Gas Dynamics
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Module - 22
Lecture - 53
Summary of Course, Unsteady Flow Phenomena

Hello everyone welcome back, I told you I will show you images of method of characteristics mesh as, solved for straight line nozzle and external flow as an flow over a edge. We look at that at in a few minutes, I just want to summaries the whole course as such whatever I am going to do today and next class, will be extra as in it is unsteady gas dynamics, which is not in the course curriculum for simple gas dynamics.

We assumed for the whole course that we have c p by c v gamma as a constant we do not change it all. So, we started with deriving equations we started with thermo dynamics from there, we started deriving whole set of equations, for the flow and then from there we said will go to steady flows. And, in steady flow we said will go to isentropic flows no body forces, no friction, no change in area none of those, we just did very simple problem.

And then, we started changing one by one, we said will change area first for the flow and we did isentropic flow through area change ducts. And once we finished that we went into will add friction to the flow at that point we said we would not change area in that moment will remove area change, will put in friction and we studied that. And then we removed friction change, we put in heat transfer we studied that we just now know individually, how to approach each of these problems, I will not put all of them together in the two classes coming.

So, will just say you can go refer to some books there are some books which have all of them together effects of all of them together. It can be done it is just more tedious. We will say for our simple course, it is not needed and after that we went into computational as and we did not to experimental methods. We said we can find various flow facilities then we said we can find various probes, which can measure whatever we need; at the end of it we can, now go and say we can decide whatever experimental set up we want, based on whatever we know already and what we want for the future.

After that we said will go into computational method and I gave you only one computational method not all of them, I just did method of characteristics which is the simplest of things that are used for compressible flows. More complicated thing will be to fully solve the set of equations, full set of equations; and you have to take into account that, the information travels only one direction etcetera, that we would not worry about in this course, that can also be done, but we will not do it here.

After that, I just wanted to show you some flow visualization that is what will start with, now and after that we going to extra portion, which is this unsteady flow field. In unsteady flows in general are all compressible this is what I started with I will come back to it again. I started sometime back in saying that if I push my hand this way, I am producing a compression wave that is going this way, which is making the fluid here move this direction and the fluid here is moving this direction following, my hand because, I am sending expansion waves from here to this side.

Now, this being said I am not moving supersonic or anything, I am moving extremely slowly and even, then I am producing compression waves and expansion waves. But, of course, you are taking it as a faith, if I had shown you the movies you would see it much more clearly, I will show you movies next class fully. So, will just think about how things really happen, so for that I have to give you a set of rules or set of ideas in your mind.

So, that you can use all these to figure out how unsteady gas dynamics really happens, I will say that the very first statement you have to know is any change in fluid, any change in a flow happening will happen only because, of pressure waves changing things. That is there is always one fluid element or the other every fluid element in fact, is always communicating with the fluid elements around it by pressure interactions.

In simple flow fluid statics you would have put a box around the fluid element and said that, there is pressure acting on all sides of the box, which is equivalent to saying there is pressure interaction between, this fluid element and all these surrounding fluid elements. So, if there is any change inside this fluid element then, there is interaction changing across that is, if this pressure increased suddenly in my fluid element then pressure everywhere around, will have to change or there will be flow around something will happen.

And, that change happening simply because, of pressure change inside and there will be pressure waves travelling, that is what I want to think about. I am stressing on this pressure waves everything I am going to tell from, now on will all be pressure waves. Now, I will tell you one more extra thing even if there is no change in pressure, the pressure waves are still happening, there is still pressure interaction from one fluid element to another fluid element, there is still pressure interaction.

So, I will still say there is a pressure wave going from here to there and there is a pressure wave, going from there to here and there is no net change that is what I am seeing finally. And these are our ideally, what we should call a mach wave, that is a wave that says there is no change or I am telling my status and the next person is just acknowledging yes I am also in same situation, that kind of situation that should be your ideal mach wave.

But, in experiments we will show you mach wave we tell that put a small bump in my wall and you will get some line, which is almost mach wave. Of course I am now using a qualifying word almost there, almost mach wave, it is not really mach wave, but it is almost mach wave. When the change is extremely small that is I am changing something, but the change is extremely small then I will either get a very weak oblige shock or a very weak expansion fan.

Where the expansion fan will not span a very wide delta theta it will just be spanning very small angles probably, one very small part of a 1 degree something like this. So, in which case it will look like one line and if it is a weak oblige shock, it is mach angle will be almost mu, how do I know that, we remember our theta beta m curve.

