Gas Dynamics and Propulsion
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Lecture – 03
Fundamental Ideas

In the previous class, we derived the governing equations for 1-dimensional compressible flow.

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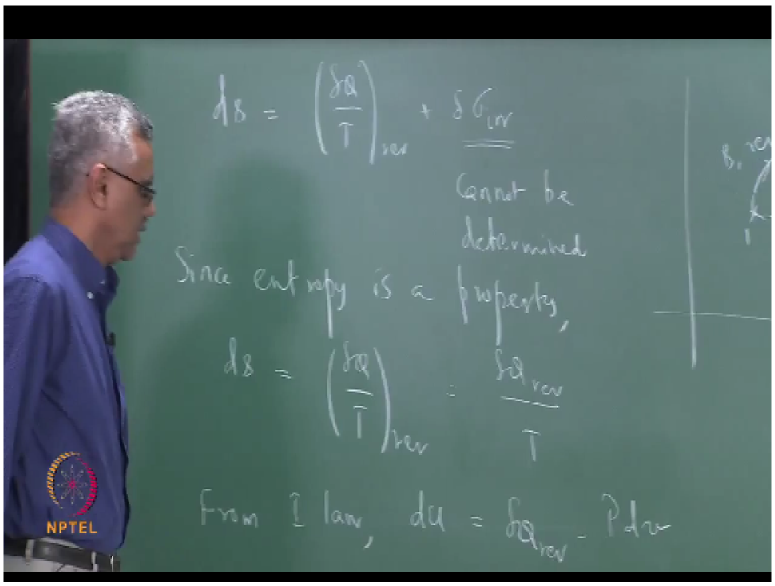

And we wrote down the change in entropy as follows. Now this equation is very useful in terms of deriving qualitative inferences about processes. So we can look to see whether there is irreversibility or not and whether the flow is adiabatic or not and then based on that, we can infer whether the entropy is going to increase or decrease. We can only draw inferences from this equation.

We can see whether the entropy is going to increase, decrease, or remain the same, that is all we can say. We actually cannot calculate the change in entropy because this quantity cannot be determined. We only know whether it is 0 or non-0. We do not know exactly what the value is for this particular term. So this equation can be used to draw inferences on changes in entropy but it can be used for calculating changes in entropy.

For calculating changes in entropy, we are going to use a slightly different approach since entropy is a property. Entropy change between any 2 states or any 2 infinitesimally separated states can be calculated just by assuming that there exists a reversible process which connects the 2 states, because the entropy is a property, let us say I want to calculate the entropy change as a result of an irreversible process but I can always imagine a reversible process that connects the 2.

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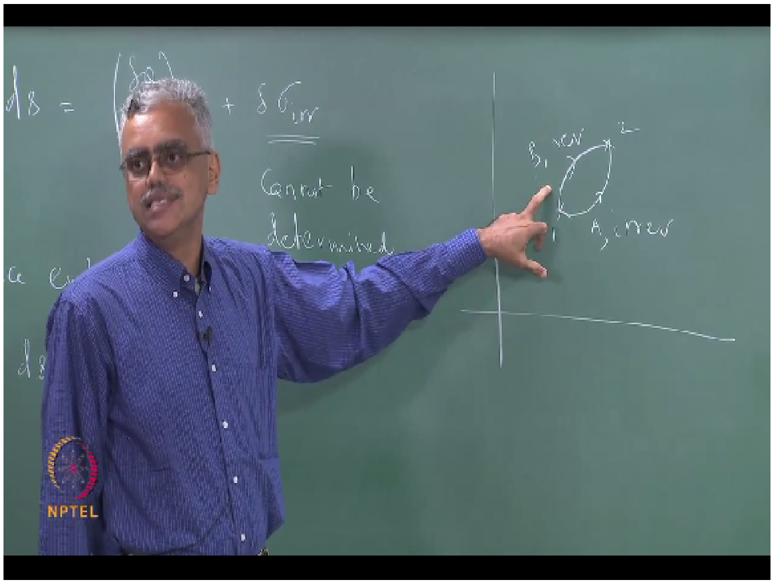

Let us say this is 1 state, this is another state and I want to calculate entropy change as a result of process A which is an irreversible process. However, for an irreversible process because I am not able to calculate delta sigma, what I will do is I will think of a reversible process which connects states, let us say 1 and 2 like this. So this is process B which is a reversible process between the same 2 states.

So I can imagine a reversible process that connects the 2 states and then calculate the entropy change between these 2 states using this. Since entropy is a property, the actual path that I use to evaluate the entropy change is irrespective of the path that I used. This only makes my calculation process easier. If I use this, I cannot calculate because I cannot evaluate delta sigma. Whereas if I use this, I can calculate because I can write ds this way.

If I know this, then I can calculate entropy change and that is what we are going to do. In fact, notice the temperature is the same irrespective of whether the process is reversible or irreversible. So I can simplify this further and write this as delta Q reversible/T. Now from first law of thermodynamics, I can write the following. I can write du which is the change in the specific internal energy=delta Q reversible-Pdv.

Notice that this form of first law is applicable only to a fully registered processes which is why I am writing here delta Q reversible. We cannot use this for just any arbitrary process, right. This is applicable only for a fully registered reversible process which is why I am du as delta Q reversible-Pdv. So if I substitute for delta Q reversible from here, I can write ds=du/T+P/T*dv.

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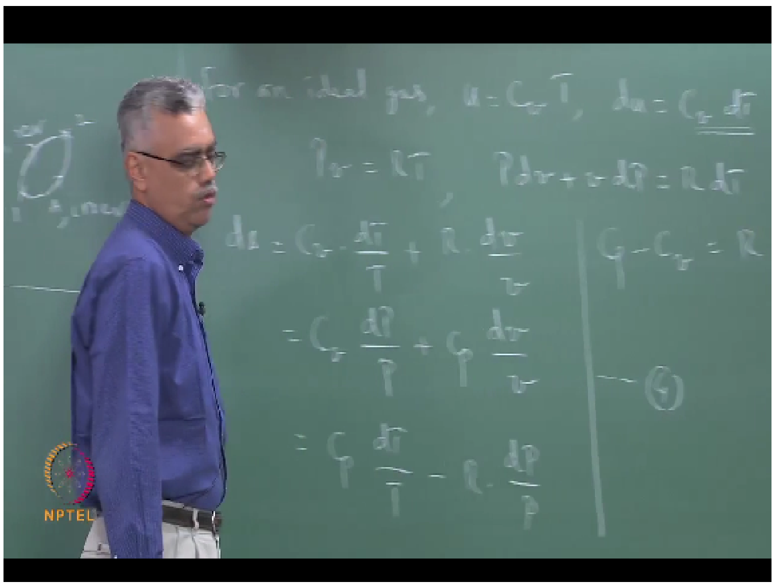

