Gas Dynamics

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Module - 18
Lecture - 46
Compressible Flow Facilities, Measurement Techniques For Compressible Flows, Experiment Design

Hello every one welcome back we were discussing flow facilities for compressible flows the only other flow facility which we need to talk about is low density facility of course, does it really fit into compressible flows in a way yes and no because if you think about when I am launching a rocket then the flow in the front of it is actually a compressible flow because a rocket will slowly accelerate all the way up to mark 20 or.

So, if it is going all the way up that very high speeds then may be the flow in the front will have will be forming the same kind of shocks which we are seeing in regular compressible flows, but there may be a situation where when it is reaching mark 20 it may be up when altitude. So, high that it is not in continuum anymore, if it is not in continuum you going to have different physics it is not going to be the same it will not exactly behave the same way shock will not be very thin shock will start becoming a big region instead of 1 thin line that also starts happening in non continuum situation when I go to more and more rarified conditions will have to worry about that.

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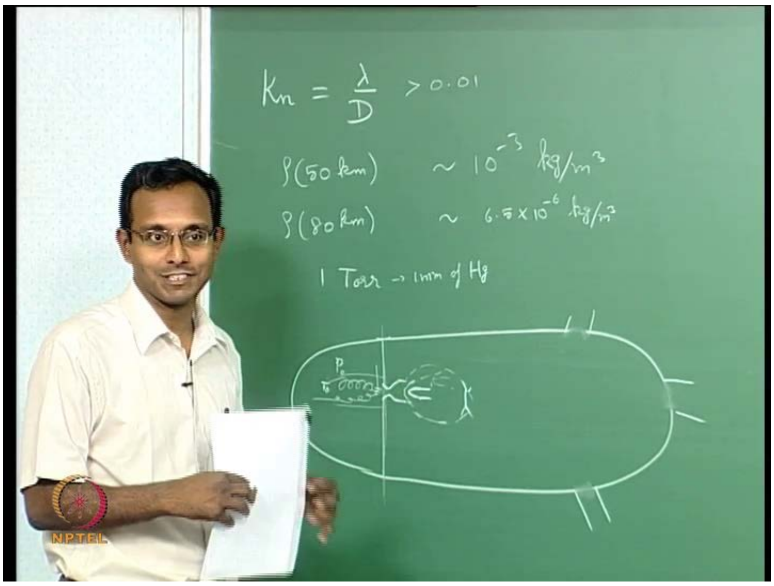

If I look at when should I worry about it I already talked about that the very first day I believe Knudsen number the mean free path of molecules in the gas divided by the dimension of interest to us typically, if I think about a rocket then the diameter of the rocket is what we will use for that that kind of dimension, if this number is more than 0.01 then we cannot say, that continuum is valid exactly you will start having more and more errors if we use continuum to study the flow fields of this type when will this happen if this number is going to become bigger; that means, my diameter is getting smaller and smaller compare to the mean free path or mean free path is becoming larger and larger compared to my size.

if I am interested in 1 meter diameter rocket then the size is going to be off the order of one centimeter mean free path is off the order of one centimeter then things will start affecting typically mean free paths are going to be off the order of less than 1 micron or even Nano meter probably at higher pressures and temperatures, but when we are going very low density conditions then things will become non continuum situations. So, if I think about density at 50 kilometer there is roughly 10 power minus 3 k g per meter cube while of course, you know density at c level 0 altitude is 1.2256 you should remember that kg per meter cube. Now, if it is 80 kilometers, then it is going to be 6.5 into 10 power minus 6 k g per meter cube if we think about it we were having order of 1 k g per meter cube at c level I dint write that number here 1.22 of the order of one it became 1 by 1000 of that density by the time we went 50 kilometer altitude and from here it went of the order of another 1 by 1000 not exactly 1000 slightly less than 1000 1 by 300 or so.

So, 1 by 200 kind of order again future down if we think about it people start using different units tor is the unit for pressure there they will start using tor for unit of pressure which is 1 tor is 1 millimeter of mercury the pressure exerted by 1 millimeter of mercury that is 1 tor and typically this will correspond to of the order of 10 power minus 3 t or that is the kind of numbers we are talking about I am talking about 1 micron of mercury height is the pressure actually exerted at that 80 kilo meter altitude conditions. So, now if we want to do this kind of experiments at our sea level or ground level conditions we have to create a set of where I can provide the conditions corresponding to 80 kilometer altitude and the corresponding velocities temperatures etcetera.

So, to that what we do is basically is to do the experiment in a vacuum tank that is the simple way to put it what we will have will be a big tank and I am going to connect it to vacuum pumps several pumps depending on the vacuum I will run all the pumps or some of the pumps will not be used some times depending on the vacuum condition I will just be evacuating on the chamber and remember that since we have doors etcetera on this there will always be a little leak and little leak matters a lot for very low pressure conditions. So, the leak should be arrested very well that is one primary problem with them other than that the pump should be continuously running to maintain the pressure because, there is always leak and the pump should be removing the excess molecules that are entering due to leak then it will the pressure will be maintained that is the idea there the pump should be running for that capable of running with the required leak rate that is the idea.

