Introduction to Fluid Machines and Compressible Flow
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Lecture - 37
Normal shock part V

Good morning and welcome you all to this session of this course. So far we were discussing the shock, normal shock and in all those discussions, we have made the shocks stationary at a locations while the fluid flowing and acquires the shock there are certain discontinuities in the fluid properties that we have seen.

Now, there are situations, where the shock is moving sometimes in a flow, relative to a flow, flow may be raised at raised flow also may be moving, which are observed in certain practical cases like in air compresses, which we discussed in turbo machines. Sometimes in the exhaust and inlet manifold of internal combustion engines, which may occur due to explosion a shock wave propagates through a medium, which may occur in case of fluid flowing in a pipe line, we just close or open the valve at the downstream. So, a shock wave is generated, which is propagated or moving to the in the fluid medium.

In those cases it is easy to analyze the mathematical relations or analyze the problem with respect to a coordinate system attached to the shock moving with the uniform velocity then the entire thing appears to be a stationary shock wave acquires, which there is a change of fluid properties, but how these analysis are being made and results are being obtained we have to see. Most important thing here in these context to find out the velocity imposed by the motion of the shock wave to the fluid medium. So, to understand this let us consider a case like this.

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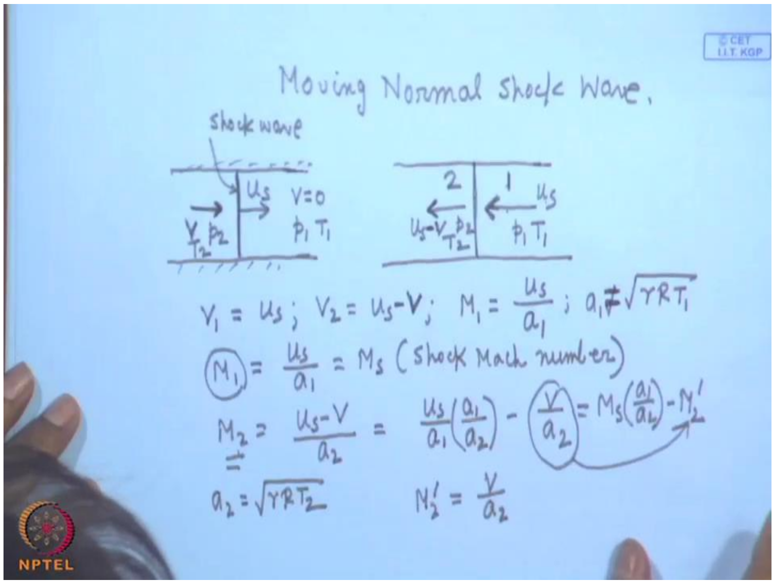

Let us consider a case like this, rather I will write here moving normal shock wave, let us consider a case like this, where in a duct a shock wave, this is the shock wave, let us consider a situation like this that a shock wave is moving in a duct with a velocity of u s constant velocity of u s and the gas behind the shock that means, downstream part of the shock it is at rest there is no velocity v is zero ok. And pressure is p 1 and temperature is T 1, whereas these shock has created a velocity in the fluid through, which the shock has passed let these velocity is create a velocity v, let us consider a velocity v ok. Let us consider a velocity v, which is be and it has created a pressure p 2 and temperature T 2 this is the velocity of flow v, that means, due to the shock passing over this fluid a velocity is imposed or induced by the shock.

Now, this problem, if you analyze in a way that this is a picture with respect to a coordinate frame attach to the wall, that means; they coordinate frame static frame of reference, which is addressed. Now, if you attach the coordinate frame on the shock that means, if we see these thing relative to the shock it is just like a stationary shock wave, normal shock wave that means, shock is addressed here that means, then it will look like that the fluid with a velocity u s and a pressure p 1 and temperature T 1 approaches the shock and while it goes this side its velocity is reduced u s minus v, usually this u s is higher than v. And therefore there is a deceleration in the same direction and this is u s minus v and the pressure is p 2 and T 2. So, there more with respect to the coordinate axis attached to the shock wave this is the picture.

Now, if this you make an analogy with the stationary shock then what you see? You see that in the stationary shock the approaching velocity is given as v 1, which equals to u s and this is v 2, which equals to u s minus v ok then p 1 T 2, that mean, section one and section two ok alright. Then v 2 is u s minus v so ok. Now, if this is the thing now, we if we define the Mach number at the inlet that is upstream of the shock ok then what is the Mach number? Now, here I can write the Mach number M 1 as u s by a 1, where a 1 is these acoustic speeds sorry, a 1 is root over gamma R T 1 well a 1 is equal to root over gamma this is known as this M 1 is u s again I am writing a 1 is known as M s this is known as this is just a definition shock Mach number M s ok.

Now, what is M 2 now? That means with respect to a stationary waves, so this is the picture so M 2 will be the velocity after the shock wave that means; u s minus v by a 2, where a 2 is what? a 2 is root over gamma R T 2 clear. This can be written as u s by a 2, which can be written as a 1 this is a style of writing a 1 by a 2 ok minus v by a 2. So, these be is the v generated due to the passing of the shock wave, but in a steady condition with reference to a coordinate frame attached to the shock wave that means, if you make the shock wave stationary by imposing velocity u s in the opposite direction to the entire system this is the situation. So I am writing in that case the M 2 is the velocity that means, the Mach stream a Mach number after the shock that is the stream velocity u s minus v.

So, these become this one that means this equal to M s into a 1 by a 2 minus this is v by a 2 is written as M 2 dash that means, M 2 dash is nothing but v by a 2 that means this v by a 2 is written as M 2 dash this is an important parameter. So, therefore, these relationship you have to first of all remember or you have to write that relations that means, it happens that a fluid with a Mach number M 1 given by u s by a 1 and with a velocity u s and p 1 T 1 is passing through a stationary shock wave and its velocity is reduced that is mach number rather is reduced to M 2, which is defined as u s minus v by 2. Now, these quantities are with respect to this problem this is unsteady problem where the shock is moving and these velocities are defined with respect to the coordinate frame static coordinate frame, which is attached to the wall coordinate frame which is attached to the wall.

Now, if we accept this now next part is that if we recall the analysis if we now recall the shock relationships just I am writing this in earlier classes in few earlier classes.