Now for an ideal gas and that is what we are considering here. We are looking at ideal gases here. For an ideal gas, u can be as we saw earlier, u can be written as Cv*T or I can write du as Cv*dT. Also for an ideal gas, we have Pv=RT. In fact, if you write this in differential form, I can write this as Pdv+vdP=RdT, both these forms are useful. So if I substitute du from here and if I write P/T as R/v, I can rewrite this equation as ds=Cv*dT/T+P/T becomes R/v, so I can write this as R*dv/v.

Now by using the differential form of the equation of state, I can rewrite this in terms of other variables. Right now we can see that the entropy change is related to changes in temperature and changes in specific volume. I can relate it to changes in other properties if I use this. So I can actually write this as, I am going to write the alternative forms and I am going to let you derive this forms.

So I can write this as CvdP/P+Cpdv/v or I can also write this as Cp*dT/T-R*dP/P because here we have used the fact in addition to these 2, here we have used the fact that, we derive this Meyer's relationship earlier. We have used the fact that Cp-Cv=R. So we have used that to derive these 3. All these 3 forms are useful. Depending upon the property changes that we know, I can use anyone of this to calculate entropy change during a process.

This is infinitesimal entropy change, right. So if I summarise the governing equations that we have written down, let us just summarise what we have written down.

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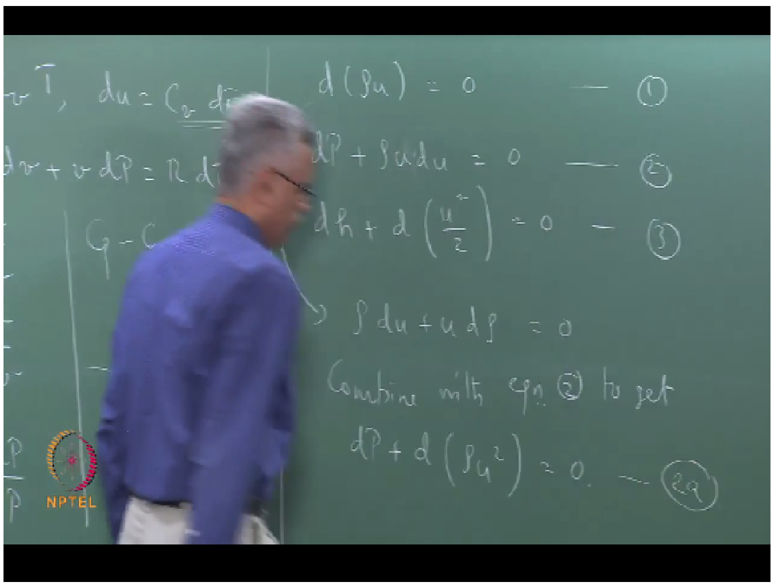

So we are going to rewrite this. We said d of rho u=0 which was the continuity equations, dP+rho udu=0 was the momentum equation and dh+d of u square/2 was the energy equation and the entropy change is governed by this equation. These are the 4 equations which govern the 1-dimensional compressible flow. So let us label them as 1, 2, 3 and this I am going to label as, this entire set of equations I am going to label as equation 4, okay.

Now it is also possible to combine the momentum equation along with the continuity equation and write this in the conservative form. So I can make use of the fact that d of rho udu can be written as, rho du+ud rho=0 and if I combine this with equation 2, if I do that, then I can rewrite equation 2 as follows, dP+d of rho u square=0. It is also possible to write it this way. This we will label as say equation 2a to be used later.

The nice thing about these equations is, notice that this is a perfect differential, right. This is also a perfect differential. This is the perfect differential and this is also a perfect differential which means that if I go from state 1 to state 2 in a 1imensional compressible flow, I can integrate these equations and applying the relation between the different quantities which is what we are going to do next. So this is for an infinitesimal change in the states, ds du dP and dT.

Now we can go from state 1 to state 2 and relate the changes in properties between state 1 and state 2.

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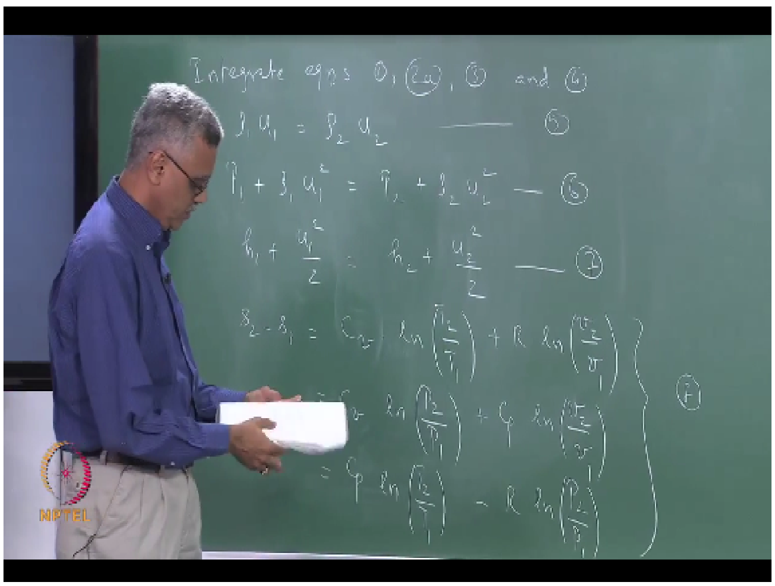

So if I integrate equations 1, 2a, 3 and 4, we get rho 1u1=rho 2u2 and we get P1+rho 1u1 square=P2+rho 2u2 square and we get h1+u1 square/2=h2+u2 square/2 and that can also be integrated to give s2-s1=Cv natural log T2/T1+R natural log v2/v1 or I can write this as Cv natural log P2/P1+Cp natural log v2/v1 and one more, which is Cp*natural log T2/T1-R natural log P2/P1.