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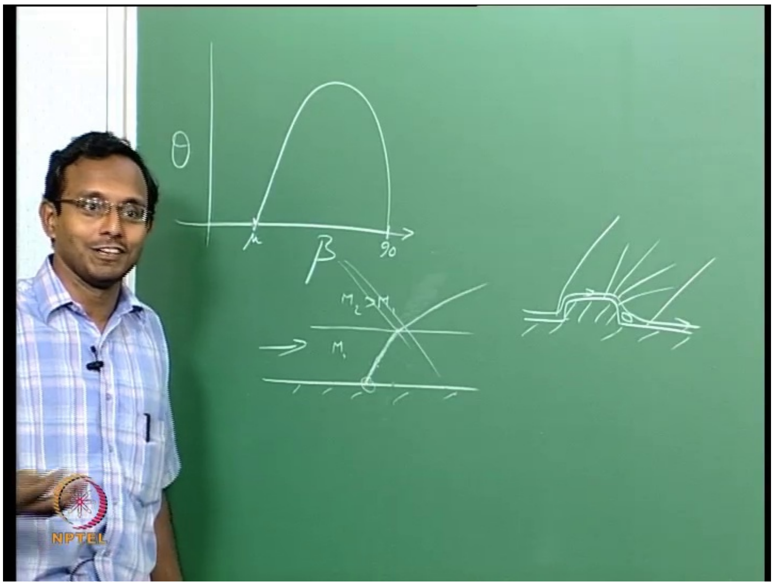

For a given mach number it is something like this is your 90 degrees and this angle was your mach angle. So, if my disturbances not changing my theta, so much then it will be somewhere here it is almost this case, in a very weak disturbance, is going to be having this condition; and in there this exact location, it will be almost mu it will not be exactly mu this slightly more than mu.

But, that slightly more than mu is extremely small that will say it is almost mu, so if I have a flow and I put a small bump in the flow. This is my wall flow field like this then ideally, if I zoom into this region it is probably going to look like this, some big block sitting in my flow. What will this cause ideally it should cause a detach shock in this corner and probably an expansion fan in here and then another shock here; this will be a stream line pattern and there may be a recirculation or need not be a recirculation there this should be here flow field.

What is happening to all these waves if this is all very tiny they are all almost starting at the same point, if there all almost starting at the same point they will start canceling each other. This is compression wave, this is expansion wave, this is compression wave, they are all going to cancel each other net effect will be, it will be very thin interaction of all these waves. There may be a shock expansion, shock all on top of each other and they are all very weak, they are all almost same angle and I eventually get some line which is almost mach angle.

And, this disturbance is still travelling into this whole flow field if my mach number changes say above this line, then it will be carried by that fluid with that mu angle. This is the disturbance it is carried throughout by this, if my say above this line my mach number is higher and this is M 1. If I had such a situation it is just going to do this something like this disturbances propagating from here, but it is carried through by here this is what I will see, how will I arbitrarily have different mach number you cannot.

But, I am just theoretically thinking something like this if such a thing happens then this will happen, how will I practically make this happen, mach number should increase after this point put an expansion fan in here. If I send an expansion fan after the expansion fan my mach number will change and because, of that my shock should change that is the way you have to actually think about realizing this situation.

If you want to realize it anyways I am not drawing exactly where the expansion fan is originating from here or here, that I have to think through I do not want to think throughout, I just wanted to say that there is mach number change. So, I am going to say the next statement which is if there is a very small change, I am going to assume it is always almost a mach wave that is how all experimental list work.

Everybody will just put a very tiny bump on the wall typically, something like this and now I can track this is very small density change and that can be tracked by, shadow graph or Sheldon experiment. And so, I can now say that this is my mach line and if I do my method of characteristics analyses, I can get this same line. Because, it is a characteristic line also, mach wave is a characteristic wave we already figure that out.

So, they are all going to match if I put a whole bunch of them ideally I will get my method of characteristic grid, if I put same thing on the top wall I will get the whole grid, that whole mesh you will get from there directly. Now, the next thing I want to say is if there is a wall that is moving into the flow, into the fluid element then it is going to create a compression wave.

What is the simplest example will saw 1 D example there is a tube and there is a piston that is moving into the fluid and that created a shock, that was our moving shock very first problem, we did with moving shock. It just compressed and that is causing a compression wave, I would just say compression wave if there are, so many compression waves together it will form a shock.

