribution as a function of x what we know at the beginning temperature as a constant. And typically, I will draw it a little higher for temperature, this is my t initial i will put t i there, t initial. This is my initial system now I want to look at this particular t 1 condition.

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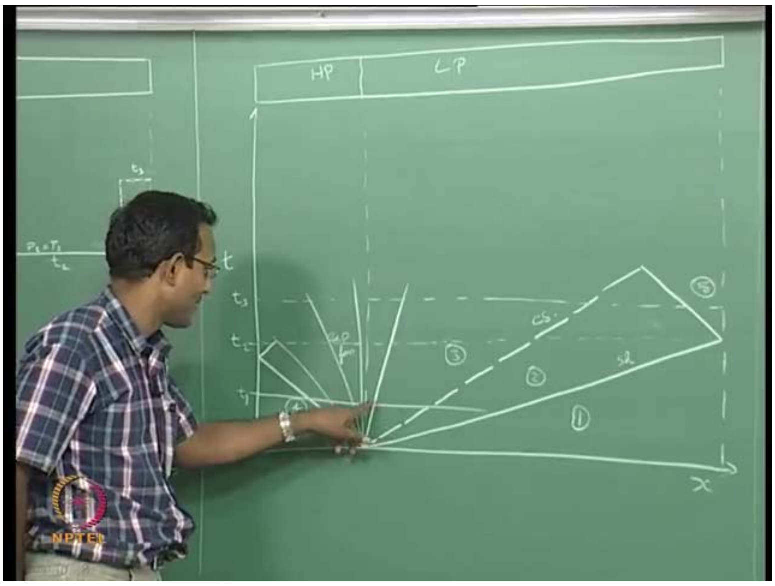

All I have to do is just go and mark these particular locations of my on my x axis, there are 4 points I need to mark. I will just go put rough distances and just go look at that time what happens.

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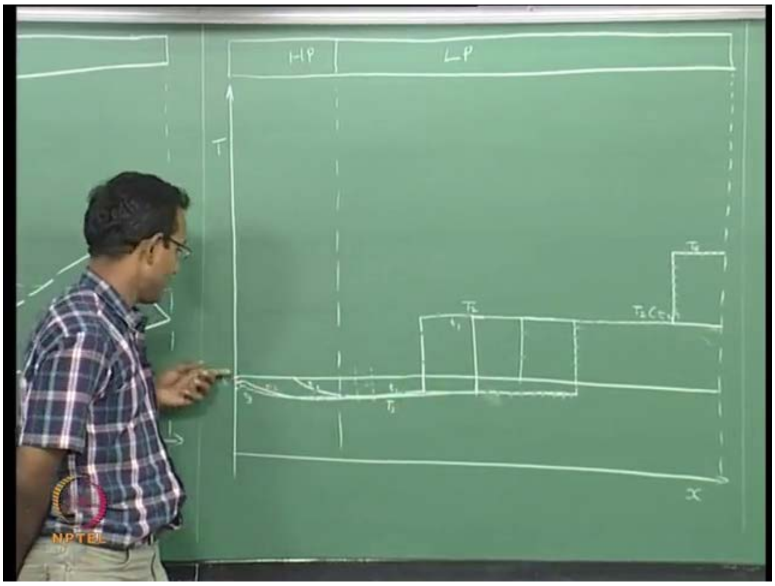

This is one point another point somewhere here and other point somewhere here and another point somewhere here, this is my expansion first wave expansion, last wave this is my contact surface and this is my shock location, at that particular time instant, but this is not the temperature for it. So, of course, when the shock is not processing the gas that is this region, region 1 will find that temperature does not change it is same as t initial.

But, this region between 3 and 2 has been process by the shock. So, it will be higher temperature and constant temperature t 2 and after that the region 3 here that is between the expansions it is better to show this picture, expansion fan contact surface between this region is region 3. Now, this region has be processed by this expansion fan, not a compression wave shock here 2 was process by shock 3 was process by expansion fan. So, this region will have temperature below the t initial.

