Gas Dynamics
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Module - 8
Lecture - 18
Solved Numerical Examples for Moving Shocks Oblique Shocks

Hello everyone, welcome back. Last class we stopped with solving a problem halfway in a sense we said there will be a flow-through a duct 20 meter per second. And at the end of the duct, I am suddenly putting a lid and making sure that there is no flow is done suddenly and that is the problem we were looking at.

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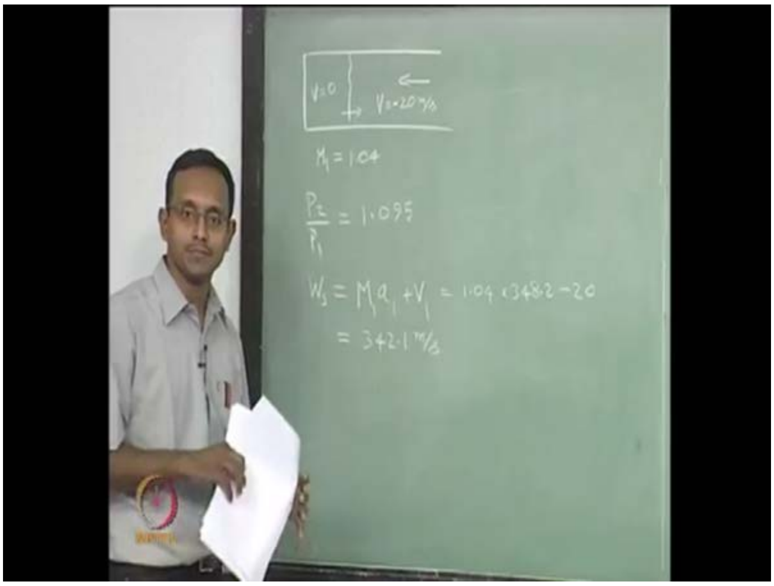

And we transformed that problem to this problem where we said there is a velocity 20 meter per second coming in since it is right-to-left, I am going to say V equal to minus 20 meter per second and here V equal to 0. And we found that the shock speed or we said shock mach number was 1.04 at towards end of the class we iterated and came up 1.04 final results, so with this 1.04, if I want to go and find the strength of the shock P 1 by P 2.

I am going to pick from gamma equal 1.04 normal shock tables for this mach number. I will get the strength to 1.095. So, if I have 20 per second flow in a duct and I suddenly stop it, I am creating a supersonic, and I am creating a shock which is travelling supersonic and it is going to have strength 1.095. So, the pressure in the duct is increasing by 9.5 percent and that is what, is causing the flow to come to rest in the duct. If I want to find the shock speed, we know this formula already I am just going to write it. I am putting minus 20 because P 1 is minus 20 happens to be 342.1 meter per second. So, what we are finding is the wave that is telling that, there is a lid at the end of the duct is travelling at the speed of 342.1 meter per second.

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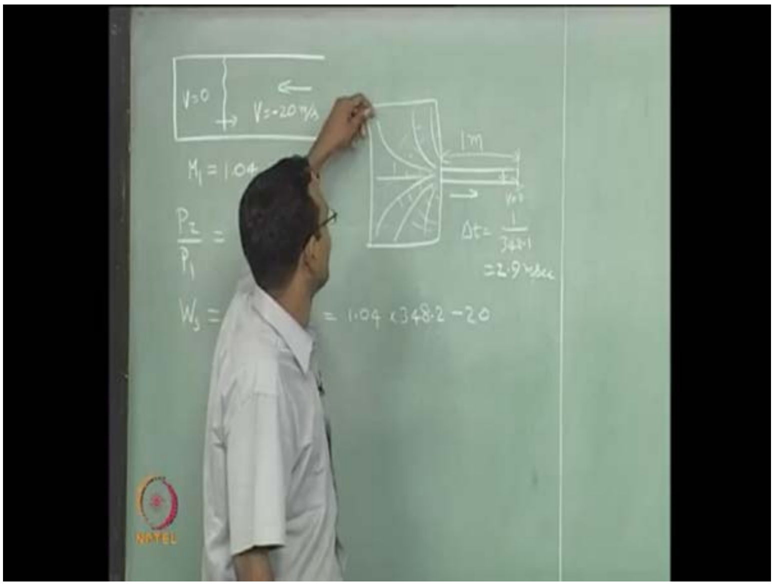

So, if I consider a case where I have a big tank with a thin tube through which I have that same 20 meter per second flow and let us call it is 1 meter long. So, I have some case like this and it was having a steady 20 meter per second flow and I just know a t equal to 0 put a lid at the end of the duct if I did this. Now, when I look at this, it is going to cause a shock exactly same situation the 342 meter per second speed the shock is going to travel.

And as it goes this way, it is going to make the flow behind came to rest completely, while initially there is a 20 meter per second flow this way, here V will be 0 after the shock. So, how long will it take for this flow situation to change full in the duct if I think about it, it is going to be 1 meter to be traversed by this whole shock, when the shock goes here all the fluid inside is stationary. So, I am going to find the delta t it will be 1 divided by 342.1, this is approximately 2.9 milliseconds not meter per second it is milliseconds 2.9 milliseconds. It takes such a short time for 1 meter flow, 1 meter long duct to come to rest if the velocity initially was 20 meter per second. This is what you are going to see.

Now, what will happen inside this duct? Here initially it is still considered to be really big but, still there is some velocity inside because gas from here is what was flowing out sometime back. So, there was a velocity from every corner into this, if I draw streamlines there will be streamlines coming like this every streamline will want to go in through the duct, that is what it was initially of course, a velocity in the streamline will be very close to 0 at the wall and slowly increasing towards 20 meter per second when it comes in there, that is the actual flow field in this region.

