Basics of Noise and Its Measurements

Prof. Nachiketa Tiwari
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

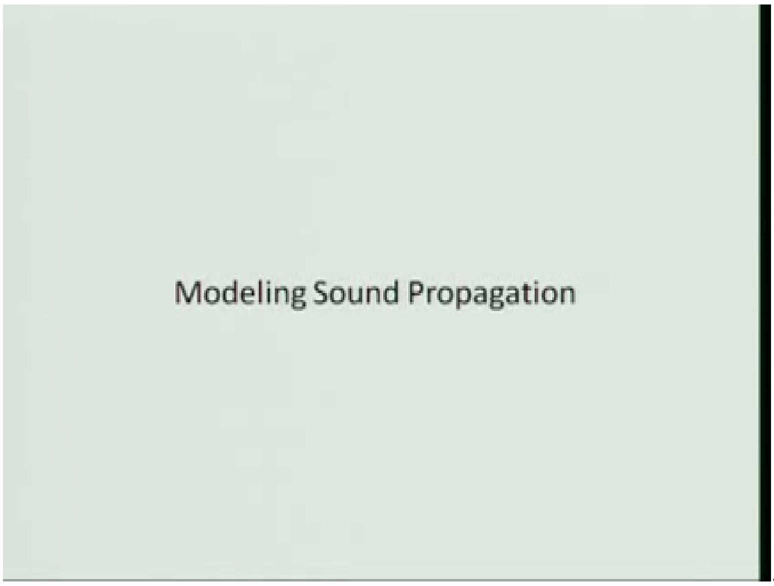
Lecture – 07
Modeling Sound Propagation

Hello again, welcome to the second week of this new course. The name of this course, as you all are aware by now, it is Basics of Noise and its Measurement. I am Nachiketa Tiwari, and I am your instructor. So, in the last week what we had discussed was essentially the very fundamentals of this course and overview of this course, and introduction to the course. Then we had delved into some details in specifically in context of some of the fundamental and important terminologies, which we use as we encounter noise, as we measure it and as we characterize it, so that is, what was our focus in the last week.

Today and also throughout this entire week, what we will be working on is, that we will be developing the equation which governs propagation of sound as it travels from point A to point B. Now you may wonder that, why is this important? Especially, if we are going to learn in this course, about how noise is measured analyzed and processed and the reason for that is pretty simple. That a lot of parameters which we measure in context of noise require us to have some if not a very detail, but some theoretical understanding, of how noise propagates in a fluid media in fluid medium. So, that is the basic reason, that we have to understand how noise propagates, because that will give us some grounding in and it will also help us, when we start actually learning more about noise measurement methods and also analysis of different noise related quantities.

For instance, there is term in whole, this area of acoustics known as impedance and to understand impedance you have to understand that it is the ratio of complex pressure and complex velocity and to have an understanding of these parameters, you have to have some understanding of how noise propagates in media. So, without having that understanding you would not be able to measure impedance and interpret all those all that information. So, it is worthwhile to get some grounding in how noise travels from A to B. That is what we will be learning.

(Refer Slide Time: 03:10)



What we will learn in this course today, and also in all other remaining lectures throughout this week will be how do we actually develop a mathematical formulation, in context of noise propagation or sound propagation through media. So, that is what we are going to learn.

So, before we go deeper into it this particular topic, wanted to introduce the overall context and some of the important parameters which are there are given here. So, the first thing before we start delivering deeper or going deeper into understanding how the noise propagates or sound propagates in media, is that and this is something we had discussed in the last class also. That as noise propagates from this point to this point.

Essentially what happens is that when we say that sound is moving or sound is traveling what it means is, that there is pressure fluctuation in air and that moves from point A to B to C to D and so on and so forth. So, when we are trying measure noise or sound, essentially what we are trying to measure is that fluctuation of the pressure. In time and also fluctuation of pressure in space, and that is what we are trying measure, and accompanied with these pressure fluctuation are other fluctuations also, so particle velocity fluctuations very small fluctuation density and so on and so forth.

