**Gas Dynamics**
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**Module - 10**
**Lecture - 22**
**Detached Shocks, Oblique Shock Reflections,**
**Numerical Examples**

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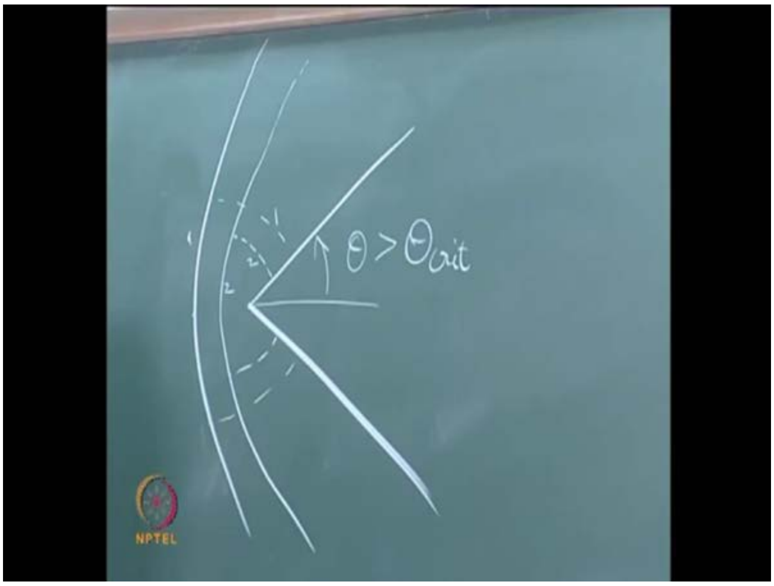


Hello everyone welcome back. Last class we stopped with discussion of flow over a wedge with the angle more than critical angle, and we said that the flow will have a bow shock and this flow is more complex. It is going to have subsonic pocket and then the flow accelerates to supersonic across it and we said that the shock angle if I go along with this line starts from 90 degrees decreases to all the way all the way up to Mach angle, all that we did last time. And then we said if the gas becomes more compressible. Then this that is I gave an example of gamma less than the previous gamma if gamma decreases, then I said it is more roughly compressible that is not the only way to make it more compressible that is 1 of the ways of making it more compressible.

If I decrease my gamma, we said that the flow has a possibility of having this as a dead shock. There is also a possibility of it just decreasing to some other bow shock, where the standoff distance has now decreased that also is a possibility. This is something I did not tell the last time. That is also a possibility if my compressibility is increased only a little bit it goes closer to the body it need not become an attached shock.

If it is sufficiently line up then the gas inside this region has been compressed more and it just goes in fully. If the shock has g1 in closer then the subsonic pocket would have decreased. It will be even lesser; remaining portion will be all supersonic. That will also happen let us just Mach this as 1 and 2 and 2 it is more like what it will be ok.

And eventually it will go to a point where the subsonic pocket will go to a point and then the shock will just become an attached shock. We know that shock will only be a weak oblique shock. While, if it is a bow shock I start with a normal shock go through a strong oblique shock all the way somewhere up to here and then from here it is a weak oblique shock all the way up to Mach wave. Which is I have supposed to happen at infinity all that will happen.

Now, we already said that there is no analytical way of solving this. So, we will just say that if such a thing happens, we will just say I do know what to do in our simple inversed gas dynamics. We will just stop this ideally there are methods by which we can do c f d analysis and solve this problem we would not do it right now. We will say we would not deal with such problems currently. We will just skip that portion and then go on to another part of oblique shock problems.

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Where I want to think about I want to see what happens when I created a oblique shock from here and it is encountering something else. It is going like this and let say it sees a wall. Now, what will happen here this oblique shock what will happen to this from here and if you have ever seen any books you can tell that it will just reflect off the wall. It would not be reflecting like a simple light ray reflecting on a mirror it will reflect slightly differently.

To understand this problem it is basically simple problem of just 1 oblique shock at a time. I just keep this 1 picture in mind, if you want to solve any problem like this always remember this 1 picture which is the basic oblique shock picture right. If there is a flow this way and I have a deflection of theta and I am assuming it is attached oblique shock right now and it is going like this and I am going to give an angle for this beta. This is the basic oblique shock picture we have been thinking about all this time. Just remember this always ok, am I drawing it correct are wrong how will I check remember piston analogy we just said piston does not move all.

The way till here and suddenly piston starts moving from here. As the piston goes in there is a shock that goes in earlier. We did this as an animation sometime back you can and look at that also ok. So, since the wall is going into the flow see streamline is going like this the wall is moving into the flow it will cause a shock remember this ok. You will need to remember this 1 statement when we go to expansions which will start after finishing the shock reflections. So, if I take this particular case I do not want to disturb this picture I will keep this picture I will go to the next 1.