When the shock comes here at the exit, it does not stop because if it stops here what will happen? The flow from here will keep on going, it cannot stop suddenly, and it will keep on wanting to go there that cannot happen. So, this shock has to go and tell all the fluid that it can ever encounter that, there was a problem. So, it will keep on going in and it will go like this, it will start expanding to meet all the fluid elements possible. It is going to expand out diffract out spherically is going to go out like this, eventually whenever it is crossing by the way it is a same shock but, now it is expanding conforming bigger area it is processing much bigger volume flow rate, if you think about it if it goes at the same velocity but, that is not possible for the shock because it has only fixed energy.

So, what it will do is as it expands, it has lesser strength will talk more about it when you are thinking unsteady flows but, anyways it is expanding. You are going to have lesser and lesser strength which means, it will cause lesser delta V but, it. So, happens that is enough for this case as I go this way along the streamline, the velocity is going to be lesser and lesser when I come to this corner of the streamline it is stagnant gas.

Alright, if that is the case then when the shock keeps on coming the delta V required to stop this fluid is going to be lesser and lesser, eventually the shock becomes very weak and stops completely nothing more needs to be done, that is what really happens inside if I ever stop a flow, in case I did not stop it completely but, I had a small leak then there will be a small velocity here finally, they are doing one day analysis remember. So, even if the leak is this way I am going to consider it to be a small velocity this way, let us say it is 1 meter per second leak, then this flow velocity is not 0 but, it is 1 meter per second. So, the actual delta V that I am imposing is only 19 meter per second that is all. Now, I have to go and solve the problem again you will find the mach number of that new shock will be slightly less than 1.04 because, it does not need that stronger change is lesser change, it will be lesser mach number that is what you all find and one more interesting thing I have to tell is this whole flow field was all subsonic, nothing was supersonic except the shock.

What we are seeing is, even if the flow is completely subsonic very low velocities, it can be considered as an incompressible flow problem right. If it is just 20 meter per second it can be considered as an incompressible flow problem, you think about mach number 20 divided by 350 meter per second, it is very small. It is less than 5 percent mach number itself we can go all the way up to 0.3 mach numbers for compressibility effects. So, it will be very small number but, still 0.07 kind of mach number will be what you will get roughly. That is extremely small but still when the flow is unsteady I am suddenly changing something in time right at t equal to 0 onwards there is a lid, if that is the case then we are finding that, there is compressible flow happening inside even when the velocities are extremely low.

This is the main point I want to drive through this whole course, I want to say that when the flow is unsteady compressible flow field can happen anywhere at any velocities, because the gas can adjust only through compressible effects, only through compression waves or expansion waves, which are all compressibility related effects. It is an only way a fluid can communicate from 1 point to another, the only way that is the fluid inside this tank can know that, there is a wall suddenly appearing is through the shock.

And that is a wave that is going through, it is a pressure wave it. So, happens that, it is a high-pressure wave. Now, I can have a straight opposite problem, if you want this is just going beyond my notes, if I have a straight opposite problem. I am having a tank filled with some high pressure gas I suddenly open this lid. Now, there will be a flow created alright this is a high-pressure region, this is a low-pressure region outside it. Let’s say atmosphere inside is let us say very high pressure than at t equal to 0. I open it, the actual velocity of final steady-state may still be 20 meter per second alright but, the process of accelerating this stagnant gas inside the duct is happening through expansion waves going this way, which will tell that there is less pressure there.

So, everybody move that way is the information, that is going inside, it is going to go into the duct and again it is going to diffract out and expand everywhere and tell that you people move a little bit slowly but, that is enough that kind of information is going all the way out. That is how you create this particular flow, this is be on the notes we have to go back to expansion fans later and talk about it again.

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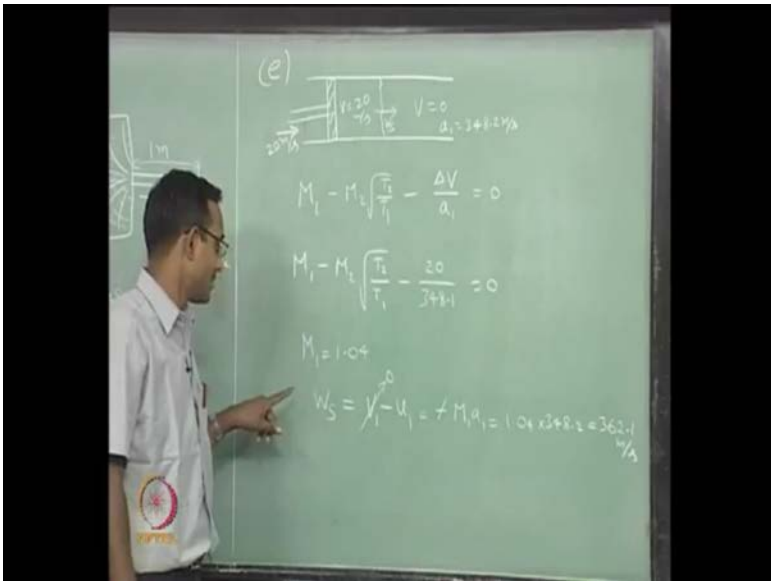

Now, we will go to another problem, this is continuing with the same numbering, It is problem d. Sorry, e; d was the previous problem e. Now, I am leading to something which I want to go to in the next lecture. So, what I am going to have is a leak free piston in a duct, there is no leak across the piston and I am going to say at time t equal to 0. The whole gas in this region is all a waste and suddenly it is moving with 20 meter per second, it is moving very low velocities, and it is not very high but, when this is happening I am going to say what will happen, there will be a shock created because suddenly this gas is going to tell there is some problem here.

We have to run away from here, that information is going through the shock is like a snake is moving or whatever something likes that kind of information. If you want more, it is like some bomb is exploding something like that. It is everybody wants to get away from this region V equal to 0 here, V equal to 20 meter per second here and of course, we do not know this was as of. Now, the speed of the shock we do not even know the strength. All we know is a 1 will keep the same temperature 300 Kelvin. So, a 1 is 348.2

meter per second, if I go through the whole set of formulation I will get to this I wrote this last class. So, I will go from here I will have this formula you will you will derive it, if you go through the whole whatever wave be solved. Now, u 2 minus u 1 equal to V 1 minus V 1 from there, you substitute everything in terms of mach number you all get to this.