So, here there is a discontinuity in temperature it drops below and it is a constant temperature t 3 particular value. That is up to the expansion fan end value, end location what happens inside the expansion wave temperature drops initially very fast and then it drops slowly assume to as to that particular fan allowing is going to do this. This is my temperature curve for t 1, I will use the same notation used in pressure long dashes for t 1. This is what I will have for time 1, now we will go look at what happens at time 2.

It is nothing special it is same thing except for at this corner temperature will be lesser than the previous one because it dropped little more. Because, expansion fan is processing only this portion is processed second time. So, it is going to look similar to the pressure curve, it is going to go join that same line and is going to go beyond that. Now, this is where my end of expansion is for this case, after that it is the same t 3 value, but t 3 value stays longer because contact surface is somewhere far away. Now, the contact surface has moved up to somewhere here, and it jumps up to the same temperature. I will draw it as if it is offset by it is actually, suppose to be one on top of the other.

Actually, I drew it on top of the other it is any way you know the difference. So, I am going here and we said t 2 is the time where the shock reach the end, that is corresponding to t 2 time 2 and the line is actually temperature 2 in the region 2. This is my current setting that is this side the temperatures are higher and this side the temperatures are lower, because 1 is going through expansion process other is going through compression process.

Now, the next time instant it is again simpler, we can go through the whole process again, if the curves are going to look similar to the pressure curves. Because, it is isentropic expansion know temperature and pressure are going to go through almost the same process going through this. This is going to go for longer distance and then this is going to jump up. We go in to jump up to the same condition, I will draw this as t 3, t 2, t 1 there is a lot of confusing pictures here.

Probably, I should I use 3 different colors chalks, so I did not think about at the beginning, but this is you are small dashes curve. And it is going to go through the same path, like the other ones roughly there is going to be small deviation here the temperature at that corner. The last one will be slightly higher, that is going to go through this whole process. This is my again small dash curve that is going to go all the way till here, at the end it would not follow that curve.

Why? At this point there is a reflected shock coming back this way, want to go at this direction it is going to have higher temperature and it reaches there. This going to be my t 5 and it is all small dashes, again the final t 3 curve is going to look like this, it is going to like this go like this. It is going to going to have 2 steps in temperature and then it is going straight down below at t 3. And it is going to go up and drop down at the end, it is going to look similar to the pressure curve. In a temperature setting what we are saying is we initially started with all temperatures exactly same t i. And then the high pressure gas is getting lower and lower and temperature, lower temperature gas is getting higher and higher and temperature. That is what we are saying.

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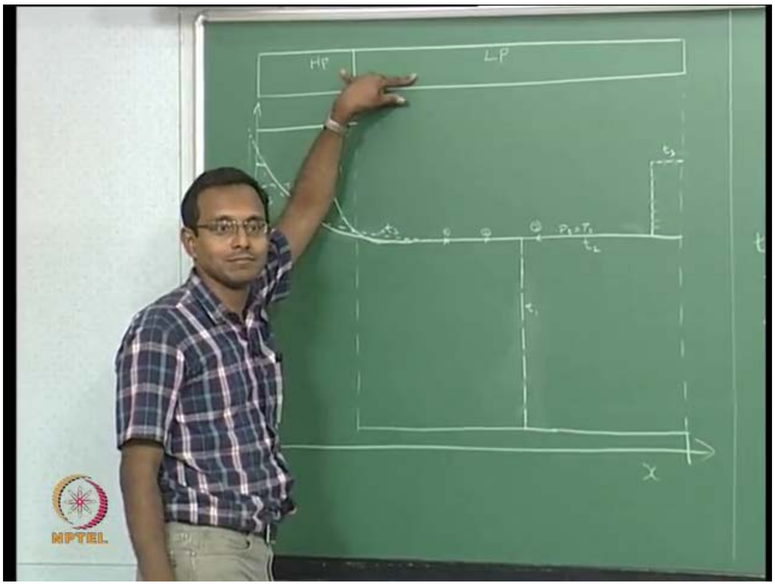

If I go back and look at my pressure curve here, we started with very high pressure and very low pressure at the beginning. And with time they are getting equalize slowly that is the purpose of these waves anyway right, they are suppose to try and make these things equal. So, compression waves will keep reflecting till all the pressures are equal, and the same thing expansions will keep on repeating.