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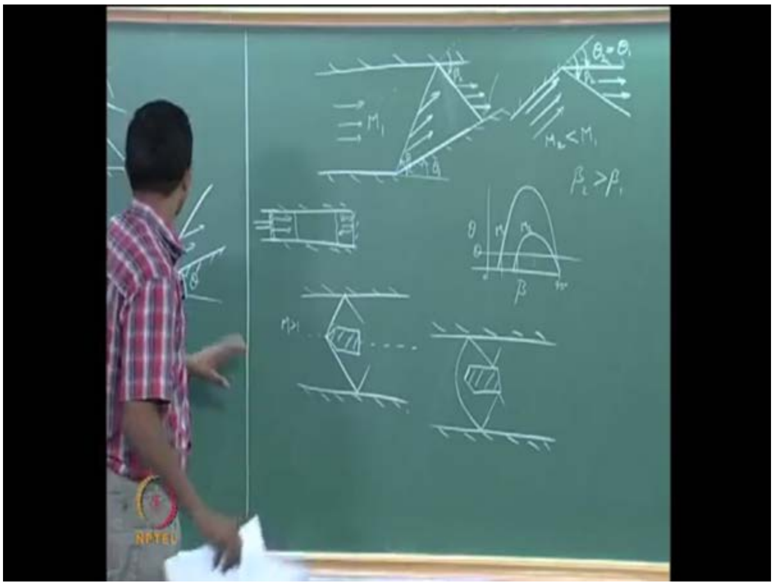

Let us say I have this particular flow situation and I have an oblique shock going like this. There is some supersonic flow incoming and I am going to say this basic problem here is just same as what we did here, exact same problem no difference, I will just copy stuff the streamline here will be parallel to this wall. So, I will just go and copy this there.

I will just put lines like this up to the last streamline where the shock goes and touches the wall all the streamlines want to turn like this parallel to this wall. Now, after this now I have to figure out what is happening when this set of streamlines go and hit on that wall that is a new problem.

The way to look at it I will use this paper I will just cover this region now what do I see I just see streamlines going like this hitting on that surface that is all I see. I will draw it as a fresh image a fresh picture here, it is as if there is a flow like this and it is encountering a wall like this. This is the way to look at this problem whatever happened before is already happened and it is all d1. Now, we will say after the shock what will happen. This is a new flow we know that it is also a supersonic flow because it is a weak oblique shock. So, again going to be a supersonic flow and then it is going to go impinge on the surface. Why will it impinge? I am going to imagine another problem I will just put a line along this and imagine a wall like this; this wall is parallel to my streamlines.

In inviscid flow I can always put a wall parallel to any streamline and it should not cause any trouble. It is not going to have a boundary layer I can always imagine a wall there. So, let us imagine a wall there and the flow is going parallel to the wall. Now suddenly there is a deflection of that wall this way alright. What will be this angle? We can find that angle also and if I go look at geometry. I can tell that this deflection angle will be the same as that deflection angle back here. Because, it started from here it went up some angle it has to come back parallel the same amount because this wall is same. So, it will again be your theta, but this Mach number is m 2.

So, now I will Mach every variable this is m 1 this I will call beta 1 because now I have a new shock. This is theta 1 and this is theta 2 it so happens that this is equal to theta 1 in this particular geometry. So, now I am having a problem which is basically, there is a flow and there is a wall moving into the flow.

If I go back and look at this problem it is roughly same as that figure except for I am looking at it upside down. The same figure I just look at it upside down, if I turn the page and look at it from behind it will look something like this. So, I will have a shock that is going to go like this and this will be its beta value theta 2 is same as theta 1 but, m 2 is definitely less than m 1 alright. Because that is what it will be from a oblique shock and beta 2 you go and calculate it will be more beta 2 will happen to be more than beta 1 why just from looking at simple theta beta m curve.

Let us, say I picked this particular theta which is our theta 2 equal to theta 1. Let us, say this my theta value what I am seeing is let us say this is my m 1 and after the first beta value, it jumped to m 2 and you will find that the beta has increased directly. This direct proof you have to get used to these kinds of numbers, if you are doing numerical examples if you make some mistake here then things will go wrong.

So, just remember this kind of figure it will be very easy to understand ok. So, this will be the situation now what should I do this is just a example problem the actual solutions for this problem is I have to put that back inside here so there is a shock there with this beta more than the previous beta we said.

Which means I have to make sure that; this angle with respect to horizontal is less than the new 1 I am drawing with respect to horizontal and it is coming from the top-downward? So, will go more like this more steep I will erase this for avoiding confusion instead I will put 1 here. So, this is what it will do here? And this angle not this angle sorry it is from that line original line it is beta actually it is it is going to look more like this I will correct it so that it is easier for me to go for the next round. It has to be like this with respect to this line.

I will draw that dotted line parallel to this, which was your original wall from there? it turned in this is your beta 2, and this can never be more than 90 degree the way I have drawn it it is close to 90, but let us assume that it is less than 9 degree supposed to be slightly there this is more correct. Ok so this should be less than 9 degree, because we know we are in weak solution it should be probably less than 60 degree or whatever but, we can find out the exact number if we have a chart anyway with us and we showed the chart last time I will put it up on the web for everybody to use later.

So, it is going to have something like this now what do I do with the next shock that is coming here again the exact same problem repeats. I am going to what is this duty of this shock? It is going to turn the flow parallel to the new wall which is your original horizontal wall this wall.