Now, we just want to solve this problem, it is a same problem we just do not know the strength. So, I have to start guessing M 1, I am given delta V, it happens to be V 2 minus V 1, 20 minus 0, it will be 20 divided by 348.2. So, I am having M 1 minus M 2 square root of T 1 by T 1 minus 20 by 348.1. If you go back to the previous problem, the last class towards the end, we solved this exact same question. It was exactly the same 20 by 348.1, when we are solving the same equation math will give exactly same answer. I do not need to solve this problem again but, if you want, you can solve this by iteration and you will get exactly the same M 1 equal to 1.04 will see the link.

Now, how are these two problems, the same not very difficult to show but, I wanted to tell one more thing is just from looking at this expression it. So, happens that if I guess an M 1, I know M 2 and T 1 by T 1, they are all related to shock strength but, this term is related to change. That is happening in the fluid one, set of terms is related to shock strength that is going to cause the change and this is the actual change, and that is caused if I tell that, the delta V that is needed to be created in the flow is some value and the speed of sound.

For the original gas the incoming gas for the shock happens to be a 1, if I give this value or the ratio actually what matters happens to be the ratio really not the values if I tell you for particular T 1 and gas if I want to make delta V of. So, much change I do not care whether V 1 is 100 per second or 0 or minus 2000 meter per second, if I tell you that I want to change the velocity by 20 the shock that is needed will be 1.04 if I were assume a 1 is 348.1. So that is important, that is what I am going to see from here. This is nice way of telling that, if I want to make a change for every change there is a particular shock strength, that is needed in the flow field and that is related to speed of sound in that medium in which I want to make the change. That is what you are going to see in this whole thing but, I can go and solve this whole problem. I do not need to the only difference will be W s from problem d to problem e was.

Now, it is going to be V 1 minus u 1 where V 1 is 0. So, it will just be minus of u 1 which is equal to minus of minus M 1, a 1 remember we used u 1 as minus M 1 a 1. So, that minus gets cancelled. So, this number will come out to be 1.04 multiplied by 348.2 which is 362.1 meter per second the shock strength shock speed is different even though the shock strength the mach number and the P 2 by P 1 are the same. The shock speed is different, that is the only change you will see speed with respect to the reference frame is different velocity depends on reference frame. So, since the reference frame is different I am going to have a different velocity, we will see the connection between these two problems now.

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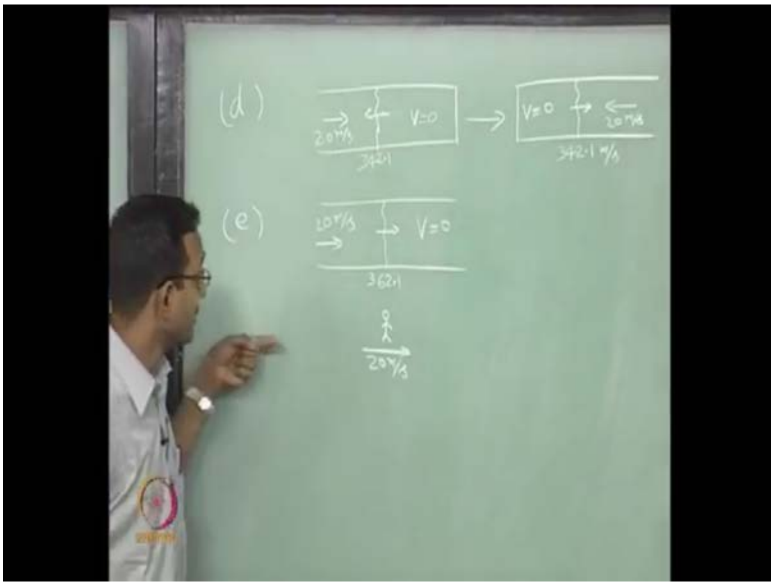

In problem d, we had a case where there was a duct there was 20 meter per second flow this way there is a shock going this way and it is the shock is going on the other way sorry, shock is going to the left and here V equal to 0. This is the problem we saw and in problem e whatever, we just solved the problem. This is 20 meter per second flow coming and that is the effect of the shock moving like this and V equal to 0 here. So, it happens in that both cases, delta V happens to be plus 20 meter per second that is why you are getting the shock strength to be exactly same M 1 and P 2 by P 1 are the same. Now, how are these two problems, the same that is the only thing I have to see, I will write the velocity values for the speed of a shock for problem d. It was 342.1 and in this problem it is 362.1. Now, if I say it is very difficult to look at it this way. I will just transform this problem to our way of looking at it I will transform this two.

Looking from the other side of the board V equal to 0 shock is going to the right and velocity is against it if I have a case like that, I have just transformed this exact problem that is nothing wrong I have just multiplied with minus 1 for the whole system or I can say that instead of looking from this side. I am looking from the other side of the board then it will look like this. Now, if I have a situation where I have an observer as of now is stationary to observe this particular problem I am going to.

Now, say that is going to move this way with 20 meter per second is moving this way with 20 meter per second. What will he observe? He is going to say that, this fluid is stationary with respect to him because they are both going parallel to each other with the same velocity and this fluid. Which was originally 0 will be seen as coming this way with the same velocity and there is going faster but, I am going this way also. So, only the relative velocity will remain, that will be 342.1 whatever I have just done because this guy is now moving. You will see that it becomes this problem that is why you are getting exactly.

Same M 1 because, this is just the reference shift from this problem to this problem itself, only change we had just reference frame was moving with 20 meter per second different in this two problems. That is the only way you will finally, conclude that is the only thing that is happening in this flow. This is the link between problem d and problem e, the same thing we discussed and we said that problem a, problem b had the same kind of link, only the reference frame was shifted like 20. I believe that was 100 meter per second that is only difference there alright. Now, this duct and a piston; actually, I will start from the next page here.