Till all the expansion are going to make it equal and the expansion will finally, cancel the compression waves and eventually you will find the there is no more change in pressures. It will end up with some average pressures for this full volume occupied by this full number of moles in the gas. That will be the final setting till that happens it is going to be oscillating inside here.

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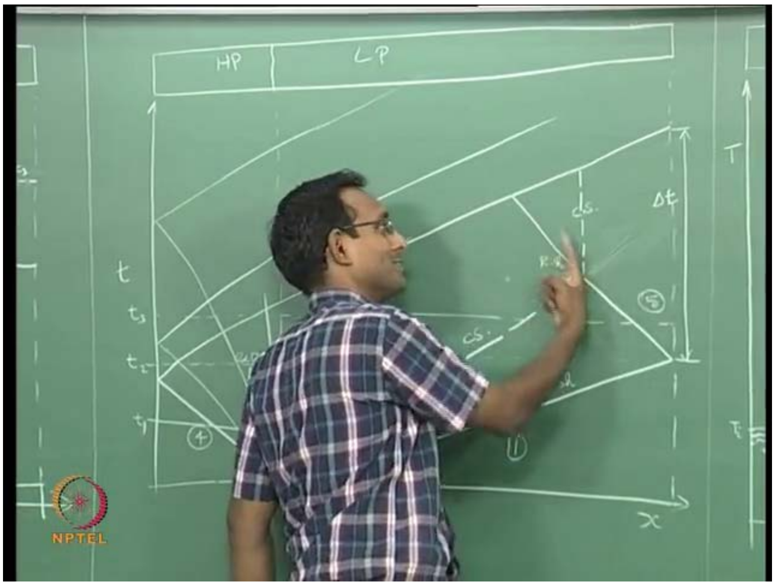

We would not go in too much details of it, but I will just want to draw this curve here, this expansion waves they are all going to reflect at the wall and come back this direction. I am worried about the last one, it is going to turn anyway it is just going to go this way, but I am not worried I am interested in looking at this waves set of waves going here. These set of waves are expansion fans which go and bounce of the wall and come back to this direction, they will keep on coming back they do not have any other job other than just transferring all information to all the gases possible.

Same thing with the shock here, this is coming this way and it is going this way. Now, let us assume for an instant that the shock when it goes from gas on the right, to the gas on the left, there is no change to the shock strength. Let us assume that for now, if we assume that then a shock will just go a straight. If we assume this, then the contact surface will just keep going straight like this and this is also see as and it is going to keep going this is my reflected shock.

It is going go this way and this going out like this, now I want to talk about what is happening in this corner? What is this axis vertical axis for us? Time axis, now typically I said chemist people who are interested in, suddenly taking a gas from low temperature, low pressure to high temperature high pressure. We will use shock tubes and they will study only near the end, because at the end you are going directly from t 1 to t 5 at the final most point, but typically they need some thickness.

So, they will probably work somewhere here, this region because metal block will block some light, if you want to study some optical methods. It will block some things we do not want that, so typically they will work in this small region somewhere in here. So, there is a small step possibly 1 2 to 5 it is a possibility that may happen, but typically people are interested in taking from t 1 to t 5 and p 1 to p 5 that is the goal. If they are doing this what is the total time they have for their test, think about that they want to study only the processes that happen in this particular right side gas the low pressure gas at the initial condition.

Initially, whatever was filled on the right side that is the only gas they are interested, till what time will you he have that particular gas sitting here that is going to be inside this region. I made a mistake with the contact surface sorry, contact surface cannot keep on going, it keeps on going then there a gas vanishes. What is the purpose of the shock? To make the flow stop right the shock kept going the flow behind it was going very fast towards this wall and then the reflected shock is going to tell there is a wall here.

So, do not go any more, so after the reflected shock the velocity here should be 0, velocity there is 0 contact surface will stay at the same location as a function of time. It is actually suppose to be here, I drew it wrong this is my contact surface . So, now, what does effectively happened is this full length of low pressure gas has now been compress to this small region with a pressure p 5 and temperature t 5. That is what does happen over all and so for a long time I can do keep on doing this experiment, till this expansion fan comes and hits this point.

