Advanced Gas Dynamics
Dr. Rinku Mukherjee
Department of Applied Mechanics
Indian Institute of Technology, Madras

Lecture - 02
Review of Basic Thermodynamics continued

So continuing from the last lecture; let us continue with the brief review of thermodynamics that we started up with. So, the first property that we will talk about is internal energy.

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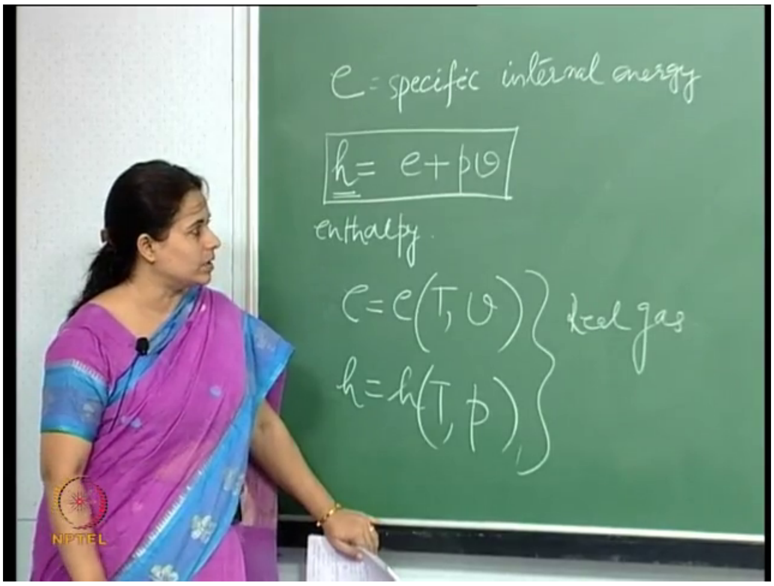

So, this typically how we do not internal energy. So, the internal energy of a particle can happen because of several motions right. Now we are not interested like we said in the previous lecture. We are not interested in the individual movements or contribution to energy right. We are not interested how an individual particle has its energy from. What we are interested in is the cogeneration of particles which we call as continuum. So, therefore, this is also a macroscopic property. And a sum total of all these individual energies in whatever way they are generated is the internal energy of a fluid right.

So, we will call this as a specific internal energy and this is basically the internal energy the unit plus. And at the same time this h is another quantity which is called the enthalpy; which is called the enthalpy and again this is specific enthalpies enthalpy per unit mass and this is my relationship. Now for a real gas right; for real gas we will take a gas; what does the internal energy in enthalpy depend on for a real gas, like compare that with what we said about a perfect gas right. So, the internal energy depends on temperature the enthalpy also depends on temperature if you see it here. So, the internal energy depends on the volume and temperature and the enthalpy depends on the temperature and pressure of the fluids. So, these relationships are essentially for a real gas right.

Now, like we did in the previous case, let us define two more concepts here: one is the calorically the thermally perfect gas.

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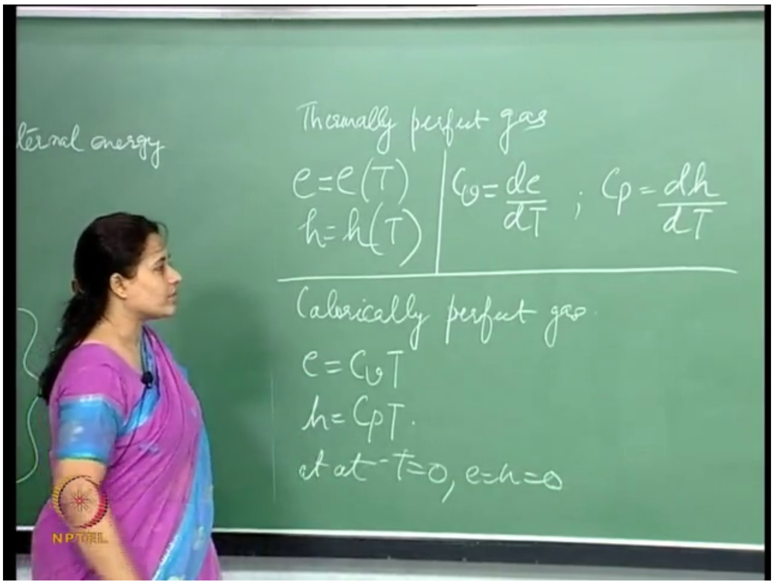

The thermally perfect gas, so that would mean; what is that mean, how is that different from what we defined over here a thermally perfect gas right. So, these properties not depend only on the temperature right. So, hence this is the definition of thermally perfect gas. Now in this case I think that is easy to see when I write equations like this a kind of spell it out, say the in words it cannot makes more meaning to may. Now C v is the; what is specific heat at constant volume? So, what is C v it is a specific heated constant volume? So, in this case this is nothing, but the change in internal energy per unit change in temperature and this is your specific heat at constant pressure and this is dh by dT, that is the fractional change in enthalpy per unit change in change in temperature right.

So, now, both these parameters a C v and C p are as you can see they have both functions of temperature right. So, this is a thermally perfect gas and this is a, what do we mean by a calorically perfect gas. A calorically perfect gas is so: right. So, in this case the assumption is that a T is equal to 0 right. So, we say examples of this also in practical applications of compressible flow. So, therefore, these relationships you know, we kind of do this a lot in fluid mechanics, we you know give labels like this: thermally perfect gas, calorically perfect gas, incompressible flow, discuss flows, compressible flows, incompressible compressible flow and you know so on and so forth; so in visit compressible flow sorry. We do that because then we are able to you know develop relationships like this which can be use for a large bracket of problems right, and it kind of helps us not to go and solve you know very generic equations.

So, this gives us more usable equations more usable relationships for you know practical bracket of problems that fall under their category. So, this is also when we consider a calorically perfect gas, we would have a large number of problems under this academy, when it should be able to use this relationships with a lot of is. I think lets now move on to let us look at this relationship.

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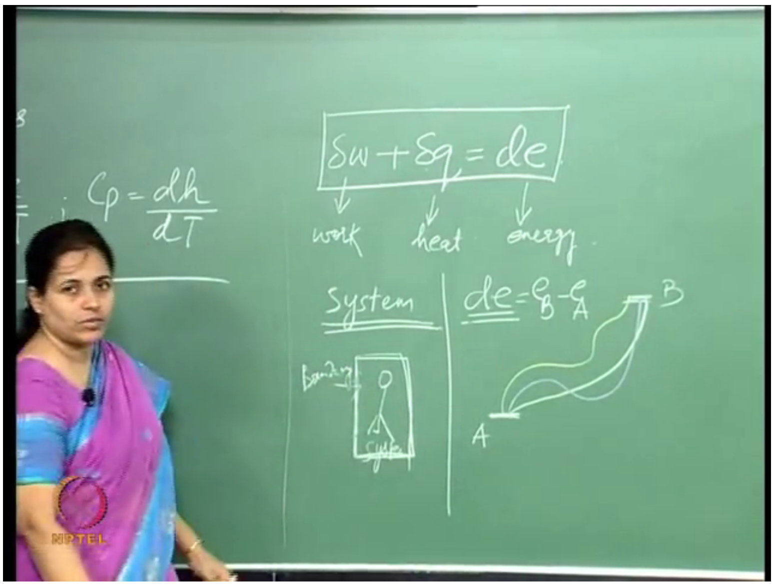

Now this is probably you have familiar with this this is nothing, but the first law of thermodynamics. Now let us look at each term separately right now. So, therefore, now here, this d q is the quantity of heat, this is the quantity of work done and this is the quantity of energy and we have these delta delta and de.