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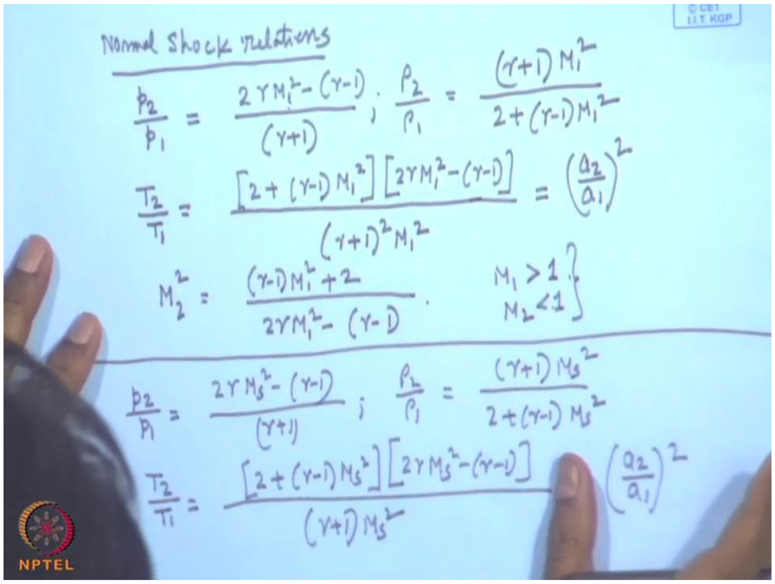

We have discussed this thing that the suffix 2 is always the shock, now I am writing the shock relations, normal shock relation, normal shock just recapitulation normal shock relations recapitulation of normal shock relation this equal to this p 2 by p 1 that means, the suffix 2 as you know is a usual symbol is after the shock and this is before the shock.

Usually in shock more useful relationships are the ratios of pressure, temperature, density in terms of the inlet Mach number, inlet Mach number is the input parameter. So pro is usually specified by inlet Mach number so, I am recollecting these formulas that we already deduce gamma plus 1. Similarly rho 2 by rho 1 has an expression, which is gamma plus 1 M 1 square divided by 2 plus gamma minus 1 M 1 square. Similarly we can write T 2 by T 1, which was all deduced earlier this is this, 2 plus gamma minus 1 M 1 square, if you remember this relationship 2 gamma M 1 square minus gamma minus 1 ok and divided by gamma plus 1 whole square M 1 square.

Now, this T 2 by T 1 can be written also equals to what is T 2 by T 1? a 2 by a 1 whole square, why? Because the acoustics speed a 2 at the section 2 is root over gamma T 2 and acoustics speed a 1 is root over gamma r T 1. So, ratio of temperature is the ratio of the acoustics speed at that state corresponding states a 2 by a 1 square.

Another very important relation is there that is the Mach number after the shock, which is the subsonic Mach number gamma minus 1 M 1 square plus 2 2 gamma M 1 square minus gamma minus 1. So, at present I recall only these relationships, again I tell you, what are those relationships this is the change in the fluid property in terms of the ratio pressure ratio the temperature T 2 by T 1 rho 2 by rho 1 the density and the Mach number after the shock in terms of the initial Mach number.

Now, this relationship are exploited to find out a chart, where against a Mach number one that is M 1 against M 1 against a Mach number M 1 we can found we can find all these properties. Another thing you have to remember with this or the recapitulation, which has been already discussed earlier from the consideration of entropy change, as a corollary of the second law we always tell that M 1 has to be greater than 1 for a shock to occur and M 2 will always be less than 1 that means; a shock always decelerates the fluid approaching the shock from a supersonic one to a subsonic one after the shock. So, this if you recapitulate or you remember now here what happens now this problem this is similar to a stationary shock, where M 1 is this one M s and M 2 is this one M s a 1 by a 2 minus M 2 dash or you can write u s minus v by a 2 so, this is our M 2.

Now, what you do, if you write the same these replace this you get this that means instead of M 1 you replace M s that means in this case for this moving shock wave I can found p 2 by I can find p 2 by p 1 just again I am writing just replacing this in terms of M s that means, rho 2 by rho 1, I am writing little fast, because it is just for your taking note. M 1 is because M 1 in this case is M s u s by a 1 M s square so according to the present nomenclature, I write this one and T 2 by T 1 will be again same that M 1 is replaced by M s that means, 2 plus gamma minus 1 M s square into 2 gamma M s square minus gamma minus 1 so this is also equals to a 2 by a 1 whole square.

So, this a 2 a 1 related to T 2 T 1 this T 2 T 1 p 2 p 1 they are scalar quantity they are not dependent on the coordinate transformations. Now, the M 2 similarly has to be replace, if you write the substitute equation for this then what will be the equation? This equation will be instead of M 2 this equation we write here M 2 is M s that in our earlier thing that M 2 is M s a 1 a 2 minus M 2 dash square.

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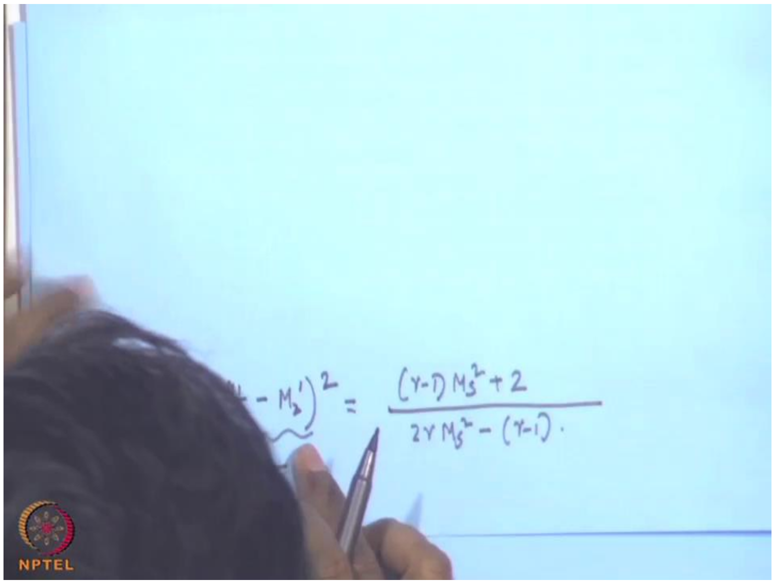

So, therefore M 2 square will be therefore M s a 1 a 2 minus M 2 dash this is the square and that equal to same thing just we are replacing the corresponding M 1 M 2, where 1 2 is the upstream and downstream section of the M 1 square minus gamma minus 1. So, this is our M 2 at the present moment M s a 1 by a 2 minus M 2 dash ok.