Now, if I want to have a flow in this condition if I am thinking about the flow over say my GSLV rocket front nose cone alone I want to study flow over rate. And I want to think about mark number say 15 then I need to create a pressure difference within that conditions. So, I will split this chamber into two parts I will call this as the stagnation chamber and this my other side this is the back pressure the vacuum chamber what I will do is I will put a nozzle inside here which is going designed to give whatever mark number we have talked about typically.

If we keep such a situation and this pressure being extremely low I can create a big jet like this of course, you know what happens there is there will be a barrel shock and the marked etcetera all that will happen here, but that is not our interest currently we are interested in putting our model somewhere in here we said GSLV nose cone in here we got to put that model in here. And then we are going to study what is the flow field around it may be a shock is formed etcetera. And if we design the nozzle well I will get uniform mark number for this whole length and then now I can study the flow around it typically in our lab here rarified gas general.

We will use temperature measurements in the front and the sides etcetera to find the heat transfer rates for this that is one way of using this facility of course, you can think about shock patterns and how to think about interaction of this with the other side part sitting here will it go and interact with that shock and will that cause any trouble that kind of things can also be studied, if I keep a particular P naught such that I want a particular static pressure in front of the model then my back pressure should be much lower than that and also to maintain the back pressure very low I have to now think about this P naught times this throat area mass flow rate right that should be able to be pumped by these pumps sitting there vacuum pumps all that should be able to be handle for this to be working in the static study conditions.

Now, if I said P naught as this and T naught as the room temperature then for mark 15 if I think about that is going to be very low temperature extremely low temperatures and that is again not good for us we want to do study exactly as, if it is in space whatever is the temperature there may be of the order of 100 Kelvin 100 50 Kelvin somewhere. So, to get that temperature I have to now create hot t naught here what people do is just have some kind of electrical heater inside here. So, that the low pressure gas here is getting hot as it is going through this and somebody should be monitoring it. So, we will put a temperature probe there in front of it. So, that the flow is going to go through this is the design.

So, that now I can set a particular P naught the stagnation temperature and stagnation pressure. So, that I will get the required static pressure T and static temperature and pressure there and for that particular mark number as designed by my nozzle. This is the reasonable design which people will use for this of course, I can now talk about what are the probes used to measure pressure etcetera, but I think that is slightly beyond the scope of this course.

So, we would not talk about it there is the special probe to used for finding stagnation temperature stagnation pressure in low density facilities. we would not talk about it in this particular course, but that is the idea for, low density facilities now we will go into we already talked about lot of flow facility we will think about how to measure pressures in compressible flows experiments, if I think about the compressible and think about the supersonic and subsonic split them separately, if I first talk about only the subsonic cases.

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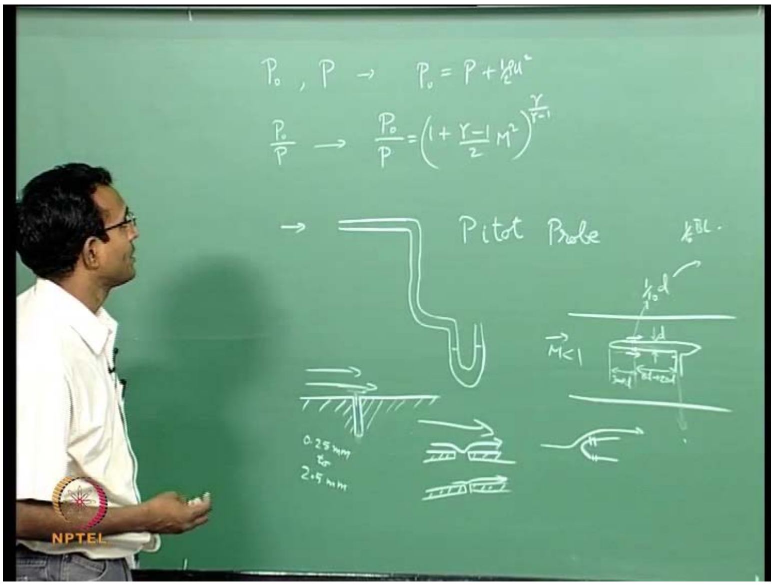

Subsonic if I want to find velocity if it very low subsonic that is incompressible word we will just use stagnation pressure and static pressure and that is going to give me based on our Bernoulli half row u square I am going to get the velocity, if I know the density that is what we will do, but if it is compressible flow we already saw the connection between this and the other expression we had from compressible flows we had the connection between this and this simplifies to this very low mark number we already did that.

So, what we do if it is subsonic compressible is just go look at this from here I am going to get a mark number, if I know the gas that is I should know gamma for that case this is the basic idea if it subsonic if it is supersonic we will come back to it most likely I want to use the same formula anyway, but we will come back to it after wards how will I measure stagnation pressure stagnation pressure is simple enough it is just going to be a tube that is facing the flow and on the other end it is not letting a flow through continuously there is going to be some pressure measurement device here say a manometer.

If I use if I use a manometer that is going to stop the flow from going it is not going to be a continuous mass flow rate it is going to go and stop somewhere. So, I am taking a flow here and it is going and stopping therein the situation, where I am saying that the velocity that is coming here with whatever is the free stream velocity in here is slowly going in and by the time it reaches the other end it is going to be brought to rest because, I am thinking about steady state measurement it is going to come back to rest.