So, the particle moves about a mean position as we have we had discussed in the last class, but the propagation of disturbance or of energy it happens at a different phase and that travels across the medium. That is what we interpret as sound. So, that is there, then the other thing we should remember is at least in context of this particular course, that whatever quantities we will be measuring whether it is fluctuation of pressure or the velocity oscillations or variation intensity. All these variations are extremely we will we will be assuming that they are extremely compare small, compared to nominal values for instance.

Well, let us look at pressure. So, the inbuilt pressure in atmosphere is about 101 kilopascals, but at the most; whenever we are talking about sound propagation, at least in context of this course and in the context of most of the sounds you will ever hear in your life. The fluctuation of this pressure about the mean position which is about 101 kilopascals will hardly exceed a few pascals up and down, maybe at the most 10, 20, 30 pascals. So, it will not even be in 1000 pascals range. So, essentially what we are trying to say here is, that whatever measurements we will be doing and ah they will be extremely, the magnitudes will be extremely small compared to the inbuilt values. This is an assumption, we will also use as we develop mathematical relations for sound propagation through the media.

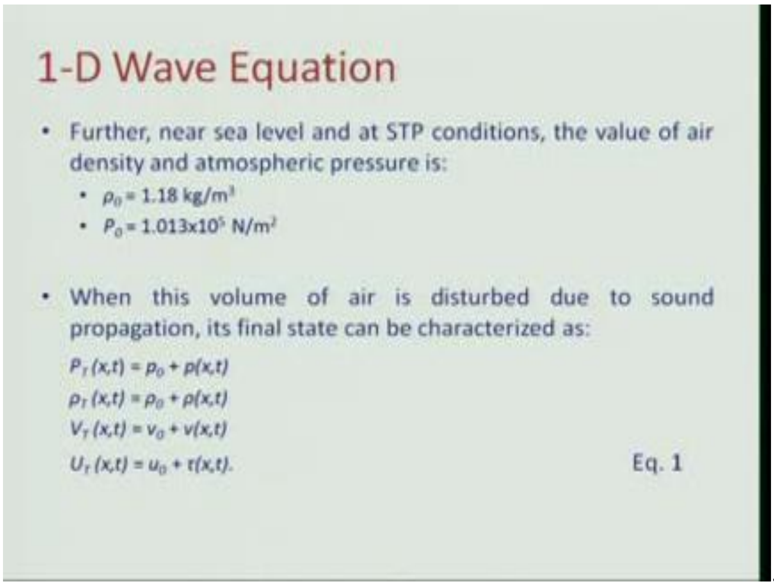
What we will essentially develop at the end of this week is an equation which governs propagation of sound, and we will specifically develop an equation which governs propagation of sound in one particular direction, and then we will generalize it to all the three directions. This particular equation is known as the wave equation. Now we can have two types of wave equation; pressure wave equation or velocity wave equation and the pressure wave equation helps us understand how pressure fluctuations move in media and the velocity wave equation helps us predict how particle velocities, fluctuations in particle velocities propagates in the media.

Now, these 1-D at the 1-D a wave equation is particularly helpful if we want to predict how sound propagates in say long tubes or a duct, that duct could be an air conditioning duct or wave guides or if we go to a spherical form of 1-D wave equation. Then you have a source in air, and sound is uniformly spreading with from this spherical source. You know point source, then that propagation can also be explained using this 1-D wave equation. So, I had explained that when there is sound which is propagating in media, there are pressure fluctuations and fluctuations in particle velocity, and fluctuations in density. So, that is what is shown here.

(Refer Slide Time: 08:32)

So, what essentially, we have what we are trying to say is, that let us say you have a room in which there is no sound. At that point of time the pressure in the room is p naught. The density of the air in the room at the point when there is no sound being propagated is rho naught this is, velocity is excuse me volume of the air is v naught and the velocity of the air is u naught. So, we have rest you know, in absences sound pressure, density, volume and velocity, velocity or particle velocity in the air.