Now, what happens? If we take this equation and if we use the a 1 by a 2 then we get a very important relationship of M 2 dash, let us do that. Now, let us again write this equation, let us write this equation again now, let this equation is, you just remember these equation, this equation is written ok, this equation again I am writing M s a 1 by a 2 minus M 2 dash I take a square root and I write like this. I think you can see that thing I write that gamma minus 1 M s square plus 2 to the power 0.5 and here 2 gamma M s square minus gamma minus 1 to the power 0.5.

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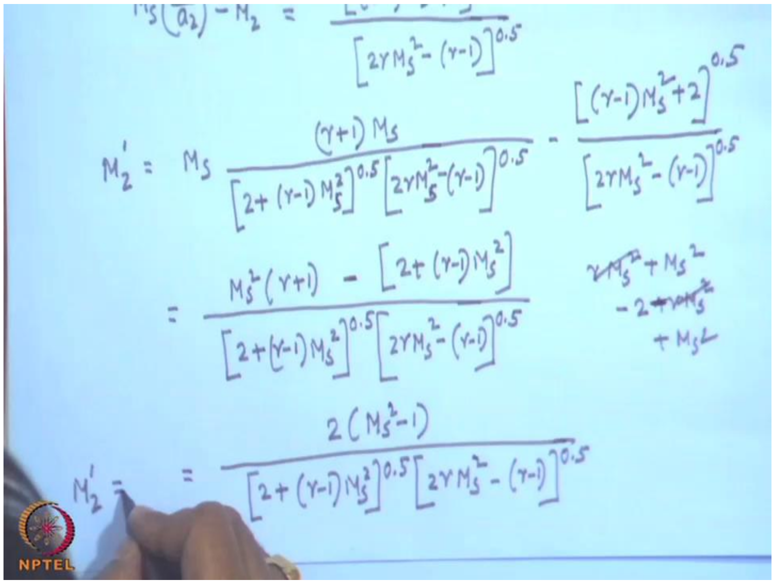

Now, a 1 by a 2 is what? a 1 by a 2 is the under root of this thing so you just see that from your note that as we have taken here I am writing then M 2 dash is equal to M s into a 1 by a 2 what is a 1 by a 2 is under root of that, that means, it will be M s this is a 2 by a 1 that means a 1 by a 2 is the under root of reciprocal of that. That means, denominator will be 2 plus gamma minus 1 M 1 square to the power 0.5 into 2 gamma M 1 square minus gamma minus 1 to the power 0.5 that means, numerator will be denominator it is a 2 by a 1 I am writing a 1 by a 2 and under root, because I am its a square and now the denominator will be under root gamma plus 1 whole square M s square. That means this gamma plus 1 ok, whole square that means gamma plus 1 into M s ok and denominator it will be sorry, M s very good, denominator it is M s very good denominator it will be M s very correct so denominator it will be M s alright.

So, M 2 dash is M s into this minus if you do that you will get gamma minus 1 M s square plus 2 to the power 0.5 divided by 2 gamma M s square minus gamma minus 1 to the power 0.5 you can see very directly ok. Then this becomes equal to what? Then this becomes is equal to M s square gamma plus 1 so this will be the denominator 2 plus gamma minus 1 M s square to the power 0.5 let me write this 2 gamma M s square minus gamma minus 1 to the power 0.5 then minus so this one is 2 gamma that means this one 2 plus gamma minus 1 M square 2 plus that means; this will be simply 2 plus gamma minus 1 M s square that means the same thing 0.5, 0.5.

So, if you now clear this thing then the numerator will be what? denominator will be this big thing 2 plus gamma minus 1 M s square it is little tedious I know, but you just follow that whether I am doing any mistake or not M square minus gamma minus 1 to the power 0.5. And now, M s square gamma plus 1 minus 2 gamma minus 1 so gamma m square gamma m square is canceled, so this is M square and then gamma now, if you write this gamma here, I make a calculation gamma M s square plus M s square minus what is that? 2 plus gamma minus minus gamma M square plus M square that means these cancels that means 2 into M square minus 1 this become 2 into M square minus 1. So, this is one very important deductions that is here I can write M 2 dash, I think you can see equals to which is very important M 2 dash why I am writing it is v by a, it is not M 2, M 2 is this one M s a 1 a 2 minus M 2 dash this is M 2, but I am finding out an expression of M 2 dash in terms of M s. Now, you see what interesting results we have achieving.

Now, you see here what it is given? That it is given not the downstream Mach number that means Mach number after the shock with respect to the shock the coordinate with respect to the shock, but it is given the ratio of the velocity induced, because of the shock in actual case divided by a 2 M 2 dash in terms of the inlet of shock Mach number here M s you remember is u s by a 1 that is equal to actual M 1 in this case.

Now, is a very interesting result it gives. Now, what interesting result? That if this if we increase the Mach number, let us consider the inlet Mach number is very very high, inlet Mach number is very very high that means; the flow approaches with a very high supersonic velocity. And as you know the strength of a shock as I told you earlier is expressed by the pressure ratio that means; the ratio of pressure after the shock to that before the shock and it is a direct function of Mach number, I tell you is a direct function of inlet Mach number, more is the Mach number more is this ratio, that means; the strength of the shock is usually expressed by this ratio, which is a function of inlet Mach number or approaching Mach number, more is the Mach number more is the strength of shock. So, therefore, a Mach number approaches a shock a fluid approaching with high Mach number to a shock wave is told as the shock is of very high strength. So, therefore, when the shock Mach number is very high we usually call that this is a shock of high strength.

Now, whatever high strength shock comes there is a limiting value for M 2 dash physically. Now, look it mathematically is there any limiting value M s tends to 0, if I ask this question that, when M s tends to sorry, infinity what is the value of what is the limit rather M s tends to infinity what is the limit?