So, this particular device is called a P i tot probe this is used in subsonic lot of times even in supersonic we can use it there will just be small change we will come back to it, but I first want to talk about all the probes in subsonic conditions then we will go to all the probes in supersonic conditions. Now, if I want to measure pressure static pressure if it is on the wall what is the definition of the static pressure it is as if I am moving along with the fluid element and measuring the pressure that is the fluid element is not really pushing on me that is the idea, if I have a side hole this way on the wall, and the flow is going like this the fluid element is not really pushing on me as long as this pressure is same as this pressure.

Then I can say that the stream lines do not want to bend this way when will it bend this way if I have a through hole this way and the pressure here is higher than this pressure then there is the through hole. There is going to be a flow this way we do not want to have that situation again the same thing is here if I put a pressure device there say a pressure transducer rand that it is going to sit somewhere here that will stop the flow. But this system will come to equilibrium when this pressure is same as this pressure and after that the stream lines will just be going straight that is what will happen here. If this is the case then I am actually measuring the pressure at this location at that entry of the port and then at that point I am going to say I am measuring pressure in that particular pressure port and it is going to give you the static value why it is not pushing any more on the sides it not turning into the flow this is the typical method this is the wall taping I am taping from the wall to measure the pressure.

If I think about I want to measure somewhere inside my flow system say I have a full test section with M less than 1 let us say and I want to measure static pressure somewhere in the middle of the intersection then I need to create a local condition like this. I have to create a system where there is a wall and a side hole from there how will we do it we will have a tube we will have a probe that is like this where it is just a straight tube with some nice smooth ending in the front. And then we will have a hole on the side typically there will be 4 hole top bottom front and back there will be four holes on the sides. So, now it is going to average around all the sides of this tube and I get a net 1 value pressure here and that is going to be taken out through this to some pressure measurement device most slightly some pressure transducer or a manometer this device which people use. What I am doing really it is the same as whatever I have done here it is just flow is going to go parallel to this. And I am looking at pressure measured perpendicular to the stream line that is all I am doing here this is going to give me again static pressure value. Now, what are the consideration I have to have what if I have a probe that is very short from the front to the hole let us say the hole center to the front typical numbers people use are 3 to 8 times the diameter of this, if this is my d then this is going to be 3 to 8 d 3 to 8 not 3.8 and the other distance the holder to the hole position of the order of 8 d to 20 d 8 to 20 times the diameter of this tube that is what we will use their why do we have to worry about this what if it is less than 1 d what will happen then if I look at zoom it into that region if it is less than 1 d then my holes are here then the flow stream lines are just now turning they are still accelerating which means the velocity is not same as what it should have been without this probe I have changed the free stream velocity to something higher here I do not want that I want to measure without disturbing too much that particular flow field.

So, I have to think about going far away from here if I go far away from here it is going to become parallel, but still if we think about it this probe is blocking some area in my hole test section ideally if I think about it the area for available for the flow has decreased what we have to do is minimize this. So, that I am not intrusive as much as possible we have to make the d as small as possible if I make that d small the hole size. So, I haven’t mark the hole size the whole size is 1 by 10 of d typically they use we will come back to that y next if I make this d small then I have to drill extremely tiny hole and it has to be accurately placed that is going to become a trouble making a small hole less than 0.5 M is very difficult of course, now we have laser machining it is getting easier, but it is still difficult it is not very easy to do all the time. So, that is that kind of precision machine is needed for that if you want good measurements why do I have to worry about this length from here to here now I have to think about this bottom flow going and stopping in front of it I am going to create a stagnation point in front of this which means pressure from here is this is subsonic flow right. So, pressure from here is going to increase immediately from here till it reaches there.

So, that the flow is adjusted by the time it reaches there a subsonic flow typically does that it adjust to the incoming flow. So, it will start adjusting from here itself. So, I will get wrong reading unless it is. So, far out typically people keep it more than 10 d. So, that things are not interfering there these are two thing now I will talk about this 1 by 10 d why should it be 1 by 10 d what if it is just 1 d its easier to think about in this particular situation I have a picture here imagine that is the same picture I will just draw that picture exactly that probe is a tube with the hole. This is where my flow field is I am thinking about this situation I am going to say if the hole is really big then flow will start doing this flow will start bending in and coming out if the flow has a small component into the tube then.

I am going to measure slightly higher velocity than the stag higher pressure than the static pressure. Because, this velocity going in has to stop this way and come back accelerating this way. So, I am going to get a higher pressure here another way of looking at it the stream line is curved this way meaning there will be a centrifugal force this way that is going to give a extra pressure gradient this way. So, that is again pushing. So, I am going to measure something more than static pressure, but if I decrease this hole size to something much smaller than the amount of curvature you have is extremely small that I can neglect that pressure change.

