Gas Dynamics

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Module - 18
Lecture - 42
Shock Tube

Hello everyone, so now we are going to look at experimental setups used for compressible flow experiments, we will start with Shock Tubes. And then we will go and deal with other supersonic facilities, which are existing, because this is also a part of compressible flow experimental setup. So, we will start with shock tube it will add nicely to the other setups.

So, shock tube by the way is a unsteady experimental setup as in it will work only for a few 100 of micro seconds and then it stops. And in that time it produces whatever supersonic flow, if you want or high speed flows subsonic or supersonic, if you want and then it stops. So, it is actually a moving shock problem, if you think about it, we will go and analyze it now onwards, but before that I want you to recap the problem which we already did on more shocks, let us go to the screen.

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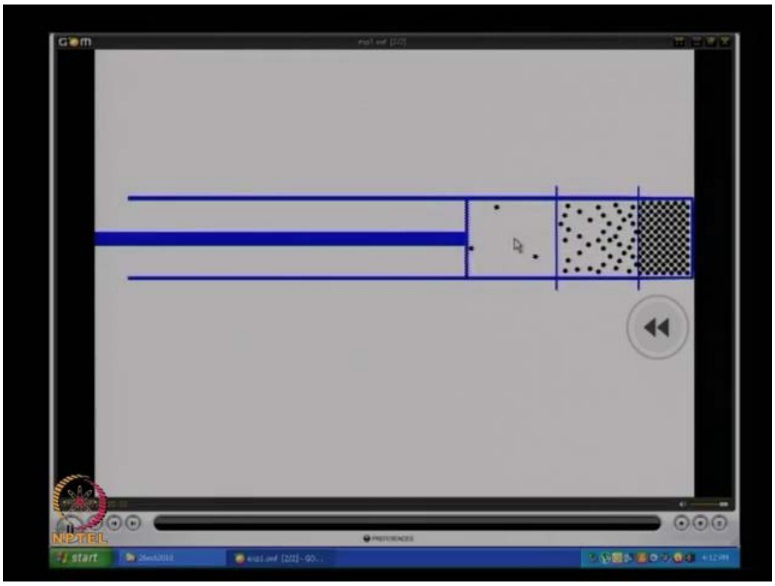

We have seen this animation already, basically if I have a piston that is moving in a duct and the gas initially was stationary, then this piston causes a set of compression waves come together to form a shock. And the shock the moving shock is going to move in such a speed and a strength p 2 by p 1 such that it will cause this gas to get compressed and move with the same velocity as that of the piston.

This we have already seen, now we will go look at another animation, where this is the opposite, if the piston goes the other way then a high pressure gas is now expanded to a low pressure gas and it is expanded in a slow gradient slowly. So, there is a big set of expansion fans sitting in this whole region. So, many expansion waves inside here, that where density is slowly decreasing from here to here and then here the density after the last wave the density remains constant, that happens in a expansion wave.

These things we already knew, we did not write expressions for the density variation inside the expansion waves, we did that only for moving shock cases, we did not do this for moving expansion fan analysis, we did not do that part. But, we will use the result from such an analysis, we would not worry about deriving that in our class, because I think it is too much of a derivation, It needs a lot of acoustics expressions to be solved, it is isentropic.

If I think about it, it is actually isentropic flow of a wave in a flow in a gas, it can be corrosion gas, it can be moving gas any of that. So, it is related to that, so we would not do that particular thing, because that will take around 3, 4 classes, I do not want to spend that time on that right now. So, what we do is, we will just go and pick up expressions that, we already derived.

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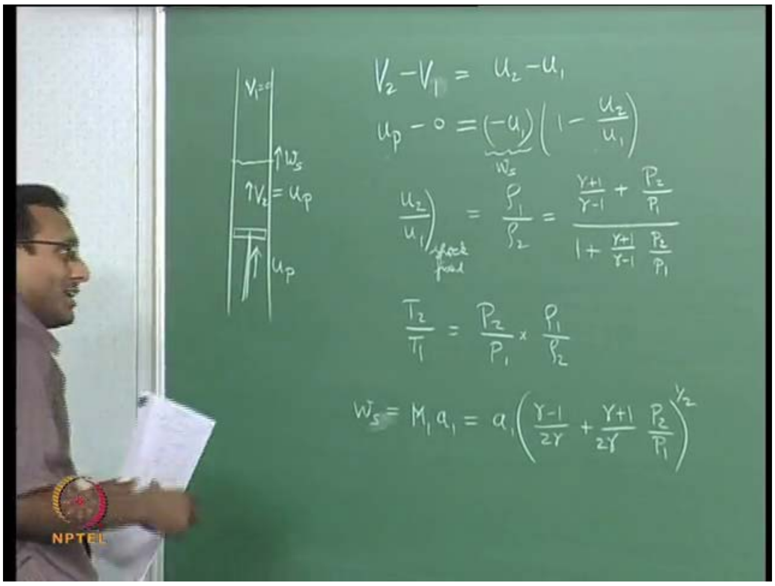

So, you will remember moving shock problem, where a piston is going this way velocity u p, we did not solve the problem like this. In a way we solved it as a numerical example in one situation like this, initially I said that u equal to 0, actually we used V variable with respect to the lab coordinates. It was V variable with respect to the shock coordinates, it was u variable that is what, we used this is going to be V and V 1 was 0 and the V 2. If there is a shock and the shock is moving with velocity W s, we used if it is travelling with W s then the velocity behind with respect to outside lab coordinates V2 is equal to my u p the piston velocity.

That is the job of this particular shock wave, that is the overall idea and I will just go and write the expression, which we already derived. We already said that V 2 minus V 1 must be equal to u 2 minus u 1, where these velocities are with respect to shock fixed coordinates, while these are with respect to lab coordinates, we already derived this and I will just substitute numbers by the way it I put V 2 minus V 2, It should be V 2 minus V 1, V 2 minus V1 on equal to u 2 minus u 1.