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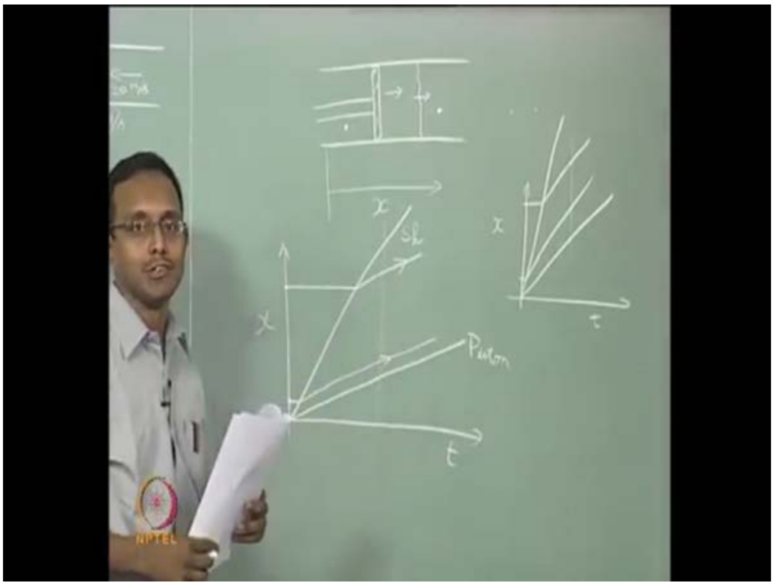

I have this duct and a piston arrangement and I am going to say it is starting to move a T equal to 0 and after that there is shock and velocity behind the same as the velocity of the piston. If I wait long enough, what will happen? the shock would have gone well past into the duct and what we will see, will be just a steady flow where the fluid having the same velocity as the piston, which is what our incompressible flow world will be talking about all the time but, I am interested in the unsteady phenomena on T equal to 0 onwards. Then there will be a compressible flow field happening there will be a shock that will be created and it will be going at supersonic speed all that is happening in there.

I am keeping on repeating this unsteady flow will mean there will be compressibility keep remembering that. Now, if I think of this problem like this and I call this is my x coordinate, I want to plot things x versus T. Let us say I want to plot this, let us say a T equal to 0, the piston was here and it was at rest and just when that moment any T that is greater than 0. It is going to be going with a constant speed will mean d x by d t is a particular value. So, it will have one constant slope let us say this is my piston this is the trajectory of my piston what is happening as time increases the piston moves this way that is what I am seeing now I want to plot the location of the shock on this plot at time t equal to 0 there was no shock because there is no change but, immediately after that the change happens from the piston and it moves away from the piston.

So, and it is moving at a constant speed which was what 362 meter per second, that is going to be something like this, it is supposed to be a straight line. I have drawn it slightly curved, imagine it is a straight line and this is your shock. Now, this will help you understand 2 d flows automatically but, we will go to 2 d flows. Today towards the end of this, if no next class beginning if I want to look at say particular particle of fluid, which was sitting somewhere.

Let us say I will pick a fluid particle that was originally sitting here at T equal to 0 when the piston was actually sitting here. If I pick such a case piston initially was here at x equal to 0 and the particle was at x more than 0. It will not move till the shock crosses this point, which means it will be at the same x for a set of time values after that, it will have a speed which is same as the piston velocity. So, it will have a slope on this thing parallel to this piston slope that will look like this. If I pick another point somewhere here far away, that is going to be somewhere here and it will stay remain constant till the shock reaches there.

Let us say that is happens at this time after that it is again going to go with the same velocity as the piston. So, it will again be parallel to the piston this is what happens, if I look at one special thing at any particular time after they have been processed by the shock, these two particles have come closer the delta x between them is lesser than before. Now, this is related to the gas getting compressed.

Initially, the gas was occupying this big volume .now, it is occupying lesser volume that is what is happening here, this is the effect of compression and depending on the change delta V, it may be very strong compression or very weak compression. The piston moves very fast I will draw another picture very quickly here, if the piston moves very fast the shock will be very strong and you will find that the delta X at any particular time will be much smaller if the piston moves fast, what happens this delta V is very strong M 1 will be very strong from that formula. We just looked at today, I am going to look at this from here this much volume is now becoming this small volume if I had this big separation initially from this and this.

Final separation may be this just that distance between them that is also going to happen. This is related to compression even when I am having piston moving that subsonic speed. it is going to cause a shock which is a compressible flow field phenomena that is the thing I just want to keep on dragging, whenever there is unsteady flow this is an unsteady flow field moving shock. It is an unsteady flow field and that is why all this is happening immediately after this next class onwards will be talking steady.

Steady gas dynamics where we would not have anything moving. It is all with respect to some fixed shock is going to be fixed with respect to my reference frame. That is also going to happen, if I waited long enough these shocks the unsteady phenomena will go all the way up to infinity into the gases, all the gas in the flow field will know that there was a change and only after that if I look at the flow field will be no compressibility effects and it will be look like our ordinary subsonic flow fields which we saw in the previous problem d. We said if I wait for more than 3 milliseconds the duct will have subsonic flow field steady-state again within those 3 milliseconds, if I have a very high speed camera. I will see that shock moving that is also going to happen. Now, we will go look at new problem, this is probably the last problem I will solve, because I want to make you familiar with solving for entropy also in a moving shocks situation.