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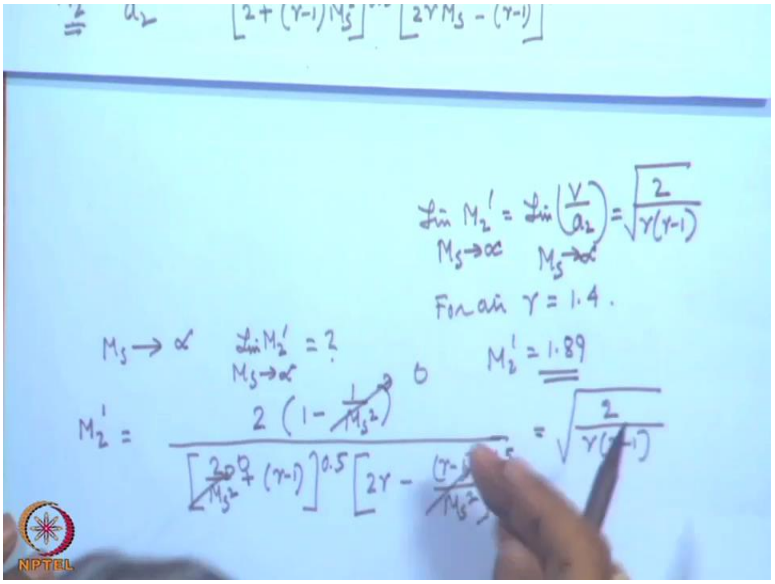

That limit I will now show you. Now, if M s tends to infinity M 2 dash can be written as so these type of thing as you know elementary mathematics that in school level you know M s tends to infinity let me express in terms of 1 by M s that means both numerator and denominator should be divided by M s square this is the standard technique, see that whether the limit is there or not so M s square means one M s I can take here and one M s I can take here. And when it goes within the bracket again M square that means; this will be 2 by M square that means this gives directly and indicates and that there is a finite limiting value that term is becoming free of M s. M s by this M s, where dividing numerator and denominator by M s square this M s goes inside.

So, therefore M s square here also 2 gamma minus gamma minus 1 so beautiful that means this give us an indication what you want that there is a finite limiting value so an M s tends to infinity it is 0, it is 0 and it is 0. So, the limiting value there is a limiting value is root over 2 gamma into gamma minus 1 this is gamma gamma minus 1 2 and 2 under root and this is 2. So, therefore, 1 2 under root will go up. So, therefore, you see the limiting value that I was telling that limit M 2 dash or equal to M s tends to infinity limit v by a 2 as M s that means the shock Mach number tends to infinity is not infinity it is square root of 2 by gamma into gamma minus 1. This is a beautiful result and you see that for air, if we take gamma 1.4 this M 2 dash is 1.8 that means;

you can say that in air whatever strength may be of the shock even in infinite strength shock very high strength shock can only induce a finite velocity, which will be always less than this corresponding Mach number 1.89. The actual velocity will depend upon the temperature we have to multiply this with a 2, which is root over gamma or T 2 that means velocity is usually specified in compressible flow by the mach number so you can tell for example in air whatever strong Mach number may be at the upstream of a moving shock this can or whatever rather this way you tell whatever strong shock may be a moving shock whatever strong the shock may be whatever velocity the shock may be moving that the M s u s by a it cannot induce a flow whose Mach number will be more than 1.89 in case of air, so this is the limiting Mach number in case of air ok.

Now, next is next we will rather now after this I think we will solve some problem.

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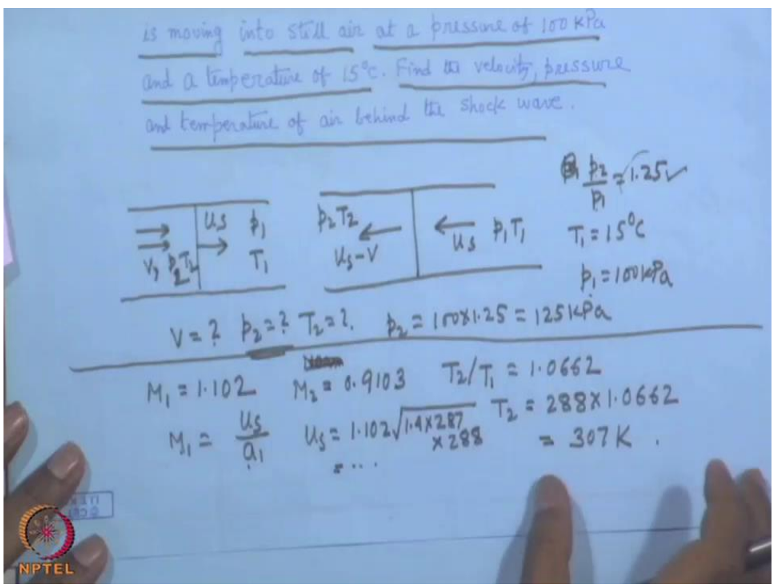

So, that your all this things will be made more clear by solving the problem before I go to a this refraction of the shock, let us ah solve some problems ok. Now, problem one, example one, a this is the first problem example say shock wave across, which just you see this thing problem which the pressure ratio is 1.25 this is not a this is a moving shock, a shock wave across which pressure 1.25 is moving yes it is written is moving into still air at a pressure of 100 kilo Pascal and a temperature of 15 degree Celsius this is the still air. Find the velocity pressure and temperature of air behind the shock wave that means it is simply the application of that, how to do it?

Now, let us again solve the problem, the shock is moving with a velocity is moving into still air and we do not know its velocity let u s similarly that u s and this p 1 T 1 the same problem and then it induces velocity v and p and T 2 p 2 T 2. So, with respect to the shock the problem is with respect to the shock the problem becomes steady with a velocity u s p 1 T 1 and it goes with velocity u s minus v and p 2 T 2, what are given in the problem? p 1, p 1 is not given rather p 2 by p 1 is 1.25, what are the given, T 1 is given 15 degree Celsius, p 1 is given 100 kilo Pascal, what we have to find out velocity, pressure, air behind a shock that mean, we have to find out v, we have to find out pressure p 2 and temperature T 2 the first one is the school level thing p 2, because the pressure ratio is given 1.25, I know the pressure p 1 so p 2 will be 100 into 1.25 is 125 kilo Pascal straight way, but we do not know T 2, how to calculate?