So, it is all going to go this way now. Now, what will happen? the whole problem repeats at this corner now and then it is going to go again bounce off up like this bounce more at this angle it will bounce off like this. That is what it should do? Assuming some things we will look at that later, we will get back to that when things are going past the critical angle.

We will look at that case separately later if I look at simply a simple model let us say this is my model kept inside a supersonic flow and this is my tunnel wall, and there is m greater than flow coming this way now I can think about shocks that are going from here assuming it is attached shock and then it will bounce off and come back. This is what will happen of course, I am not talking about what happens in this corner which will deal with after we understand expansion there will be expansions here. We will understand that after we deal with expansions which will be the next section we will deal with.

So, as of now we will just say this shock is going straight and then its bouncing of that corner and coming back like this. That is what will happen in a typical supersonic. What if my angle is more than critical angle? Let us, say I put such a model. If, I have model with angle more than critical angle then I will have an oblique shock sitting here. Which is same as whatever we discussed last class and today? At the beginning after that this is going to be some shock oblique weak or strong depending on how close the wall is.

Let us, say it is weak oblique shock it is again going to bounce off like this, in here it is going to reflect to off this way we would not worry about what happens if this comes and hits here, it may reflect again ok that could also be a case we would not worry about that if I pick this particular problem. And if I imagine my piston analogy I will just look at only 1 axis line let us say if I draw an access line for this.

If I think about piston analogy I will look at only the top half of my picture, as it comes there was no piston for this vertical fluid element. It is just going straight like this, suddenly a piston starts moving upward which means there will be a shock going in front of it ahead of it and that is what is happening here. It is moving ahead of it. And then later it finds that the piston the cylinder has a top wall closed, I think about it that way then this shock goes hits and reflects back this kind of problem we already dealt with.

Where did we do this? We had a case where I have a closed tube and there was a flow coming like this and this there was a piston moving like this. We did this problem I believe we had a piston that was moving inside the cylinder which caused a shock running in and that caused flow behind it and then eventually.

When, the shock goes and hits there? It will go hit bounce and come back this way with another shock and all the velocity here will become zero again. We did this problem as an exercise example problem. We did numerical example you can go back and look at it this is the kind of analogy.

I am going to imagine just take this cylinder put it vertical and put it here and let it move along like this same way to our animation, you will find that the shock goes there reflects on the wall and comes back, that is what will be happening in this place? 1 cautions though piston analogy does not always work in fact it does not work in this particular case. When my shock is detached shock piston analogy breaks down.

Because, now even before the piston starts moving or in our case, the wall starts changing we see that there is a shock. This is no more a simple 1 d analyzable problem this is purely a 2 d problem with subsonic solutions also present, our piston analogy does not work very well for any detached shock cases. But, remember this simple picture, if I have a wall changing thing then there will be a shock produced there and this is the procedure for analyzing whatever we did now is the procedure for analyzing such flow cases that is the idea.

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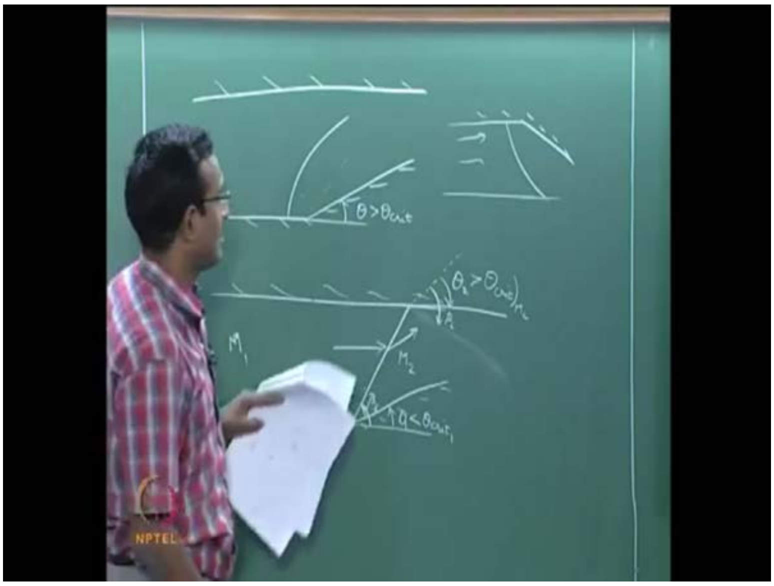

Now, we will go and consider a case where things go wrong the next question will be I go to this case.  I have the same flow situation but let us say my Mach number is different and now it is such that, this theta is greater than theta critical. What will happen in this case? This is actually already solved problem, we did this before. What will happen? It will not have an attached shock ever it will just directly jump to a detached shock in front of it.

It will look like this, this is 1 possibility this is nice and simple possibility I just wanted to recall this before I go for the more complex case. Let say I keep this picture I will draw once more, I have a case where I have m 1 coming and this theta 1 is less than theta critical based on Mach 1? So, I will call it theta 1 theta critical 1 also and so it is having an attached shock it goes there. Now, we will go and do the analysis I have incoming flow this is a new direction and I'll block this with my paper and then what will I see I have a flow going like this and it is hitting a wall, which is facing inward, this must be the original direction from there it turned by so much.