So, de is the change in energy d q and t w is the corresponding changes in heat and work, now this is defined over a system. So, this there is would define over a system. Now I talked about what a continuums in the last lecture, now what exactly is the system how certified from a continuum. So, what makes a system? So, you can read up the you know general definitions you know book by think of an example of what you can call as a system we have systems round us all the time. Now for example, say you have fever right you have fever and you use a thermo metal to take your temperature now you place. So, basically in this case you are the system right you are the system and you take the thermo metal and take your temperature right. So, then you are looking at the temperature profile say of u which is the system in this case.

Now, in this case certainly there you have a heater say nearby yourself. So, in that case if you are taking a temperature in that case when we have a heater nearby right. So, then the temperature will shows slightly different then what your individual temperature is. So, we do not want that we on only your temperature. So, in that case what we will do is, say we will take you and we will put a surface around you we will put a mark boundary around you right. So, this will be a surface and I have this will be a boundary which will mark my system which in this case was you. So, then this becomes my system and this is my boundary. So, this boundary is not any tangible box, it is not like you know it is a wooden box or a steel bar nothing like that, it just a imaginary you know boundary is basically we are saying that if you are going to take the temperature, if you are interested in certain temperature we are interested just in this.

So, if this is something which will corner of sorry speak. So, this system; this piece of you know material the in this case you know this piece of mechanism, in this case the mechanism being you know human being. So, and then this becomes your system and you are going to you know study your properties in this case temperature change only on this system. So, that is basically your system. So, now, the next thing to ask here is there what you make of these symbols. On the right hand side we see a de right and here we see deltas now is that you know I just write it like that or I have a specific reason why I have write it like this.

You know can I just write whatever I want can I just write the why do not I write the w and d q over here of that when I (Refer Time: 11:09) write delta over here in I do not you know delta w and delta q and I wrote d e what is a reason for that. So, now, let us try and see if you understand that. So, d e is a change in the include energy right now the d e is essentially a change. So, say we have certain change in. So, say this is point A and say this is a point B right. So, these are basically say two different levels of energy. Now say I move from A to B in this fashion, I follow this route right I follow that route or say I move from this pattern that much in this way right or I say I move in this fashion.

What happens to my d e? So, do I have three different d e's the answer that is no. So, in this case d e is only basically which means the final energy minus the intern initial energy. So, it does not depend on the path. So, this change is independent of the path it is path independent it does not matter how you go from A to B, all that all that we are concerned about is the final value minus the initial value . So, therefore, we write that as d e. Now del I think by this and you can infer the delta w and delta q on the other hand, r path dependent; r path dependent and there are more than one ways of adding heat and doing work and therefore, we write these as deltas. So, when I say that. So, therefore, when there is more than one ways of doing work and a heat, what could now we can categorize these ways as well ok.

So, there are basically three categories of that, we will I think understand little more you know as we go along, but brief if would now will write the what are those processes actually.

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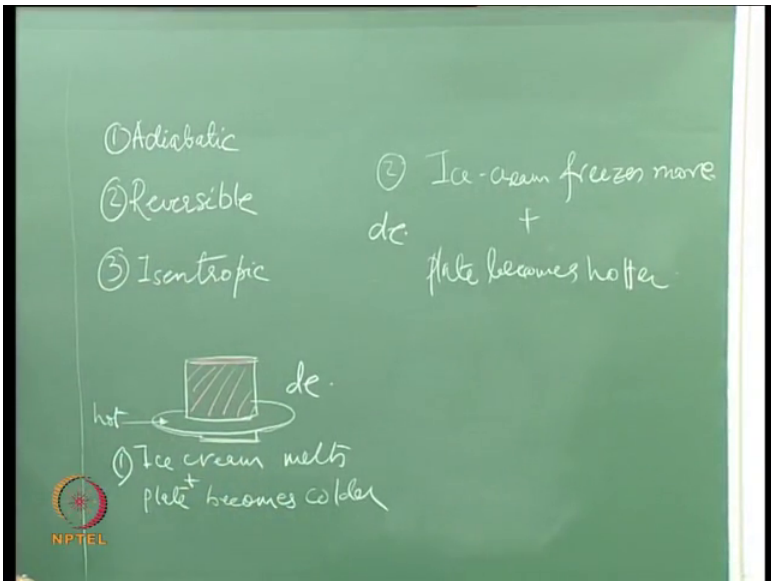

So, essentially this is when I say it is an adiabatic process or reversible process and a and isentropic process. Now and adiabatic process is one where the net heat supply to the system is zero. Reversible processes something the processes reversible, you take a process from say A to B then you are able to bring back the system exactly to this original state, because from one state to the other comes back exactly to the same state that is reversible.

So, even that happens; obviously, we do not have any sort of deceptive mechanisms like you know this conductivity this viscosity and so on so forth chemical reactions of course, not considered then we considering anything. So, over here and isentropic processes one which is both adiabatic as well as reversible. Now once the moment we talk about. So, now, this becomes and important concept here we will come to that in the little bit. Now let us go back one more time over here this is the first law of thermodynamics, which says that for a given system the energy change is the function is equal to basically the heat supplied plus the work done right.

Now, let me give you to scenarios now I have say I have an ice cream I have say a ball of ice cream or tub of ice cream you call whatever you wants, I have an ice cream and let me I have just. So, this is my ice cream and I what I do is I take that and I put it on this plate and this plate say is slightly hot it is kind of a it is a heated plate slightly hot plate, it is a it some is not at exactly at room temperature. Now there are we have probably guessing what will happen, but let me give you a two scenarios. Now one scenario is that is the ice cream melts right and this temperature drops slightly right.

So, we have the ice cream melts and colder let us say colder, all if the temperature drops slightly that is one scenario Now the other scenario is now the ice cream actually does not melt the opposite happens, the ice cream actually freezes is in more and the plate becomes hotter right. So, in this case this is something a probably you know you would expect it right. So, the ice cream melts and the plate become slightly the temperature of the plate drops now on the other hand. So, there is a certain energy change here, you can see that that is certain energy change here right.

In this case the ice cream freezes even more then what it was and the plate actually becomes hotter right and this is has the same energy change the energy change here is exactly the same as it is here of the system. You know if there is just given take between there is a certain given take between the two a within the system, the ice cream on the plate right. So, the entire the total energy change is still d e you know whether you to this or do that. So, what is the problem over here? Well clearly a nature this does not happen clearly nature that does not happen. So, what happens is this, the first scenario.