And let us label these equations as 5, 6, 7 and 8. We will make use of this equations as we go along. So as I said the other day 4 solutions are possible from this set of governing equations, some are continuous solutions, some are discontinuous solutions and we are going to start with the simplest possible solution which is propagation of an acoustic wave in a compressible medium.

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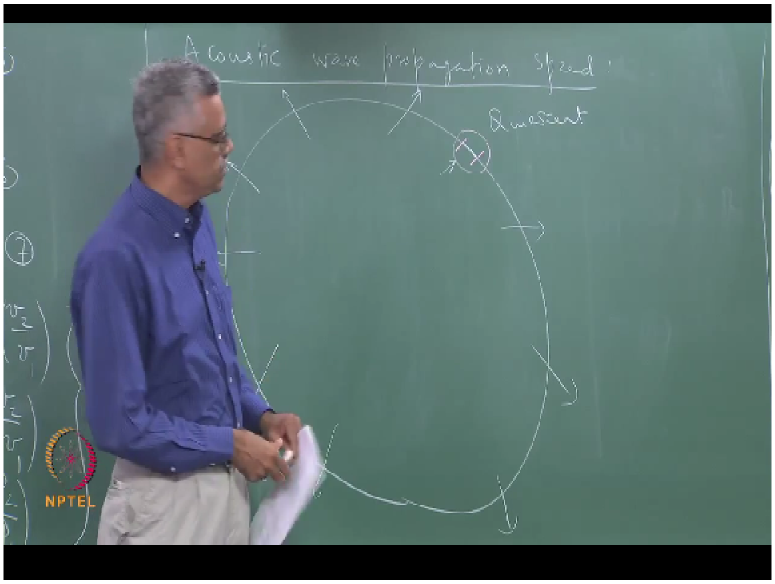

What we mean by propagation of an acoustic wave is we generate a small disturbance in a flow and the disturbance that we generate like you throw a stone into a pond, the disturbance travels out in the form of a wave. Whereas here, we are talking about the air in the room and we create a small disturbance. The disturbance travels outward in the form of spherical wavefronts, right. They are all spheres.

It travels outward with the certain speed. You know that it travels at the speed of sound. We are going to show that the speed, we are going to prove that the speed is indeed equal to speed of sound using these governing equations, okay. So we are talking about spherical wavefronts which are moving outwards, right and if I take, let us say that if I draw a big sphere, right and let us say that this is a wavefront and I will cut at a small point of the wavefront like this. So the wave itself is moving outwards, right.

So the wave itself is moving outwards and I am looking at a small part of the wave which is moving outwards and notice that when I look at this part of the wavefront, the curvature effects are not present. So I can look at this as a plane wavefront and the flow is also 1-dimensional, right. So here the fluid is quiescent, it is still. So the wave is propagating into still air. So the flow is quiescent here and the fluid here will probably have a certain velocity as a result of the wave passing through it.

So the wave has passed through this fluid, so it acquires a certain velocity. For example, when you drop a stone, the wave begins to move. Once the wave passes, you notice that some of the leaves and other things through which the wave has already gone, they begin to move up and down or they also begin to move sideways like this. So there is a small change in the property of the fluid as a result of passage of the wavefront, okay.

So we are looking at a very special case where this wave imparts only an infinitesimal change in the properties of the fluid through which it passes. In other words, once it passes through, the quiescent fluid, the pressure becomes infinitesimally more, temperature becomes infinitesimally different, velocity becomes infinitesimally different. So the passage of the wave and the change in property, the process through which this occurs is an isentropic process, okay. This is the scenario that we have depicted in this figure.

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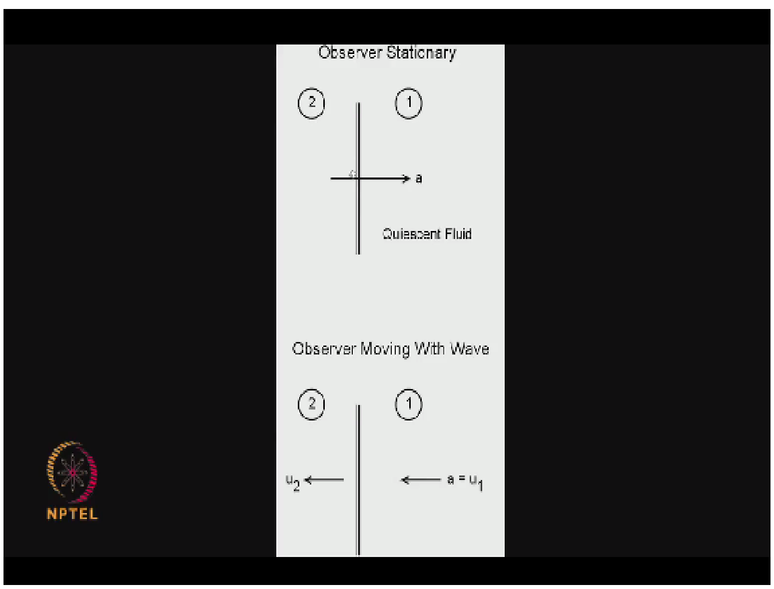

So you can look at the figure and you see that the wave passes through with certain speed a and we denote the state ahead of the wave by subscript 1 and we denote the state downstream of the wave with subscript 2. The top figure shows the scenario that an observer will see. So in other words, I am standing here and a wave passes like this. So this is the scenario I will see. The wave passes through and the flow ahead of it is quiescent and the flow downstream of it has gone through an infinitesimal change in the property.

So the wave is passing like this. Now for the purposes of our course, for the purpose of calculation, this is not a convenient reference frame, okay. A convenient reference frame is if I get onto the wave, the observer also travels along with the wave. In other words as the wave passes along, I am an observer here, I begin to move along with the way. So when I begin to move along with the wave, I see the flow approaching me with the speed = a, right.

I see the flow approaching me, the speed = a, and then when I look back, I see the flow receding with a slightly different speed than a. The flow approaches with the speed a, the recedes with the slightly different speed which is not = a. This is a more convenient frame of reference. In this frame of reference, all these equations that we have derived are valid but not in the previous reference frame. So we will get on to the wave and use this reference frame to calculate changes in quantities, okay and that is what is depicted in the bottom figure here.