And I will get as good reading as possible ideally this hole should be as tiny as possible if it is too tiny then there is the possibility of dust coming and blocking it that is the other extreme problem will start getting in took, but we have to think about this size also typically they talk about the hole diameter of the order of one fifth of boundary layer thickness one fifth of the boundary layer thickness is what they typically talk about if I think about a static pressure holes typically if my set up is small enough we will think about something between 0.25 millimeter to 2.5 millimeter even it is one big room size of dentinal have I still use only 2.5 maximum size for the port typically. These are the typical numbers people use only inside this is for static pressure the wall pressure measurement now if I want to measure velocity with just one probe what we do is use static and stagnation pressure together.

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I will just give you a very complicated probe it is going to be a static probe with a pitot probe inside it that is the idea it is going to be a there will be holes on front back top down. And they are all going to open up into this annular region and the centre pipe alone is going to go separately, if you look at without this front hole it is actually whatever probe what we already do for static pressure measurement along with that I have this extra centre line hole for a period pressure measurement.

Now, I will have to take it of course, to two separate pressure measurement devices. This is going to go for static pressure this is going to go for stagnation pressure measurement and from these two now I can go and get my actual mark number or pressure depending on whether it is compressible or incompressible I can get to that particular situation from here this is the probe people use and of course, now I can think about modification to this instead of having at this power out I will just draw the front portion of it in an isometric view. There is a centre hole and then there is 4 holes around it imagine as sphere hemisphere in front of a cylindrical thing and you are having 5 different hole and of course, in this particular thing each hole is separately connected to individual tubes going out all the way And So, you are going to have 5 different pressure measurement devices which are going to give you individual pressure readings here this probe can measure the angle of attack of the flow with respect to the probe also, if I send a flow like this is going to measure close to the stagnation and that is going to measure much lesser differential between these two will give me my pitch angle differential from this side versus from that side will give me your angle like from these 2.

And if it is going straight in front then I can use these values with the centre value to get a velocity, but that has to be calibrated it is not going to be same value as top this probe because it is not going to give you static pressures on these 4 pros they are going to give something between static and stagnation and that has to be calibrated. This all this time we had been talking about just simple measurement of velocity and pressure and this is all used typically in subsonic situations. When it goes supersonic the primary changes, if I introduce anything in the flow there is going to be shock in front of it.

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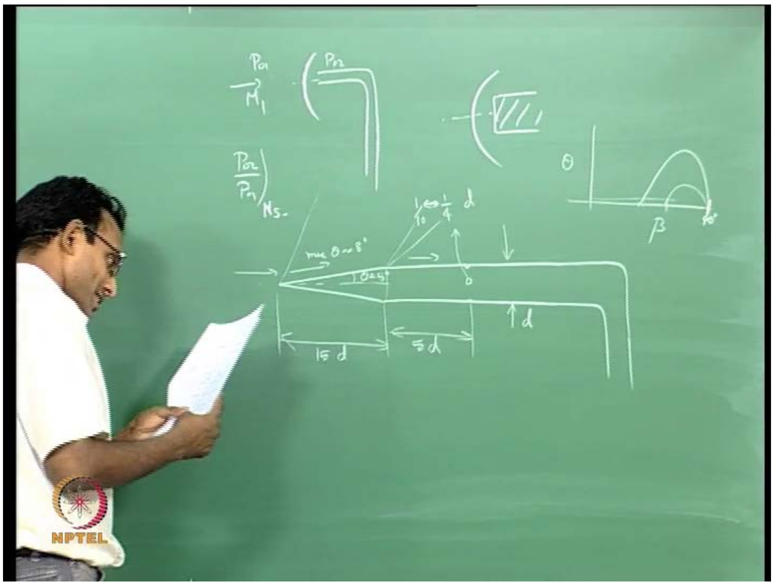

So, if I think about putting a stagnation probe you put a stagnation probe then there will be shock in front of it if there is the shock in front of it then I will get if you think about it about it is going to be a bowl shock and why will it be a bowl shock because, it is like a bluff body stopping completely it is like even if I put a body like this in my flow it is going to form a bowl shock like this and the centre line region in front of it is always going to be a normal shock that is what it will happen here also it will form a normal shock at the free stream mark number M 1 and of course, you should know that P naught one is the original P naught which is what we want to measure, but we will get only P naught 2 because it is measuring only the post shock subsonic region p i tot pressure it will give me only p naught 2. So, now, it tells me that now in this particular condition I need one more extra information to get my mark number out of this so

So, I am going back and saying I need P naught 1 typically what they do is they know their internal settling chamber P naught 1 they are going to set it because they want to run the facility they want to measure it somewhere they will typically measure it in settling chamber P naught 1 they will use that value here and P not 2 here now you just go and look at P not 2 by P naught 1 in normal shock tables normal shock table for that particular gamma value for the gas then from there you can back out the mark number that is the way they measure it once they know mark number of course, they can tell what is the static pressure here or static temperature if I know stagnation temperature all the information you can get out of this is one simple probe if I really want to measure the static pressure somewhere.

then they use a long cone probe they will use a long cone probe in supersonic typically things will be very sharp why that avoids over shocks if it is very sharp and the angle low enough it will avoid bowl shock it will be an attach oblique shock. So, this particular situation they are going to form a cone and then some tube of diameter d and typically they will have a hole somewhere far away from this cone end and typical distance 5 d and this one 15 d where d is the diameter of this tube 5 times the diameter 15 times the diameter etcetera. And typical this basically 15 by 1 gives you the diameter to this cone angle order of theta s half angle of the order of 5 degrees and sometimes if you are constrained with length then they can go as much as max theta of the order of 8 degrees more than that this probe cannot be used this basically this is very long probe.