This is u piston the piston velocity minus 0 is equal to I will pull out minus u 1 here, the same thing, we did even before 1 minus u 2 by u 1, I have this and this u 2 by u 1 is with respect to shock fixed coordinates. So, I will go and use normal shock relations and shock fixed coordinates, we have this relation to be rho 1 by rho 2, which is given by gamma plus 1 by gamma minus 1 plus p 2 by p 1 divided by 1 plus gamma plus 1 by gamma minus 1 P 2 by P 1.

We wrote this expression as rho 2 by rho 1 and this reciprocal, I just wrote it the other way in here, in this case. And of course, you can write T 2 by T 1 also, but I will just write the simple one P 2 by P 1 into rho 1 by rho 2. So, P 2 by P 1 multiplied by this quantity in here, will be T 2 by T 1 and finally, we want to find W s. The shock velocity W s, I used capital S, which is M 1 a 1, where M 1 should be expressed in terms of P 2 by P 1 that is what I wanted. So, I am going to write it as a 1, we already did this derivation also in our moving shock case, I just wrote expressions from a few pages ahead in my notes. This will be the relation you will get, it is basically, inverse of that M square term, that is why you get this half in here, just inverting the P 2 by P 1 in terms of M square, you get to this relation.

Now if I want to find the actual velocity behind this u p, now I can find that based on this substituted inside here, where this minus u 1 is going to be nothing but this velocity right W s why, I am having V 1 0 very important, I am assuming V 1 0. Because, of that with respect to shock the incoming gas velocity will be equal to the shock velocity with respect to that gas right, They are standing my bus is moving equivalently, I am going to see that they are coming in this way with the same speed as the bus same relative example. So, that will be minus u 1 will be my W s.

So, this is going to be my W s. So, now I can find the velocity V 2, which is equal to u p from this relation, I know W s from the formula here. And I have a u 2 by u 1 formula here, in terms of P 2 by P 1 that, I substituted in here, I can find a u p in terms of just P 2 by P 1 just 1 variable. Of course, there are other variables like gamma and a 1 will be there, we will keep it as a 1, we do not want to substitute it as T 1 as of now, because shock tube people want to work with only a 1. Now we will go and do the expansion problem.

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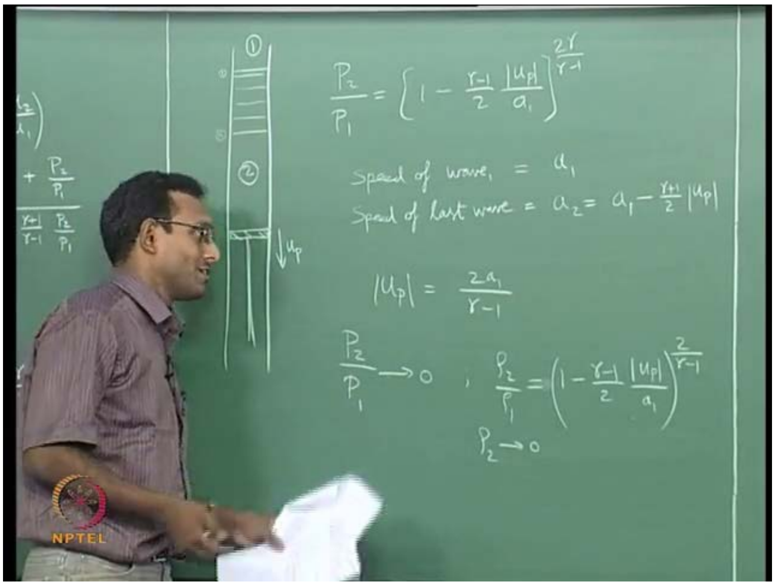

We saw this animation also, where I am having a piston moving the other way and I am going to say the expansion waves are already started and they are moving all the way out there. They are going to look something like this, this is the first wave and this is the last wave, first wave. I will put 1 and N here, first wave and last wave and I want to label this state as 1, this state as 2, similar to what we did there, 1 is before the wave affects the problem and 2 is after the wave affects the problem.

So, this of course, I am not going to derive this, I am going to say, if I solve the problem of isentropic propagation of expansion waves in a gas, I can find this solution. I will just write that final expression here, I am putting this modulus sign, because I have already taken care of the sign of that u p. So, only the magnitude needs to be omitted there, I have this expression, I may need this.

So, I will give this also speed of wave 1, that is the very first wave, it is going to be a 1 that is it is going to move with speed of sound of that free stream gas, the upstream gas and last wave speed of last wave. We define this as a 2 and I can give an expression based on that analysis, which I am not doing in class this 1. Because, of that much change in pressure due to this velocity, I will end up with a slightly lesser a 2 and that is what this is showing, why is it lesser a 2, I am expanding the gas, it is going to be cooling down.

So, when the temperature goes down, your a 2 will be lesser, this is assuming same gamma as of now, we are assuming constant gamma in a flow, I have a whole set of relations here. Now if I look at this P 2 by P 1 expression, it looks a little tricky, if we look at it, this to the power 2 gamma by gamma minus 1. This is always going to be more than 1, definitely more than 1. In fact, it is probably more than 2, we will keep it as more than 1 that is enough for me right now.

We will keep it like that, but the function inside will decrease with u p increasing, if my piston moves faster and faster, my P 2 by P 1 becomes lesser and lesser. If it is say 1 then my u p is 0 in, which case P 2 equal to P 1 piston does not move no change in my pressures. If my piston increases then there is less than 1, which means that to the power more than 1 means, it is like the square or cube or power 4 or something that is going to be much less than 1. So, it is tending closer and closer to 0, this particular value.