So for an observer who is moving along with the wave, you see that the flow approaches the observer with the speed u1 which is = a, right and the flow recedes from the observer with the speed u2 which is not = a, which is slightly different from a, may be more may be less, that is what we are going to see next. It is slightly different from a. So this is the first solution that we are going to derive.

So what we have shown here, please remember what we have shown in the figure is a close up view of a small part of the spherical wavefront that we have described here, okay. In this case, the observer is sitting on the wave and moving along with the wave that is the scenario that we have depicted. We have already derived the solution for this case, right. We have already derived integrated the governing equations and derived the solution.

Now let us see what happens. What we are going to do in this case is specialise this solution little bit further.

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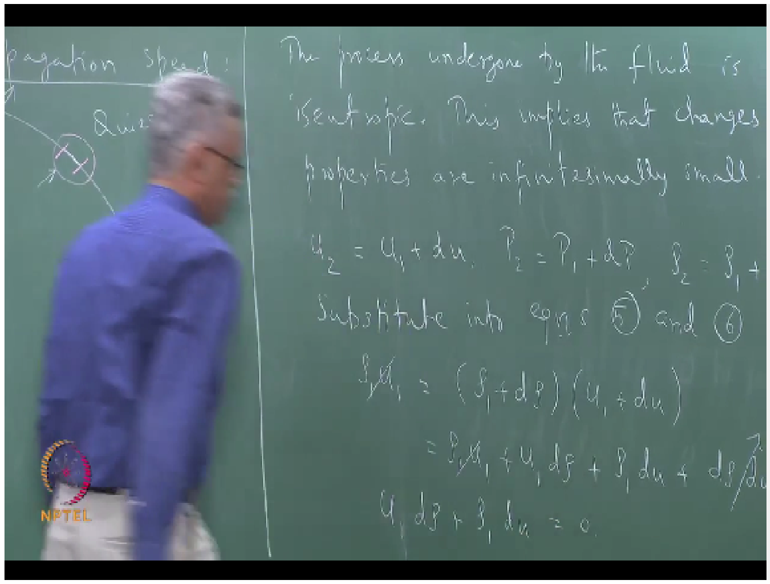

So the acoustic wave is special in the sense that the process undergone by the fluid is isentropic. This means that changes in properties are infinitesimally small, okay. So this implies that changes in properties are… So what we do is we write the changes in the properties like this. So we write u2 is nothing but u1+du, right where du is the very small quantity and we rewrite P2=P1+dP and we write rho 2=rho 1+d rho and so on and we substitute this into the previous equations.

So substitute into equations 5 and 6, what do we get? We get the following, rho 1u1= instead of rho 2, we substitute rho 1+d rho*u1+du. Remember du, d rho are all already very small quantities, okay. So we expand the right-hand side and write this as rho 1u1+u1d rho+rho 1du+d rho du. When I say that d rho and du are small quantities, what I mean is they can be like let us say 10 to the -5 for instance, right. They are all of the order let us say 10 to the -5.

So if d rho and du are of the order of 10 to the -5, then the product d rho du is going to be in the order of 10 to the -10, very very small compared to the other terms in this equation, correct. So we can actually neglect this products of differential terms. So we set them = 0 like this and we can also cancel out these 2 and we end up with the following equation that u1d rho+rho 1du=0, okay. So we neglect products of differentials in this equation.

Now we will substitute this again into equation 6 which is given over here. So let us see what that gives us. We use the same technique as before, substitute and then see.

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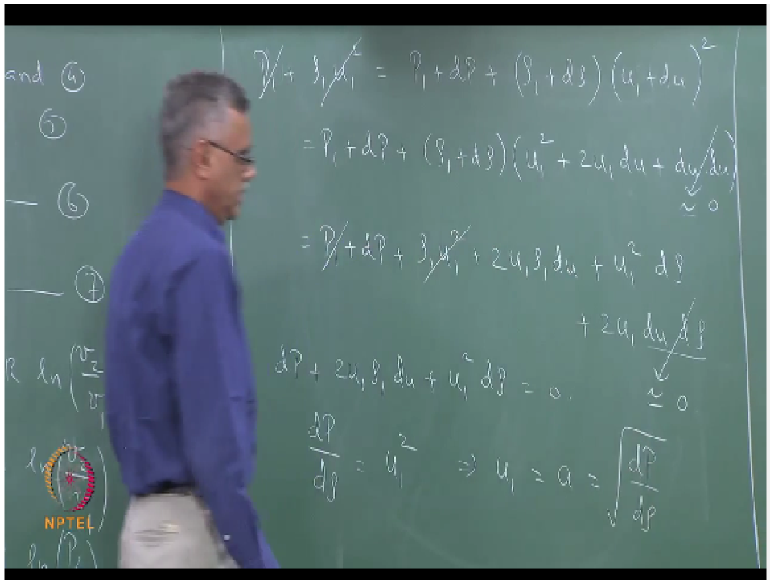

So P1+rho 1u1 square=P2 which is nothing but P1+dP+rho 2 which is rho 1+d rho*u1+du whole square. So we simplify the right-hand side as follows. So we write this as P1+dP+rho 1+d rho, we expand this. So this can be written as u1 square+2u1du+du*du and since du*du is going to be a very small quantity, we say that it is negligibly small, so we say that it is = 0, neglect that.

And then we expand this product again which gives me P1+dP+rho 1u1 square+2u1rho 1du+u1 square*d rho and one more term which appears is, this times this which is going to give me +2u1dud rho and once again since it is a product of a differential, we set this, we neglect this and set it = 0. Now I can now look at the left-hand side and the right-hand side of this equation. And I see that the P1 term cancels out and the rho 1u1 square term also cancels out.

So I end up with the equation which reads like this, dP+2u1rho 1*du+u1 square*d rho=0. Now if I substitute from there into here, if I combine these 2 equations, I end up with the following equation which is dP/d rho=u1 square, okay. I simply take out the u and then I can substitute for u1d rho from here, I get this type of an equation, right or this tells me that u1=, remember from our diagram, we said that u1=a, right which is the speed of sound that is what we said from the diagram.

So u1=a=dP/d rho square root of that, okay. So this is the speed of propagation of an acoustic wave or a sound wave in a compressible medium, in a quiescent medium. We have not made use of the fact, remember we said that the process undergone by the fluid is isentropic, right. That means that entropy change across the wave is also = 0. So we should be able to simplify this further by using that fact, okay, that is what we are going to do next.