Let us, call this our theta 2 and this is your m 2, right it started with m 1 it deflected by theta 1 and it produced m 2 and this is your beta 2, sorry beta 1, sorry this 1 this is your beta 1 and from here I am going all the way there. Now, I have I blocked this portion and I look at only post shock flow, what do I see I am seeing flow going this way I draw a dotted line parallel to this and from there it has deflected by theta 2. Which means the wall is coming into the flow, which says that there will be a shock.

If there is a shock it has to be from there some beta 2 and we already know that beta 2 will be more than beta 1, I have drawn it such that it is more this would be the case right this is same as whatever we did before in here exact same case. Now, I will put a small trick I do not want this condition to be as simple as that I am going to say this theta 2 is greater than theta critical for m 2, if I have such a case.

Now, I cannot draw this, beta 2 is not a well-defined function anymore. Beta 2 does not exist so there should be a bow shock for this wedge al1. I think about it so with respect to this flow I will go back and lis10 to this 1 I just look at this flip it over and look at it, and then you will see I will draw that for easy imagination it will look like this. This should be your picture finally; if that is the case I have to tilt this slightly so that this wall becomes parallel to this dotted-line if I do that.

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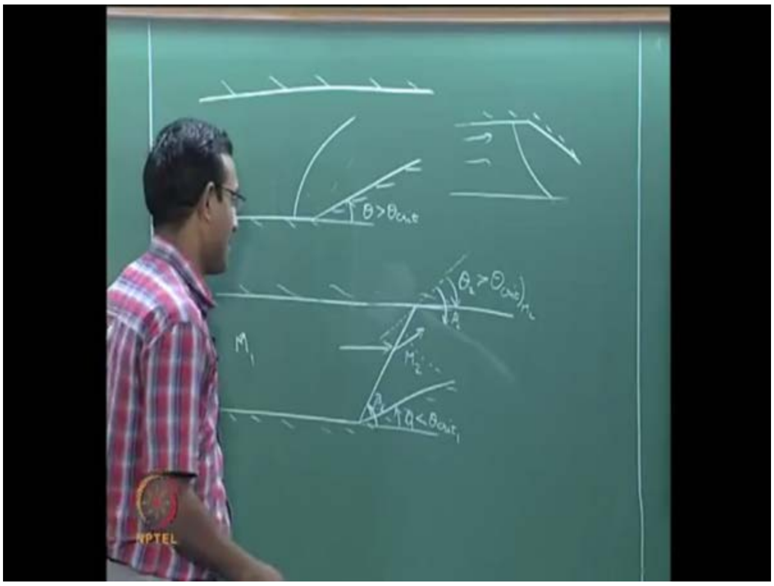

Then I will end up with a shock having too many this is causing more lines, anyways, so I have this original dotted line this is what is imaginary wall for the post shock flow field, which is going like this and that angle is more than critical, so there should be a shock that’s going like this. Is what should happen? If I look at this picture with this slightly rotated if that is the case what happens to this shock? That should merge with this 1 and form something new. So, I have come to a case where when this oblique shock goes and hits and it has to reflect but, the reflected solution should be a bow shock if, I think that then my solution changes. I will just erase some parts of it because the post shock solution should come ahead of the previous shock. Which means I have to erase this shock after some region? And I will redraw it no more beta 2. So, I will erase that beta 2 r everything else stays.

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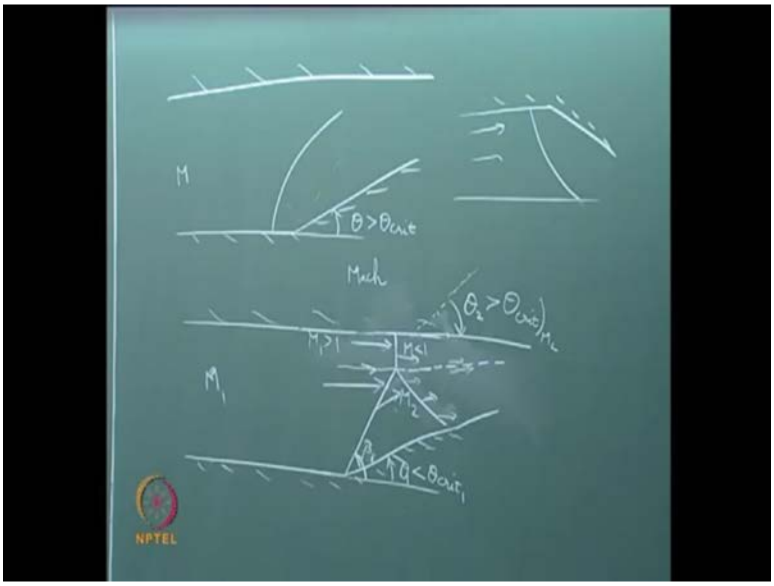


Now, this is how it forms it is roughly true I cannot give you the exact shape the shape depends on the exact problem. It is not very easy to solve this problem. So, again similar to bow shock solution this is a complicated bow shock attached with already existing oblique shock. This is why it will finally end up with, what is happening here is? There, is roughly a normal shock sitting here and then there's some what curved shock sitting here this is what is called a Mach reflection?  Again, Mach Ernest Mach was the 1 who explained this very well. He explained it for blast waves travelling across wall but, anyways it works very well for our case also this is shock reflection at a wall that is explained like this. It could be any of those reflections all the reflections were explained first by Ernest Mach.