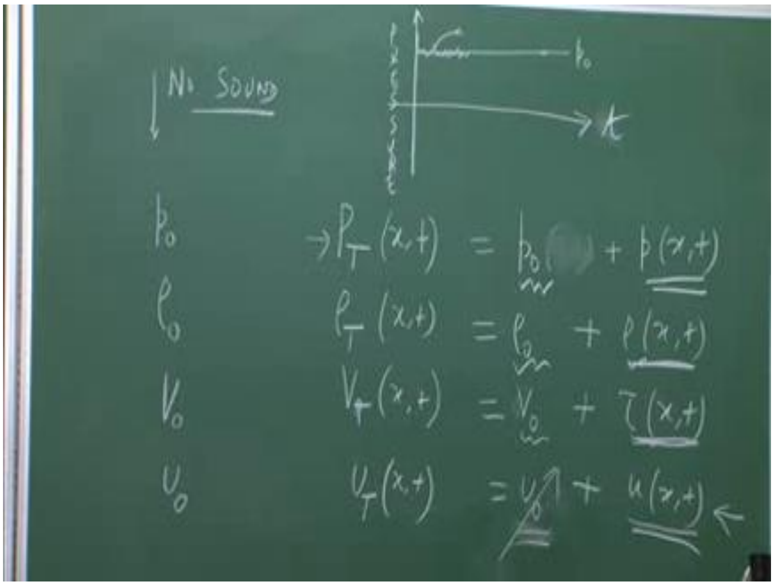
(Refer Slide Time: 09:17)



.

These are the reference conditions. So, you have the ambien pressure it typically assumed to be 101 kilo pascals and the density is about 1.18 kilograms per cubic meter.

(Refer Slide Time: 09:37)



Now, when. So, this is the case when there is no sound, and suppose there is a small speaker and its gets activated and it generates sound. Then all of a sudden there will be fluctuation of pressure and the air. So, then we will have a new pressure, PT we will also have different density of air and this pressure will be a function of x and t.

Where x is position and t is time. So, this pressure will be varying from point to point in the whole 1-dimensional medium. Similarly, the densities vary from point to point in the room. The volume of air will also undergo a change. So, what does that mean that if you have a small piece of material of air and initially its volume is v naught, then it can expand or contract and this expansion and contract in the amount of expansion and contraction could vary from one point to other point in the room. So, this is again VT and this is the new velocity.

I can express all these new entities in terms of original values. So, this was p naught excuse me, the new is basically earlier pressure when there was no sound plus some fluctuations in sound pressure level. Similarly, earlier density plus some density fluctuation and then the volume changes by small amount tau and velocity changes by small amount u. So, what does that mean? Let us look at this graph. Let us assume that this is time and let us say I am plotting pressure.

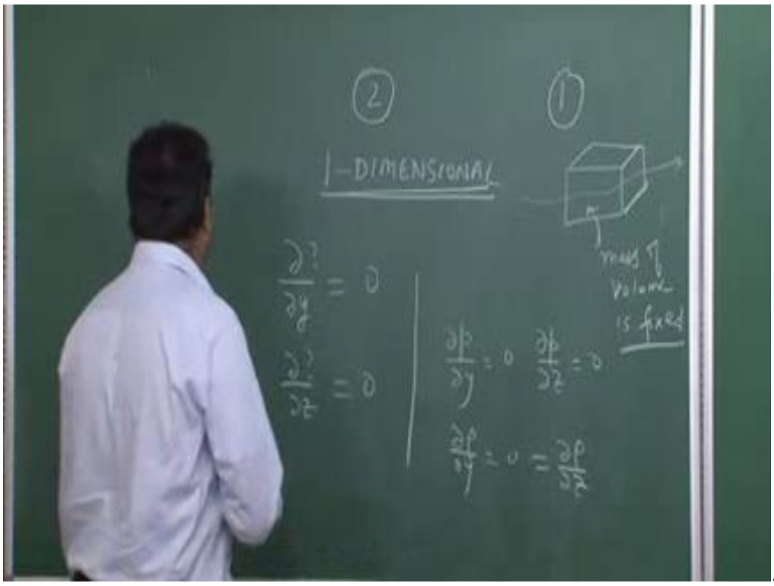
I am plotting pressure on the y axis. So, when there was no sound in the room, then at a specific point the pressure was constant and this pressure was p naught and then when I generated sound in the room, then there was a small fluctuations about this mean position and so on and so forth. So, this is that small fluctuation with respect to the mean position. Sum of this fluctuation and the mean pressure which was there in the room prior to sound getting created is p t and that is essentially p naught plus PT. So, that is what these expressions imply.