So if I set ds=0, we wrote down 3 possible forms of the equation for ds, let us see what happens. If I write ds=0.

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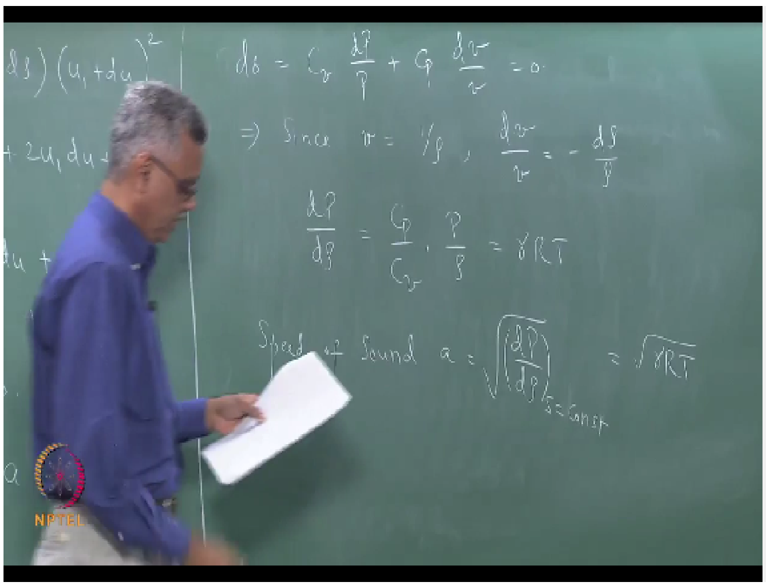

So if write ds=0, one of the equations that we wrote down earlier was this, ds=CvdP/P+Cpdv/v=0. So this is one of the equation that we have written earlier and now we are setting that = 0 because the entropy change is 0. I can easily rewrite this equation, I can easily rewrite this equation and show that since the specific volume v=1/rho, the reciprocal of density, I can write dv/v=-d rho/rho and so if I substitute into this, I get dP/d rho=Cp/Cv*P/rho.

And since it is an ideal gas, I can write P/rho as RT and Cp/Cv=gamma, so I can write this as gamma RT, which means that the speed of sound a=square root of dP d rho, remember I am now going to add this also that it should be an isentropic process, right, dP/d rho with S=constant and for an ideal gas, this comes out to be gamma RT. So the speed of sound is dependent upon the local temperature and in a 1-dimensional flow, the speed of sound can actually, the temperature varies along the flow, the speed of sound will also vary along the flow, right.

That is one of the most important concepts that we will make use of as we go along. Are there any questions? Okay. Now having derived the, so you can see that the solution that any infinitesimal pressure disturbance must propagate with the speed of sound, comes out of our governing equations naturally, that is one of the permitted solutions and notice that because we are talking about wave, this is a discontinuous solution.

The changes in properties across the wave are discontinuous, although at infinitesimal, it is still discontinuous, okay. The next solution that we will look at after sometime is if you relax this requirement that the process should be isentropic, the same equations that we have derived, give us the solution which is that of a normal shockwave, okay. If you relax the assumption that dP=0 then you drive, you get that type of a solution, that is the next solution that we will look at.

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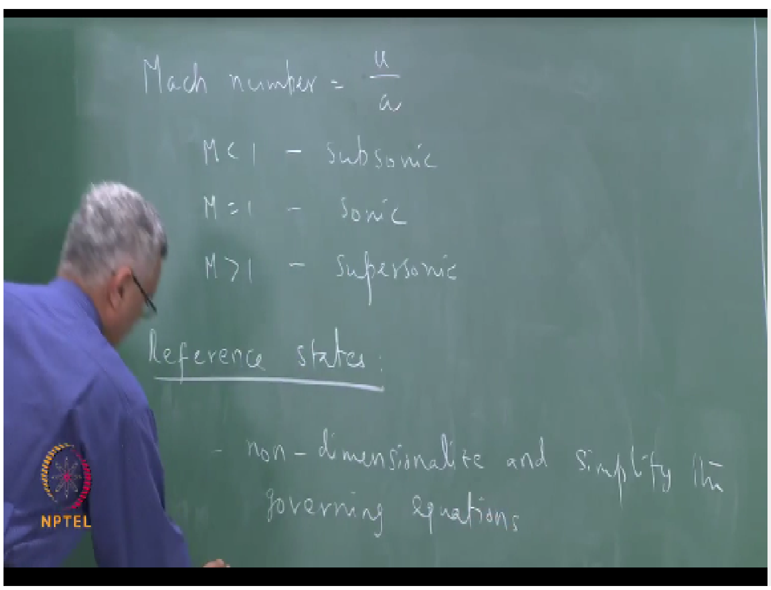

Now having derived the equation for speed of sound, we can define the Mach number. We have already defined the Mach number earlier but let us do it formerly now since we have derived the speed of sound. Mach number is a very important parameter in the study of compressible flows. So we can all define Mach number formerly=u/a.

And as you know, M<1, if the Mach number is < 1, then we say that the flow is subsonic and

M=1 says that the flow is sonic or the flow speed is equal to the speed of sound and M>1, the flow is supersonic, meaning the flow actually moves with the speed which is greater than the speed which the sound waves can propagate.

“Professor - student conversation starts” Yes. Sir how is Mach number defined in space as in space, there is absolute vacuum, a is 0 and how we define Mach number in space then. In absolute vacuum, you cannot have propagation of sound, so Mach number cannot be defined, right. Pressure waves, sounds waves require a medium to propagate. So in outer space, there is no medium, so you cannot have propagation of sound, okay. **“Professor - student conversation ends”**

This definition is very important dPd rho with s=constant is very important because when you are working with reacting flows and reacting compressible flows, this quantity, it is not possible to calculate speed of sound even in those cases because by virtue a chemical reaction entropy does not remain constant. So it will be very difficult to define this. You can either calculate a frozen speed of sound where you assume the composition to be frozen so that s becomes constant.

Or you can calculate an equilibrium speed of sound where you assume that the substance exists, the given composition is at equilibrium temperature which means again that ds=0. So you can calculate 2 speeds something like an upper limit and the lower element but the actual speed of sound in a reacting flow itself cannot be calculated because you cannot have s=constant in a chemical reaction, okay, alright.