When this comes and hits it now the pressure and temperature are not the same, I cannot use this gas anymore when the pressure and temperature are changing to something other than t 5 and p 5. Till that time I can use it, so this becomes my time of operation delta t that is my time of experiment really, that is the only time I have to think about this particular experiment. Of course, this is only for applications of chemist currently, I have not show you other applications yet, but think about this application for now, and this is one application.

Of course, you can think about having a nozzle taking this stagnant gas sitting at this corner take it out through a nozzle, and that will become another supersonic flow will go in to that probably towards end of today’s class. We assumed one thing in here which was the shock does not get affected by this change in gas medium, it is not always true. It is, so happens that there will be times when the shock goes this side, expansion waves will go this way. If such a thing happens then contact surface does not go straight, contact surface starts going this way.

And you will start seeing this expansion wave changing the pressure and temperature of this gas, your run time suddenly drops down, this is most common case run time decreases. So, now, will look at that particular case what is happening currently is we are talking about contact surface effect and reflected shock and so it is effects on the run time of the atonal. That is what we are looking for? We look at only this region currently, we are interested only in let us say this box only this region we are interested only in this region, so I will draw that separately.

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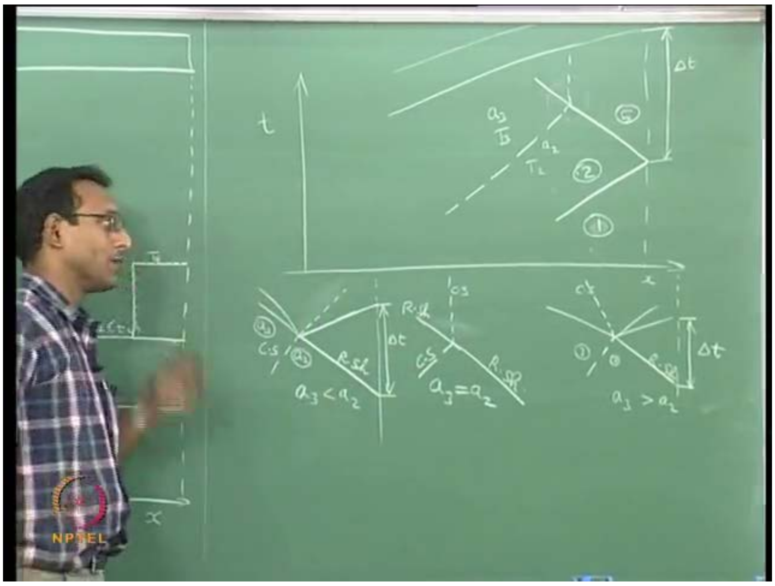

There I am going to say time x shock has somehow come there, it is returning this is region 2 this is region 5, sorry this is region 2 this is region 1, before shock is region 1 after shock is region 2. And then it is going like this I will now put a contact surface coming from here, and now let us think about what all can happen across the contact surface. There can be several possibilities, I will tell you a quick answer is shock wants to stay in a medium which has a higher speed of sound, will just stay this statement this works for most cases.

Shock wants to stay in a medium or the gas which has higher speed of sound, now speed of sound can be depending on too many things. Now, we set gamma and r different for each of these gases and my t 3 is different from t 2. So, now my speed of sound depends to much on the exact shock strength and exact expansion strength etcetera. So, if it, so happens that this is my p 3, this is my t 2 actually I will put a 3 and a 2. What matters is a 3 and a 2, if I so happen that in this corner, now I look at only this corner.

I will draw that picture alone here, contact surface reflected shock, if it so happens that a 3 equal to a 2 then there is no difference in speed of sound in the medium. So, the shock does not think that it is 2 different media it just go through straight, shock just goes through straight as if there is no change in anything. And if this happens this is the case I just discussed, it will just have contact surface just going straight like this, this is you are reflected shock.

This is one case, now I will look at the 2 cases to the side of these, a 3 less than a 2 and a 3 greater than a 2. If I look at a case a 3 greater than a 2, then I am going to have reflected shock coming here. This is your region 2, this is your region 3 and I know that a 3 is greater than a 2, I already made a statement saying shock likes to travel and faster medium, faster a medium speed up sound higher as in 3. Now, shock wants to go this way and it wants to go a little faster because P O sound is faster.