Now, if I look at this particular expression, this can become 0 exactly, when my u p is equal to 2 a 1 by gamma minus 1, if you look at this number 2 by gamma minus 1, if I assume gamma as 1.4, 2 by 0.4, 1 by 0.2. It is 5 a 1 5 a 1 is not very difficult for my piston to move, if you think about it, what will happen. If I move my piston faster than this 1, if I move my piston faster than that value P 2 will go to 0.

If it is equal to that value, what will happen, if it is lesser what will happen, if it is lesser that is u p is more than this 1, the this whole function is more than 1. So, you are going to have a negative number to the power something huge, you are going to end up with pressure P 2 negative, which is not possible pressure cannot be negative. If you think about it, so I am getting unrealistic solutions is that right, but you have to think about 1 more thing, I assumed continuum all through.

That is what is violated when I go past this point, we will see how when, I make it u p tending to this value, I put it in here this tends to 0, which means my P 2 by P 1 tends to 0, if my P 2 by P 1 tends to 0. Now I will look at my rho 2 by rho 1, this is equal to similar formula of course, you can get it from isentropic relations with the P and rho, you can get to this point.

You are going to get this formula and you can again see, when this tends to 0 and this is more than 1 always to the power. So, this also tends to 0 rho 2 tends to 0, if I am making this equal to this. So, there is a point, where my density goes to 0, basically the gas is very very rarified, it is not in continuum regime and my analysis breaks down. So, I cannot be using this expression for u p value is more than this specific critical value. In fact, it I cannot be using it, even when it is close to his value and less I cannot be using it for roughly 5 a 1 for gamma equal to 1.4.

I should not be using it for that that is just way of thinking about it what will happen in real life, when I move faster than this it becomes. So, rarified gas molecules do not even know that, the piston is moving, because there is no molecule near the piston, there is no molecule near the piston nothing is going to go. And hit it and find out that there is nothing, there is no piston anymore, the piston moved out nobody to go and check whether the piston moved out or not nobody is around there. So, that information never got transferred or another way of thinking about it, the piston moves there is no molecule, there to take the information and give it to the next molecule nearby, there is no first molecule itself and there is no next molecule either. So, there is no transfer of the wave. So, it cannot be rarified anymore than that particular value.

That is what you will end up with if you think about a prankley mayer expansion curves, you are reaching the ultimate expansion point M tends to infinity point by then if you think about it in 2 d case, this is not 2 d, this is just 1 d. So, you cannot really talk about that in here, this is just a analogy part of it. Now I have the expressions on the board for whatever, I need to do.

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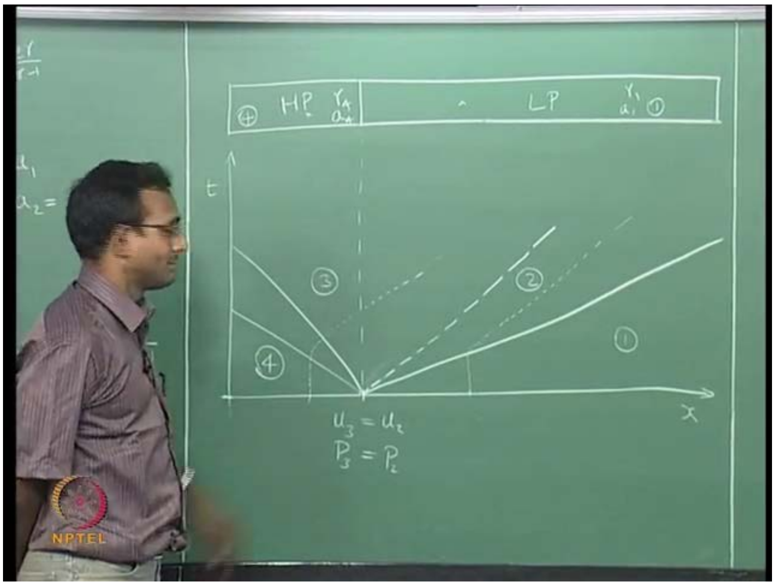

Now, I want to go think about what I call a shock tube, it is basically a long tube with a 10 diaphragm in there and I am going to put high pressure gas here and low pressure gas here. We will see why 1 of them is longer than the other obviously, because shock travels faster than expansion waves. Now the idea is I am going to call this state 1 and this I will call state 4, which means I am going to it need not have the same gas filled in these 2 regions. So, I am going to have separately gamma 1 and gamma 4 or can be a 4 a 1 let us assume the temperatures, initially are the same pressures are of course, different P 4 and P 1 they are very different that is what I have.

And I am going to say at time T equal to 0, I am going to puncture this diaphragm there somehow I make it cracked, there is no more diaphragm suddenly, the high pressure section of the gas meets. The low pressure section of the gas what will happen, it is like opening the gate at the stadium, which is crowded in the outside, there is nobody it is going to be a whole set of people running out and an expansion wave travels into the stadium.

We already talked about this problem and what happens to the outside world, if there is some people standing there, they are going to be pushed out more away from the gate. So, what is going to happen in here is it is going to be expansion wave that will go in this way, if I look at only the high pressure gas section, it looks as if there is a piston that moves out at some speed I do not know, what speed as of now at some speed such that that expansion waves will keep travelling here and making things adjusted to the other section.

Now, I will look at it the other way in here, there is a huge high pressure gas sitting here and suddenly it is going to be pushing at T equal to 0 onwards, if it is pushing against this low pressure gas then I am going to have the other problem of a piston travelling against the flow. And thus the now the develop a shock and the flow is going to go behind it this way. So, overall what is going to happen in here, I am going to have a shock travelling this way and a set of expansion waves travelling this, way let us draw that case as a function of time.

This is my time axis, this is typically how they represent a shock tube dynamic, I am going to represent things in x versus T plot and let us say this is my T equal to 0 line. This bottom line and at T equal to 0, let us assume that the shaft instantaneously formed, which is not really true. We will come back to it later, it is instantaneously formed let us assume and it is travelling in a constant speed.