Now, if I look at what is the hole size here can be anywhere between 1 by 10 to 1 by 4 d. typically if you are using smaller is better than bigger when it is bigger you are going to have slight problems of stream lines bending into it and out of it and of course, you should know they are going to have the holes on the top and bottom front and back 4 holes to average around all the 4 sides and this tube is going to go to your pressure measurement device and that is your final static pressure device you are going to get how does it work why does this work this is also going to form a shock it forms a shock I am going to have P 2 immediately after that, but think about it the angle is very low which means if I think about my theta beta M curve for any mark number it is going to be some curve like this point is 90 degrees of course, And we are going to say it is weak shock and theta is only 5 degrees if this is the case.

Now, beta can be whatever angel, but it is very close to mark angel depending on the mark number if I have some other lower mark number it is going to be somewhere here it is very close to mark angle which means it is a very weak compression wave if it is a weak compression wave P 2 by P 1 is almost 1 it is close to one that is the first thing. So, I am going to have a shock here it is slightly stronger than a mark wave and the flow coming here is going to turn along the cone like this and after that it sees expansion.

So, it is going to have an expansion wave here which turns it back to this now this expansion is also turning by the same angle 5 degrees went up by 5 degree coming back by 5 degree. This 5 degrees change will roughly negate the increase in pressure in this wave that is the idea of this probe. And this approximation that this expansion will negate the compression will go invalid as the theta increases, the theta increases then this shock is much stronger than the expansion this is isentropic and this is non isentropic. So, there will be more losses here. So, that is the main idea you have to think about the probe work because I am going to say that the shock is increasing pressure, but the expansion is going to decreases it back to the original value and I am going to measure it here this is the idea of this probes that is the way it works.

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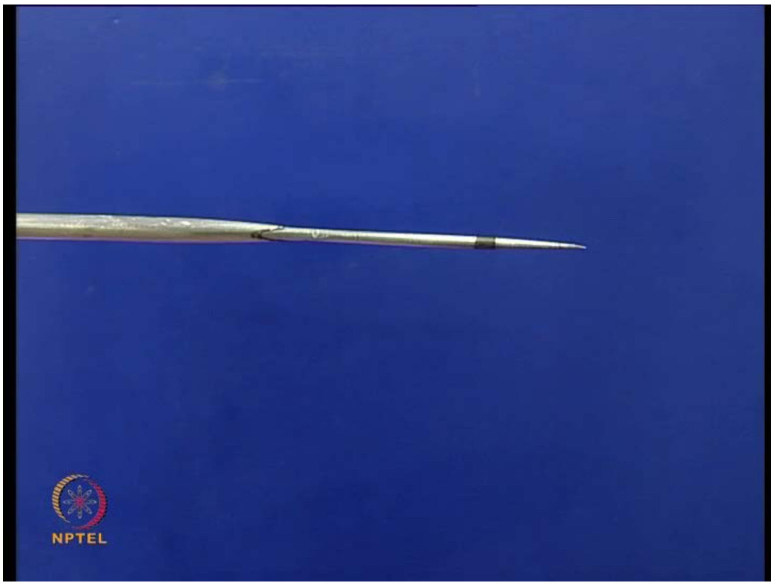

So, actually I will show you the probes. So, this is the long cone probe we are talking about you can see the cone portion is only up to here and after that it is a straight tube and this is the portion where we are going to do the measurement and you can see one of the holes here there are 4 such holes in all the other side's.

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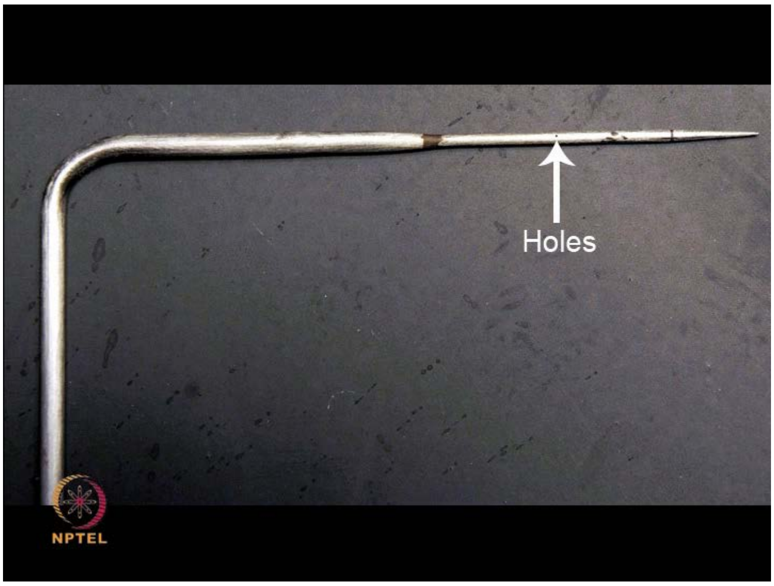

Here we can see this arrow which is showing that hole in detail. And if you see the next one we can show actually much closer 2 hole setting in there and inside this tube goes all the way into this and then it becomes the bigger tube diameter and that goes to our measurement device the actual shock wave formed here will be very weak shock wave and after that you are going to have a slightly higher pressure coming here static pressure and then there will be the expansion at this point because the flow is again turning back to parallel to this tube. So, that expansion will roughly bring it back to the original free stream pressure along this tube and that is what we are measuring using this that is the idea of using this long cone probe this is the other probe the P i tot pressure.