All the analysis and derivation as we walk through today's and this week's lectures we will assume that, these entities are extremely small compared to this entity. So, p extremely is small compared to p naught this rho is extremely small compared to rho naught tau which is the change in volume, please remember that tau here designates change in volume is extremely small compared to v naught. u which is the change in velocity is extremely small compared to u naught.

Actually this condition may not be necessarily required because, the smallness condition may not be necessarily applicable to the last case that is, when it involves velocity. So, u may need to be extremely small compared to u naught because, in a lot of cases you may have the situation. Where the air while when there is no sound it is not moving and it is stationary. So, u naught may actually b 0. So, that smallness condition may not necessarily apply to this situation. So, this is what we have assumed and then, later what we will also do is that we will assume that this particular parameter is 0.

So, the other thing I wanted to explain is. So, one assumption what we had did was about smallness. Then there are some additional assumptions, as we further progress and try to develop these 1-D equations. And the first one is about the constant mass particle assumption. So, what does it mean? That suppose you have a material volume.

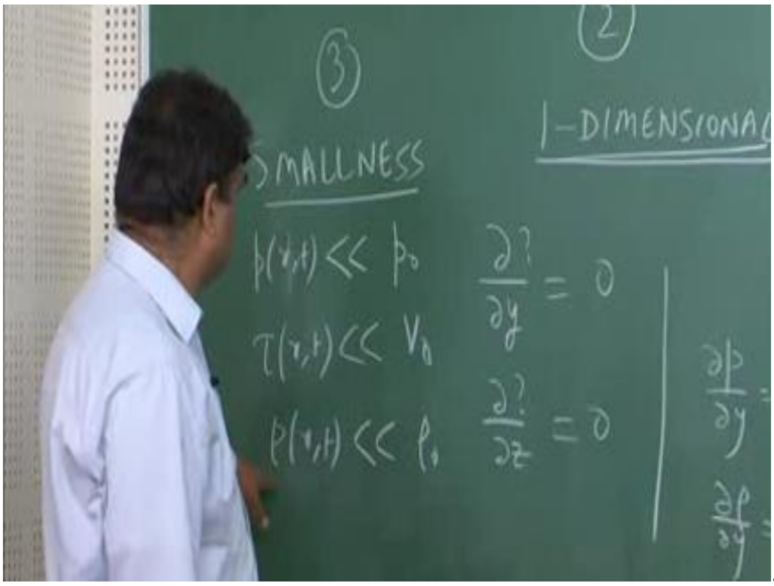
(Refer Slide Time: 15:19)



So, this is a small volume of air and that is what we are observing. And what we are observing is that, how this small volume of air is moving in air. So, the volume is moving in air, and its changing its position from one point to other point and as it is moving the mass of this particle, mass of this volume is fixed. That is what we assume if the mass of this volume is fixed, as this material particle moves through space. So, no mass is the total it flux and the balance of total flux of mass into and out of this thing is 0. So, this is one assumption because we are assuming that it is a constant mass particle this is very important. The other thing is that even though this is constant mass particle, it can lose or gain energy. So, it may be constant mass particle, but its energy state may change over a period of time and also as it walks through the media.

The second assumption is about 1-Dimensionality. What that means, is that there are no variations in y and z directions. So, the process is 100 percent or strictly 1-Dimensional. Mathematically what that means, is del over del y equals 0 and del over del z equals to 0. So, partial derivative of any entity with respect to y and partial derivative of any entity with respect to z is 0. So, in specifically what that means is that partial of p with respect to y is equal to 0, partial of p with respect to z equal to 0, partial of density with respect to y is equal to 0 and partial of density with respect to z equals to 0, and the same condition are also to the partial derivatives of change in value and change in velocity. So, that is the second condition. So, this was assumption one; constant mass particle this assumption two; 1-Dimensionality.

(Refer Slide Time: 18:10)



The third assumption, which I had already sighted, but I will just recap it again is smallness assumption. So, that the assumption of smallness and what that means, is that p is very small compared to p naught. So, actually there should be p is a function of x and t. So, for all values of t and all values x. p is extremely small compared to p naught tau is again very small compared to v naught rho. So, density fluctuations in density, in pressure volume and density, they are extremely small compared to their rest values. So, this is the third assumption. So, under using these three assumptions, what we do is that we develop three different equations, and then we actually merge those three equations into one single equation. So, what are these three equations?

