**NOISE CONTROL IN MECHANICAL SYSTEMS**

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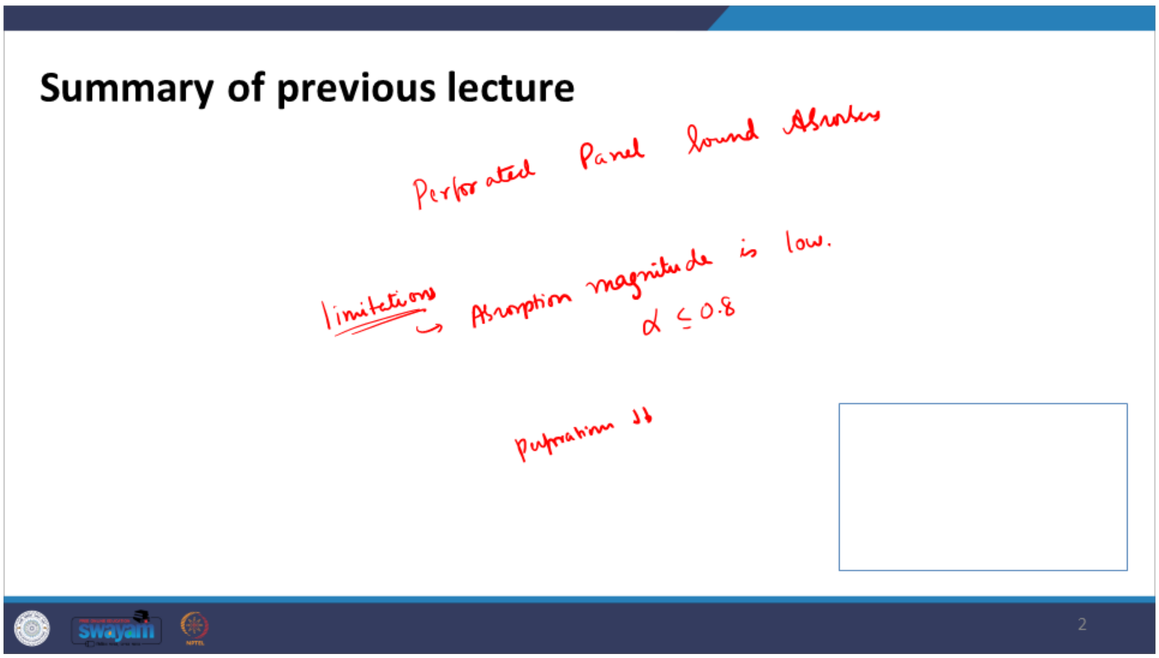
**Week:9**