Now, can we can we say for show that this is what will happen from the first law of thermodynamics at least I cannot tell this equation does not tell me that in what way heat should be generated in which way heat should be generated and how work should be done by the system right. So, all this tells me is that the is long the net energy depends on more than one ways of providing heat or work. So, for as this equation goes both these scenario should work, but clearly it does not. So, therefore, I mean; obviously, that will not happens this happens. So, in that case we need something else we need another relationship which really gives thus a direction, in which the heat and work heat will flow and work will happen right.

So, what is that is relationship now that relationship is essentially this second law of thermodynamics. So, therefore, this is now sufficient this is not a sufficient condition. So, that is where we come up with the second law of thermodynamics and let me write that here right.

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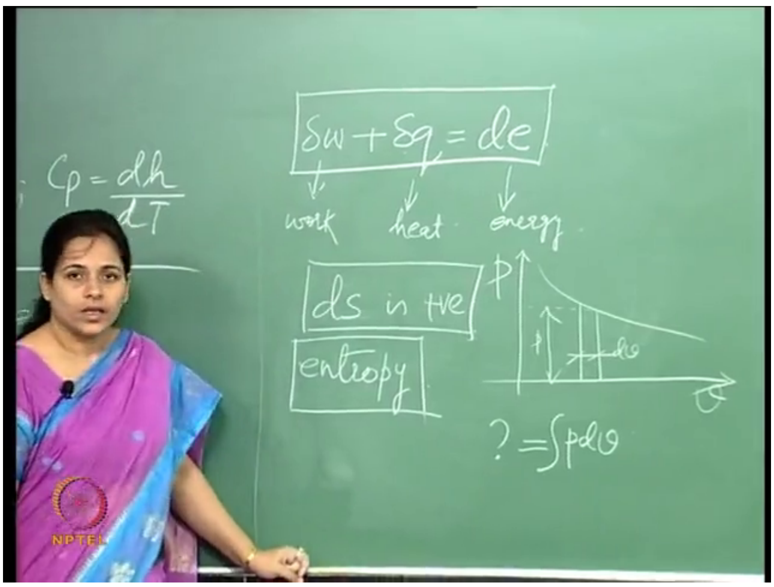

So the what is the second law says if this case the introduce something like this, the entropy the causes for the concept of entropy, that for a system you know the process we will happen in such way that the entropy of the system is always increasing and at least it is constant.

So, that this is the second law of thermodynamics and this gives us a condition in which should be a there to when the system is proceeding. So, unlike in in this first equation which does not really give us any clue has to in which direction the process should be proceeding. So, that is given by the second law of thermodynamics that is the concept of entropy. So, let me sort of do little bit explain that little bit more now for example, if we have to look like this and for example, there is a pressure this is a p v plot. So, this is the volume and the pressure.

Right now if I take at a this integral what do we get. So, essentially what is I am saying is that for a given at a for a certain pressure, I have a change in volume right. So, there is a pressure that is creating a change in volume which is d v this is nothing, but do work done right.

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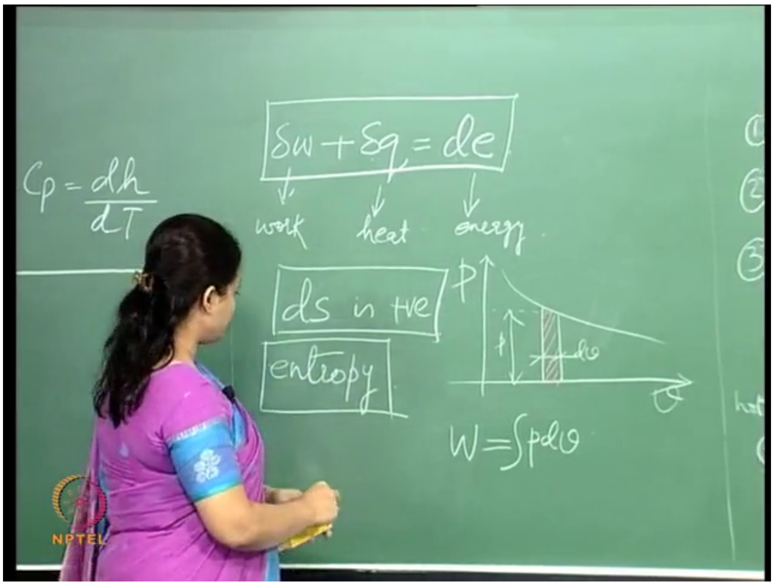

This is the work done. So, mathematically all way doing here is taking the area under this parts of the curve. So, that is the integral. So, this is the integral. So, pressure in tube the change in volume gives us the work done.

Now similarly, if I made it over here right. So, if I take this integral over here.

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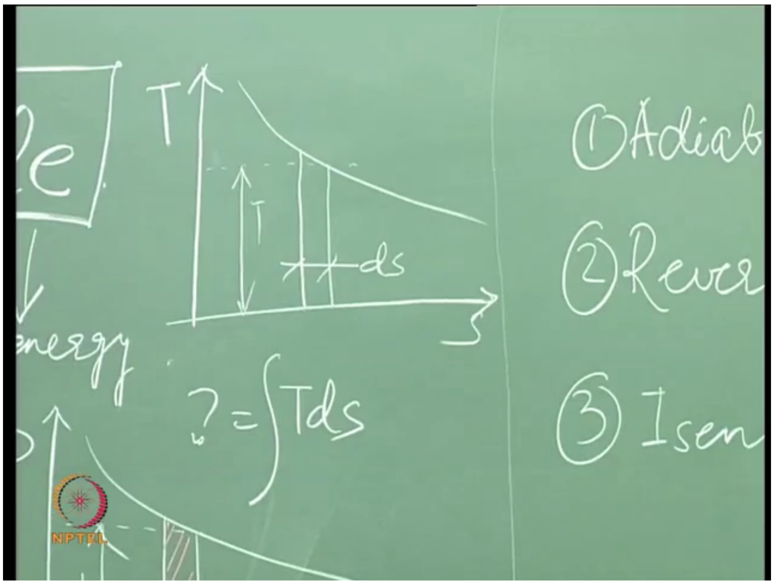

What is this? So, this is temperature and this is the entropy this is the temperature this is the entropy, if I take this integral where the entropy change into the temperature gives us what this is what gives us the heat this is gives us the heat supply.