I am going to say it is travelling in a constant speed d x by d t is the constant. So, it is a straight line slope thing, it is just straight line and d x by d t will correspond to that speed of that shock speed, We already have expressions for it anyways, we will get back to it later, on the other side there is going to be expansion waves, we said initially the temperatures are the same. But, a 4 can be different from a 1, I said even if the temperatures are same T 4 and T 1 are same a 4 can be different from a 1.

Because, gamma is different may be r is also different r can also be different, we will keep it that way typically, r 4 is far greater than r 1, that also happens in there. So, now if I think about what is happening here, this shock is travelling at this speed, if I think about any particular particle that was sitting at this location, let us say that was here. It is going to be sitting at the same location till some information about this diaphragm breaking comes to this point.

What is the first information that comes to that point, it is the shock is telling that there is a high pressure section run away from there. So, till that point that gas element just sits there. So, I am going to say it will be sitting there as a function of time, after the shock it is going to travel at some speed, but definitely less than the speed of shock. So, it is going to be going something like this, that is what will happen in this case.

Now I will look at some point in here again this 1, does not know that there is low pressure on the other side, immediately at T equal to 0, it knows it only, when the first expansion wave comes and touches this, then only it thinks about starting to move this direction slowly. So, I will put that point in here and it stays at the same location till the very first wave travelling at speed a 4 comes and touches that, after that since it is an expansion wave coming this way, what will it do.

It will induce a velocity the opposite direction. So, it this point this fluid element at that point will want to travel the other way, expansion fan will go this way to the left and the fluid element will want to go to the right. So, it will start going to the right and it will keep on accelerating towards the right, only up to the last expansion wave after that things have come to equilibrium, it does not want to change any more.

Now I will ask this question are these 2 lines parallel, I have drawn it in some way I do not know whether it is really parallel, it looks like they are not parallel, what will happen. If they are not parallel this fluid element will go and crush, the other fluid element, if that happens what is really happening, this fluid is still pressing on that fluid. So, there will be one more extra compression wave created on that fluid, which will go and increase the shock strength, till it becomes equal and parallel that is one way of thinking about it wave be the other thing might happen, may be this thing is going far away like this. It is going out like this very low velocities d x by d t is less that means, it is almost vertical, it is going like this.

If it is going like this well that one is travelling faster, what will happen now, there will be empty space created, because the fluid element here and here are now diverging. The space in the middle will be empty that means, there will be expansion fans from here going all directions, expansion fan from here going this way will tell the fluid to go accelerate and fill that space. So, the fluid will turn this way expansion fan going here will go and decrease the shock strength.

So, that it does not go that far, but it will go a little more like this. So, it will go to a point, where it will finally, have a nice equilibrium of these 2 velocities being exactly equal, that is these 2 lines are parallel, till that time it is not a stable system and all this happens in this small region itself, which I am not going to discuss too much, I am going to assume it is a single point. And everything is already discussed and assumed fixed, fluid element immediately calculates all this and puts it out there.

That is what, we will assume that is a small assumption, it works reasonably well for our cases, we are not interested in that small time scales, in a very short time probably within a micro second or 2 all the strength of the shock how much expansion fan should be there all that are all decided within that time. And finally, what should be the velocity of the fluid element, behind the expansion and behind the shock everything is set by their ideally. It is not set when it is this far it is set for that particular fluid elements very, very next to these diaphragms, immediately after that this wants to go this way while this one wants to turn and go this way.

If they are not going parallel then they will interact and send out extra waves this way or that way to make it equal. So, now, I arrived at a particular condition for my flow, which is similar to what, we did in 2 d gas dynamics. We said the velocity direction should be the same for both, the fluids and the pressures must match did I talk about pressures really not yet. Let us talk about pressures again, what if the pressure on the compression side is higher that the pressure from the expansion side, what will happen. Then this pressure is higher than this pressure, there will be compressions going this way, what will it do, it will go and decrease the expansion strength and equivalently the other side will have an expansion, which will go and decrease the compression strength.

Then this strength will decrease eventually, it will come to a point where, it is higher pressure after expansion and lower pressure, after compression that they both match now. You can now argue for the other case where, this is the other way, it will work correctly. So, I just gave arguments, now I just have to label these parts, I label these 1 2 3 4 right. I label I have labeled it wrongly it looks like.

This is the correct labeling, I labeled it in my notes wrongly right in my notes, I have it wrong, this is the correct 1 I will call this region 2, this region 3, this region 4 as of now I did not discuss the difference or the boundary between this regions 2 and 3, let us assume I have gas 4 different gas 4 different from gas 1. If I assume something like this, now what will happen that is the next question.

We want to think about this, if this gas is different, they are both going to be travelling at the same speed, we know that already, we just figured out that u 3 equal to u 2 and P 3 equal to P 2. We know these 2 things already, if they are travelling equal then the boundary, if I draw a boundary between these 2 that is immediate fluid elements next to the diaphragm on to the either side. They will go both be going parallel to each other and I will just draw that line here, I just draw that line.

And that line should be going exactly parallel to this u 3 and u 2 lines. Now I am calling the region 2 as the region, where the gas that was processed by the shock is present and 3 as the region, where the gas that is processed by the expansion waves, all the expansion waves together are present. And region 4 is untouched and it is the high pressure section, region 1 is untouched in the low pressure section, this is what we have.

So, now we want to see what these values are that is the next step, I want to find, what will be the velocity in this region u 3 and u 2, what are the values that kind of relations, we can find the values, it is not very difficult. We already know stuff from for this, if I know the shock strength, I can give u 2 by u 1, we did this as a moving shaft problem and I wrote the notes today on the board anyways and similarly from here expansion. If I know the strength, I can tell you, what will be the velocity u 3.