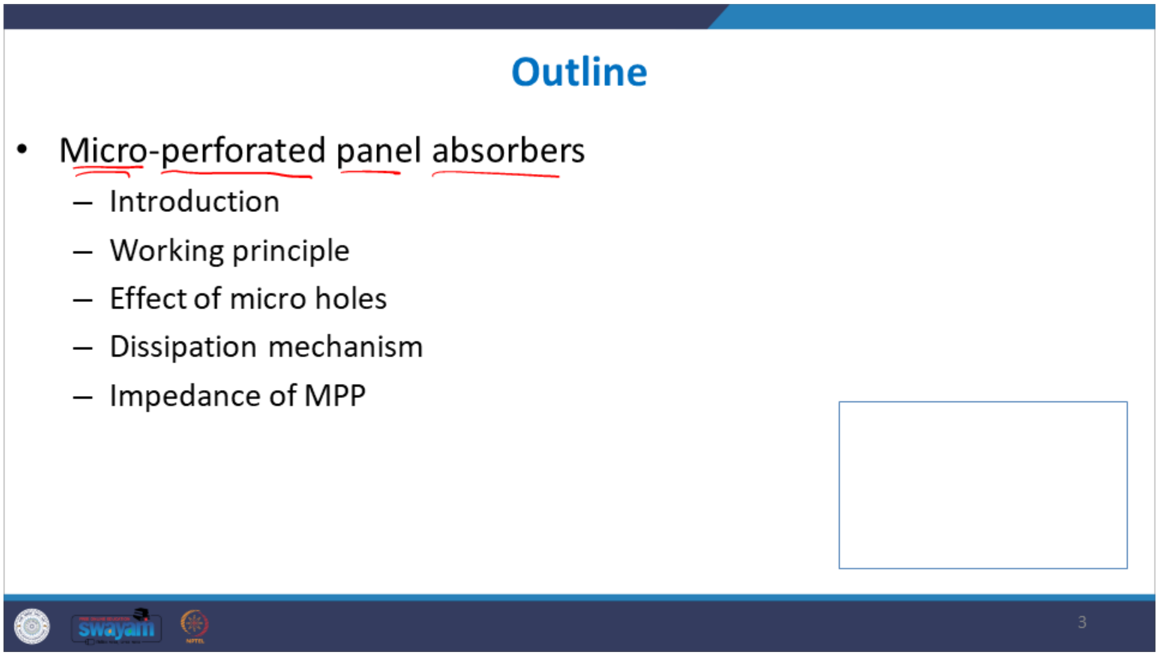
**Lecture:43**

**Lecture 43: Micro Perforated Panel Sound Absorbers : 1**

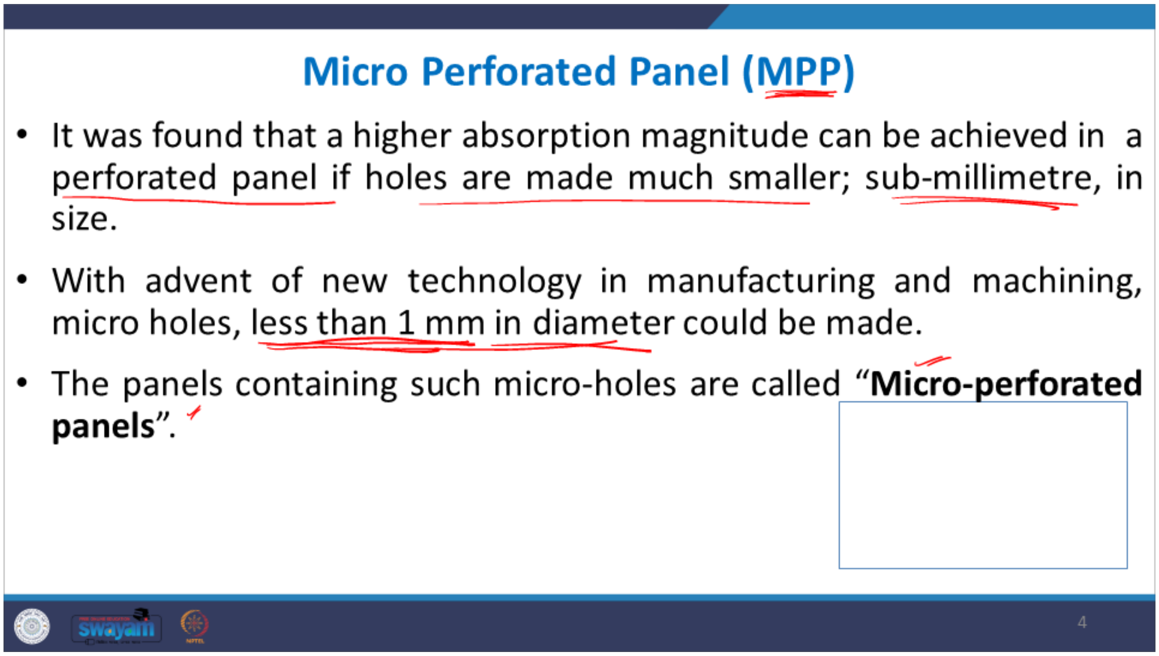

Hello and welcome to the series on noise control in mechanical systems with me Professor Sneha Singh from IIT, Roorkee. So, we have started the discussion on perforated you know sound absorbers, perforated panel sound absorbers and we saw various kind of you know advantages and limitations. One of the limitations of these perforated sound absorbers or perforated panel sound absorbers was that the absorption magnitude is you know low in general it is low because you know the absorption magnitude is low even at know low frequencies or high frequencies you do not have usually you know α is smaller than equal to 0.8 it is not usually for most of these it does not go beyond that. So, that is what you was initially the case then it is not worth using them. So, but with the advancement in the manufacturing we were able to design perforated panels where perforations would be very small in size. You know you are reducing the size of the perforations.