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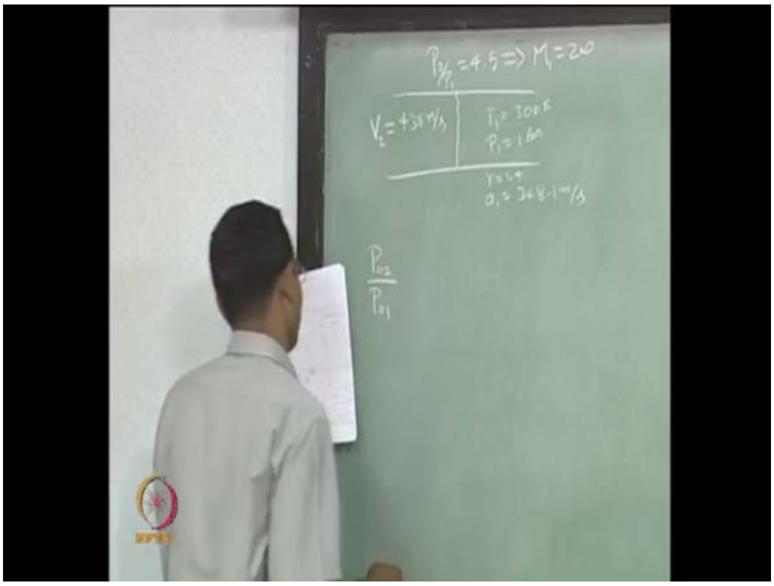

So, we are going to pick a case, I am going to pick the same case as what we solved before problem a. So, that it is easier I will just solve only whatever is needed I was given P 2 by P 1 in problem as to be 4.5 which immediately gave me my M 1 was 2.0, 2.0 and we had T 1 equal to 300 Kelvin P 1 equal to 1 bar gamma equal to 1.4, a 1 equal to 348.1 meter per second and we found that time we were interested in finding V 2 which was 435 meter per second, this is what we were interested in that time. We solved this and we said that is the answer. Now, we want to go beyond this, we want to solve for the entropy change. Across this before that I want to solve P naught 2 by P naught 1 only after I solve this. I can solve entropy change anyway. So, we will solve this P naught 2 by P naught 1. Just for an instance let us say I will put a parallel.

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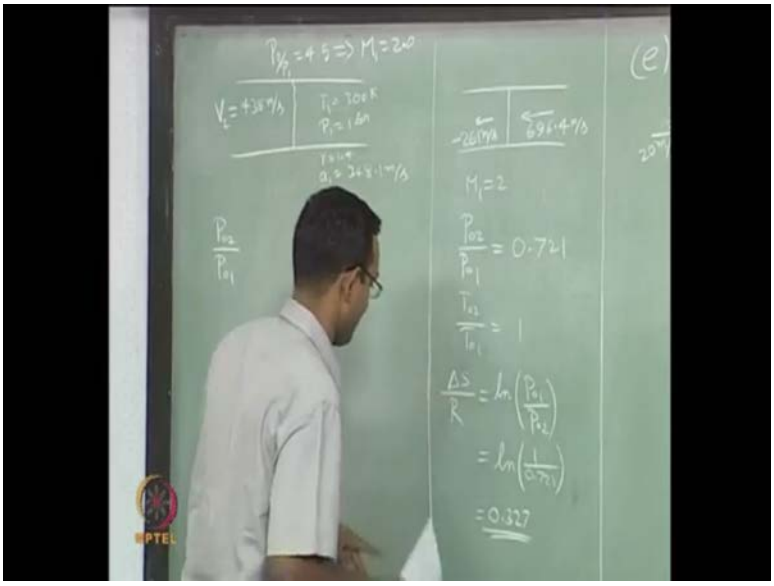

The shock fixed coordinate system shock fixed coordinate system my u 1 was minus 696.4 meter per second and my u 2 was 260 minus 261 meter per second, this is what we had this is all same problem. I am just repeating it, if I have such a case and for this problem M 1 equal to 2 case I go to shock fixed coordinates right. So, I can directly go to normal shock tables gamma equal to 1.4 and I will get P naught 2 by P naught 1 is 0.721 of course, we already saw that in a normal shock P naught drops, that is what you are seeing here and we know that T naught 2 by T naught 1 equal to 1, this also we know from normal shock tables.

Normal shock not really tables data S by R was given to be log of P naught 1 by P naught 2, which is log of 1 by that number 0.721, it happens to be 0.327 happens to be 0.327, This is one way of solving. Now, depending on what units of S I want for mole or per mass we did that kind of exercise already per mole or per mass depending on that I will use the correct R. Here, 8.314 or 288.6 whatever needed, we want deal with that. I just want to look at the ratio right.

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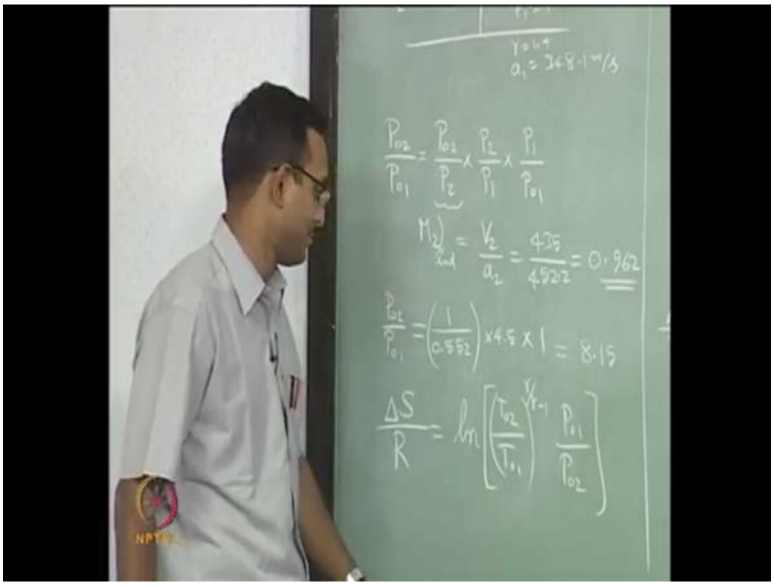

Now, if I want to solve this in the moving shock problem I have to go and do that cyclic ratios, I will do it this way because these are the numbers, that I can get from my tables and this is coming from M 2 my induced mach number for the flow behind the shock in the moving shock, this is equal to V 2 by a 2 we know that V 2 was 435 and a 2 also be calculated based on T 1 by T 1 and 348.1 a 2 happens to be 452.2and M 2 happens to be 0.962. That is a number I am having for calculating this.