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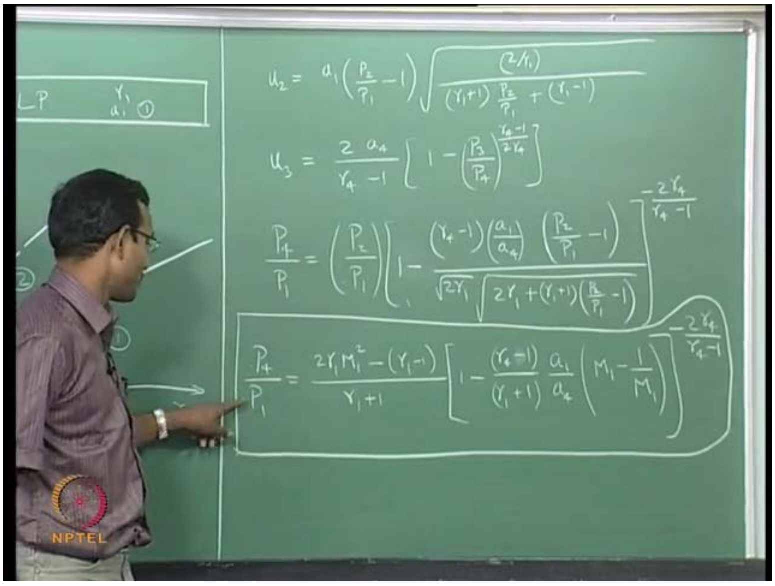

So, all we have to do is go and write expressions for those. U 2 is equal to a 1 times P 2 by P 1 minus 1, I have done some rearranging of terms, which I do not want to discuss here, I believe you can get to this point with a little bit of algebra, it is not very complex.

If you look at the formula there, it will be easily rearrangeable to this form, it is not very difficult, this is coming from the moving shock expression. Now I will write another for u 3, the expansion site and that expression, now I am writing, I am being careful about the gamma, I am saying gamma 1 and gamma 4 remember that. Now I want to say I will enforce u 3 equal to u 2, which means I am going to equate these 2 expressions on the right side and I will again say P 2 equal to P 3. So, I will replace this P 3 with P 2 then I will see what I end up with oops it is 1 minus a fraction.

It is a big expression, this is why I did not want to derive this whole thing in class. Because, that itself will take probably half the class, we do not need to derive this, it is not that important for our course, we just need to know that it changes in a some particular way. Now I have P 4 by P 1 in terms of P 2 by P 1 the way I want to look at this expression is for a given gamma 4 and gamma 1 and a 1 and a 4, that is I pick the gases 1 and 4.

If I want a particular P 2 by P 1 across the shock then I have to choose this particular P 4 by P 1 that is the expression, I am having here, it is better to express this in terms of mark number. Because, then after that it is easy for us to calculate velocity behind the shock, it is a moving shock problem after that, we know how to solve that problem. So, I will rearrange this P 2 by P 1 can be substituted for M 1 from P 2 by P 1 relation, we already know that. So, I will just substitute that, of course again I am not going through the full derivation.

Gamma 4 minus 1 divided by gamma 1 plus 1 times a 1 by a 4 times M 1 minus 1 by M 1, this whole thing to the power same thing minus 2 gamma 4 by gamma 4 minus 1. I have this big expression very useful expression, in shock tube analysis. Now I have decreased it to a little bit easier expression, it still does not look very yielding expression, if you look at it.

There is M 1 and then the properties of gas 1 and gas 2, those are the things that I have, if I want to create a particular mark number M 1 with a gas gamma gas with property of gamma 1 and a 1 on the low pressure side and gamma 4 and a 4 on the high pressure side. Then I can use this expression to find what should be my P 4 by P 1, that is what I have if I said these 2 pressure values here, across that I only what matters is only the ratio.

Typically, I do not need to have very high pressures, what they do is they make it more and more vacuum. So, that I get this ratio easily P 4 by P 1 is obtained by decreasing P 1 very well, we will go the operation of it after understanding, what happens exactly. If I think about I want to have very high mark number, what should I do from physical field, I will go look at this picture.

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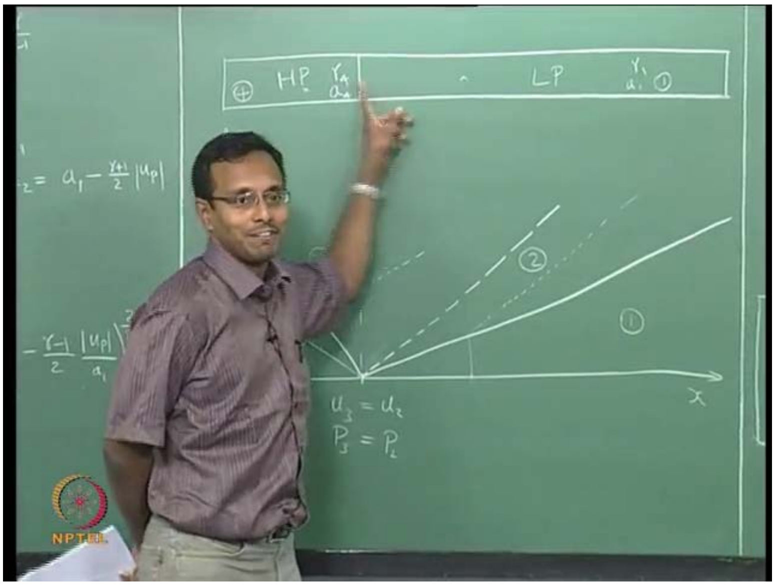

This is easier to think about I want the shock here to travel very fast, what should I do the jump in pressure, should be really high. Then it will say the information that is travelling will tell run extremely fast. Because, there is, so much crowd there nobody, there you just run extremely fast, that is what it will tell. So, just by physical intuition, we will keep that it will help us a lot. So, I want to say I want to have maximizing my M 1, what should I do.