We will go a little faster which means, it will cover more distance in the same time, it is going to be slope more horizontal. And when this happens shock is going faster, there will be an expansion fan created the other side. And if you look at this region is like a local shock tube in the opposite direction, the beginning of a shock tube case expansions going that side compressions going this way. If these the case let induced velocity will be form right to left, because of that the contact surface going to travel like this, this is going to be my contact surface.

Now, the main impact of this is simple my run time at the end of my tunnel, this becomes my delta t. Instead of in this case I will go and look at the original picture the expansion fan from the other corner comes after long time and that becomes my delta t, that is the difference. Now, expansion wave comes from here all the way to there and that was my original delta t. If I have the special case of a 3 equal to a 2, I will continue the shock linear, if I do not have that case then my delta t decreased.

What if I go a 3 less than a 2 will delta t increase? Let us look at that, what will happen, again I have this contact surface I have this reflected shock, and here I said shock like to stay in a region where speed of sound is higher. So, this is my a 2 and this is my a 3 and we know that a 3 is less than a 2. So, the shock stays on this side itself it does not go back, so the shock goes this side. And because of this there will be an expansion fan going the other side is a inverse of what we saw on the other side a 3 greater than a 2. This is a 3 less than a 2 will have the flipped shock tube local shock tube exist like this.

If I look at it expansion fan goes to the left, compression wave goes to the right because of that the contacts surface till it is more to that side going to go more, I have drawn the shock exact angle correct. This will start happen, so now, if I look at my delta t of run time, this is my end line I am going to see that, my delta t is again lower. It is not going to be as high as the center case were the expansion fan will come later and hit in this picture which is what I have drawn in this plot.

So, what we are seeing is if I have a 3 equal to a 2, then only that is a very special case only then you will have maximum run time for your experiments. If we are conducting experiments at the end of the shock tube, I always make that statement also that need not be my experiment. My experiment may be just simply, I want to have p 1 and p 1 such that there will be a shock with a particular mark number created. And I am studying the shock mark number probably that may be my interest.

May be I want to see what if I have hydrogen and oxygen mixture and I send the shock through it, will it heat it and will it cause a declination will it cause explosion because it is high pressure high temperature suddenly. That kind of experiments may be I am interested, that is different from the reaction kinetics people, they will be doing experiments in this p 5 t 5 region, for them this is important. So, depending on who is interested in using the shock tube, it may be differing if you are interested in the end of the shock tube then delta t depends on what is the a 3 versus a 2 relation.

Now, we; obviously, found that delta t will be maximize if a 3 equal to a 2, this particular condition is called tailoring of the shock of what they really doing is they are tailing the contact surfaces. Actually, it is called tailing of the contact surface I believe I am giving wrong, name here tailoring of the contact surface this is called the tailoring of the contact surface, such that a 3 equal to a 2, if this is happening will get maximum delta t.

People having doing work on this for a long time problem 1950s, when they started working on shock tube tailoring, and this is one concept which you will have to understand. If you are using shock tubes for measuring pressure and temperature at the end, your run time will depend on this. I will just tell you one more thing viscous effects in shock tubes, now I do not think you need this temperature plot I will remove this.

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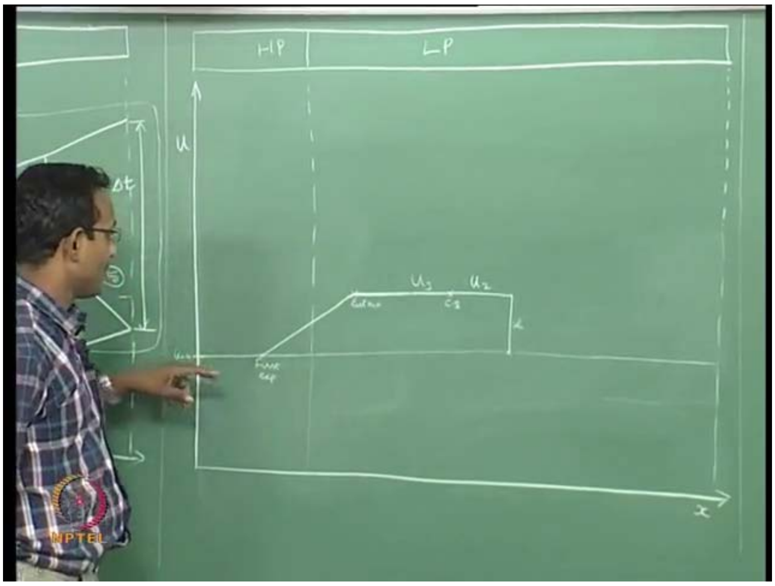