So, I will wait for that statement I will come back to it by just giving this interaction between compression and expansion wave. I will say if there is a compression wave ahead of the second wave, I do not tell what wave it is second wave it could be expansion or compression. There is a compression wave ahead and compression wave is moving forward and behind there is either compression wave or an expansion some wave, if that is the situation then the second wave will catch up with the first wave.

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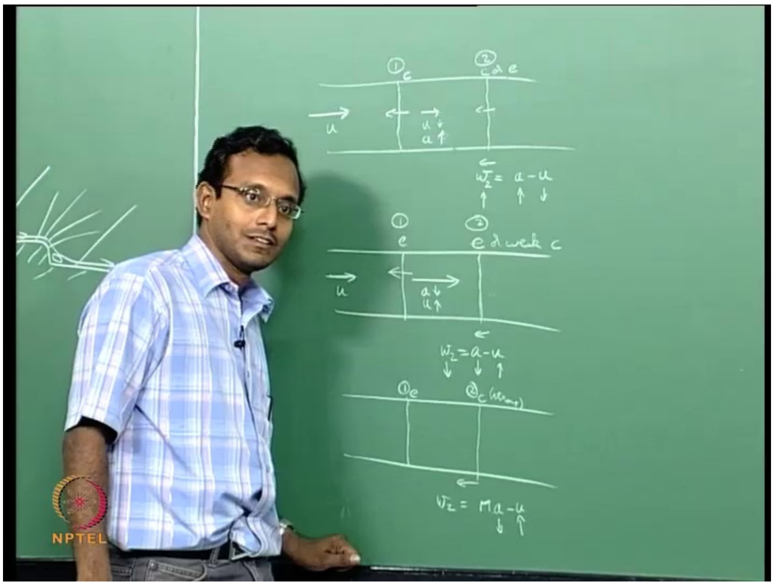

If there is a compression wave it is slowing down the fluid think about it like this, I am having a flow or may be fluid is static I do not care, some situation and I am going to let say, I have some flow u and this is my first wave and I am telling you it is a compression wave. I will put a c here that is a compression wave and there is some second wave, it could be compression or expansion wave it could be any of those, I do not worry c or e one of those.

If this is a situation if there is a shock here and it is travelling here, then what will this do it will induces a flow in the direction of the shock moment, which means if this velocity vector was this long it will, now becomes shorter that is the final outcome of this. I am talking 1 d here because, easy to understand the same thing will happen in three d also anyways.

So, this is happening which means my u decreased, but my a increased a increased, what is the way velocity with which is this is going to travel finally, w for the second wave I will put W 2. It is going to be equal to this velocity, flow velocity that is like whole train is moving with this velocity u and on top of it, somebody is running on the train, the other direction with velocity a.

Because, the wave wants to travel upstream I am picking such a case current, if that is the case then it is going to run, this way what will be the final velocity a minus u. If it is a minus u, a is increasing u is decreasing my W 2 will increase because, of this wave I had these changes. So, because of this wave my second wave will travel faster originally I am going to say this wave will travel at speed of sound.

Because, it is only a simple compression wave or a simple expansion wave it is not a shock yet, then if there is a compression ahead. The second wave will reach the first wave, this is what will happen you can of course, go and think about the other opposite situation. Where the flow velocity is other direction, then you will find that the velocity will increase this direction, then the train is running faster from. So, it will go fast run hit the previous wave that will again happen, I do not want to discuss that example you can find out that is not very difficult to think about.

But, if the first wave is a expansion wave I will pick another case this is my first wave and it is an expansion wave and the second wave, let us say is a compression wave, actually second wave let us think a expansion wave first thing easiest. I have flow and initially my velocity was this much, after that velocity will be higher why expansion wave will induce a velocity in the opposite direction.

It is telling there is more space there go there that is a information told by this first wave, wave is going this right it is telling everybody to go the opposite direction that is what is happening here. Now, I have the second wave let us say its expansion wave what is its going to run with, it is again going to run with the local speed of sound against the velocity.

So, it is still going to run with a minus u this is my W 2 this is what it will be, now if I look at it after the first wave my a decreased why expansion temperature dropped a decreased and u increased. So, now, I find that this increases this decreases overall effect is this whole thing decreases, which means the second wave is slowed down by the first wave.

If the first wave is expansion wave if the first wave is compression wave, then I am going to say that the second wave will be accelerated. This is the reason why compression waves come together to form a shock and expansion waves go away and form a fan, the reason is sitting inside here. Now, what happens if it is a compression wave the second wave is a compression wave, first wave is a expansion wave second wave is a compression wave.