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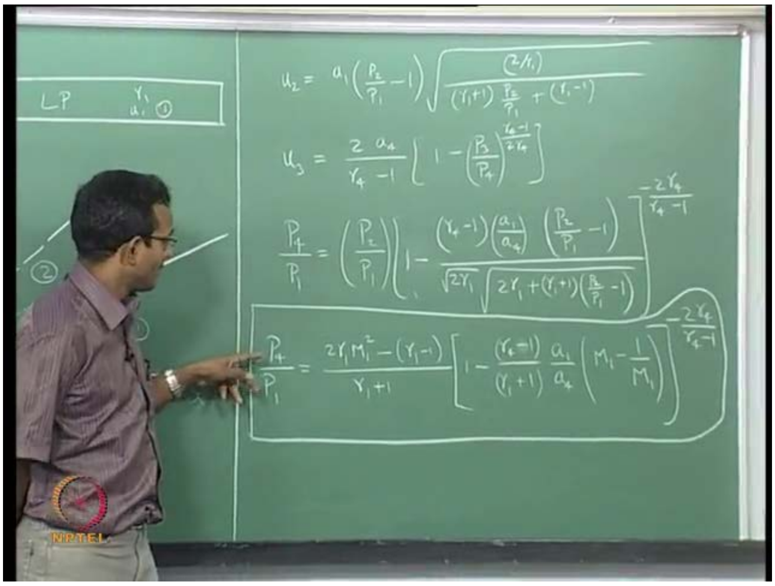

I will go here and say, I want to maximize this P 4 by P 1, I look at this expression not much under my control, they are all gamma 1 gamma 1 only thing is M 1.

If M 1 increases P 4 by P 1 increases that does not tell me anything new. So, I will look at the remaining expression, this 1 has ratio of a 1 by a 4 gamma 4 by gamma 1 kind of ratio is there. And M 1 minus 1 by M 1 is there, if I say M 1 is very large, I am going to neglect this 1 by M 1 with respect to M 1, very nice to neglect, if I think about 5 itself. I can neglect this term 1 by 5 is 0.2 compared to 5.2 is very small.

So, if M 1 is 5 itself, I can neglect it, if I think about M 1 going to 10 15 and now you can definitely neglect this number. So, let us say I neglect this part also, now I have an expression, that is 1minus this fraction times M 1 to the power minus this thing, which we know, we already saw this kind of formula somewhere back where, we know that without the minus sign this is always more than 1.

So, this is square bracket reciprocal to the power something more than 1, that is what I have. And I want that whole expression to go to infinity where, I want it to be maximized. So, I want to make sure that this square bracket tends to 0, that is the idea, I want to make this square bracket tend to 0, which means this ratio, this expression the 2nd term must be almost equal to 1, that is what you have to think about, we will make it equal to 1, if I think about it that way.

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I have to say that my M 1 must tend to gamma 1 plus 1 by gamma 4 minus 1 times a 4 by a 1, this is what I will have if I want to maximize my mark number then the maximum mark number, I can get will be just this. If I want to produce a very high speed u 2 or u 3 of course, you know u 2 and u 3 are the same, if I want to produce high speed of flow behind the shock then I want to maximize this M 1.

If I want to maximize this M 1, now I have to think about maximizing this quantity that is the way of thinking about it. It will be the maximum for whatever this value, but I want to maximize even this, if I think about it that way then I am going to say I want to have gamma 1 high, gamma 4 small right or better yet I want to have a 4 by a 1 high. I will write a 4 by a 1 high first, but think about this, this also has gamma 4 by gamma 1 inside of course, having a square root on it that is also inside this.

We already assumed that T 4 and T 1 are the same. So, the main ratio happens to be gamma 4 r 4 divided by gamma 1 r 1, whole square root, that is what this expression is. So, if I want to maximize this. I can also think about 1 more possibility gamma 1 by gamma 4 high, I will say this is not as important as this 1, I will say this is more the first 1 a ratio is more important than this 1, this is not important.

I will say if you want to think about it, gamma 4 less than gamma 1 helps, because both of them may not be achieved all the time. How will I make this speed of sound at 4 very high compared to speed of sound at 1, molecular weight is the good way of doing things or gamma does not change much across gases. It is going to go somewhere between 1.2 to 1.66 for all the gases, it is not going to change a lot, that is why I am telling this ratio may not be very very interesting, more interesting is to look at this 1 a 4 by a 1.

If I think about it that way, I want to maximize a 4 what should I do, I will look at R for the gases, universal gas constant by molecular weight of the gas. So, if I want r 4, it is molecular weight of 4, whatever gas at 4. So, here minimize molecular weight, I will get maximum. So, typically people use helium for this, helium is really light people can use helium and now they will say yes, I will get very high a 4.

A 1 typically, should not be helium right, if we want it to be as high as possible in molecular weight. So, that a 1 decreases a lot and then along the same direction, I want to think about a 1 should be having higher molecular weight gas, but based on the application. Typically, we will not have the luxury of changing the gas at 1, we will see why in the next class on probably, even in 5 minutes probably.

We will have only the luxury of changing this, where most people use this particular shock tube, for changing the pressure and temperature of a gas suddenly to a new value. So, if I want to think about that this particular gas 1 is our test gas that is what it will be typically. So, if I think about it, I am going to use helium on the high pressure section and on the low pressure section, I will use whatever test gas I need, the next things I need to do will be go and observe, what will really happen there, I will start with this picture again.