Now, I will go and find from my isotropic tables for this mach number gamma equal to 1.4. What is the P naught by P value then I can get to this ratio P 2 by P 1, I am getting directly from my mach number M 1 equal to 2, actually we were given 4.5 directly I will just use 4.5 year and P 1 by P naught 1 is given by mach number of the initial flow based on V 1 by a 1 V 1 was 0 for us. So, M 1 is 0 which means P naught 1 equal to P 1 it is stagnant gas it is not moving. So, it is going to be 1. So, if I put all of them together P naught 2 by P naught 1 in my tables.

So, happens that, they give P by P naught for isotropic tables. So, I am going to write it as 1 by 0.552 because that is the number I get from my tables into 4.5 into 1. This number happens to be 8.15. So, we are getting a P naught 2 by P naught 1 as 8.15 while P naught 2 by P naught 1 in shock fixed coordinates was 0.721. This is less than 1 and this is very high compare to 1, that is what you are getting remember this. It is not yet done if I go and calculate delta S by R based on this formula. It will be wrong we have to use the appropriate formulae I told this, that time also alright. We will go and use the correct formula later the correct formula we were deriving this sometime back when we wanted to find.

Delta S by R and then we simplified it in one step. I am taking one step back in that we had a formula like this, you had a formula like this when we were doing fixed coordinate normal shock, when we did that shock fixed normal shock. We said that T naught 2 equal to T naught 1, 3 and we made this 1 and. So, we had log of P naught 1 by P naught 2, which is the formula we used for shock fixed coordinates.

Now, for this problem we know T naught 2 will be more than T naught 1. We saw plots last week actually, I think 3 classes, 2 classes behind whatever and. So, we know that, this is more than 1and it is not equal to 1. So, I have to take this also into account then only we will get correct answer. Now, we have to do that for this problem. We will go to the next section. We want to find t naught 2 by t naught 1.

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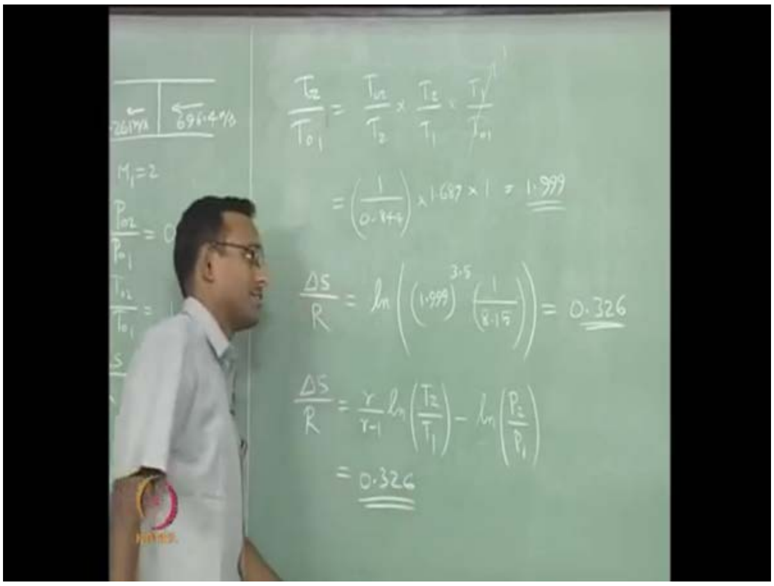

Same procedure cyclic ratios and of course, this is going to be equal to 1 because my gas is stagnant based on V 1. The remaining things I will just put numbers directly you know how to calculate same as what we did for pressure? This is the number I got, I could have made it 2. I just wanted to keep it whatever my calculator gave. Now, my delta S by R comes out to be log of 1.999 to the power gamma by gamma minus 1 which we know is 3.5. If you do not know you should know it for gamma equals to 1.4, this is 3.5 P naught

1 by P naught 2 which is 1 by 1.81 by 8.15 this answer happens to be 0.326. Now, let us say I do not want to use this complicated T naught based formula I directly go and use delta S by R equal to gamma by gamma minus 1 log t 1 by t 1 minus log P 2 by P 1 where did I get this is same as delta S equal to cp log T 1 by T 1 minus R log P 2 by P 1 it is the same thing I just took the r out of here. So, this is the formula now I know T 1 by T 1 for the shock. I know P 2 by P 1 for the shock, I can find this way also ideally I can substitute all the numbers.

You know all the numbers I will just substitute it this also gives me 326 exactly the same answer. Both are exactly the same formula it is just 1 the other both should give the same answer. Now, I want you to look at the previous thing we did here. Where, we had a shock fixed coordinate system and here we are having delta S by 0.327. This is approximation error it should be same 0.326, it is just approximation error. It should have been 0.725 or something, and then you will get to the correct answer something like that. I just missed that fourth decimal anyways these two numbers are same.

What this means is entropy change for my fluid whether it is moving shock or static shock, stationary shock, it does not matter I am going to get the same entropy change for the gas. Even though my P naught 2 by P naught 1 or t naught 2 by t naught 1 are very different. Very important information you have to note it. We have to see the reason for this because entropy is a state property of the gas that is the main reason. The gas was initially something at state one and now it was processed by the shock and now it went to state 2 and that delta s is just s 2 minus s 1.

That is a difference you are going to get and it does not care whether the observer was moving or not with respect to the shock. That is the difference between these two problems right. If I have my observer moving along with the shock then, it will look as if shock is stationary with respect to the observer that will become your shock fixed coordinate system or if my observer is stationary with respect to my V 1 gas then, it will look as if the shock is moving. That does not matter as far as the gas state is concerned. The state of the gas is a same T 1 and P 2 from T 1 and P 1. So, the delta S for the gas on my state diagram should not change. It will change only in the reference frame that is the only thing that is what we are going to look for. So, how will I say this is the first thing I can say directly is it is a state property. So, it does not depend on reference frame. Why do P naught and T naught depend on reference frame?