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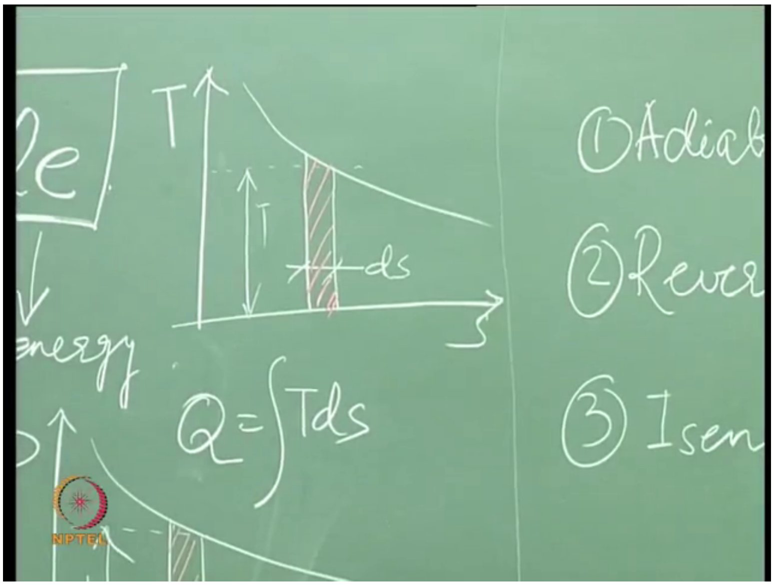

So, in this case we have this are under the curve this area under this T s curve. So, this is basically the entropy. So, which means if I have to write it from the if I just use that expression right if I use that expression right.

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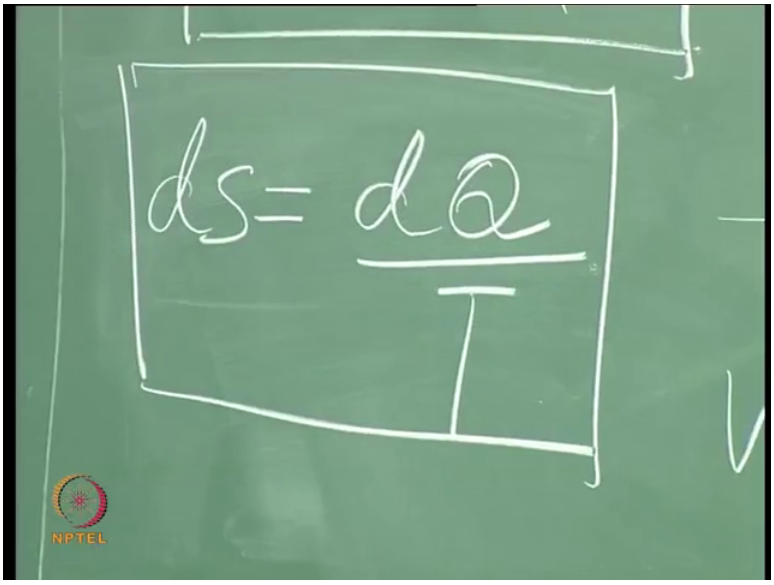

So, that should give you some idea. So, if you have to. So, if you have the measure say entropy what would you do?

So, therefore, what we do is the change in the heat right the change in heat supply or the heat supply by the temperature that is the entropy change right. So, this is the comes at of entropy and so, therefore, heat is going to be supplied. So, as you can see here that heat is going to be supplied in such a way that the entropy is always positive right its entropy is always positive.

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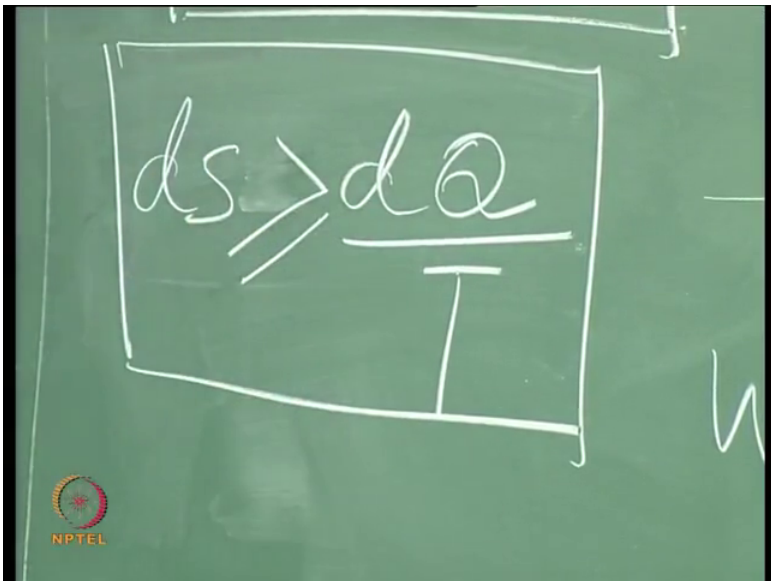

So, why do not have write it like this right. So, at least is to equal to this the heat is supplied in such a way that d s is equal to d q by t and it is increasing. So, this is your concept of entropy which is given by the second law of thermodynamics.

Now, what will do is will sort of look at some of the relationships right which we drew up and we will just see how they look like because we have defined so many things, we said real gas then we said thermally profit gas calorically profit gas. So, isentropic process, we kind of sort of (Refer Time: 25:42) on the block sort of speak. So, what will do is just look at a few relationships, which we have probably you know a familiar with. So, we will kind of mixture that we have understand what is those whatever we have learns of for. So, we have understand that. So, ok.

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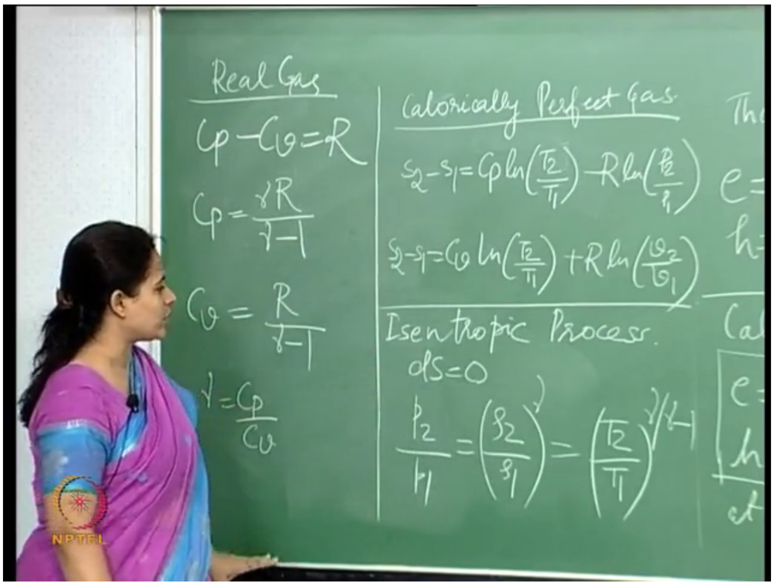

So, I think you will remember this expression; right now these relationships are probably real gas. So, you must be familiar with this right. So, the and you know the gamma is the ratio of the specific heats. So, this these are relationships for a real gas and now for a calorically perfect gas, you remember for that was we just said that what was calorically perfect gas.