Now Mach number is an extremely important quantity in the study of compressible flow but Mach number distributions must be evaluated very carefully because Mach number is a ratio of 2 quantities, the numerator is the local velocity and the denominator as you know depends on square root of T. So in an actual flow when both the velocity and the temperature changes, you need to be very careful when you interpret Mach number variation.

If the Mach number, let us say decreases, we cannot simply say that the velocity is decreasing, the temperature may be increasing as a result of which the Mach number is decreasing or vice versa. So when you look at variation of Mach number, inferring variation of velocity or speed from this, is a very difficult thing to do, you must be very careful, okay because Mach number is a ratio of 2 quantities and again if you remember in one of our earlier lectures, we said that the flow in the combustor section of an engine is more or less incompressible.

Again the velocity maybe, let us say 200 meter per second, flow velocity of 200 meter per second in an ambient temperature of 300 is a high Mach number. The same 200 meter per second in a combustor where the prevailing temperature is let us say 1500 Kelvin or 1700 Kelvin, becomes a incompressible flow because the Mach number goes down. So the speed remains the same but because the temperature is higher, speed of sound is higher.

So the same velocity may actually behave like an incompressible flow in one case and compressible flow in the other case depending upon the temperature. **“Professor - student conversation starts**” (()) (30:45) velocity is frame dependent, velocity is frame dependent so in the frame in which we are operating, we are calculating the Mach number to be equal to this value. If you switch to a different frame of reference which we will do later on.

Then you need to calculate the velocity in that frame of reference, then calculate the Mach number in that frame of reference. We will do that as we go along, okay. We will look at quantities in one frame of reference and another frame of reference and see which are frame independent and which are frame dependent. Some quantities are frame independent, some are frame dependent, we will discuss that next, okay. **“Professor - student conversation ends”**

So those are some important ideas about the Mach number and the next fundamental idea that we are going to look at is the so called reference states. Reference states are very useful in fluid mechanics in general and incompressible flow in particular, okay. It is possible in gas dynamics that we can simplify the governing equations. The governing equations if you remember for 1-dimensional flow involved 3 unknowns, right, depending upon your equation of state, let us say velocity, pressure and temperature, right.

Now it is possible in many of the applications that we look at that we can combine these equations very cleverly and write one single equation which governs the Mach number. You get a single equation or single variable or single unknown and once you solve for that, all the other quantities can be obtained very easily. So that is the usefulness of reference state. It allows us to simplify the equations.

And it allows us to a non-dimensional wise and simplify the equations, the governing equation that is one important advantage that you get from using the reference state.

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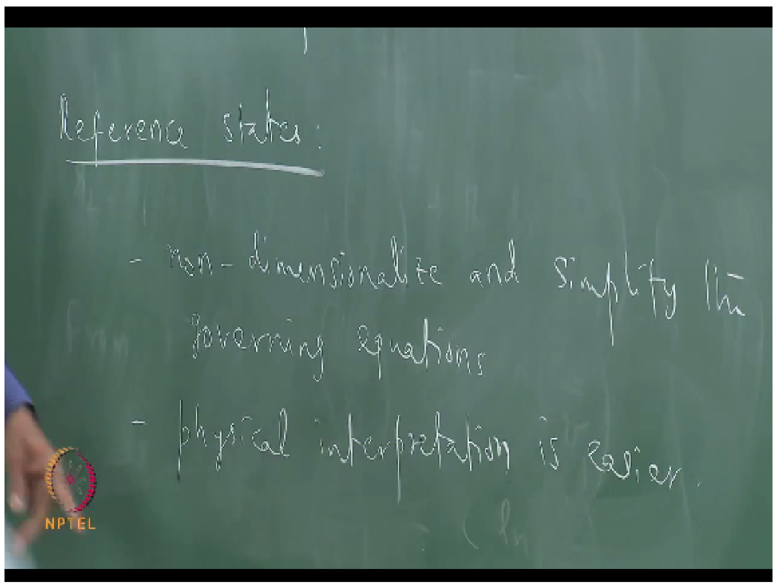

The other important thing that you get from the reference state is that the physical interpretation of the flow is much easier if you use reference state. We can compare states from one part of the flow field to another part of the flow field and draw inferences, okay. This will become clear as we go along. So physical interpretation also becomes easier. Now in gas dynamics, customarily 2 different reference states are used and let us look at both of them.

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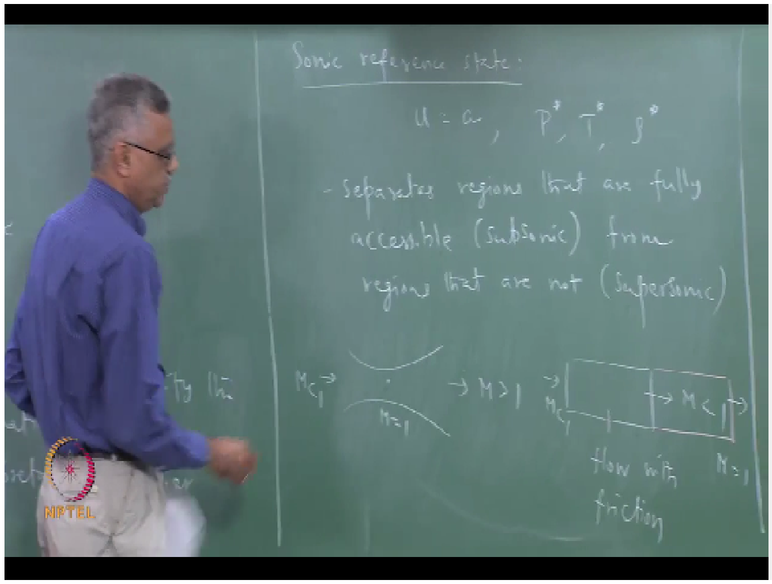

The first one is the so-called sonic reference state. Now the sonic reference state as the name itself suggests is a point in the flow field where the local flow velocity becomes equal to the speed of sound, right. So the sonic state is one where the local velocity becomes equal to the speed of sound. Now other properties at this state point are indicated with the superscript *. So pressure at the state is usually denoted as P*, temperature is denoted as T*, right, density is denoted as rho*.