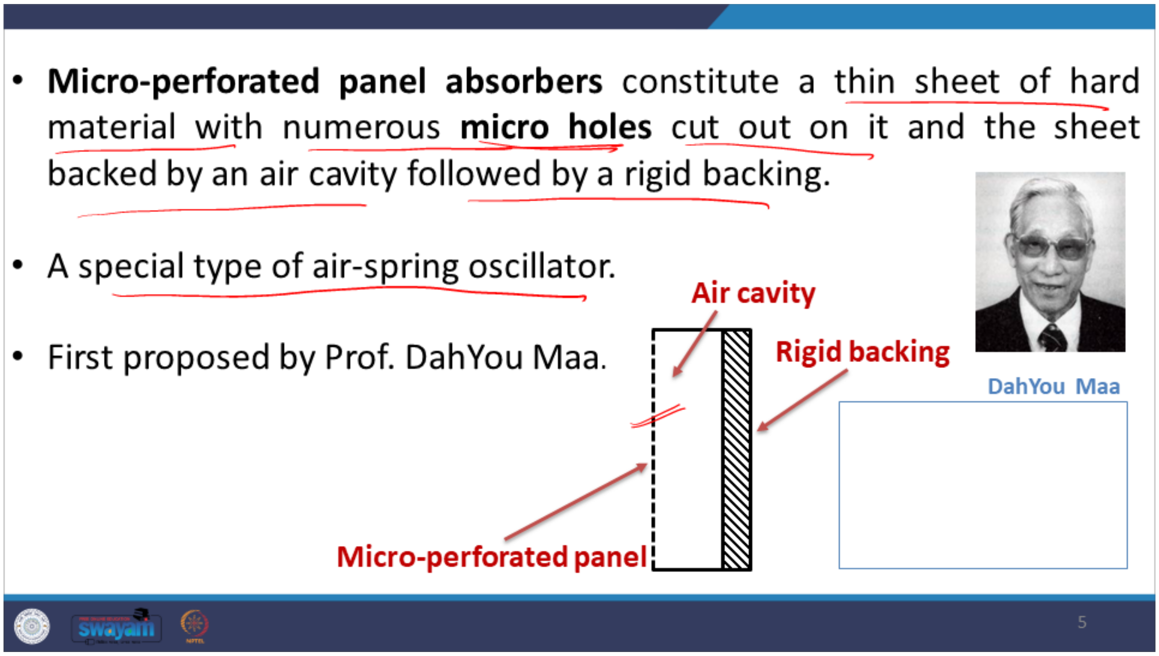

Then a new kind of phenomenon was observed when in the perforated panel itself we have the perforations that are very small in size or sub millimeter in size then they are called as micrometer range. then suddenly you know the absorption magnitude shoots up. Then what was found was that not just the resonance phenomenon is there, there are additional mechanisms that are coming into play to increase the absorption in such kind of panel absorbers and hence these new kind of panel absorbers were known as the micro perforated panel absorbers. which we will be discussing in this lecture.