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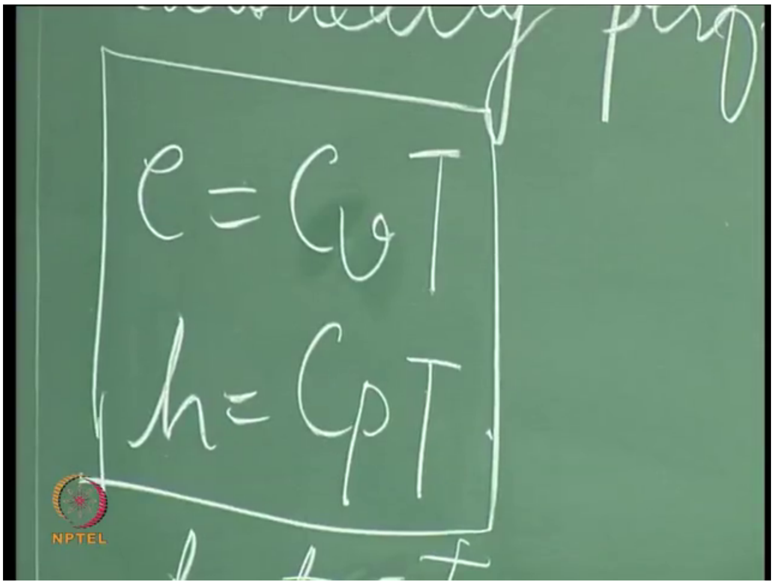

So, calorically perfect gas is this, this is the relationship between the specific heat temperature internal energy and entropy ok.

So, this is the calorically perfect gas. So, in this case, I will get typical relationship like this or you can write this as well. So, this is sorry. So, this is basically for a calorically perfect gas. So, these are relationships for a calorically perfect gas and then. So, isentropic process and isentropic process is adiabatic, reversible and what is the mathematical quantification of that the entropy is constant right.

So, d S is 0 right. So, we as we just said d S is 0. So, in that case we get relationships like this now. So, this is just to kind of familiarize to familiarize you with the kind of equations or relationships that mean that we will be working with when we even with say a real gas when we say a calorically perfect gas isentropic process. So, like I said you know and the start of this lecture, then we constantly kind of do that because then it gives us a lot of workable you know relationships in this fashion and there are practical problems in which there large number of practical problems of bracket of problems which will for which we can use this sort of these relationships. So, these are very hand book kind of relationship that we can use.

Now, one more think to ask here is what do we mean by this what are the subscripts mean, what do the subscripts mean 21 here I seem to be writing that everywhere what do these mean? S 2 minus S 1, T 2 by T 1, P 2 by P 1 what is that mean right. So, what that essentially means here is pretty much like we talk to about the ice cream and the plate right. So, say the ice cream initially was at a temperature you know say at a temperature say 5 degrees, now the ice cream is the temperature 5 degrees. So, should it become ten degrees should it become say one degree you know what besides?

So, that is the second law of thermodynamics. So, if I have a particular system which is initially say it has a temperature say 5 degrees and than that goes to say twenty degrees and the corresponding pressure say you know what say one atmospheres and then the pressure went up to say 5 atmospheres. So, what we basically talking about is we are looking at the system right at a certain point of time and we are looking at a pressures temperatures volume velocities etcetera right. So, it is we are and the. So, therefore, the when the system is you know moving from one state to the other when this properties are changing.

So, we are looking at the change in property which is entropy in this case right. So, in an isentropic process on the other hand whenever there is a change in terms of heat supply work done, the entropy change we say is zero entropy the change the process is such that the entropy change is 0, in that case how are the pressures temperatures densities etcetera related to each other right because there is a change happening and that relationship is given by something like this. So, I think that would sort of complete brief the review of thermodynamics, I think the next thing to do where we should look at some ok.

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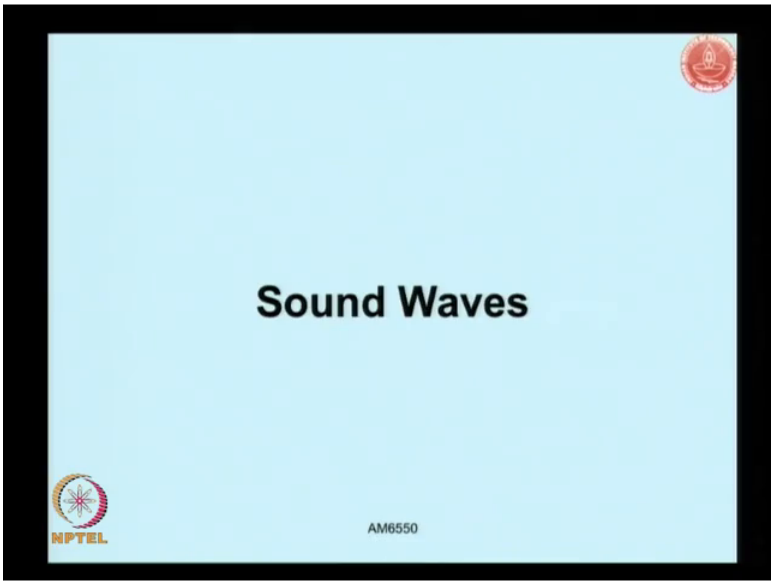

So, I think with that more or less brief review done, we cannot you know take a look at some pictures and this is the classes call advanced comprisable flow. So, you might be wondering where as the shocks while. So, I guess we will just go head and look at you know some pictures or shocks etcetera and before I do that, though we keep talking about every time we think of comprisable flow or you know gas dynamics or its previous talking about shock waves right l l b talk about shock waves we talk about high mark number flows right.

So, I guess you know that mark number is speed by speed of sound right now. So, what is this connection with speed of sound by mark number is such a big deal or why are we are going to talk about mark number when we study something like this right and. So, we saw the connection between thermodynamics and compressible flows hopefully. So, now, the next question is what is the connection of a mark number with compressible flows right. So, we are talking about changes in pressure, density volume temperature etcetera. Now what has marked numbers to do with it ok.

So, I think we will start simply we will try kind of try and look at a few things here, we will look at some interesting things in terms of sound waves say. Let us see what sound does for I start in what way sound is different from say light what is the difference of sound and light well sound is a material wave right unlike light which is an electromagnetic wave. So, it means the material medium to travel now what is thus mean in terms of mathematics, we will come to that in you know next lecture or in the couple of lectures time. Now lets you know do something fun and you know try to see there is something interesting over here ok.

I had like it a pair tension over here and like keep see as they see and listen at the same time we attentive here we go.

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We will do that one more time we will do that yet one more time. So, what did you know which is over here. So, you had the sound first when you saw the car and as the car up the nature of the sound changed and as the car passed, the sound also failed of. Let us just look at that one more time and see what I am trying to say over here right; heard the sound first and then the car move fast yet.

What is that tell you the sound reached you faster much before then you then the curve reached you. So, you saw the curve much later on you heard the sound first right ok.