So we use the superscript * to denote that it is a sonic state. Now the sonic state is a very important reference state because this separates regions that are fully accessible, which are the subsonic states from regions that are not, which are the supersonic states, okay. Let us see what we mean by this. Since any disturbance in the flow, we have already shown that, any disturbance in a, small disturbance in a compressible flow travels with the speed of sound, right.

So any part of the flow will know that there is a disturbance when the pressure wave travels at the speed of sound and reaches that point, right. Now if the flow is, let us say at some point between the receiver, let us say there is a receiver here and we created a disturbance here. Now the disturbance travels with the speed of sound. If in between the receiver and the source, the flow itself already reaches a speed which is equal to the local speed of sound, remember the propagation speed is the local speed of sound.

It is not constant. If the temperature varies then this will also vary. It can start out at let us say 330 meter per second, it will keep changing as the flow properties also changes because it is dependent on square root of temperature. So if between the source and the receiver, the flow somehow reaches the speed of sound, the local speed of sound, then any disturbance will come up to there.

It will not be able to overtake and then go beyond this because the flow itself is already moving with the speed of sound, right. So the flow and the information about the disturbance arrive at the same time at the receiver, okay. So this means there are certain parts of the flow field will not be aware of changes that we make in certain other parts of the flow fields. So if you make a change in this part of the flow field and the velocity in between reaches the speed of sound, then that part of the flow field is unaware that I have made some changes in this part of the flow field, right.

So I cannot control that part of the flow field by making a change here, let us say by opening or closing a valve here, I will not be able to control that part of the flow field. So that is what we mean when we say it separates regions that are fully accessible which means if I open or close a valve here, I can change the flow only so long as the speed in that part of the flow field is subsonic. If the speed is supersonic, then I will not be able to control those parts of the flow field which is why the sonic state is a very important reference state.

It tells us which parts of the flow field are accessible from where. So if I want to control that part of the flow field and the speed in between is sonic, then I need to have a control on that site and not on this site, right. I will somehow try to control it from some other manner and not from this site, okay which is why sonic state is a very important reference state. The sonic state itself is very useful even if the flow never reaches the sonic state.

For example, later on we will look at flow through a converging-diverging nozzle, right. So flow comes like this, flow goes out like this. We will look at situations where the flow enters at a subsonic Mach number and the flow let us say exits with the supersonic Mach number with the flow on the throat becoming sonic which means that the throat, the state of the fluid at the throat is the sonic state, right and we will be able to use this information when it is a sonic state, this is subsonic, all the subsonic states are on this side, all the supersonic states are on this side.

Now we will also look at applications, for example let us say a flow through a pipe with friction on the walls. So here let us say flow comes in at a subsonic Mach number and the flow may actually leave with the subsonic Mach number but at a higher value of the Mach number. This is flow with friction. In this case, there is a change in the Mach number but it may not reach M=1 in this particular situation.

Even then, it does not matter because we can always imagine that if I make the pipe longer, right, let us say I make the pipe longer like this, then at this point, at the exit here, M may become = 1. We make the pipe longer, then I can actually make the sonic state appear in the pipe. So even in this case where M does not become = 1 in the flow field, the sonic reference state is still a very useful reference state. In fact, all our calculations for Rayleigh flow and Fanno flow will use this concept.

We will extend the pipe or the heat addition in an imaginary sense to the sonic state and then do all calculations using this. The usefulness of the sonic state lies in the fact that I know the Mach number, M=1 here. M is always = 1 in the sonic state. So that if I am going to write a single equation involving M, knowing that M=1 at a point is very useful for me to integrate and get a solution for the governing equations, okay.

That is why sonic state is a very important reference state whether it appears, whether the flow reaches the sonic state or not, it is still very useful, okay and another important thing about the sonic reference state is that this is a global reference state, okay. The sonic state is a global reference state in the sense that it can appear only in 1 or 2 locations in the flow, right.

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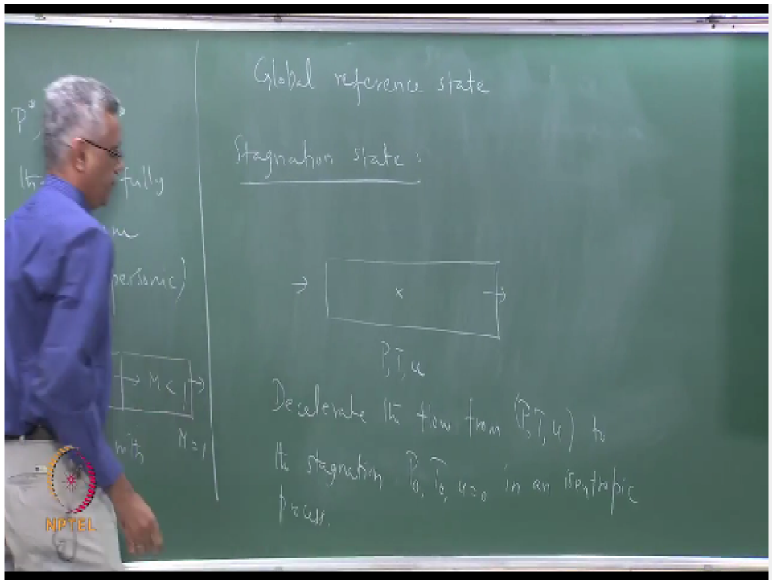

It is a global reference state because it will appear in 1 or 2 locations in the flow field, okay. The next reference state that we are going to look at is the so-called stagnation state. So here, we start with the following. Let us say that we have a 1-dimensional flow. This is the inlet section, this is the outlet section. Let us say that we take some point in the flow like this. At this point in the flow field, the pressure is P, the temperature T, velocity u and density can be calculated from the equation of state at this point in the flow field.

Now the stagnation state at this point in the flow field is defined as follows. So we carry out an imaginary experiment where we take the fluid in this state and we decelerate it in an isentropic manner to a velocity of 0. So we decelerate it to velocity 0 in an isentropic process, this is an imaginary process, okay. So take the flow at this state, decelerate the flow to from the given pressure, temperature and velocity to the stagnation states which is defined as, which we denote as P0T0and u=0 in an isentropic process.

So in this sense, the stagnation state is a local reference state in contrast to the sonic state which is a global reference state. So I can do this experiment at any point in the flow field and obtain the stagnation pressure, stagnation temperature and stagnation density from this, right. So the idea is if I know P T and u, how do I calculate P0 and T0 in an isentropic deceleration process.