Anyways, I am going to have this case, what is going to happen here? This is a normal shock will go straight it sees a normal shock it slows down becomes subsonic here it is m less than 1 and it just goes straight. Here it is m greater than 1 m 1 greater than 1, here it is forming some m 2 which is all a fixed value, because it is a straight single line oblique shock after here this is going to have different Mach numbers in different points. It will be slightly curved shock it is not very clear, how to explain this very well? It just becomes complicated problem to solve after, and there is 1 more feature to this I will draw this dashed line it will go roughly like this it is supposed to be a single line going straight along at an angle.

Ok, it is going slightly towards the top 1 towards the subsonic side. This is a slip line that is this is an online across which velocities are not matching. Here the velocity is higher than velocity here. so, the fluid elements are slipping along this line why is it slipping in this case we do not have viscosity, no viscosity case fluid element can slip across each other only when there is viscosity there will be a gradient and it will start decreasing gradient.

Anyways so because of that we see that fluid element here is having a very high velocity and this 1 is having a lesser velocity and they can just go as if nothing went wrong. Pressures across here will still be matched velocities would not be matched that is 1 thing I want to tell next thing just notice this region since the flow is going along this line.

Ok this is also a streamline this is a slipped stream streamline. Since, this is a streamline what is going to happen to this stream tube? A streamline that goes through this and then it is going along this line. What is happening here? This is a subsonic region and it is seeing that the stream tube is getting compressed this is the wall remember that the top line is your wall top line is your wall and this is a streamline wall is also a streamline flow has to be parallel to the wall so it is going like this.

Now, you are seeing convergent duct for subsonic what should happen? Flow should accelerate. So, the flow here is going to accelerate what about the other section. Here there is possibly a region I am not sure about what will happen in this z1 probably there is some subsonic region but, mostly it is all supersonic region, most of these regions are supersonic, where it is going to form supersonic flow? And it is going through a converging duct. What will a converging duct do to a supersonic flow? It will decrease Mach number it will go towards m equal to 1 all converging terms.

So, it is going to decrease Mach number here and it will increase Mach number here. What is essentially happening? This flow is slowing down this flow is accelerating they are all trying to come to a single Mach number that is what is happening here? What will happen to this shock? when it goes and hits here depends on how strong it is it may bounce off again, I have not seen much cases where it bounces off several times it may bounce off once more and by then viscosity will come and eat it up we would not see it. But, here inviscid world it should bounce off again and we have to worry about will this Mach number be ok or whatever we have to think about 1 more.

I drew this final angle wrong it should still be parallel to the top wall because this reflection is coming for this wall going to be close to that but, it may be slightly tilted. And now this wall this streamline will go and interact with this bottom wall and it will again bounce off from here. Because it is seeing a wall going through the stream line so it will again bounce off 1 more round that is a possibility. If there is viscosity these things would not happen, this bad that will be more difficult things to solve. Now, overall this particular problem I am showing you all this but, it is very difficult to solve from our gas dynamics if I go and simulate it there I cannot get analytical solutions for this.

If, I go and simulate it in some c f d programs or numerical algorithms I can solve this problem exactly and I will get some nice solution for it. But, I cannot give you an expression saying for this much h8 it will be a normal shock after that the shock will start curving like a bow shock. I cannot tell that from here. Because, similar to bow shock all the same reasons it has transonic regions, Subsonic region, supersonic region, everything together. It becomes more complex problem to solve and we would not solve that right.

Now that being said I have given you enough whatever feels for oblique shocks and normal shocks already. Now, it is time to go to expansions but, before that I thought I will give you some numerical examples, so that it is complete and I can give you a separate exercise for solving this later. Of course, go and look for exercises next to the video on the website will give you those also in time. Now, we will start with numerical example first example very simple one.

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I am having a 15 degree wedge, that is it is half angle is 15 degree its 2 d problem. And my incoming Mach number is 2 it is 1 atmosphere pressure static pressure p 1 equal to and t 1 equal to 300 Kelvin. And we want to find all the properties at this point close to the wall on the wedge that is the idea. Basically, I want to find let us say I have to start with find the beta the shock angle m 2, p 2, t 2, p 0 2, t 0 2, let us say I want to find every variable.

Ok, so how will I find this I have to go and start with this is my theta I know that theta equal to $15^0$. But, I do not know beta I will just draw a line this is my beta I need this. So, I have to solve this for beta how will I know the beta I have to go back to my theta beta m curve. If I go look at the charts, I have a gas tables which gives you the chart for a particular Mach number for a given deflection.