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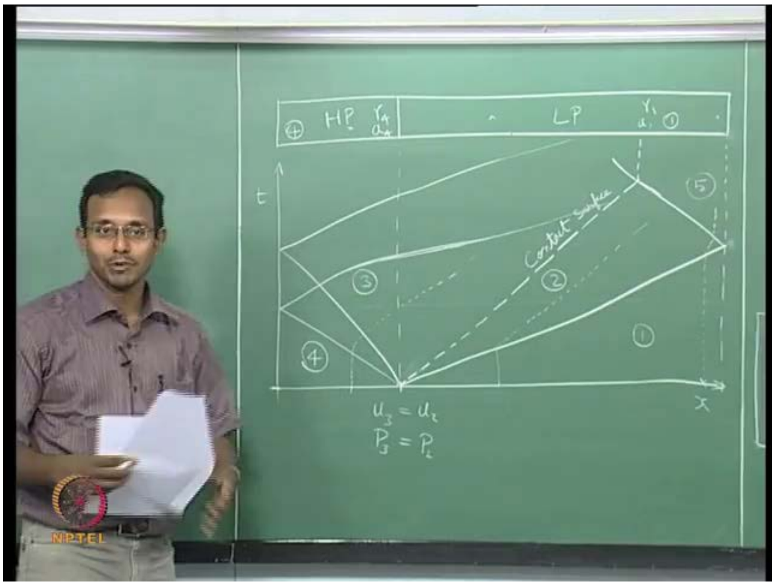

And here I have put some gas inside here, let us say typically there are people who are using this will be chemistry people or combustion people, people who want to study reaction rates shock tube. If I just want to use the plain shock tube, it will be used by people, who are in reaction rate determination kind of people. So, they will have some reaction mixture, which they want to study in here and then probably very low molecular weight gas here depending on what P 2 and T 2 they want they will work with that.

And they put it in here, they give the shock and this whole situation will just all this gas will get compressed and go to this corner by the way what happens, when the shock goes to the end. We did this problem already, it will reflect back at the end wall, I am saying it is a closed tube. So, it is going to reflect back from there. So, if I think about it I will draw a dotted line, the shock goes there and it turns back, when the shock turns back, I will make this by the way this boundary between 2 and 3 regions is called a contact surface.

So, shock when it reaches the contact surface, after that the shock makes sure that the gas in region 2 will come to stagnant point. This is region 5 by the way comes to stagnant point, which means my contact surface will now go straight like this, I would not worry about, what happens in this region after that, currently we will just say the shock just goes straight. I would not worry about this right now.

I will talk about this probably next class as of now it is just going straight and region 5 has stagnant gas. So, I have finally, taken my gas at 1 to state 5, which is T 5 T 5 and now I can study suddenly pressurized gas and at a very high pressure and temperature, it has been compressed processed by 2 shocks. And all this is happening in micro seconds time scale within say 100 depends on the length of the tube of course, could be anywhere, in the order of 100 to 500 micro seconds.

So, that kind of time scales within that time, it has get it got compressed, now I can sit and wait for sometime, I have some time before the expansion from the other side think about this expansion goes and hits this wall. Now this is going to reflect back and of course, the first wave and the last wave are going to be diverging as it is, this will eventually come and reach, this I have curved it more.

So, that it does not go outside the board and if you think about it, this will reach slightly out there, if I have designed my shock tube correctly, it will reach slightly after and. So, I will get some time in this region 5 where, there is no disturbance that is where people will do the experiment and then people will start observing this region somewhere, close to the end that gives the maximum time. And they will start observing, what is happening in there at that new pressure P 5 and T 5 and now they will do this chemistry reaction rate experiments. They suddenly take this reaction reactants from T 1 P 1 to T 5 P 5 and then they we will study what happens there is it really sudden yes it is if I think about this particular particle sitting here.

This particular fluid element at this location, that fluid was sitting at P 1 T 1 for this longer time and within a short time, it got compressed and it is now sitting here. This is all the time it had, shock is travelling supersonic remember it is going this way supersonic and then it is coming back supersonic. So, the whole thing together it is going to be very short time and if I am thinking very close to the end of the tube probably a few centimeters supersonic speeds, it is going to go within a micro second or so.

Of maybe think about 20 micro seconds at most going to be compressed within 20 micro seconds, I have increased it, suddenly now I will study what is happening to the gas it is going to react probably it is going to burn. If I put hydrogen and oxygen in that gas 1, that is going to start burning and producing water in there or probably H 2 o 2 also. If you are in combustion then you will know that, they study this h 2 o 2 reaction systems in basic combustion books also, you see this where, they have come up with all these reaction mechanisms, that comes from these kind of structures.

That us a parallel used for this shock tube, we would not understand the gas dynamics part of it and then we will see how it can be used for compressible flow experiments, that I will deal with next class currently. I just want to look at the simple section up to this particular time, whatever this time is up to this particular time T equal to 0 to this particular time no changes right. It is very simple flow, this wave wants to go this way, I want to understand and look at pressure along, the tube at all points in the tube, if you think about P versus x, I want to plot.

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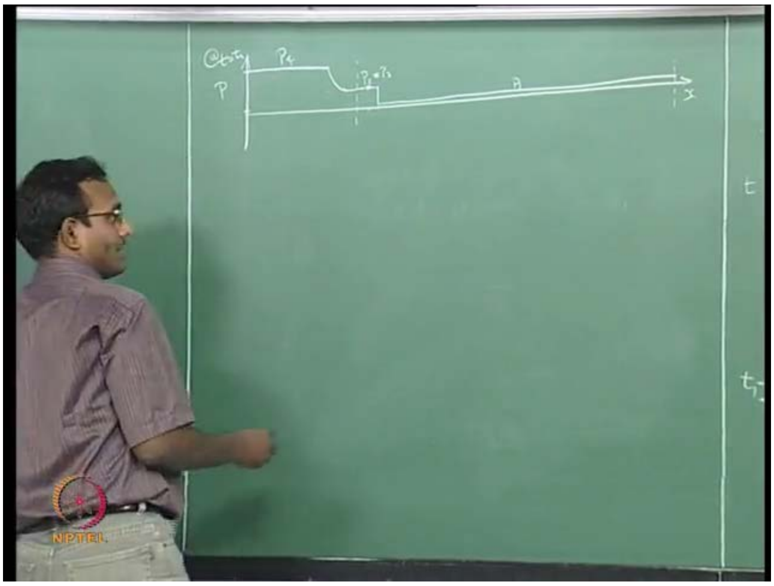

I am putting some dotted lines corresponding to the diaphragm original location and the end wall and the other end wall is this axis itself. I am having this situation let us say I will pick this time T 1 at T equal to T 1, I will draw a line. So, that you will know where, we are references.