If I think about the same thing if it is a very weak compression wave, it will still obey all these properties and it will behave like this. But, I will put that here or weak compression it will do the same thing weak compression it will follow mach wave almost, so it is travelling with speed of sound and everything will say have the similar thing. If it is a strong compression, then it will have a good speed of sound it will travel with the mach wave mach number, will travel with the mach number more than 1, it is like a shock a shock can travel more than speed of sound.

So, if that is the situation then there is a possibility that this will cross this, then there is the possibility that this may reach. I am still saying there is a possibility it need not reached may be I just have to multiply this with say 1.1. It will it will look something like this right W 2 is equal to m of that wave multiplied by a minus u, this is what it will be finally.

Now, I am going to say m is more than one, but still a is decreasing u is increasing after the first expansion wave that is still happening. But, now I cannot tell for sure what will happen a decrease may not be as much compare to u increase in which case. It is just going to go far apart if it is the other way a decreases there, but I multiply it with number.

So, I am already having a huge number that decreases very small if that is the case then it will still reach this. So, I am saying it is not sure whether it will go touch it or not, if it is a very strong thing then m a is going to be very high compare to the u itself and it will definitely go and hit it that will also happen. Once, you know all this now will go back and look at wall moving case, now I can tell for sure what will happen we already told this once I am just going to repeat it here because, this is a unsteady flow discussion.

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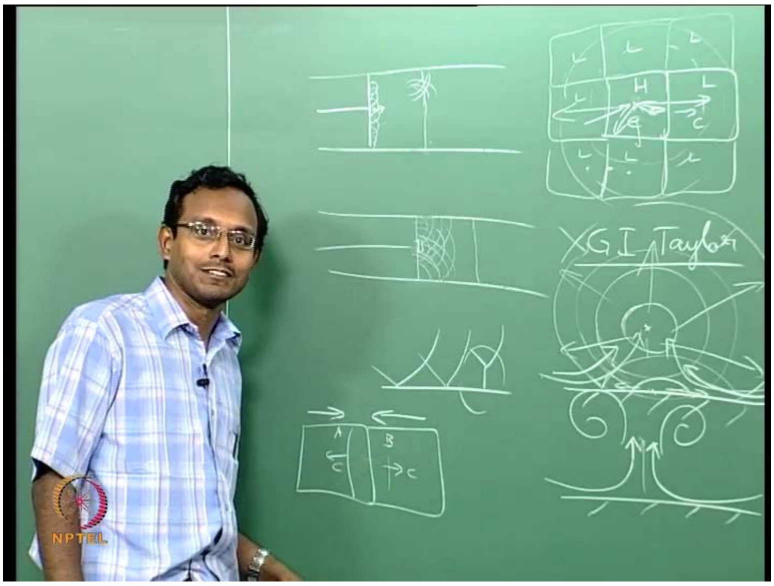

So, if I had a condition where I have duct and I have a piston and if the wall is moving into the fluid element, then this fluid element is every point on the fluid element will create a compression wave. Now, since I am thinking 1 d I am going to get a 1 d wave what if I think really 3 d ideally, I have to think about each point individually then and I will say each point is going to send out compression wave, with that point as center this u dot delta with in light most slightly.

Each of them will create a spherical wave and eventually all these spherical waves put together will have an effect, as if it will form a straight line wave that is what will happen in this in this case. If I think about 3 D inside here very close to the piston it need not be true, it can go wrong especially with friction on the wall it will definitely go wrong we are ignoring friction in this whole discussion for now, so I am forming. So, many spherical waves next to each other all of them, interfere to form one straight line wave that is our 1 d problem.

If say the wall has a gap here then that will have a hole there also and this hole will just start covering this like this, will start doing this the waves will keep crossing up and down after, that it is no more a simple one dimensional problem be if there is a hole in the wall, then it is actually three dimensional problem, fully three dimensional problem that can also happen, let us say we want worry about discussing that problem, now will just think simple stuff.

If this is the case when it moves a little bit, there is one compression wave created after that the fluid is travelling same velocity as the piston. If the piston is not accelerating anymore and there is no more compression wave created because, the wall is not moving with respect to that fluid element. They are both having same velocity in which case there is no more compression waves created.

If I move it a little more if I accelerate the piston a little more there is more compression waves created, what will happen if there is a another compression wave created that will go and reach the first compression wave, why we already discussed that previous was a compression wave. So, second wave will reach the first wave two compression waves together form a stronger compression wave.