It will give you the beta value or you can just go use the charge I typically use the chart even though I have a table. I typically use the plot on the chart, I will go look at that and I am getting beta value to be 45, to some extent it will be correct it could be like for 45point 2, 5 to 3, 5 somewhere there I just put 45.3. It so happens that I interpolated on my tables and I got exactly the same number also I have this. Now, I have to find once I know this I can solve the whole problem.

Once, I know the beta I can solve the whole problem m 1 normal it is given as m 1 sin beta which is 2 sin 45.3 degree, which happens to be 1.42, now the problem is simple I have inverted this to a normal shock problem. All, I have to do is go to normal shock tables for gamma equal to 1 point 4 find that all the properties across the shock. So, I will get p 2 by p 1 is equal to 2 point 1 8 6 which implies my p 2 is equal to 2 point 1 8 6 atmospheres. Because, p 1 is 1 atmosphere and t 2 by t 1 I will just directly write t 2 equal to 300 times, 1 point 2 6 7 that is going to give me 380 Kelvin. That will be the temperature across the shock.

Now, I will find Mach 2 m 2 in normal shock tables will be called as m 2 normal in my oblique shock, m 2 normal happens to be 0 point 7, 3, 1. Which is equal to m 2 times sin of beta minus theta, beta is 45 point 3 theta is 15. So, I will put 30 point 30 point $3^0$ ok. So, when I use this and find out my m 2 value this thing gives my m 2 as 1 point 4, 4, 9 that is going to be my m 2 value. Now, we know beta we know m 2 we know p 2 we know t 2. We need to find let us say I do t 0 2 what will be the t 0 2 value t 0 2 across a shock suppose to be a constant.

Ok, t 0 2 does not change at all, t 0 2, t 0 2 is same as t 0 1 t 0 does not change at all, t 0 2 is same as t 0 1 it just stays the same does not change. Now, I will just do the p 0 2 by p 0 1 this is where we said we have to be careful. All right, we said I will do the normal shock p 0 2 by p 0 1. And then use that number as p 0 2 and then solve for the whole case that is all it should be.

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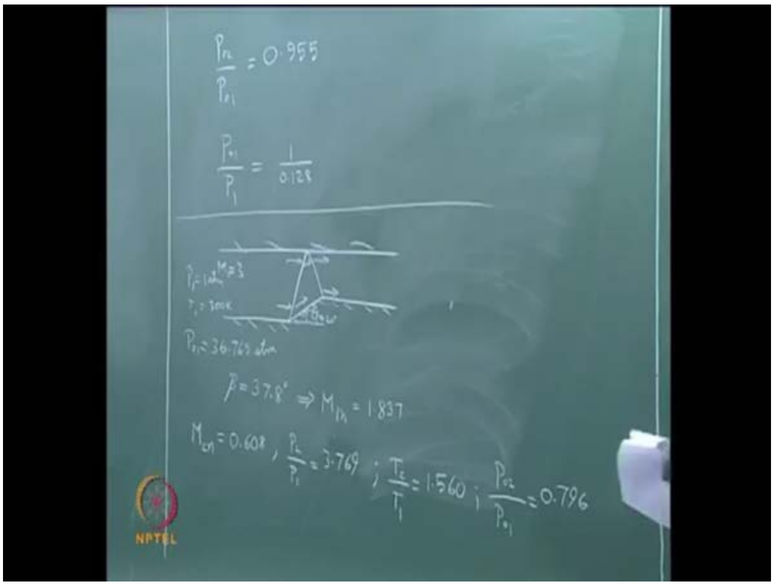

p 0 2 by p 0 1 happens to be point 9, 5, 5 from here we can find p 0 oh I did not find the p 0 1 actually here p 0 1 by p 1 I have that value. But, I have not calculated the whole thing point 1 2 8. So, I know p 1 is 1 atmosphere so I can find this number that multiplied.

With this must be your p 0 2 I did not find this final number which I believe you can find out it is not very difficult to find. Now, I am going for another example: where we want to find shock reflections I am going to pick a problem where it looks like this. I want to solve this problem and we will first worry about the first part I am picking m 1 equal to 3 theta 1 equal to 20 degree. I am picking this and currently we will say that I am having a reflected shock and I picked a wall.

Geometry such that, that shock comes and meets this, otherwise, the problem becomes very complex we will deal with that problem later after a long time. Currently let us, say there is a reflection and it goes and meets this point exactly. What is the advantage of that? Flow goes like this turns like this and goes back straight parallel same thing happens here also.

There is no more problem about it could be an expansion that is happening in the corner. Which we will deal with later after we deal with whole set of flow fields in supersonic. We are picking this particular special case we want to solve flow field through the whole region. If I picked this and I am giving the same thing p 1 equal to 1 atmosphere, t 1 equal to 300 Kelvin, giving you the same condition, oh here I have found p 0 1. But, this is a different Mach number p 0 1 is 36 point 7, 6 this is given. So, now to start the problem I have theta 1 and I have m 1.

So, I can find beta 1 it is not very difficult to solve. So, I go to the chart the plot and I am going to find that my beta happens to be 37 point $8^0$ of course. There is some error in reading out when I look at the data tables I found that this number was 37 point $75^0$. Of course, there is some error lets live with that error it is fine we can still give reasonable accuracy. If I use this and I find my m 1 normal this is going to be Mach number m 1 times sin beta. So, its 3 sin 37 point 8 that is going to give me a number of 1 point 8, 3, 7, that is going to be your number.