Since, I want o talk about viscous effect. I have to draw the velocity plot, u versus distance here similar to pressure and temperature. Now, you want to plot velocity in this and I will assume a convention going to the right is positive and let us say this is my u equal to 0. Initially, I have a t equal to 0, u equal to 0, everywhere gas is stagnant inside this is my situation. Now, I am going to say shock is started moving because the shock started moving temperature went up I am not talking about temperature, I want to say that velocity went up inside there.

Say the shock is currently sitting here, this is my shock and velocity is high here and this velocity. Is u 2 is this same as u 3? Yes, it should be that was the condition we imposed on the contact surface, pressure and velocity must be equal. So, this is same as u 3 this is where my contact surface is sitting, after that what will happen let us say contact surface this region is a little longer let us say. Now, let us say this is my last expansion and this where my first expansions, if this is the case now what should be the velocity? In the expansion fan when the expansion goes this way velocity induces that way.

So, it is again positive velocity because of that it is going to have some such curve, how linear is it? It depends exactly on how the diaphragm is broken etcetera. We will just assume it is a straight line currently, if you do it perfectly it might be a straight line. I am not sure of that we would not worry about that part right now, but it is going to be almost a linear curves sitting there straight. We will keep it like that, so what we are seeing is wherever the gas has been processed by either an expansion or a compression wave it is always travelling through the right. This is one case this is corresponding to let us say our t 2, I did not draw it exactly, but it is something like that, it is something similar to something between t 2 and t 1. Now, if I consider another case where it is t 3 where the shock has gone hit the corner and is reflecting. Now, what will happen, it is going to go the same way all the way up to that.

And suddenly because of the second processing shock velocity becomes 0 again, at exactly t 2 this is let us call it t 1 only at t 2 we said the shock reaches the exit the end if the shock reaches the end, it is one straight line all the way till there. And the other side it has gone a little more that side and it is going to be a slope like this going to the end or may be it crossed and came back something like that. That is what we will have, now I am going to say at this corner shock has come back because of that velocity is again 0.

What we will see is it goes straight there was a point where all this fluid are moving with the same velocity into the wall. Immediately, after that 1 millisecond after that it is going to be back here with velocity 0 at that corner. And I wanted to draw at that particular t 3 which means the shock is sitting somewhere here, this is at t 3. And we are seeing again that all these fluid are going like this shock is travelling this way, telling the fluid to come to rest. And on that side it is all suppose to be 1 straight line, if I think about that side expansion has gone more inside.

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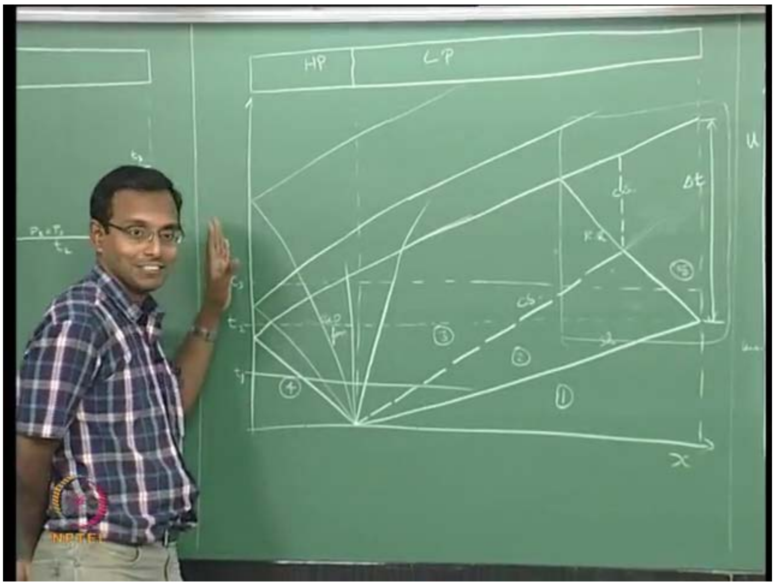

Now, what will happen with this corner, we know when all these expansion hits the wall and turns back, then the velocity will become 0 at the wall, will it be the same even if the velocity only one expansion way of fan turns and come back. It should be because wall is a serious forcing condition, it cannot have any other velocity other than 0 there at the wall.