And, the all eventually if I accelerate the piston at the particular acceleration then it is going to go through with some particular shock strength and that is how it just goes propagates. Now, if I think about other case I pull the piston back I already showed you animations of this, if I pull the piston back then fluid element is experiencing wall moving away from it, if wall is moving away from it is creating empty space if the empty space is created it is 0 pressure.

So, its seeing low pressure, so it will send out expansion fan it will again send the same spherical part of expansion waves. But, there are, so many spherical waves coming that it will finally, become all will together look like planner waves going that is what is happening in the this case. If I do not have a planar piston, if I have a crazy piston then I will have waves going up and down up and down it will not be a simple problem.

But, when I move the piston I will see this is expansion waves going up and down well I see it my Sheldon most likely no because, the density changes are, so small that we are sensitivity is not, so high for that. So, will not worry about that particular part will just try and see compression waves, that I have seen I wanted to show video I will show you next class to you.

So, the next thing if there is two fluid elements around next to each other, somehow if one fluid element is higher pressure and the other fluid element is lower pressure, I do not know how I create such a situation most likely it is not possible. Let us say if I ever have such a situation immediately what will happen, this is like a shock tube beginning right.

So, there will be a expansions going this way and compressions going this way depending on this strength of the difference between, the pressures here. If it is very high difference in pressure lot of compressions waves will be created, they will all form a shock. And, that becomes your shock tube problem and this side there will be a lot of expansion waves they separate out and become a big region of expansion fans that is what will happen this side.

But, locally if there is one fluid element alone is having this high pressure, let us say all these fluid elements also exist and they are all low pressure same, as the other low pressure. If such a situation ever happens then it is going to send out compression wave in all directions and that, becomes something like a blast problem right. If there is a bomb exploding here, then this fluid element experiences very high pressure why sudden release of energy huge pressure all that solid inside the bomb is now gas, they all vaporized they need space.

So, it pushes out everything that is your expansion compression created from here this is high pressure region, which is now going to expand and form compression waves around all around and that is how this is going and while the compression is going out, expansion is going in from all directions. Which is decreasing the pressure at the center that will also happen.

And, if you go read some papers by G I Taylor, our old fluid mechanics person he is no more, but he is he was really good at explaining things. He explained the nuclear blast in Japan, if you go look at the blast video you will see that it forms a mushroom cloud, it if it is just fluid expanding all through from here, it will never form a mushroom cloud from fluid mechanics point of view.

If I think about it exploded near a wall and they did not exploded on the wall, by the way they exploded it some two kilometers above or something. That is pick some point they exploded it is sending out expansion, expanding compression waves right, it is spherically expanding compression wave. It is a shock spherically expanding shock of course, you should know that the shock strength will decrease with expanding, its occupying its processing more and more volume that is it becoming weaker and weaker and weaker.

It is it is trying to process more gas with the same amount of initial energy it had, so it is becoming weaker and weaker as it expands out, that is not the case with planner waves. It will have the same area of cross section, this is not going to have the same this is not cross section area it is surface area I am correcting myself. So surface area is increasing it processing more and more gas with the same initial energy, it will become weaker and weaker.

But, anyways lets ignore that part if I just do this what will this point see, it will just see a shock coming and touching it and then a shock going on the surface outward. If that is the case then I will never have flow coming inward, it will just be a flowing go outward like this, it will never be flow coming back inward. In fact, this shock will bounce back like this I have a simulation of this some other time, I can show that also I guess.

It will do something like this the shock wave will reflect back on the wall and it will go out like this and by the way, our earnest mach got his name for this mach wave based on mach reflection, based on reflection of shock here. He studied this part and found that if I draw it more clearly it initially bounces of like this, after some time it becomes more normal and its bounces of like this, at some point. It does this is just one surface just this corner, how does the blast wave reflect and go along the wall that is his study that is how it became mach reflection.

He did not do that whatever I showed you as an example barrel shock or anything, mach disc that is not what he did, he did this mach reflection. This is how it came up anyways long time back they were, so much interested in blast explaining blasts for that this is all Japan explosion bomb that time. Now, I will tell you one more thing I forgot about that already by, now see I am sending expansion waves to the center, what will happen after that those expansion waves removed all fluid from there.