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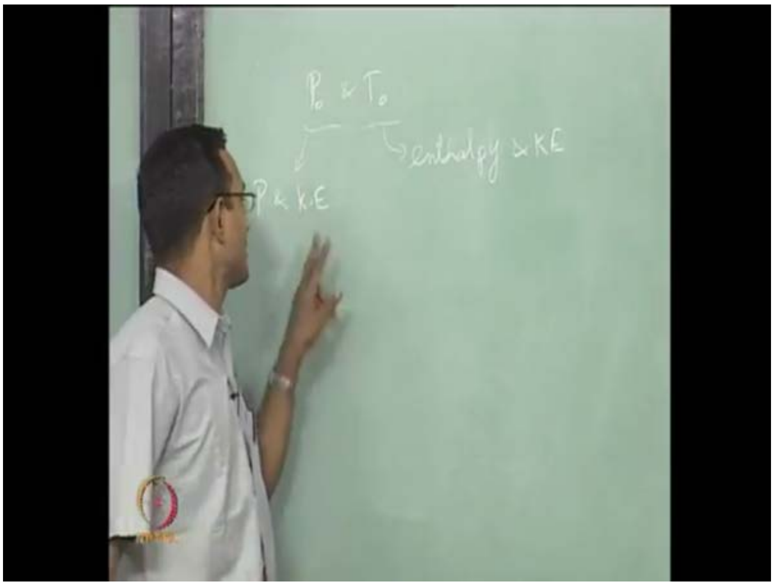

Because, P naught and T naught both of them have I will do individually P naught has pressure energy and kinetic energy T naught has enthalpy and kinetic energy of the gas it. So, happens that the kinetic energy part is what is going to cause trouble. The kinetic energy depends on velocity and velocity depends on reference frame. And that is what is causing all this trouble. Kinetic energy depends on reference frame because velocity depends on reference frame. But, two overall the gas is processed by some particular shock, that is moving and that is going to experience some particular state change and that says my delta S cannot change any more. It is just the same value irrespective of what reference frame I am on. Now, from here the next step what we want to take is go to 2 d shocks, we have been doing 1 d shocks till now, one-dimensional we said 1 d flow field, quasi one-dimensional, whatever we did till now, we are going to move onto two-dimensional flow before I go and show something. I will just give you video that, we took from the lab. Let us go to the screen.

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And here we have actually it is a bolt, it is actually a metallic bolt you can see the threading on it after that it was ground to become a wedge. It looks like a wedge shape here, it is flat surface here and here it is still having the curvy surface on the side in fact it has the threading on the side also and now this is kept in a approximately mach 2.0 flow field it is actually mach 1.98 or something it is roughly mach 2 flow field in our lab and you are seeing this a window through which we are seeing, what is happening in front of the flow in front of this body, there are some scratches on the wall ignore that. Now, I will start it you will see the flow starting to happen alright.

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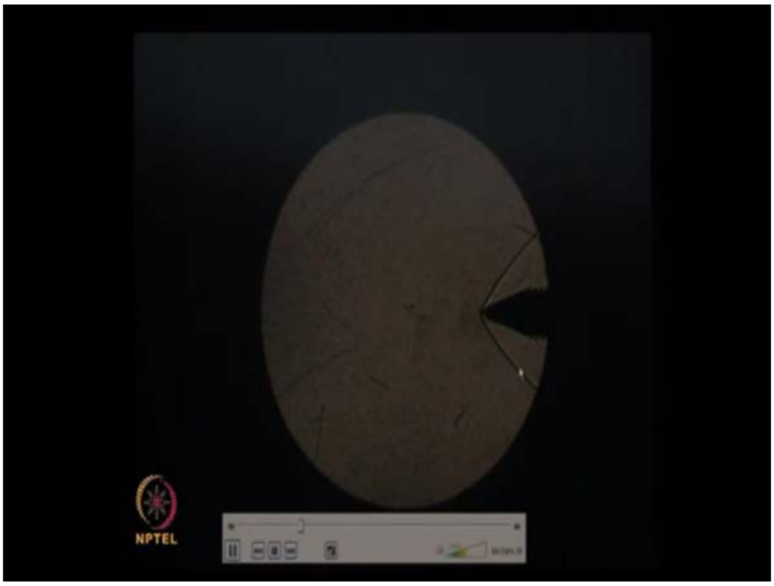

Suddenly, you are seeing there is a nice line coming like this and on the other side and they are continuously increasing the pressure the pressure jump across is going to be higher let us not worry about that part currently.

You are getting a clean flow field. Now, it is having a fixed line of jumping pressure you do not know how you are seeing this currently ignore it we will go deal with how to visualize shocks or expansions in a flow field later. But, what we are seeing I will run it again what we are seeing is your, there is a sudden jump in pressure after that there are some weak lines similar to whatever we saw here. Some weak lines, those weak lines actually are coming from I told now it is a bolt, the edge of the bolt is disturbing the flow and that disturbance is what we are seeing as if you want to call it mach cones along the flow. The flow field is going to come straight is going to turn along the bolt and go out from here. Let us not worry about what happens at this corner, it has to turn back and go what we are seeing is those extra lines that coming like this.