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So, this is just a straight hole since we want to measure the same probe volume we want to put same diameter tube as the static and then we will say that the actual measurement is of this size resolution and then this tube is just going straight into the other tube and then the tube size becomes bigger for easy handling of pressures and this is just going to measure stagnation pressure in case if it is a supersonic flow there will be a shock in front of it and we will get only P 0 2 value from here.

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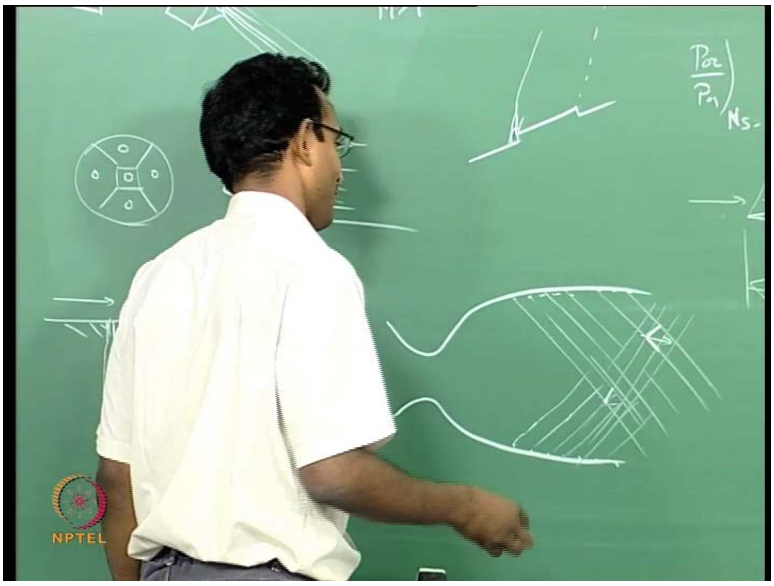

If I want to measure using some other probes say I form a wedge in my supersonic flow. I am putting a wedge in the supersonic flow. And I am going to put holes on the side of the wedge and then I am taking two pressure data out how do I store this if I look at three d isometric view of this wedge what we typically do is we will have a tube which is going to take the hole from here and take it to this way there will be two tubes running inside one bigger tube and that whole big tube is here holder for this wedge I am going to put it inside my flow measure it flow is going this way I am going to put this way and measure it.

if I put this probe inside and I have the flow coming like this what will I get I know the original angle of this which and if I get some pressure here if I already know static pressure here and I get the static pressure here P 2 and P 1 will give my shock and that will give me my mark because I know this angel theta I know my deflection if I know my P 2 by P 1 I can back calculate my M 1 that can also be done from here this probe also has a specialty of giving us the angle of attack for the flow if my flow is not going straight along the wedge axis while it is going slightly this way then I will get individual values that are different from top and bottom I can use that to give you the pitch angle of the flow.

typically people use this in aircrafts when they are flying an air craft for the very first time they want to have all kinds of probes on it this will be one of the probes sitting there on it when they are testing what is the acutely flow field around it and they are measuring it they will use this kind of probes also and a better version of this is to get a pitch angle and yaw angle you know pitch is looking going up and down and yaw is turning side as left and right the next better probe will be I will try and give you the front view first imagine something like, this there is hole something like this now I will tell you what it looks from the side this is what it will looks from the side if I see its going to be a straight flat portion in the front which is going to get measured up P naught value of course, remember if it is the supersonic it’s going to have everything behind the shock only. So, it has to be calibrated for conditions and then I am going to have these side holes if they both the top and bottom are giving the same value then I am not having any pitch angle pitch angle is 0, if top is giving more than bottom I am having the flow coming downward. So, like that I can now think about left right also same thing the picture looks the same even if I look from this way this side view and other top view both will look similar to this one that is the kind of probe we are going to have it is actually having a wedge like shape this way and wedge like shape this way and the front portion cut of say this is a 5 hole probe, people do not use it much it is called the yaw pitch probe or pitch yaw probe I do not want I have see. So, many papers using this now now-a-days people just put pressure tapings on the model and just leave with it this is probably just to calculate your fentanyl also after that I do not think they use it now, if I think about what kind of problems will I have in measuring pressures using these probes the first thing I have to think about is what should be the hole diameter you know that if the hole diameter is too big I am going to get wrong reading if it is too small is there going to be any problem can I make one micron hole, machining is the problem let us say I have micro machining devices will there be a problem what will be the problem response will be really small why now I have to think about I have a very small hole in a wall and.