Now, I have told you earlier that in shock all those relationship, we have derived that means for example p 2 by p 1 is known I can find out M 1, because p 2 by p 1 is expressed in terms of M 1. Again I tell you that just also at the beginning of this class I told you that all these relationships, which was derived earlier for example this important relationship here one can find out algebraically p 2 by p 1 I know I can find out M 1 ok. So, if I know M 1 I can find out rho 2 by rho 1, T 2 by T 1 over these algebraic calculations sometimes are tedious. So, therefore, a table is drawn based on this calculation as usually drawn for different cases that table as I now tell you earlier also I told which is known as normal shock tables. So, this is their just you see how to see a normal shock tables a normal. Now, I not I will do here, I will rather do it here a normal shock table we just how does it look like you can see if in any book normal shock table just I show you probably, I told you earlier also.

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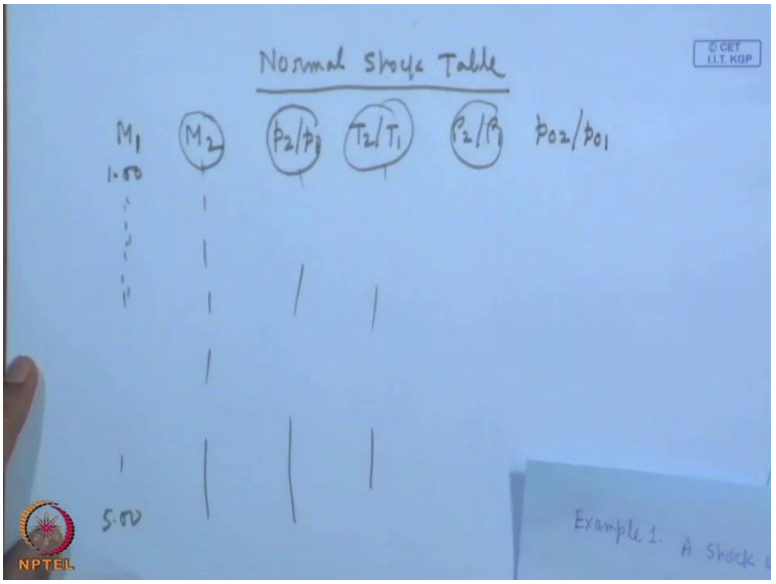

Normal shock table looks like that in the left hand column these are the different column M 1 the corresponding nomenclature you know that is the Mach number approaching the shock with respect to a stationary shock this is the aftershock Mach number then this is the ratio of pressure. 2 is the section after the shock and this is all the ratios of the static pressure, temperature, the density and there is a ratio of stagnation pressure also because of the losses shocks is an across the shock the process is universally, so therefore p o 2 by p o 1 ok.

Now, these there are a number of Mach numbers different values starts from 1.00, why? Because shock does not occur when the approach Mach number is subsonic, so therefore, it goes some for example 5.00 so corresponding Mach number all these things and there. So, then if I know the p 2 by p 1 now, we have to see that what are the quantities given in these problem, we know p 2 by p 1, we know p 2 by p 1 is 1.25. So, if we know p 2 by p 1 I can find out everything M 2, T 2 by T 1 that means, any one of these is known other things are known through the equations. So, therefore, it is not that always M 1 has to be known anything has to be known, we can find out from the chart ok. So, from these chart, if you read with p 1 p 2 by p 1 1.25, you will get a Mach number of M 1, which from normal shock table you will always M 1 and M 2, M 1 means inlet Mach number M 2 means outlet that means the downstream after the shock Mach number 9 and T 2 by T 1 you get 1.0662.

Now, when you get T 2 by T 1 straight T 2 is T 1 is given T 1 is 15 that means; 288 into 1.0662. So, you get T 2, your T 2 is 307 k in this case. Now, in your case M 1 is what? M 1 is u s by a 1 now, what is a 1? a 1 is root over gamma R T 1. So, therefore, u s is the Mach number, I have got from the table into root over gamma that is 1.4 into R is 287 into the T 1, T 1 is 15 degree means, 288. So, therefore, you straight forward get the value of u s, if you know M 1 already you know a 1 root over gamma R T 1 and you get the value of u s ok.

Now, you have to find out the velocity behind the shock that means this velocity this is very simple to do this what you have to do, you have to write the expression for M 2 in your case.

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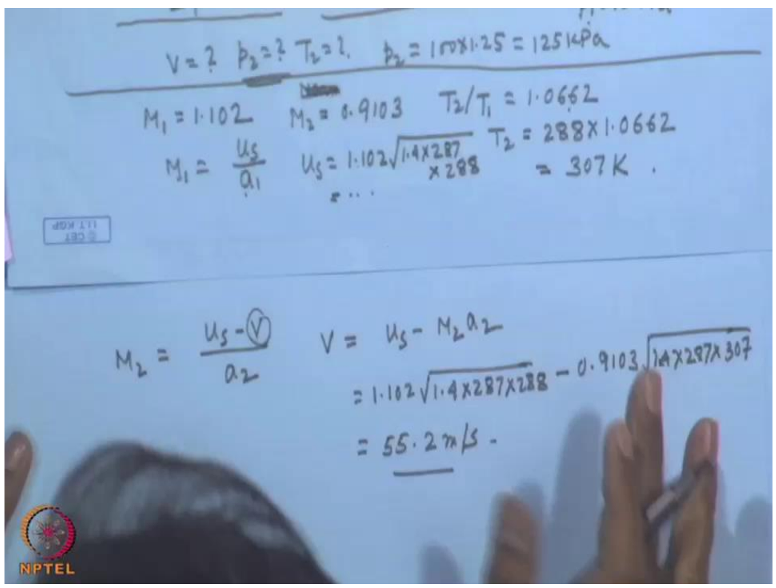

In your case M 2 is, what is M 2 u s minus v, which you have to find out by a 2. So, therefore, you can write v is equal to a 2 a 2 u s minus M 2 a 2, u s is always I know that this is found 1.102 into root over 1.4 into 287 is the value of R into 288 minus M 2, which I have found out 0.9103 into again a 2, a 2 is root over 1.4 into sorry, 287 into T 2, T 2 I have already calculated, because I know T 2 by T 1 from the table, so T 2 is calculated 307. So, most important parameter is this we want to know this, this comes out to be 55.2 as per as this calculation, I know the answer, this is the answer. So, this is a straight use of this formula, which we derive the analysis, which we have made for a moving shock.