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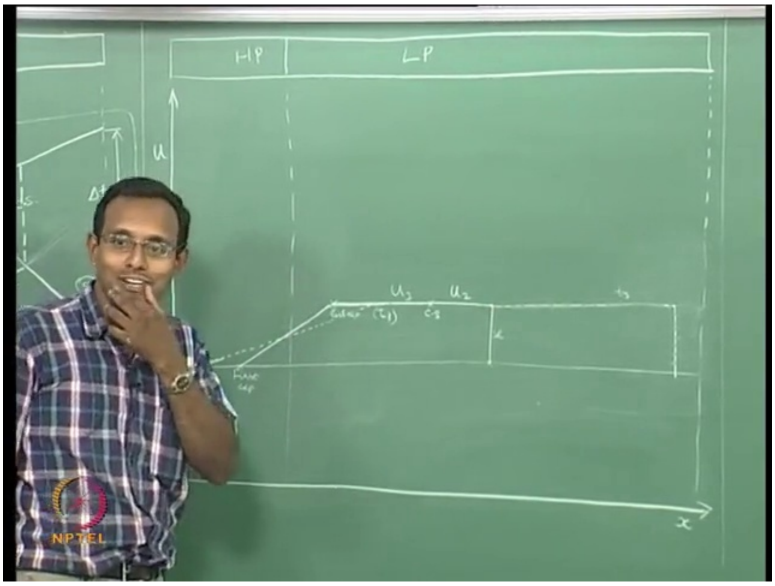

But, it may have regions where it need not be 0, but it will go through a non-linear curve somewhere there, because it is processed by 2 3 expansion fans in here. The one going this way and the one coming this way, everything is being processed. So, it will not be a straight line from there all the way here, it will go through a lower slope and then increase slope to that. So, think about it this is roughly what will happen. Now, I want to think about this particular curve which I have drawn in solid line, this particular curve I will make this t 3 line that short dash line there as before.

Now, I am interested in this particular curve where I am finding there is one small chunk of fluid which is moving to the right and on the left of it and the right of it the fluid is not moving. This is crazy some person in the middle is moving both ends are not moving, now what will be the boundary layer for this particular flow in a duct. Next question, so let us look at that situation I am having a shock tube, actually I want to draw this separately, I will going to erase. This we have seen one effect of contact surface that is contact by tailoring which will increase the run time. The other effect of contact surface is viscous flow we will look at that.

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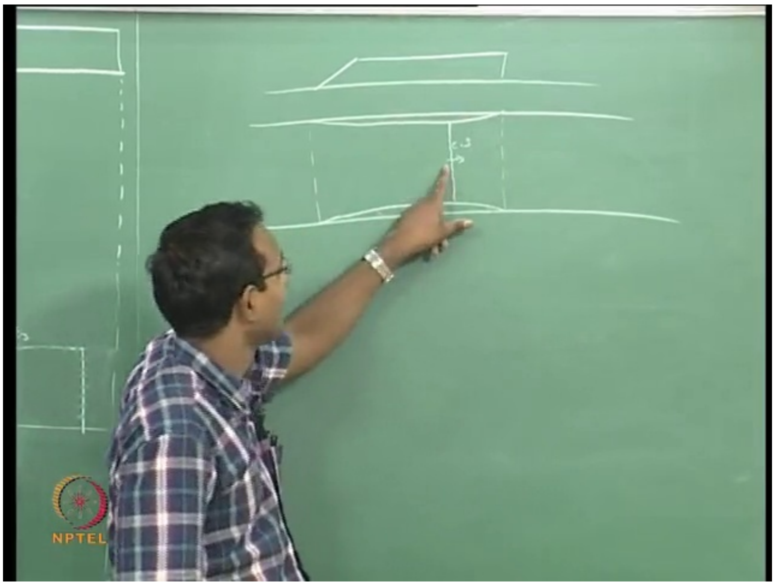

Now, I am going to say there is a shock tube and velocity profile here is looking like this something like this. If this is the case then fluid from here to here are moving to the right which means; obviously, on this side there will be a boundary layer growing like this. When it is 0 velocity what will be the boundary layer thickness, there is no boundary layer if it is 0 velocity, but that we will just say it is going to be something like this.