I am going to take it to some pressure measurement device somewhere there say manometer or something sitting there now, if it is a very tiny hole then when there is a pressure change here suddenly static pressure increased let us say then what will happen this small hole will now restrict the flow from going this way initially since the pressure is higher here and it is not same as this pressure inside here will rise how will it rise flow will go through this to increase this now flow going through this is resisted by this very small hole and because of that the flow takes a long time to go through this to fill this hole section only after this hole section is filled with that new pressure it will start giving correct reading here. So, that is going to be a problem how will I avoid this problem I will put my pressure transducer directly here this itself is my pressure transducer, if I use a piezoelectric or piezo resistive transducer I will directly put it there at the wall and that will be a diaphragm deflection based guage

So, if the diaphragm deflects this way this way that immediately gives me signal that will avoid this transit lag act it is just a its actually not just a transit lag it is also going to have a response problem because, it is a tiny hole there will be response problem if I have the long enough tubes then long tubes will have transit lag if I am taking this going 100 meters and then only measuring things then I am going to have when there is a change in pressure that effect has to go all the way through there before it starts measuring that will take its own time how much time will it be the minimum time will be speed of sound and the length based time calculated length divided by speed of sound will be the minimum time before this will start sensing it that itself will have a pure delay on top of that they are going to have response delay because, it is a very long system and I have to fill the whole tube with new pressure then only I get the final pressure here to be correct. So, that will have some response ideally we should want to decrease the volume inside these leading tube So, it should be very thin tube as much of possible nobody will use a 5 M I D tube for this people will use one M or half M I D tubes for this that is easier tube simple its response will be better that is the idea.

So, there is a limitation on how small or how big I can go with the diameter of the tubes now the next thing is if the flow is going changing pressure oscillating pressures the pressure is oscillating up and down up and down, if it is oscillating too fast then before it responds itself the pressure is started coming down then I am having a band width limitation based on this length those problems are gone if I use a pressure transducer directly at the wall now by the time I start filling this the pressure decreases then what will happen I will measure only half of the pressure rise that kind of problems will start happening we want to avoid all that we want to put pressure transducer directly at the wall that may not be always possible if you want to put at the wall and the model is very small you may not get a transducer that is small enough to be put at the wall on the model that may also happen .

Now, typically I talked about P naught and static pressure measurements for finding velocity or mark number, if I want to directly measure velocity or mark number without using pressures this is actually inferred value right instead I want to use directly the value, then the easiest thing to do in supersonic flows is to if I put let us say I will put wedge this is my supersonic flow. And I will put a wedge and I want to see the flow field all I have to do is put a very thin cellophane tape on top of my wedge let us say my wedge diameter wedge size is of the order of 15 m m. I will put a very thin cellophane tape on top of it the flow sees it as a very small bump what will it do locally if I zoom into it looks like this and immediately after that it goes down like this is what it looks like locally. So, the flow sees it as a shock followed by expansion its very small change, but it is going to do this. So, there will be a shock and then expansion they will both cancel each other and finally, there will be only a mark wave it is not exactly a mark wave it is probably slightly a compression wave or slightly an expansion wave most likely in this point it is a slightly compression wave and in this point this will be slightly expansion wave you will see that, but since it is almost mark wave I will get lines that are having angle with respect to the flow exactly mu. And that I can now use to find mark number that is another way to find mark number, but this will work only if it is supersonic if that region is subsonic flow I would not see mark numbers there mark waves there. So, I cannot find the mark number that way typically they use this method in nozzle flow if I want to look at my nozzle typically I will show you the picture of this one some other time may be in two classes, if I have a nozzle like this and I want to find the mark number in this region what we have to do is put this cellophane tape all along this way or some small bumps in the nozzle all along this way what will happen because of that its going to send out waves everywhere each of them is going to give you one set of mark waves and they are just going to go straight through same thing will happen from other side also now you are going to get a full grid of mark waves now, if this grid is all exactly looking like parallel lines crossing each other then I am having very uniform flow, if the grid is not always having the same mark angle and it is changing from point to point then the situation is such that locally it is going to have that mark number at some other point it is having some other mark number; that means, this point angle is lesser means higher mark number like that it will start becoming. So, now, with this full grid I can now tell exactly what is the mark number at every location also I can tell the flow angle because now I have two mark waves, if I have mark waves going like this then I know the angle by centre between this will be my flow velocity direction that also can be told from here just all this is coming from flow visualization simple enough experiment to do I will tell you how to visualize the flow that is my next class mainly.

Other than this if I want to measure the velocity directly people you can use something like hot wire it may not work very well because the wire is. So, feeble it will just break nobody uses hot wire in supersonic flows it is too fast and it cannot with stand the wire is too thin to with stand this forces, but people can use laser top velocity meter I do not want to go in to that a big problem by itself that will take one more class I do not want to do that. So, people can use l d v for measuring this l d v or l d a whatever they call it. they can use that also now the only thing left is experiments when you are trying to design an experiment what should you think about after that we will stop.

I have already talked about little bit when we were discussing transonic flows transonic tunnels will anyway formerly represent here.