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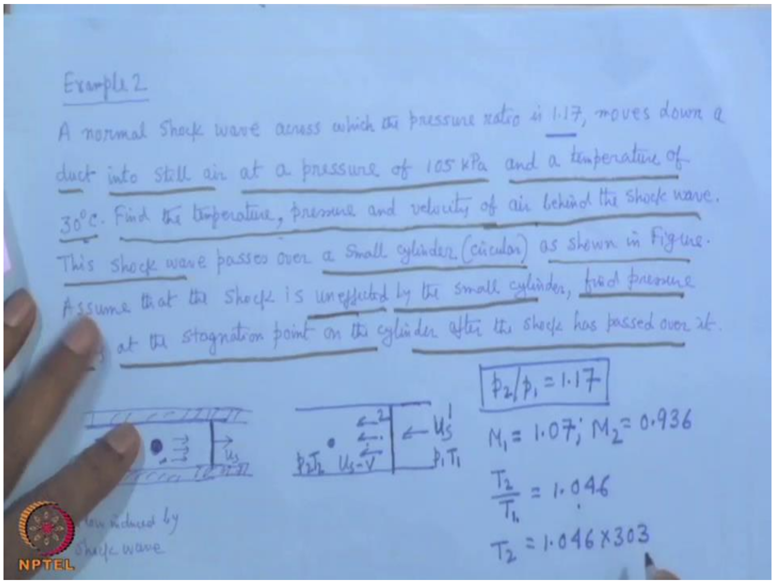

Now, another interesting problem you see this is a relatively more interesting problem. This problem what does it say, what does it say, a normal shock wave across, which the pressure ratio is 1.17 moves down a duct into still air at a pressure of this is almost the same and a temperature of 30 degrees rest part is little interesting. Find the temperature, pressure and velocity of air behind the shock wave, this part is routine that means; you can say that said this is the total repetition of the earlier problem we probably difference in the data.

Now, next one this shock wave passes over a small circular cylinder, it is actually it will be here circular cylinder as shown in figure that I will show you in the figure. Assume that the shock is unaffected by the small cylinder, find pressure acting at the stagnation point on the cylinder after the shock has passed over it. Now, this is a problem here, now this problem if you solve then how you, what is the problem? Problem is this one that this is the shock, shock and this is the small cylinder. So, shock has started from somewhere else in the upstream it has passed different sections so at any instant as the problem tells when the shock has passed over the cylinder and shock remains unaffected, what is the condition, that means; in the entire upstream part of the shock through, which the shock has already passed the fluid these are the attain some induced velocity v ok.

Now, let us find these induced velocity v. So, therefore, our case is similar to this then our case is similar to this that let this is be cylinder our case is similar to this so u s same thing u s minus v this is one and this is two. And let this is p 2 T 2 so p 1 T 1 so I can find everything, but first of all I have to see with respect to the stationary shock, what is the thing in pressure ratio same thing that means; I am having pressure ratio that means I can immediately go to the shock table normal shock table and see against this pressure ratio what is my value M 1 M 2. So, this pressure against this pressure ratio the M 1 has found from the shock table is 1.07 M 2 has found from the shock is 0.936 ok and T 2 by T 1 has found is 1.046.

So, therefore, since T 2 by T 1 is known I can immediately calculate the temperature behind the shock that means this temperature behind the shock in this case there that means this temperature T 2 I can find out T 1 is what T 1 is 30 degree that means T 2 is 1.046 into 273 plus 30 that means 303. So I can find out this equals to 316.9 k.

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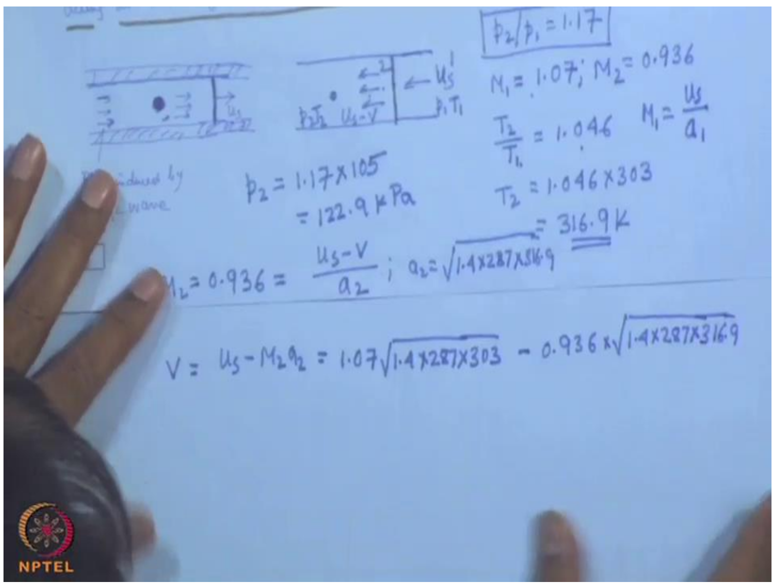

So, I know this and p 2 I can find out how? p 2 is equal to this is the school level thing 1.17, it is already given 1.17 so 1.17 into 105 kilo Pascal so I can find out and this becomes is equal to 122.9 kilo Pascal.

Now, what I have to find out next, assume that the shock is unaffected rho, before that I have to find out the velocity of air behind the shock this is again the same thing that M 2 I know that means M 2 is 0.936 is equal to what? u s minus v divided by a 2. Now, a 2 is what? a 2 is equal to root over gamma R T 2 that means 1.4 gamma R 287 into T 2, because T 2 is 316.9 so I get the value of a 2. I will just substitute to get the value of a 2 M 2 that means I can write better v is equal to u s minus M 2 a 2 that means u s what is u s? u s is again M 1 is what is M 1 here, M 1 is u s by a 1 and a 1 is root over gamma T so u s is M 1 times a 1 root over gamma R T, T is 303 minus M 2, M 2 is 0.936 times root over gamma R and T 2 that means 316.9 so that is very simple 316.9 you understand 316.9.