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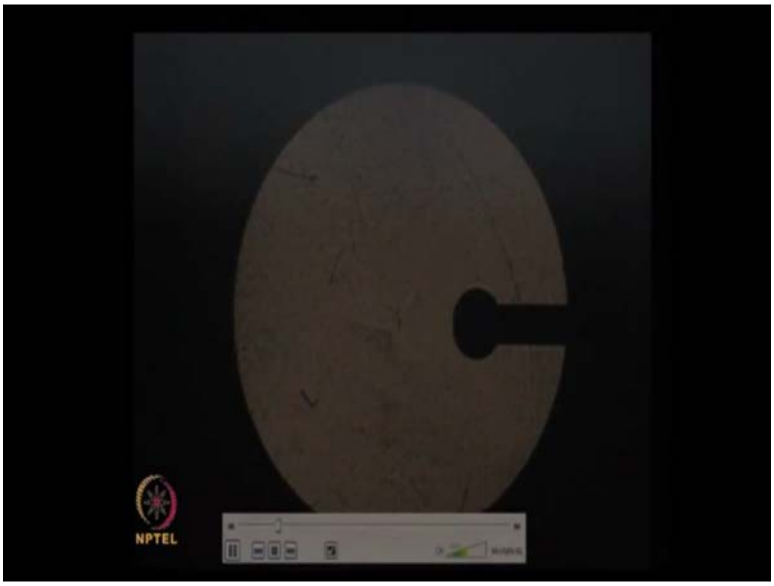

Now, we will go to the next case, where I am having roughly is spherical body sitting in that same tunnel and again we are starting the flow you can see the vibration of this body is flow starting. So, let us say we will it is forming anyway.

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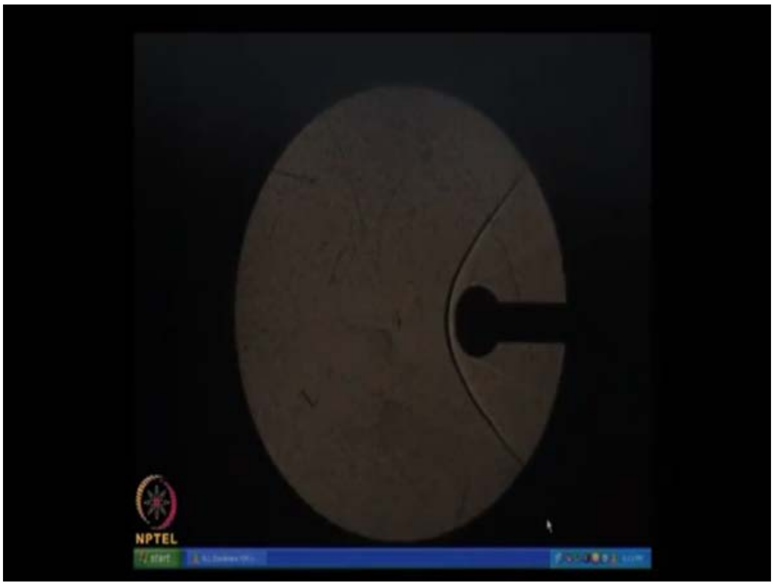

When the flow field forms here, actually you are saying that the body is having a optical illusion it looks like it is more flat, that is optical illusion, because of density gradient in that region light bends in density region, density gradient other than that you are seeing that there is a thick line here, which is what they call a bow shock. This line is what they call a bow shocks this line is the bow shock. Now, after that there is some set of lines here very weak, which we would not worry about right now.

We will deal with it when it is time to look at it. So, that is the end of my video session we will come back to what we want to say on the board next if I had this piston and cylinder we talked about and actually I have it on the board here. Let us not go anywhere else. If I look at the flow field which we saw before, the first video we saw today it looked like this. I will draw it here and then, we will compare with that picture.

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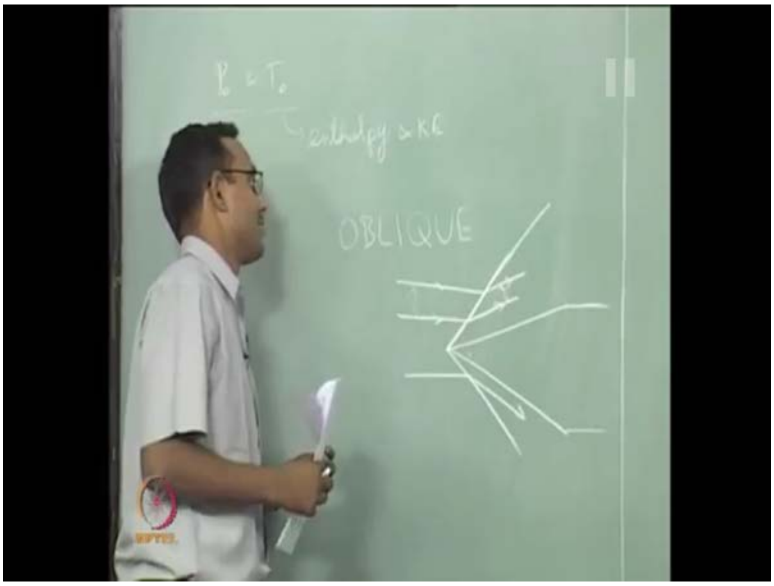

I had a wedge that was something like this and there was a supersonic flow over it and it created a thick line like this we talked about all this before. Now, I am going to say that, when this line is created the flow incoming is straight up to this point after that, this wave that was running from this tip is. Going into the flow like this normal to this and it is now able to see this streamline is now able to see that, there was a change occurring here. Now, because of that, this flow will turn will turn and go along with this line, that will start happening at this point. So, if I look at another streamline is going to do something like this, I will pick another close to this streamline somewhere here. They are parallel and when they go out and again they should be parallel.

Similar to that picture which we had here, there are two streamlines coming here they are going to meet the shock line and then they are going to turn go along the wall. Same thing happening here, parallel initially and they are going parallel to the wall if I look at it. The streamlines have come closer distance is less than this distance. The streamlines have come closer which is what tells me that the fluid element which was sitting inside between these two. Considering this is my stream tube. Now, my stream tube has gotten crushed which is what is my compression, It is got compressed.

So, basically this is actually sitting is a shock here, this is what they call as a oblique shock. It is not normal to the flow but, it is slanted, it is oblique the word oblique means slant anyway, it is going to become oblique shock and now from next class on words we are going to look at oblique shocks and I will bring an animation next class, where I will show that. This analogy with this flow can be easily seen, if you look at that particular analogy. It will be very easy to see that particular animation will stop at this point I could have brought the animation today. I just did not thinking it will take more time. So, we will start with animation and then move onto analysis of oblique shocks in the next class onwards see you people at next class.