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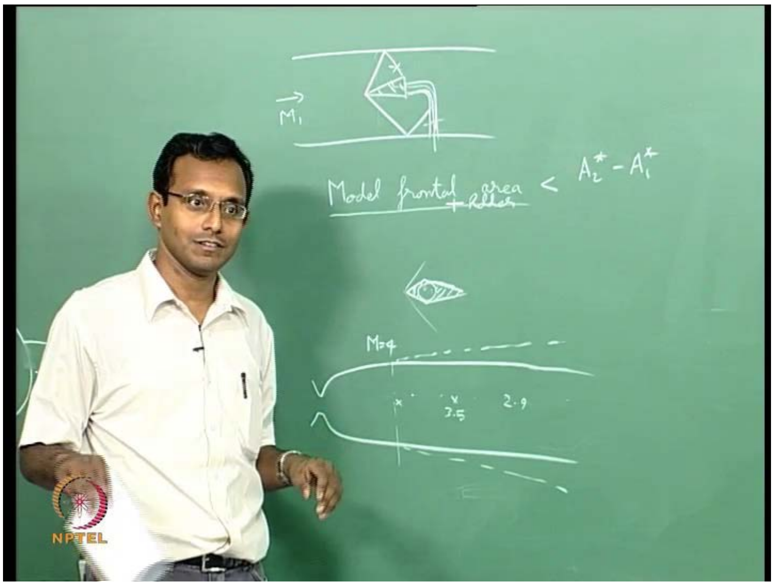

If I think about a particular test section I have and I want to put a model inside that we know the model shape and we know what we want to put in and study and I know my mark number for my facility if this is the case now I have to think about first thing whether this is actually blocking too much area that is model frontal area. model frontal area not the surface area model frontal area should be less than A 2 star minus A 1 star you guys know this A 2 star and A 1 star for this tunnel right even if the tunnel does not have the A 2 star you will calculate an A 2 star as if the tunnel should be having one and then check whether this is matching if this number is less than that then there is no problem if it is less than that then there is no problem if this number is more than this then what happens is this portion forms a nozzle second throat this point will get choked.

and your flow will be different now suddenly and it. So, happens that if it is more than this value then this portion is less than the A 2 star which means my tunnel itself gets un started the whole tunnel get un started and the starting shocks it somewhere here it never crosses I will show you actually the videos of this also starting shock never going through I have video of that also initially run we will come back to that later may be classes from now also the other thing we need to think about the if there is the wedge or somebody in the flow I have to think about the shocks from here going and interacting with the wall if the shock from here is.

Going and interacting to the wall and coming back and hitting the model that is the problem we should not be using that design, but if it is going more like this then it is good then there is no problem. So, this is related to the size of the model if I decrease the size of the model then that problem length along the axis if I decrease that than this reflected shock will not interact with it then it is better for us that is the way we have to think about this now, the only other thing about the model holder as this when I think about the holder here when I think about the cross section area it is not just this frontal area I have to put plus holder holder cross section frontal area also matters everything together should not be more than this, but if I put it behind then at this location model area can be lesser behind the model like I can have a thinner tube holding the model why do is a y tube, if it is the tube now I can have some information from here transported through this say wire going through the tube or actually a pressure port tube pressure tube can also be going through it any of those can be taken into this typically people use the tube and typically the cross section for this is again a sharp edged thing they will typically use something like this with a centre hole. So, that I can transport wires through this is the cross section, if I cut it like this and see from the top it looks something like this were this is the actual material present.

And its hole in the centre now this is going to take the aero dynamic loads and I am going to form only oblique shocks here that is again beautiful right we are not loosing lot of P naught and finally, I am going to have the hole through this and I have to design such that it should be able to with stand the aero dynamic load on the model, if you make a mistake the model will be broken at this corner and the whole probe and holder and the model will fly through typically happen in the experiment once in the while if your test section is very long then I will have a talk about, if my nozzle ends somewhere here and my test section is very long now I have to talk about friction now because of friction I may be losing P naught continuously and my mark number will go towards M equal to 1 we have a tunnel for mark 4, if we have parallel plates here then the mark number is 4 around here and 20 centimeters inside its 3.5 and 20 more centimeter is 2.9 that is what you will get, but to compensate for this what do we do we already discuss this is fanno flow if we are having constant area and mark number is going towards M equal 1 we will go expanding area will make this diverge a little bit. So, that the expanding area is going to increase the mark number while the friction is decreasing the mark number. So, overall effect will be constant mark number everywhere. So, I will have 4 4 4 4 every were that will happen only for one particular divergence angle that is related to the friction co efficient f for that particular surface and the mark number there four f l by d and the mark number relation need to be used to calculate this. So, that is one more thing we need to think about I think after this we will go into flow visualization which will start next class any questions.

Will the diverging be linear? That is easy for experimentalist to do. So, they will keep it linear because that is one big plate I will just shift the whole plate hinged about this corner that is easier to do. So, people will do this of course, I have seen some facilities were it is going through two deflections also, but mostly it will just be one straight line thing that is nice that is easier to do as the mark number goes closer to one the change will be more, but if I am trying to maintain constant mark number all I need to do is one particular angle that is enough if I want variation in a mark number in a particular way then I have to have this thing curved to some particular manner otherwise we will ignore that any other questions. So, we will go start with flow visualization next class see you people next class.