Now, I have to start with normal shock tables and I have only 2 decimal place accuracy. So, what I will do is I will interpolate for the third decimal place, accuracy between the 2 values I have numbers for 1 point 8 3 and 1 point 8 4. I will interpolate 7% between these 2. So, I am getting a whole set of numbers from normal shock tables m 2 normal is 0 point 6 0 8 p 2 by p 1 is 3 point 7, 6, 9, t 2 by t 1, 1 point 5, 6, 0, p 0 2 by p 0 1, 0point 7, 9, 6. I have a whole set of numbers just read out from that 1 row of data.

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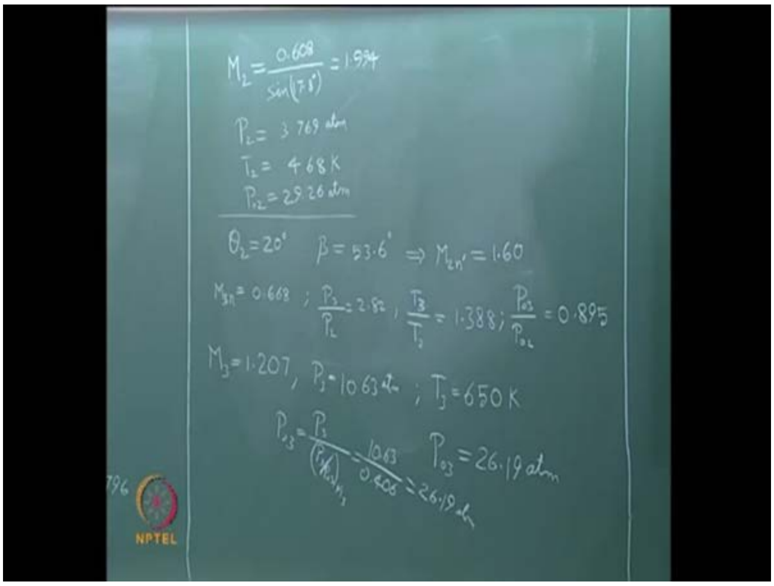


So, from this set of numbers, I can find my actual Mach number m 2 which is going to be point 6, 0, 8 divided by sin of 17 point $8^0$ that comes out to be 1 point 9, 9 4 it is a very special case Mach 3 with $20^0$ gives Mach 2 behind it its roughly that it is a very nice number to remember and p 2 is 3 point 7, 6, 9 atmospheres t 2 is 468 Kelvin p 0 2 is 29 point 2, 6 atmospheres and t 0 2 does not change it is the same all over do not need to worry about that. Now, I have a new problem to work with what do I have.

It will be the same deflection back here the flow is going like this 20 degree above horizontal, it has to go back to horizontal. So, I will again have a 20 degree deflection and it is again going to be a compression wave so it is going to be another shock.

So, I will put a theta 2, equal to till here it is 1 shock problem after this I am going to the next 1 theta 2 is 20 degree and we have m 2 is 1.9, 9, 4. So, with this I am going to use my chart and I am going to get a beta value roughly 53.6 degree. Roughly, 53.6 degree and this is going to give me my I have to call this again m 2 normal, because the original 1 is called m 2. But, I will put a prime here because this is a second reflection m 2 normal; this is not the same as the previous m 2 normal. Just at this moment when once I go to m 3 normal I would not care this happens to be 1 point 6 0.

Now, I am going to go to normal shock tables use this number read out all the data from the row, m 3 normal is 0 point 6, 6, 8 p 3 by p 2 is 2 point 8 2 t 2 by t 3 by t 2, 1 point 3, 8, 8, p 0 3 by p 0 2, 0.8, 9, 5. I have all these numbers and from m 3 normal I can immediately get to my m 3 value by dividing by this minus this sign of that value that is 33 point 6 sin, I will divide this point 6, 6, 8 by sin of 33.6. I have done that and that number comes out to be 1.2, 0, 7 and p 3.

We already, have p 2 I just have to multiply out this 1 and p 3 is 10 point 6, 6, 3 atmospheres t 3 is going to be 650 Kelvin; p 0 3 is 26 point 1 9 atmospheres and I did a quick check by seeing whether if I use this m 3 and p 3 will I get this p 0 3 it should also match I got this p 0 3 from this data from my m 2 normal prime. If I go and calculate it another way. I will just use isentropic tables and calculate based on this Mach number and this p 3. What do I get? If I use that p 0 3 equal to p 3 divided by p 3 by p 0 3 at m 3. If I do this that number yeah 10 point 6, 3 divided by I am going at an angle ignore that for now divided by 0 point 4, 0, 6 and this number comes out to be exactly 26 point 1 9 atmospheres. I had 2 ways of calculating p 0 across the shock and they give the same answer. So, I can use just m 3 p 3 and then use this with isentropic tables to find p 0 3 that gives the same answer. I can use this p 0 3 by p 0 2 across that particular m 2 normal and that will also going to give the same. But, this is going to be from normal shock tables. I can get to the same exact answer and we have around few more minutes I will just give you an example: where things go wrong.