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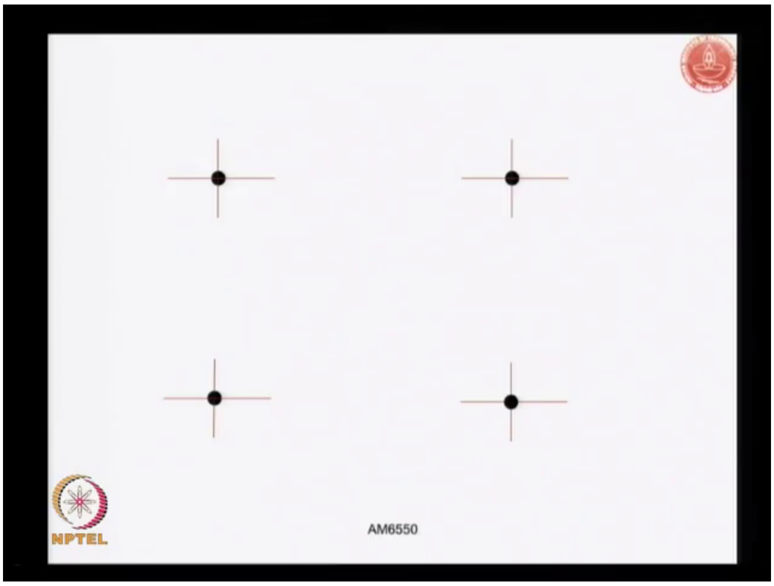

So, in that case let us set of try and look at few more things. So, I have these you know four pictures over here we sees of you things over here now these black little dogs right these black dogs that you see. So, you can think of these as say you know the curve horn. So, that matter or say the source of sound in this case, just think of that now in that case just look at the first one.

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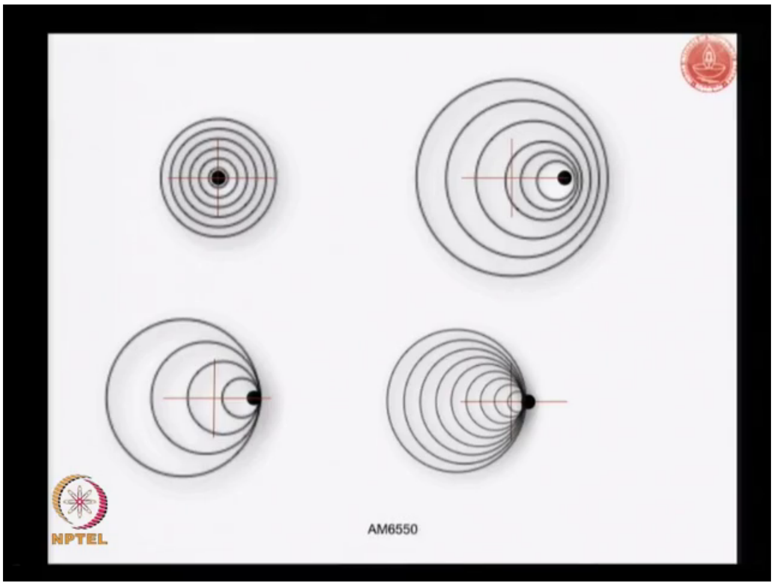

All right look at this one, I hope you see the difference you kind of re do the couple of times and we will trying to see what happens, and we see the one more time ok.

So, what is the difference between these four pictures or is there a difference at all. Now the thing is in the first you know first plots of speak the first diagram that we saw this so on, the on the in the black circle in the middle that does not move in all the other three cases that black circle is moving. So, you can say that the source of sound is moving right in the first case; however, does not move.

Now these circ of that you see is basically each one is a sound wave right. So, when the curve is blowing its horn. So, basically blows its horn. So, there is a disturbance right now that is gets transfer a from here to certain distance. It is pretty much the simple has to if I am speaking enumerable to here you know right they cross there how is these sound moving from where I am standing to by your sitting how does that move that. So, it basically a you know change in the fluid properties, the fluid in this case being the air right. So, the that disturbance moves from when I am standing to various sitting and we are able to here right. So, similarly here, what these circles are essentially these are sound waves.

So, this sound waves are moving through the air. Now what you see in the first figure over here is that the source of the sound itself is stationary now that does not move, but on the second one what you see is that the source of the itself is moving. So, you can see that each of this sound waves each of the sound the center of each of this sound wave is also different. Now the next thing a here now the next question to ask is how the important point here is how is this source of sound moving with the respective the sound waves itself; now what you see in the second diagram here is that the sound the source of sound is moving slower than the sound waves right.

In the second case the source of sound is moving exactly the same speed at which the sound waves are moving, and in the fourth one the source of sound is moving quicker its moving faster than the the sound waves ok.

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So, in lets the sort of look at that. So, this is the case where the sound waves the sound source is stationary right and you have the sound waves basically emanating from that stationary sound source.

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So, you have that and in this case you can see, that the sound source is moving slower it is slower than the sound waves themselves. So, then can I say that the sound way source basically this is subsonic case right. So, the speed of that source of sound is less than the speed of sound right.

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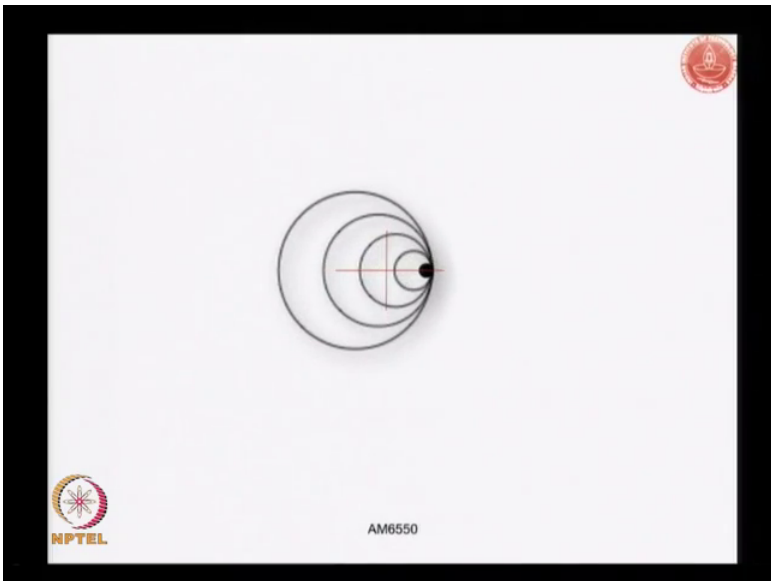

The next thing is here. So, in this case the source of sound is moving exactly the same speed right as that of the sound waves. So, I can say this is a sonic case right.