I am not very clear on this particular part I believe it is doing this, I am not very clear in this corner I am not seen any research papers dealing with this corner. I know that it is going to go up like this, I believe it is going to go and go down like this, but I am not very sure of it. If I look at this region going to do something like this, these regions are my boundary layer where my velocity are less than what we have been telling as my u 3 or u 2. Whatever they are lesser suddenly inside this region, so I am not going to have a straight line profile, but a profile which goes to 0 at the wall increases. And then goes straight line, then goes back to 0 that kind of profiles I will have.

Now, I will think about where is my contact surface, it is sitting somewhere inside here. My contact surface is sitting inside here, typically my contact surface is travelling supersonic. Why? My velocity induced behind a shock most likely will be supersonic because my p 4 by p 1 is so high. My mark number is very high supersonic, because of that the flow induced behind it is subsonic with respect to that shock.

So, it should be supersonic with respect to outside, it is almost travelling that speed. So, it is going to be supersonic flow behind and the contact surface is travelling with that particular u velocity. Contact surface is travelling like this, now think about diverging section, why do I say this as diverging section? You have to go back to fluid mechanics, people they will tell you the boundary layer is equivalent to decreasing the area available for the flow. There is something called displacement thickness, I will just push the fluid push the wall up there and imagine there is no boundary layer. It is equivalent to it something like that, so if I look at this region it is acting like a convergent divergent duct for this supersonic flow inside here because of that this particular supersonic flow is experiencing at divergent duct always.

Why? As the shock moves, this whole structure of boundary layer also moves with it right because that is what is creating it. It is like a car going and behind it there will be this dusty gases behind it, if you have seen some Toyota add I believe recently. Whatever, if you have leaves lying down on the road and the car goes leaves will be travelling along with it, that kind of thing is what is happening behind this. And in this region this whole thing is moving with the shock contact surface is always seeing a diverging duct. Supersonic flow in a diverging duct, what does it do it accelerates. So, what happens is slowly it has a tendency to catch up with the shock, it is not going to accelerate by so much, because this is actually caused by this. It is going to go closer, but we do not have really long tunnels long tubes where it will actually go and catch up. We have never done that I have never seen any paper which talks about that, but it definitely gets closer than what we predict, because of viscous effects.

All this time we have been drawing straight lines for contact surface location versus time, now it will be a curving line it would not be a straight line that is what will happen. That is one effect this is contact surface acceleration, due to viscous effects that is what it is called contact surface acceleration. That is one thing now the other effect viscous effect the shock is wasting it is energy trying to give energy to the boundary layer fluid, it wants to pull the gas.

Shocks job is to make all the gas from here go that side, so it wants to give energy to this, but immediately this fluid will give that energy to the wall and it will not move. So, what is this shock doing it is wasting energy kinetic energy which could be given to the gas. It is wasting by giving shear forces on the wall it is wasting by giving stress on the wall, because of that this lesser and lesser energy for the shock. So, shock is flowing down contact surface wants to go faster.

So, what we are eventually finding is the region between the shock and the contact surface is shrinking slowly, that will also decrease your run time. Another effect I round up about effect this is a smaller effect than the previous one we discussed, that is direct effect of waves this different from them. All this can change the run time of your shock tube, so now, the next thing we want to do is just the see how we can apply this shock tube for supersonic flow experiments and look at all the other possible tunnels.

So, I will say I would not start with shock tubes just remember this, I will use it in the middle of next class again. I will now go out of this and start using simple supersonic tunnels and then I will go and say we just know about shock tube from there. How will I create a super sonic flow from there? That is the next direction we will take in next class, so I will see you people next class.