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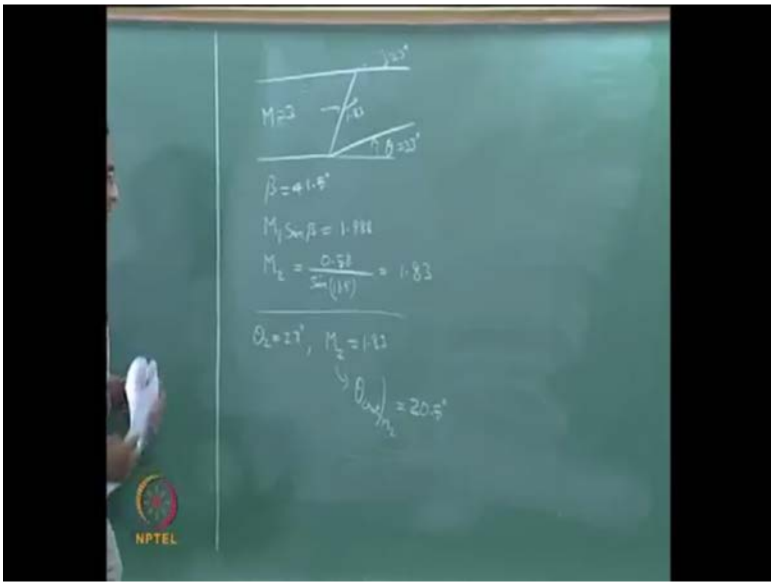

Let us, say I will pick similar configuration. I am putting theta equal to $23^0$ now the same m equal to 3 same problems. Ok, now I will find that for this case beta equal to 41 point $5^0$ compared to the previous problem it is lightly higher angle. So, this number is also higher previously it was 37 now it is 41 slightly higher numbers. Now, from here I am going to find m 1 sin beta this comes out to be 1 point 9, 8, 8, m 2 is going to be I am I am cutting short some steps here m 2 here is going to be point 5, 8. This is your m 2 normal divided by sin of 41 minus 23 that is 18 point $5^0$ here this number is 1 point 8 3 of course, I could also calculate p 2 t 2 p 0 2 everything but, let us say I want to avoid all that.

I just want to see what will happen the flow from here has now turned with a Mach number of 1 point 8, 3. That is my new Mach number and that is again facing the same deflection $23^0$ that is your theta 2. Now, theta 2 equal to 23 degrees and my m 2 the Mach number here is 1 point 8, 3. Now, if I go and look at this particular problem it so happens that is passed the critical angle ok. For this Mach number theta critical for m 2 is of the order of 1 point 9, sorry 1 point 9 is the it is of the order of 20 point $5^0$ or so for this case. 1 point 9 is your Mach number from which I got this data twenty point 5 or so roughly angle. Because, of that now I am not going to have this angle deflection ever possible using an attached shock. If this is happening then, I should have a bow shock here.

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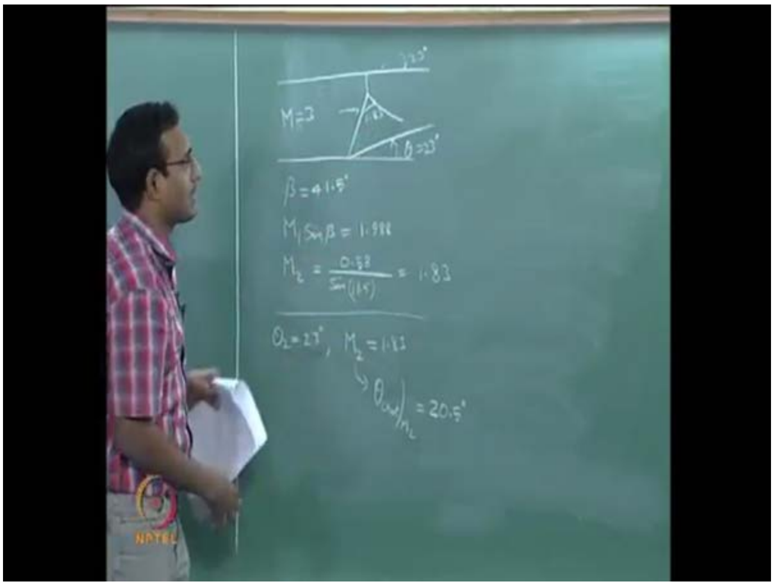


For that problem which means this problem is solvable up to only this part after that. I do not know how to solve this problem using these simple gas dynamics. After that the problem will look something like this and this should be your final answer. Till here, I can tell 1 point 8, 3 Mach number I can tell from here. After that, I do not know where this will start. I do not know what the height of this whole picture is and that is all I can say at this point. So, we have come to a point where we have given some example problems of oblique shocks and I will give you a lot more of these problems later. The next important thing I have to think about is expansion waves how expansion waves affect flow field? And we will start with that next class onwards see you people next class.