So, many expansion waves converging to a point it is, so strong of an expansion right at the end of it the pressure there become, so low compared to pressure somewhere here. So, the reverse starts this pressure is high that pressure is low because, of which now this will send out expansion waves, outward that is what we will think of as expansion waves just go through, this point and cross and go the other side you can think of it that way or you can think of it as expansion waves, come to the center converge and bounce of the center point and go out again.

Whichever, way you think about it, the expansion waves come out again those expansion waves what will they do they will induce flow opposite direction, that place is too empty. Now, go back the other direction that is what the expansion waves are, now telling that is what is causing the reverse flow till this point. All fluid elements were all going out in all directions, this is just going to create some big cloud of exploding gas.

But, after sometime suddenly fluid wants to enter it is wanting to enter from the other side also, but there is a shock which is still sending out stock. But, from the bottom this easier to send staff in and that caused this suction back inward and this is the reason why you got that mushroom cloud, flow coming back in here why will it come back up because, they are again converging on to that straight line point on the ground they are all coming from all directions radially inward.

So, after that they just have to go out up that is the only freedom they have goes up and this started forming that mushroom cloud, which we saw in your explosions some over Japan. And, Taylor use this pictures of this and predicted the explosive energy, energy of the explosive inside based on pictures and timings and. So, he was called by American army or air force whatever and then they questioned him. So, much do you have any secret inside, somehow, you know the our energy values etcetera it was. In fact, very close he put a range and it was exactly inside that.

So, they questioned him, so much and then he just told this is pure mathematics, so that is genius there, but anyways. So, this is what will happen if I think about unsteady flows where there is 1 point alone having very high pressure, this will send out expand compression waves out, expansions go in and then expansions go out after that, they come bounce off and go out again, all this will happen in an unsteady flow this will keep on happening multiple times till you come to a point where those waves are very weak.

Now, what will happen if I think about the expansion going out, all the fluids are coming together, now they come together they collide and they, become very high pressure again that will send out expansion compression waves, which will again make the fluid go away from the center. So, it will go out come back and then it will become slower and then becomes stop, that is what should really happen. So, if you start feeling all these I am just thinking about giving you some feel for what will happen in an unsteady flows.

And, still defining what all can happen later will go and discuss one particular case say for some reason, I have two fluid elements colliding against each other. It may happen when there are two jets suddenly forming and they are just colliding on each other, if such a thing happens, I will draw it here itself. I am going to say these two fluid elements are colliding against each other.

What should happen here let us say fluid element A and B what should happen of course, it depends on the net velocity say the velocity is A and B are different, then I can think of a center of mass velocity for this and relative velocity between these right, finally they should move with center of mass velocity of course, and the relative velocity between these two is what I am considering here.

If I consider only that one fluid element is having relative velocity, normal to its surface on other fluid element, if that is the case then they are colliding against each other. It is as if this surface is moving into this is equivalent to wall moving into fluid element, I am going to create compression waves going this way and similarly this is going into that. So, this will also have a compression wave going this said this is what should happen.

If this is happening for several fluid elements then there will be a planer compression wave, which is happening only for two fluid elements and everywhere else it is not happening, then it will be a spherical wave depending on what is the case. And, now of course the converse I can, now say that they are moving away from each other, then I will have expansion waves going this way and that way, which will again try to induce velocities, such that they do not go far away they are inducing velocity opposite direction that is what should happen.

Now, I just talked about only perpendicular component can they have this component up and down, can a go up and b go down relative to each other, yes it can will it cause any pressure waves, this will not cause pressure waves in our gas dynamics. We assume no shear effect right, we assume no viscosity, so these two will ignore each other moving sideways they can just perfectly slip, on top of each other in reality that is not the case in reality they will start having ((Refer Time: 34:50)) at this point.

Which will be diffused both sides by viscosity and because, of that these things will start rotating in a big shear layer form, I have already discussed shear layer separately. So, you can go back and think about what will happen in the shear layer that will happen here. It will produce compression waves one side expansion wave the other side and it will alternate compression expansion you. I already discussed it you can go back and look at that, that will happen currently we are thinking about only perpendicular components because, we are ignoring shears.