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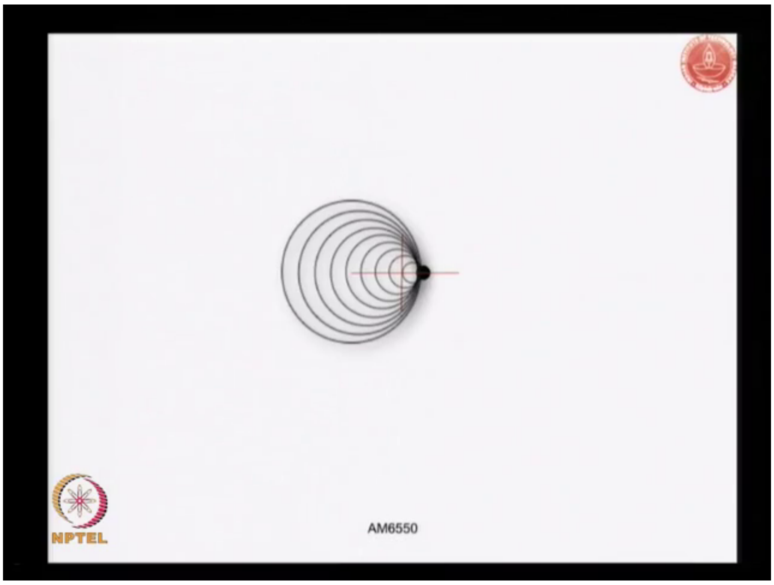

And here you can see that the source of sound is moving faster than the sound waves themselves. So, therefore, this is the case where this is a moving fasters. So, this is a supersonic case. So, therefore, what we able to see here is that, you have essentially sound wave which is moving right and how the source of the sound moves and how that compares with the actual disturbance moving right based on that we said something has subsonic sonic you know and supersonic ok.

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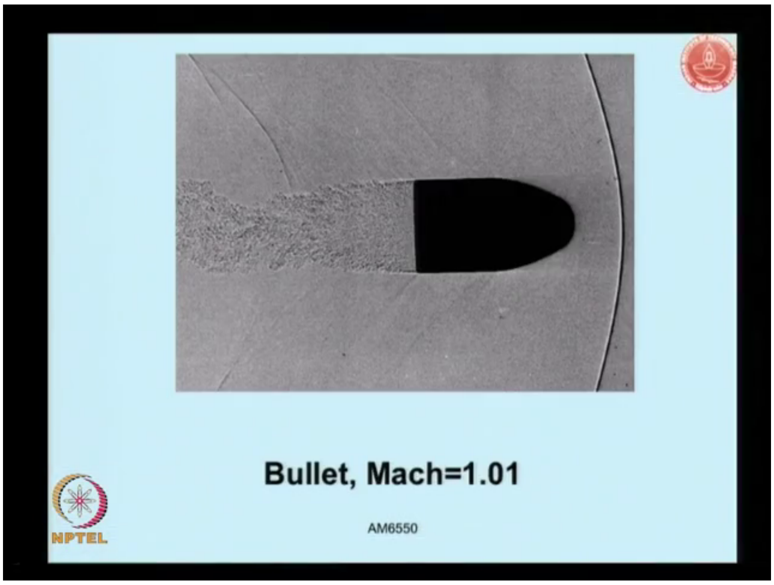

So, I think now let us look at some pictures over here. So, this is these are pictures here probably seen or your aware of you seen somewhere. So, this is a bullets that you can see the slightly you know over the sonic shown its Mach number is 1.1 and what you thing this is what are you seeing over here, this is large any actual wire it is not like an actual barricade this is actually a picture what you showing bow shock over here. This is a detached bow shock now what exactly is the shock is something that will you know introduce say talk about in the next lecture. So, for the time being let us just say that this is a demarcation where there is a very sharp change in your properties, which of the fluid properties which is the pressure volume density temperature etcetera.

So, this is that has the interesting part is we are able Mach is to measure it, but actually see. So, I think the innovative part over here is that you are actually able to see change in pressure, actually able to see change in density or a change in temperature is just think about it. You can actually see it and that is the photograph of that. So, this photograph is the Schlieren. So, usually Schlieren shadow graph. So, we will talk about that little bit because this is very interesting and that is to how to how you can use a very basic you know simple you know principle and physics, to actually capture something like this you know something very very important and complicated actually.

So, this is a bullet I would like you to notice the shape of the bullet here and this is the kind of shock that you get this is essentially a detached this this disturbance is detached from the body dislike we head of the body and this is the bow shock ok.

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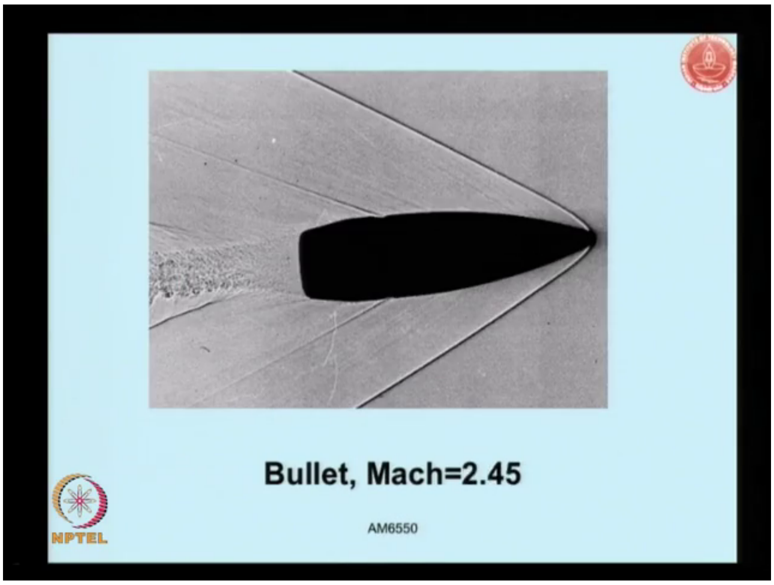

Now, you can see here you know the clearly. So, you can see that you have a sharp (Refer Time: 44:03) bullet which is traveling and a faster mark which is 2.35 and you can see that the change in shape of the shock wave, and also it has move closer it is attached is attached oblique shock. So, if I am a just move back over here. So, essentially what I am saying is if I have a blunt (Refer Time: 44:22) bullet like that right.

Now, if I sort of make this slightly less blunt of slightly more pointer, then I would expect that this would become a little you know little more taper at the edges and would probably get let us closer to this bullet right. So, till the time I get a shapes something like that and then it attaches itself to the bodying itself right. So, this an attached bow shock. So, therefore, the question is that how do I relate that how do I relate the shape of this body and the shape of the shock and whether it will be attached or not now we will do that, we will do that as we go more into details of this.