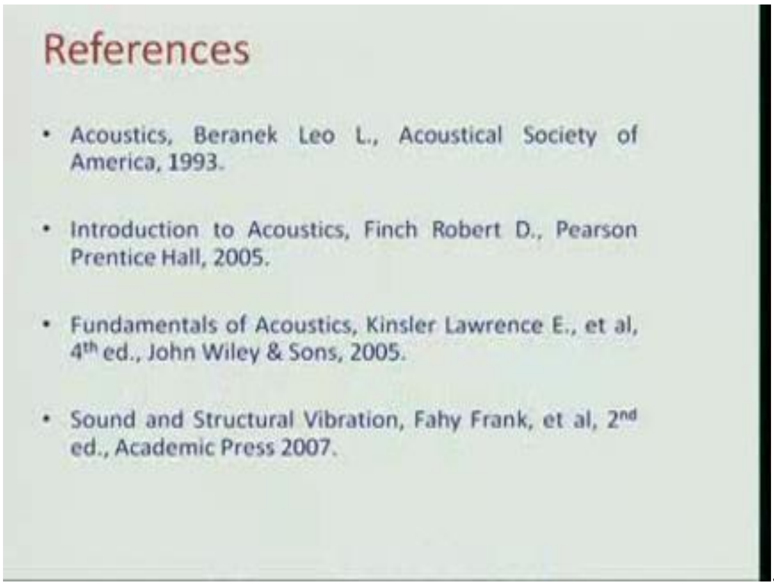
The first equation is equation of continuity or equation related to conservation of mass. So, if you have any flow and it is actually not necessarily even applicable to flow for any physical process, which we are talking about mass has to be conserved because, mass cannot be created or destroyed at least in classical mechanics. So, we will develop a mathematical relation in context of wave propagation, and we will use this particular principle and develop a relation, known as the equation of continuity. That is same as conservation of mass. So, that is the first equation conservation of mass or also known as the continuity equation.

The second equation is that, if you have a material volume and its seen some external forces. So, it has to obey newtons laws, it has to obey newtons first law, second law, third law and everything because again, it is real physical particle. So, what we will do is, we will take a material volume. List all the forces outside on the boundaries which are present on this material volume find out the balance force and this force which is the net external force, which is being applied to this material volume, will have to equal the rate of change of momentum. Which the material volume experiences as it moves through media and that particular law or equation known as the momentum equation, and essentially it is another form of newtons second law. Which is force equals rate of change of momentum. So, we have continuity equation and then we have newtons second law or the momentum equation.

The third more equation, relates to the nature of gas. So, the gas because in this case, we are particularly going to talk about gas because, most of the sound which we are talking about it propagates through air and that is, at least in context of this course the overall picture. So, what we will do is that we will model the behavior of gas as it goes through expansion and contraction using some assumption. Now, whenever we have a mass of gas, finite volume of gas and I apply some pressure it can obey variety of laws. This expansion and contraction, and change of pressure and change of entropy, it can be driven by isothermal conditions, it can drive by adiabatic conditions, it can be driven by isobaric conditions, it can be driven by also constant volume conditions. So, we have to model the gas in an appropriate way and what we will assume is that the gas follows and the adiabatic gas law. We will explain that why, later as we ah develop this topic in detail. Using that we will develop a differential form this adiabatic gas law.

So, we will develop differential form of conservation of mass equation or continuity equation, differential form of newtons second law known as momentum equation. A differential form of gas law, that is p v to the power of gamma equals constant and once we have these three equations we will club them together. So, we will have three equations and then we have three variables; pressure, velocity and density. So, then we can eliminate these two variables velocity and density and come up with one final equation, for pressure. That is what we will term as pressure wave equation. We can do the same mathematics for velocity and we can get velocity wave equation using a very similar approach.

(Refer Slide Time: 23:46)



So, these are the references and I hope this has been fruitful beginning and what I have tried to do in last 15, 20 minutes is, introduce you to the overall strategy for developing this 1-D pressure wave and velocity wave equation.

Thank you and look forward to seeing you tomorrow. Thanks bye.