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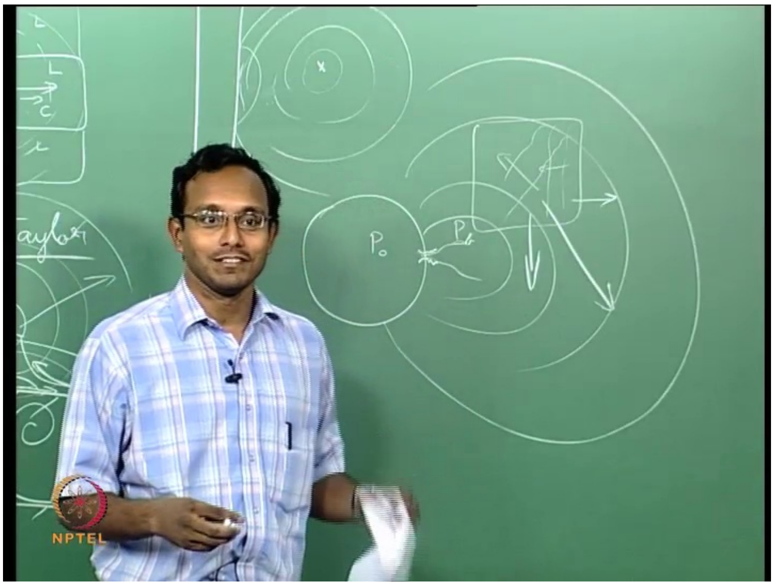

Now, the next one more important thing, If I have a point and it created some wave I do not call what waved now it could be any wave compression or expansion any wave, that wave will keep on going all the way to infinity in all directions, till it has any energy if all its energy is dissipated and the energy becomes 0, then it will stop moving, but energy can never be dissipated completely.

So, it will always be moving even if it is moving with 1 micro meter per second or anything, even if that is the speed it is keep on moving forever. How far will it go it will go all the way up to infinity it wants to tell this information to all the fluid elements around, if it experiences a wall on one side then this fluid elements stops there. Because, it has finished all its jobs this is the last fluid element it sees it stops there, after that this is the way I want to think about it, after that there is a flow created by this wave which may be towards the wall or away from the wall.

And, because of wall being there the wall, now creates new pressure waves that is the nice way of thinking about it other than just saying this goes and reflects and comes back ,you can think of it two ways. I can now say if it is a compression wave I already talked about the blast problem. So, if it is a compression wave then it will bounce off like this, this I will call as a new wave created by this wall that is a nice way of thinking about it easy way to think about it, this is a new wave.

Because, this is not going to have a same mach number as this wave why this is not experiencing the same flow field as this one, this is experiencing 0 moving flow while here the fluid is already going this way and this is fighting again that. So, the mach number etcetera will be different here, this is going through a gas that is already processed by the previous gas.

So, it is a new shock think of it that way it is easy to think about, so if a wave is created at a point it keeps going all the way to infinity in all directions, except when it meets a wall. When that waves stops moving that is it, its job is done in that direction that is the last fluid element it sees, after that it sees a wall it stops no more fluid element it stops doing its job, that is what should happen ideally all waves are 3 d that is the best dimension we know all waves are 3 d.

But, if we are thinking a planner problem we can say that all those points are exactly on top of each other like, what I showed in a piston all those will form each of them will form a spherical wave, overall it looks like. It is a planner wave coming out, that is what should happen, so now, if I have a wave that is travelling in some fluid, which is not moving then it will move with speed of sound or almost speed of sound.

But, if it is in a flow then it has to take into account that also I already used that information in calculating the W 2 etcetera sometime back, but it is as if there is the fluid element inside the fluid element, that wave is travelling say the wave is travelling like this may be the fluid element itself travelling like this or maybe, it is having velocity in two directions.

So, the net velocity is something like this inside that the wave is travelling like this that may happen may be, wave is travelling at an angle also it can also happen like that, any of these cases inside that this is happening. So, ideally then net velocity of this with respect outside reference frame is going to be fluid velocity plus or minus depending on the direction.

The velocity of the speed of sound locally or if it is a shock wave, that is travelling then you have to take into account m times a not just a, shock mach number multiplied by a, all that should be taken into account next class, I will give you an example of how a nozzle shock moves unsteady. If I can use all these statements whatever I am telling today next class I explain that then I have done a reasonable job, after that you can go and solve any other problem.

So, now I will put more strong statements after all as, I am going to say the only we have to change pressure of a gas is by a compression wave. I cannot change pressure of a gas by any other means, I can change pressure of a gas only by sending a compression wave. I can change I can decrease pressure of a gas only by sending a expansion wave increase pressure by compression wave, decrease pressure by expansion wave.