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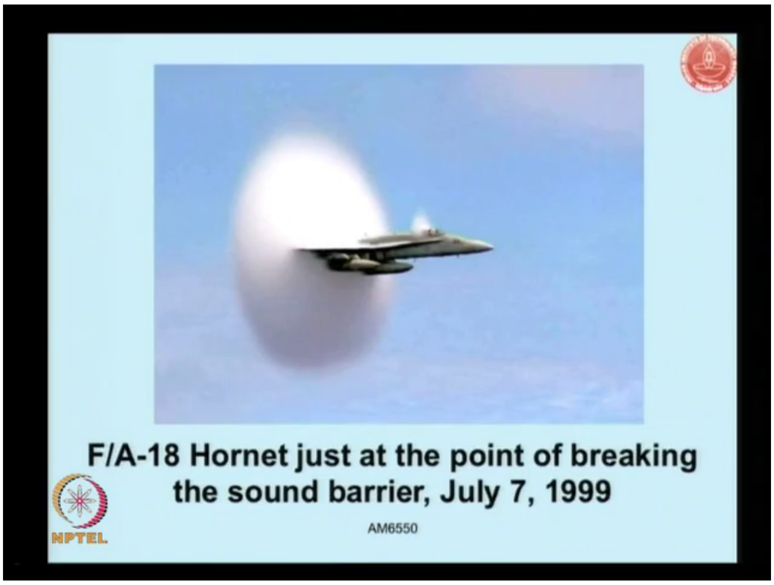

Let us just look at some you know pictures and you know. So, these are some pictures what you see over here is conversation in the year you can sort of do your own research and think.

These are very interesting phenomena which is happening because of shock waves and briefly there is you know certain change and temperature dropping temperature. So, it freezes the it causes freezes in the atmosphere around that. So, that is closing a cloud like that, you can sort of you know do a (Refer Time: 45:45) search.

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So, then you see a several shock waves here, several shock waves here in this picture.

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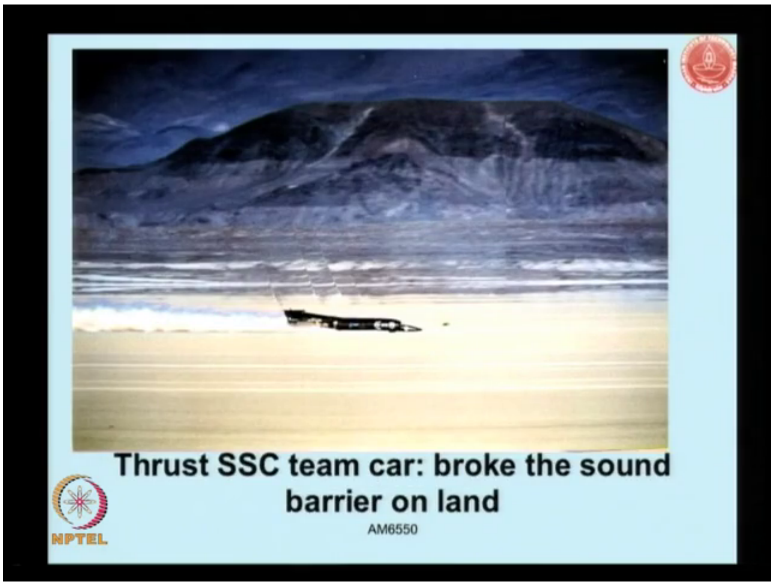

Now, this is a something you can see you know traces are shock waves here in the atmosphere right of the here, you know because of this a vehicle which broke the sound barriers well which is travelling as supersonic speed.

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Again you see some you know shock conversations of here, and this is also something which is in and outcome of shocks.

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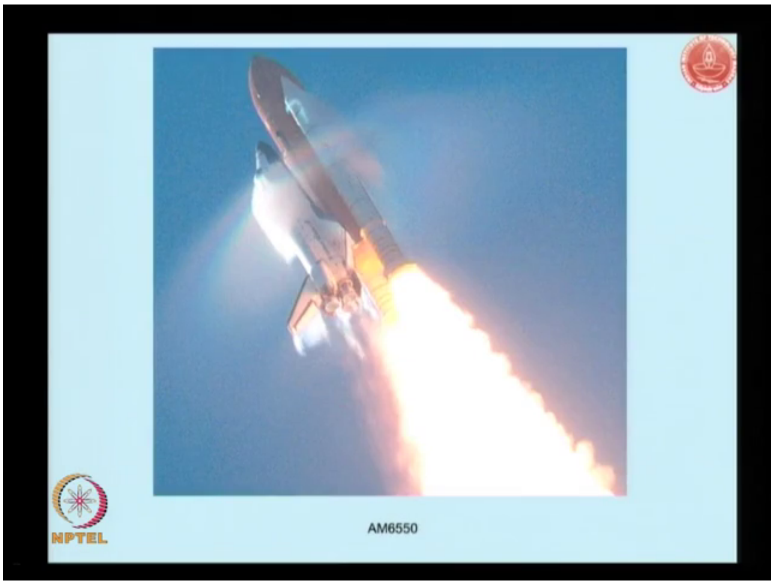

So, again you have one more picture here.

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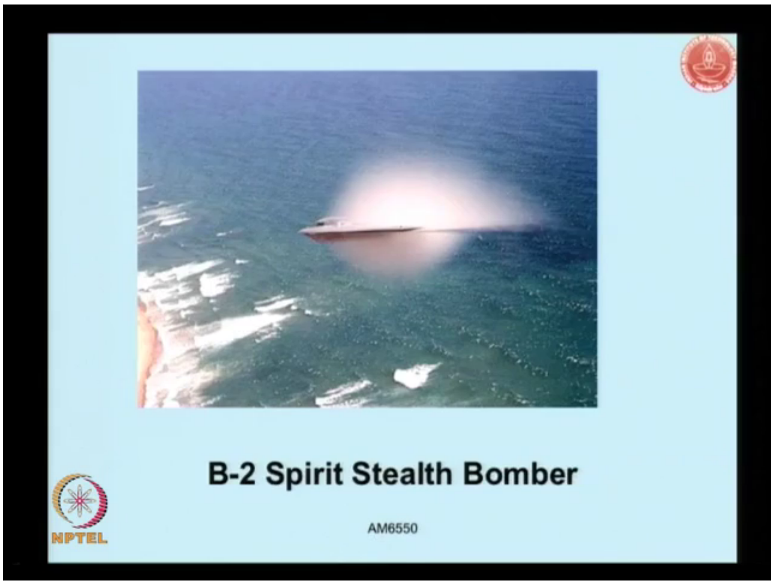

So, you have this has stealth bomber here. So, this is also another picture of showing shock waves.

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So, this is some pictures that you know we saw examples of basically shock waves what not the next question is this connection of Mach numbers. So, what we will do I think in the next few lectures is that we will take a look at. So, what exactly the shock wave now that is an important question to answer. So, I think the first things to do is will try to answer the question what exactly is the shock wave right and the next thing is that how do the properties change across the shock wave and how are we going to find out.

So, if I know the pressures temperature volume etcetera say for example, in this room and in exactly there is a shock wave now I generate the shock waves somewhere here on the middle now by some means, then when the properties change well the answer is yes then how will it change, how much will it change, how will have relate those to cases. So, I think that something we were trying to calculate or do it and the important question is; what is this connection of Mach number now with compressible flows or shock waves.

You know in all the pictures that I showed you there is Mach one a one its breaking the sound barrier, the first picture in the first lecture with self an I said. So, we said you know this was it so breaking the sound barrier seems to be big thing now why? Now why is the sound barrier such an input fact? So, what is the connection of Mach number I think we will we will sort of do that in the next few classes. So, that should be all.

Thanks.