Notice that the very important thing is, we are not saying that the flow should be isentropic, this may be a non-isentropic process. The deceleration process from this state to the stagnation state is an isentropic process that is all we are saying, that is a very important distinction. So the next task is to calculate P0 and T0 given P T and u at a point in the flow field.

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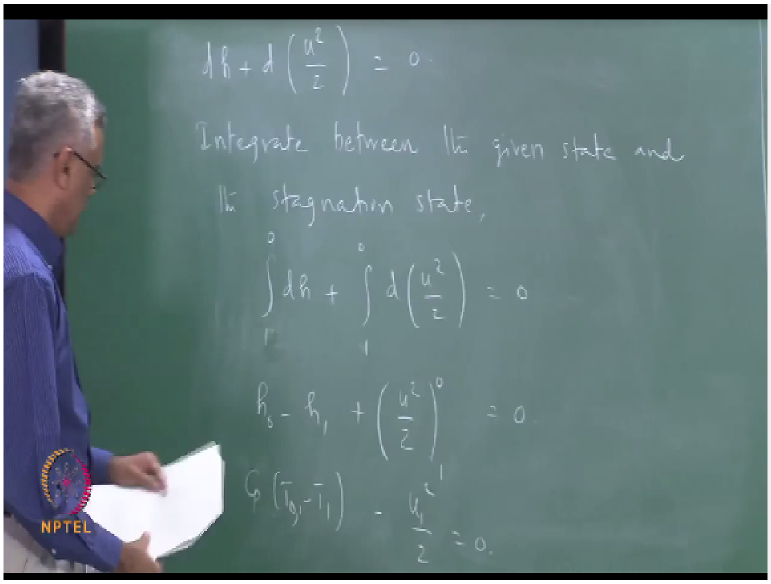

So we start with the differential form of the governing equation which was written as dh+d of u square/2-0, this was the differential form of the governing equation. If I apply this between the given state, for the sake of simplicity let us denote this state as 1 or is this okay. We will just leave this state as it is. So let us integrate the equation between the given state and the stagnation state which means I go from the given state to the stagnation state, right.

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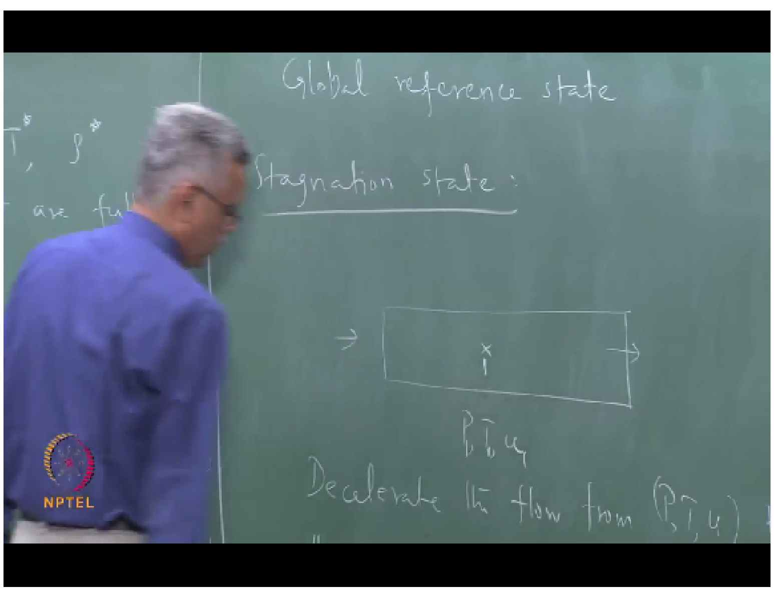

Or if you wish, I can call this state, let us say state 1, right. Let us call this state 1 so that this is P1, this is T1 and this is u1, right. So we go from P1 T1 u1 to a state where we have P0 T0 and u=0, so that makes better than I will write this as from state 1 to state 0, so that is how we are integrating this equation. So we get h0-h1… =0 and since it is a calorically perfect gas, I can write this as Cp*T0-T1-u1 square/2=0. So if I rewrite this equation, I can do the following.

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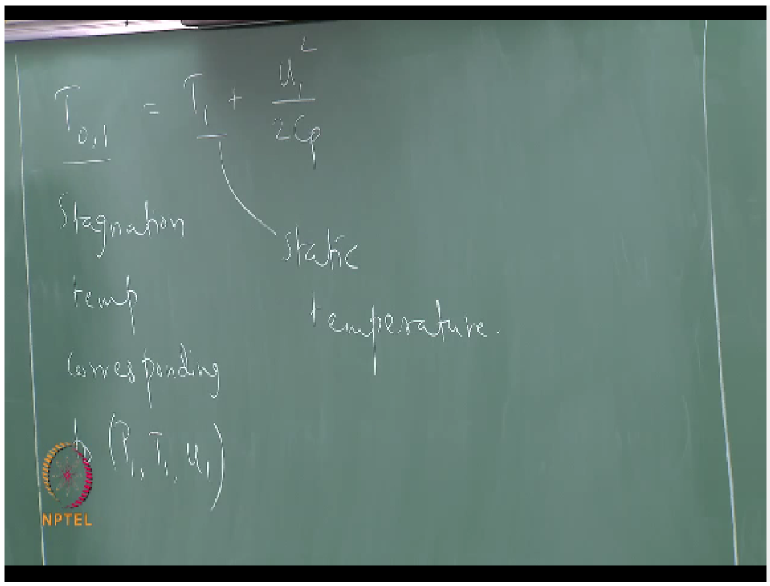

If I rewrite this equation, I can do the following, I can write this as, I am sorry, this is Cp*P0 from the static state 1. So the stagnation state is denoted as 0 and the additional subscript tells the static state is 1. This is the stagnation state corresponding to static state 1 that is why we are adding that subscript. So this is T0,1=T1+u1 square/2Cp. So this is the stagnation temperature starting from, corresponding to…

So that is called the stagnation temperature, right and this temperature from know onwards, because we are calling this stagnation temperature, this temperature from now onwards will be called as the static temperature, okay. So now we can make the distinction, stagnation temperature and static temperature. So notice that this is the local reference state because for each static state 1, we have a stagnation temperature. We will calculate the stagnation pressure in the next class and then discuss this further.