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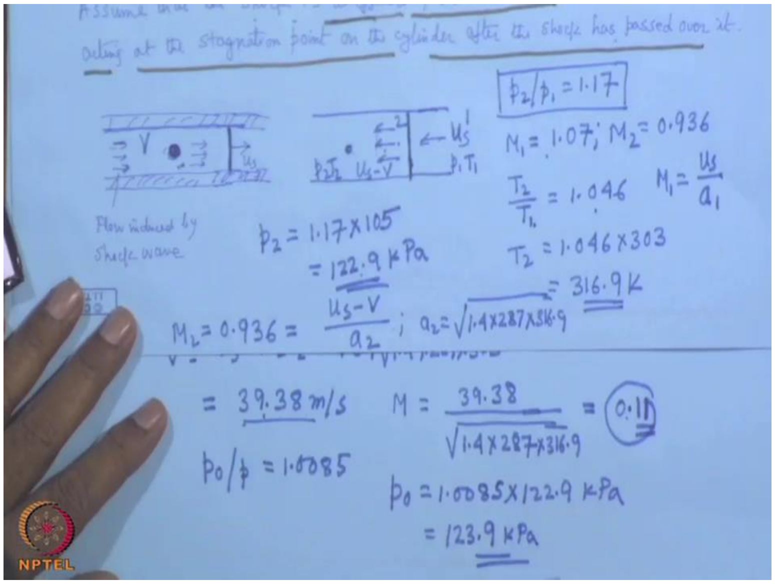

So therefore I get the value of v, that this v becomes equals to some 33 ok, this becomes equals to v becomes equals to 39.38 meter per second I think it is absolutely alright so it is just the repetition of the earlier problem.

Now, the question is this that we have to find out the stagnation pressure. Now, what happens, if you see this picture now this cylinder actually here this is the model physically translated but actual problem is this. This is the problem as we look with reference to a coordinate frame attached to the moving shock and flow become steady and this becomes stationary. So, actually this is the problem this v, we are getting which is 39.8 that means, now it is a problem that a cylinder circular cylinder is exposed here another thing is told stagnation point. Assuming that the shock is un effected by the small cylinder find pressure acting on the stagnation point on the cylinder after the shock has passed over it and there is another thing, which has to be told that consider this flow to be isentropic consider the flow the pressure acting at the stagnation point on the cylinder assuming that the flow is isentropic.

Now, if we assume the flow to be isentropic then what happens, there is an isentropic flow a cylinder whose velocity is 39.38 meter per second. So, we can find out the stagnation pressure. Before that I have to tell you that, if you recall the this isentropic flow relation, the isentropic table that isentropic flow relations are unnecessary without going to all algebraic calculations through the algebraic equations of isentropic flow relations rather isentropic flow isentropic flow table that is normal shock table it is given in a tabular form. Similar to normal shock table that one column the extreme left column is M then these are the stagnation, because here most important part of calculation is the ratio of stagnation temperature to static temperature.

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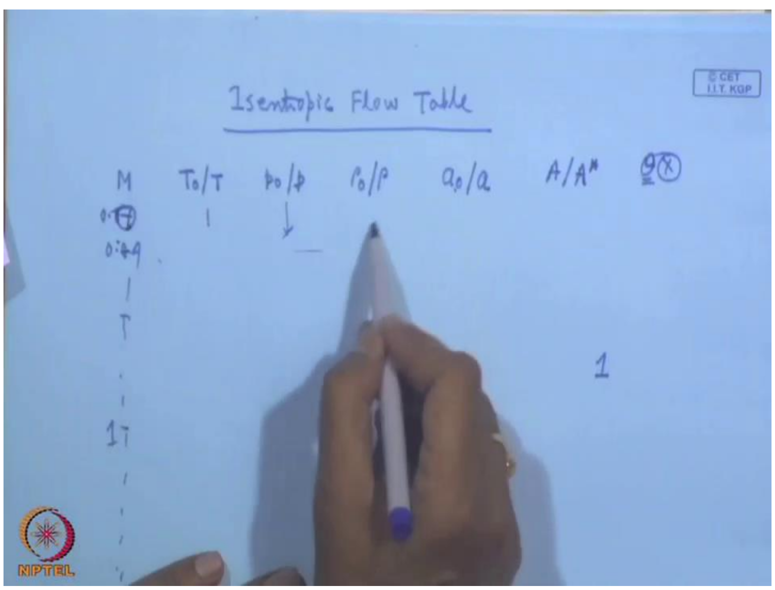

Stagnation to static, all stagnation property with respect of density to the corresponding static is the function of the Mach number of flow. So, therefore, if you would know the Mach number of flow at that particular location we can find out all this thing.

Similarly, a 0 by a what is that acoustic speed at the stagnation condition to the local acoustic speed A by A star probably you recall this thing A star is the area, where the sonic velocity is reached that is the minimum area known as throat area corresponding to M 1 and this A is the area local area at which we are concerned with. And another parameter is theta I told probably earlier that does not come into picture here that will come when you discuss the expansion wave this is the angle related to the expansion wave this is not coming and that there also the problems are treated as an isentropic flow that is why in the isentropic flow table itself this that is given this is not required now.

So, now, if we know the Mach number at a particular location in a isentropic flow this here Mach number start 0.01 0.04 like that very small, because all subsonic supersonic all labels are there. So, there will be somewhere one when the value of A by A star will be one this thing probably I have discussed earlier. So, now, if we know the local Mach number I can find out the p 0 by p 0 by T, I can read that everything so here I have to find out the local Mach number. Now, how to find out, because I know, now, the actual problem the cylinder is exposed to this uniform velocity 39.38.