There is no other process by which I can change pressure of a fluid element, this is a very strong statement I am making. Now, there is a possibility that I can accelerate a fluid some other way by external forces or something that is a possibility. But, pressure this is the only thing I can do if I put a bomb and explode it in a local fluid element what will happen, I am suddenly moving the walls of the bomb which is like piston, which is creating a compression wave which is, now sending out the compression which is causing that expansion of that other fluid elements, having other fluid elements are sent out.

Because, of this shock going away from that way that is what is really happening or if the bomb wall cracks what will happen inside the pressure is, so high that the bomb wall cracks which means a pressure is high inside outside is low pressure. It will locally forms a jet flow or a nozzle flow right, if I have a bomb and it cracked this part is open high pressure here, low pressure outside this is a nozzle problem. It could have some vary some crazy crack whatever be the shape, but it is still a nozzle.

So, it will have that jet like flow when a jet is starting what will happen pre high pressure is experiencing low pressure, it has to see a shock tube locally. So, that shock tube is going to send out a first shock that shock will just go out fully, I tried to simulate this by exploding a balloon I wasn't very successful with it. We did it there was something, but we could not capture it we were not fast enough in our high speed camera to capture that.

It was too fast for us to capture at will see something that is what I wanted to show I will show it next class, there will be a some wave going out. Now, if I think about another example where typically we hear very loud sounds I picked an example like that, we take a straight flat surface table we took a metal sheet, which was supported by legs and then we dropped thick plank of wood on it like this.

What will happen when I do this dropping it is going to crush all the fluid in between these two layers, this surface and this surface all the fluid in this triangular edge like shape thing is all going to be getting crushed what will happen. Because, of that this is whole fluid element has to, become very high pressure and they have to escape in all directions, what all directions it will escape this way.

How do they really escape how do they know that they have to escape they send out pressure pulses inside it is high pressure and how did it, become high pressure wall moved in wall moved in compression waves bouncing up and down inside here, that increase the pressure inside, while it is bouncing up and down this way. It is also going out on the sides remember its spherical wave goes all directions, when its goes on the sides they see nothing what it will do will keep travelling.

Because, of that it induce a flow along with it, so flows starts escaping in all sides this is your unsteady flow phenomena, I am talking about this is all fully compressible flows I do not care what speed it is. In fact, I will show you a experiment where we did we measured the actual velocity at which its going and hitting, it was 6 meter per second and we can see a shock in front of it, that is very easy to think about 6 meter per second creating a shock anyways.

So, it is going and hitting like this during this whole time there was multiple bouncing up and down of this compression wave which is compressing on top of each other. So, the pressure inside is getting very high, but on the sides it is escaping continuously, so pressure is dropping from the sides when the flow is going out this way. It is like a shock tube problem expansion fan comes outside towards inside, from the sides it is getting expanded from up and down its getting compressed, over all it will increase pressure to some extent that is what will get.

So, eventually when I do this I will get a nice shock coming out on this side if it is strong enough, if it is very strong I can capture it. We tried with the wooden plank falling on a metal plate wasn’t strong enough we could see something, but not really clean shock it was something like a compression wave. But, the next we took a metal ruler and we hit it hard that it gives that shrill sound, we hit it hard we tried it several times and there was 1 point where we could hit really flat, then we hitted really flat we actually got a clean shock here and following that of course, you will still have all that shear layer effects and vortex shading etcetera.

This is all fun to watch I will show you that video in the next class, at you will see all these changes happening and now ideally when you go and see any flow field with this kind of thinking should just go and say, how did it all start where is the energy coming from, that is where the whole flow started energy of this wooden plank falling on a table stated with my pushing it. I gave it kinetic energy gravity is accelerating it further and that while it is moving it is sending that energy into pressure energy pressure waves are going pressure waves are going in all directions.

But, some of them are going bouncing and coming back to this wall it comes in it is getting bounce back against a moving wall, which is becoming even stronger. So, it is going up and down, and getting stronger and stronger eventually it gets much more compressed, while at the same time on the side it is getting expansion waves from the outside, outside is sending expansion waves to see all that is happening like, this you have to start thinking about what are all the different factors that are happening in a flow field.

If you start thinking about any flow like this eventually you will go to a point where you will become good at understanding unsteady flow field. This is the basics for it I will pick a two particular problems and explain, how they are working in the next class of course, only simple analyses more complicated analyses my research students are still working on it, only simple analyses.

I will give you just heuristic argument based analyses I will give you more theoretical analyses will be done by student and probably will publish it some other time, that is what it will be we doing a lot of experiments in a unsteady flow field, now will try and see a lot of movies in the next class see you people in the next class.