I do not need to draw it anymore there is nothing there. So, if I look at it there is expansion between these 2 points and there is a shock somewhere here and there is a contact surface there, these are the key points. So, if I tell you that P 4 is somewhere here and my P 1 is somewhere here, I can tell that before the shock, this whole region is my P 1 value.

And before this first expansion wave all this region is P 4 value, this is your P 4 and that is your P 1. Now, we know after the shock the pressure goes up, but cannot go more than P 4, it has to be something in between P 1 and P 4, because P 4 is the 1, which is causing the shock. So, it will be something intermediate and then I know that is the P 2 value, which is same as P 3 value goes all the way till there, P 2 equal to P 3. This is what is happening there and this particular location is the contact surface location and due to expansion, I did not give you proof for this, I will just tell you that the curve looks like this.

The very first wave causes a lot of change because that is the wave, which tells that there is a huge pressure difference and after that the pressure drops a little bit. The next wave comes and tells the pressure difference is in slightly lesser value. Because, that is what it sees, that is why it perceives. So, it goes drops drastically, when it is a very first wave and then it goes gradually down it ascend towards at a last wave, that is what, you will see comes like this and then it becomes. This will be your pressure as a function of distance in my shock tube at time T 1, let us say, I will do another time somewhere here.

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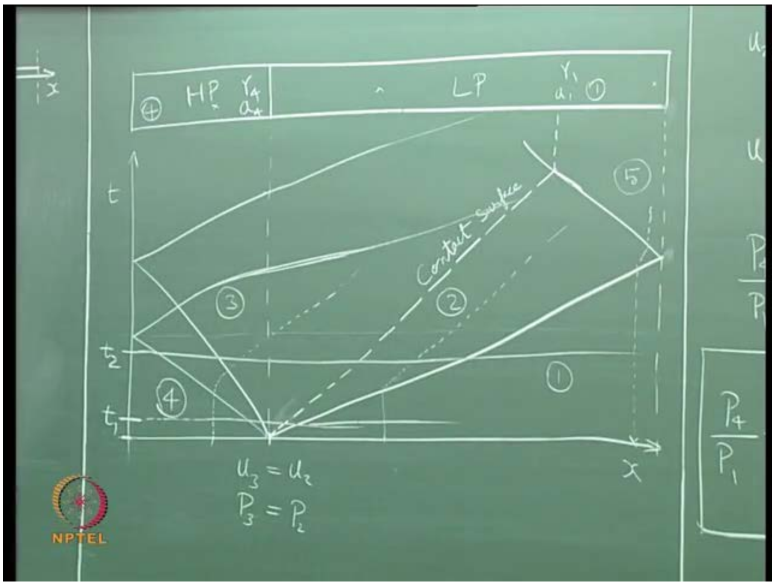

T 2, if you think about that…

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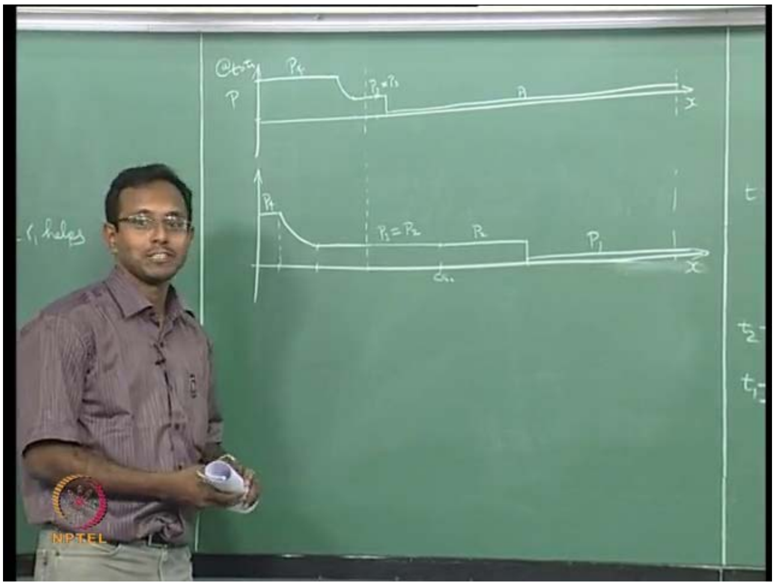

Now I will tell my expansion reached a lot of distance contact surface times some more this much shock time somewhere here, those are my points. Now I can draw P 4 should be exactly the same value and before the shock it is always P 1 and we know the shock is the same strength travelling all the way through. So, that is also P 2 jump is also exactly the same. And then this whole region is my P 2, this is my contact surface location and till here is my P 3, P 3 equal to P 2 of course and this becomes my pressure profile in my shock tube, what is happening is there was initial condition what was it was a sudden step from P 4 to P 1 at time T equal to 0. After some time this is developed a shock and the pressure is something in between P 4 and P 1. It is trying to come to some equilibrium between these values, it is coming to something in the middle.

When this whole region is becoming that value and this side it is going this way and you can notice that, this curve is now less steep compared to the previous one, why the expansion fans are going apart expansion waves in the expansion fan are going apart from each other. So, they are going to split out slowly like this. We will go deal with more stuff after this next class where we will start thinking about, what happens to velocity at these times and then we will think about other values like temperature, what happens to temperature, And then we will deal with what happens when the flow reflects at the corner, that is times more than T 2. So, we will I will also show you probably an animation of this, which is what is missing at this moment, see you people next class.