So, local Mach number is M for example here is 39.38 by the local acoustic speed, which is root over 1.4 gamma into R into this temperature, that means; this is 316 that means, it is nothing but a 2, it is nothing but in our this problem this is a 2. So, you find out this M and this M, if you calculate this M will become equal to I tell you the value, which is already calculated by me, this M has got a value this M, if you find out this M is I tell you just wait, I will tell you the value of M this is a problem, where the M 2. So, therefore, we take a value of M this M is equal to this is a v 2 and a pressure the Mach number is 0.11 just I see the calculation only so that you can check 0. it has been calculated by me earlier so 0 see that. So, therefore, in the table, if you see this Mach number you can find out the value of p 0 by p and that p 0 by p, if you see from the table this also I tell you for this problem is this.

So, therefore, you can very well find out p 0 is 1.0085 into the static pressure there, which is p 2 122.9, because the condition prevailing is this p 2. So, this becomes is equal to 123.9 let me see the value 123.9 as I have calculated already kilo Pascal. So, this is the value, so it is clear that you can find out the value of the Mach number you can find out the value of the stagnation point pressure ok. So, this is one very interesting problem.

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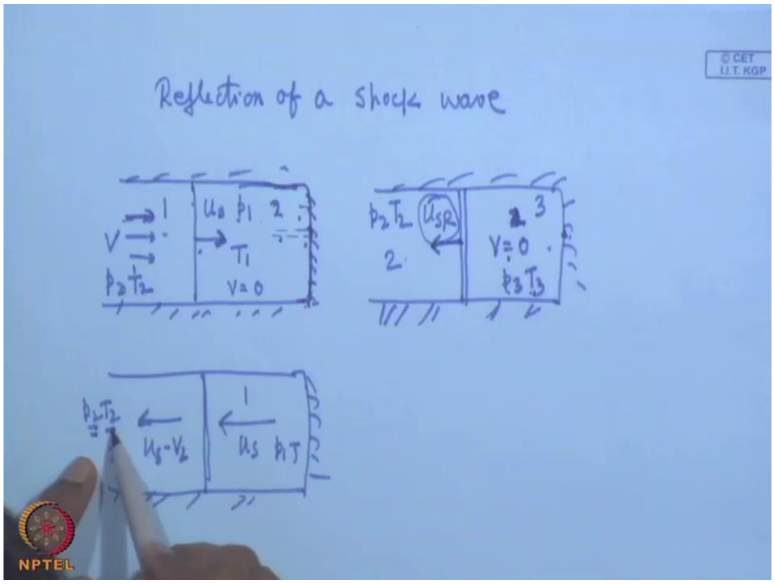

Now, I will tell you something regarding the reflection of a shock wave, regarding the reflection of a shock wave ok. What is reflection of a shock wave? So, what is reflection of a shock wave, let me tell you what is reflection of a shock wave, this happens when the shock wave is moving so moving shock wave analysis we have done reflection of a shock wave. Now, reflection of a shock wave if we have to understand then just how does it happen, I tell you the physical picture. Now, if there is a cylinder, we have so far consider that it is moving with u s ok and it is creating a velocity v and a pressure p 2 T 2 and this side the pressure is p 1 and initial velocity v is 0 and temperature T 1 that was our thing that it is moving in this direction so with respect to this things are happening now this is the actual problem physical problem as we have discussing.

Now, what happens if this thing is closed at the end? That means, there is a closed end or the pipe was open suddenly the valve is closed that means, the shock wave is moving and the pipe is closed at the end or is being closed by the closer of a valve at the end, what will happen? Physically you try to understand what will happen, this velocity will be induced so long the shock moves now try to understand what happens in reality. Now, when the shock comes here the velocity will be imposed v but after that what happens this is the closed end so at this solid end the velocity will be zero there has cannot be any velocity the velocity cannot penetrate into the solid like that so there will be normal velocity so therefore this velocity will be zero.

And slowly in a compressible fluid they entered fluid will attain a velocity zero for an ideal incompressible fluid this will be instantaneously zero but for a compressible fluid the velocity will first fall here zero and its it will take some time it may be infinitely small depending upon the compressibility of the fluid that the entered velocity will again be zero. So, this thing is perceived in a way as if the shock wave after reaching there is being reflected back in a way that it creates a zero velocity here is reflected back in a way that usually the velocity it created in this direction v again it created a velocity v in this direction in the opposite direction so that the final velocity is zero, that means; the strength of the shock will be such for the reflected wave so that it can create a zero velocity, while passing through it, so that is the philosophy of the shock, reflection of the shock.

Now, let us do that reflection of the shock let us do that the reflection now if reflection of the shock is to be understood let us consider not the initial one the shock is being reflected, the shock is being reflected now and we can just consider a case that when the shock is reflected ok. And this is the reflection, that a reflected shock velocity and here let one and two, if we see that one sorry, this is why one and two I am telling that this can be expressed as we did earlier in this way that this is coming with u s p 1 T 1, so this one and this is two this is p 2 T 2 and this is going with u s minus v 2.

So, now, what happened so this two will now prevail here that is here two that is p 2 T 2 so now this is p 2 T 2 I am sorry, now this will be sorry, sorry, this when you will come here so entire thing was then p 2 T 2 that means two when it reaches when it reached here that the entire fluid was at two. So, when it is coming here this side is two that is p 2 T 2 I think you have understood and this side is three, that is p 3 T 3 and velocity is zero. So, this is the reflected shock that means the reflected shock, if we analyze you will analyze this way.

Now, with the help of the shock tables we can calculate things that means; shock will again be reflected back here. So, this is a typical reflection and under certain circumstances shock will go back again. So, there will be a repeated movement of the shock, so one such reflection of shock problem, we will now solve that how a shock moving ultimately moving in this direction and a particular direction ultimately reaches the closed end and backs, when it reaches the close end automatically the velocity become zero this is the reality that means; this is conceive as a movement of a reflected shock wave with velocity u s r such that this velocity become zero. And the condition which is being created is p three t three again it is changed that means from p one t one this is p two t two the shock this is with respect to the shock then the entire thing will become p two t two here also the when it reaches here the entire thing becomes p two t two pressure p two temperature then again it will be changed to p three t three when the reflected shock will pass through that.

So this is the scenario physical scenario, I think that this will be more ah easily understood if you solve a problem and this time we cannot I cannot continue because the time is up. So in the next class i will solve a problem in relation to the reflection of a shock wave.

Thank you, close.