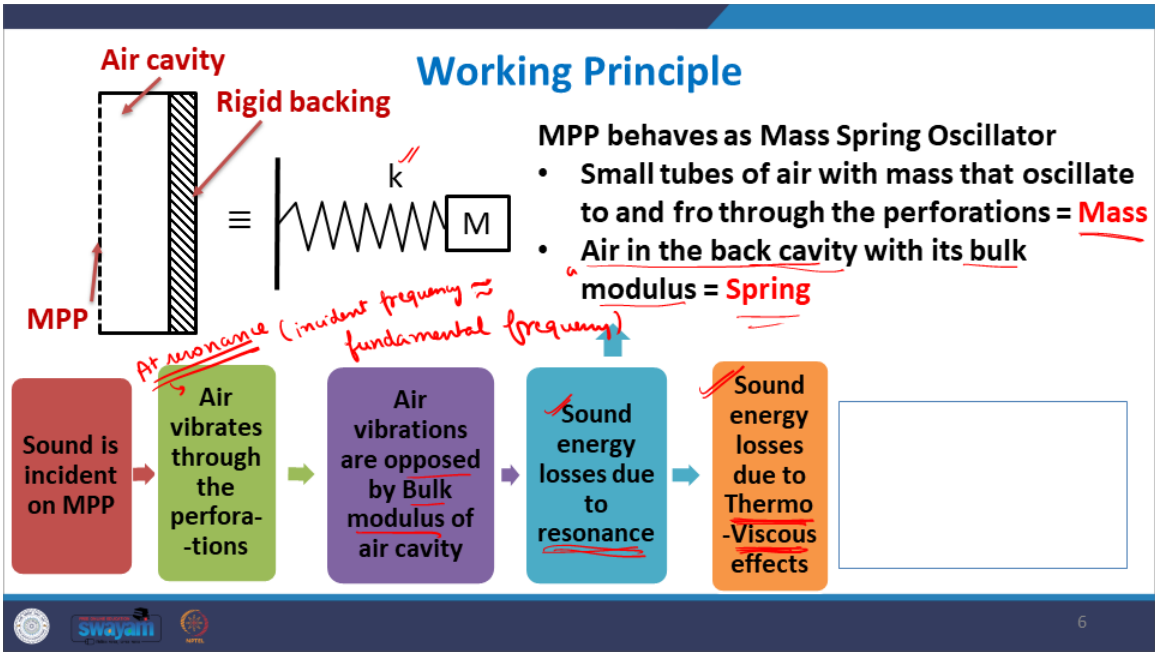

So, micro perforated panel which is shortened as MPP in the literature most of the times you know it is a very common term used by this noise control engineers. So, as I already told you that you know in the perforated panel it was usually the magnitude is not that high. So, you know various research studies were going on and initially you know you did not have that manufacturing capability to manufacture the holes of very small size. But with the advancement in manufacturing technology, it has now become possible to manufacture holes that are less than 1 millimeter in diameter. And when such small holes were made in these panels. What was observed is that when perforated panels have holes of these smaller magnitudes, or less than 1 millimeter in diameter, a new kind of absorption mechanism takes place, and such panels came to be known as micro-perforated panels, okay.



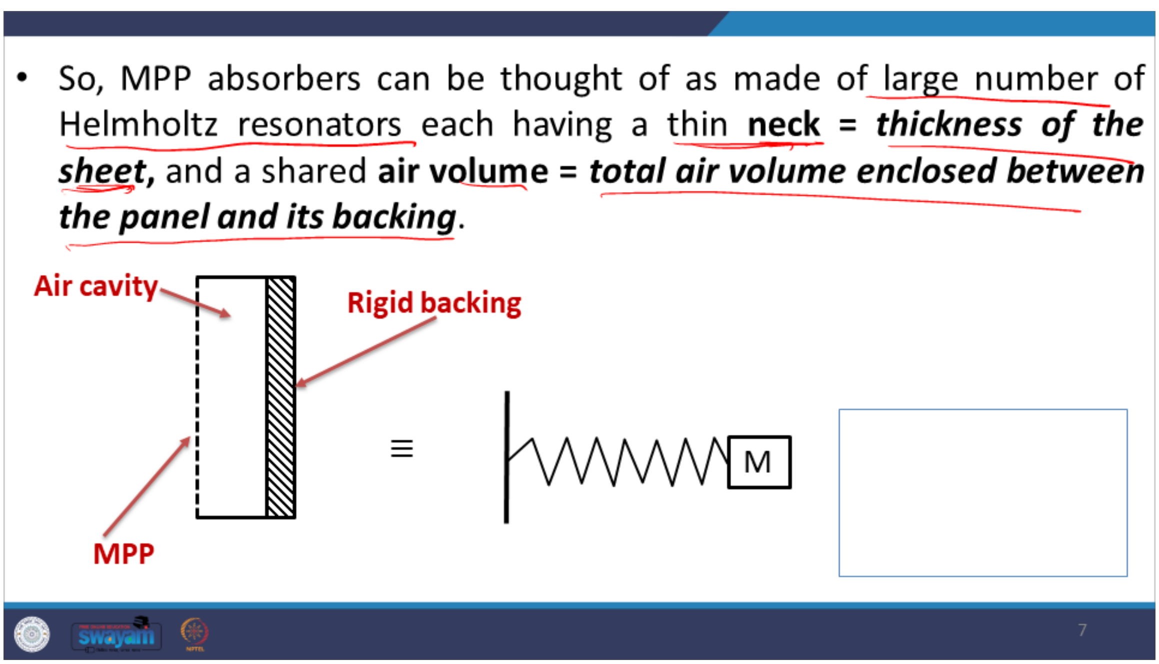

It has been highly researched, and a model for that has been derived by Professor DahYou Maa, who is credited for most of the theoretical underpinning in MPP absorbers. Okay, so what is an MPP absorber or a micro-perforated panel absorber? It constitutes a thin sheet of hard material with numerous micro-holes, and by micro-hole, I mean holes that are in the micrometer range or less than one millimeter. Okay, so numerous such micro-holes are cut out into it, and the sheet is then backed by an air cavity followed by a rigid backing. So, very similar to a perforated panel, the difference being that now the holes are less than 1 millimeter in size, okay. So, this also acts like an air-spring oscillator.



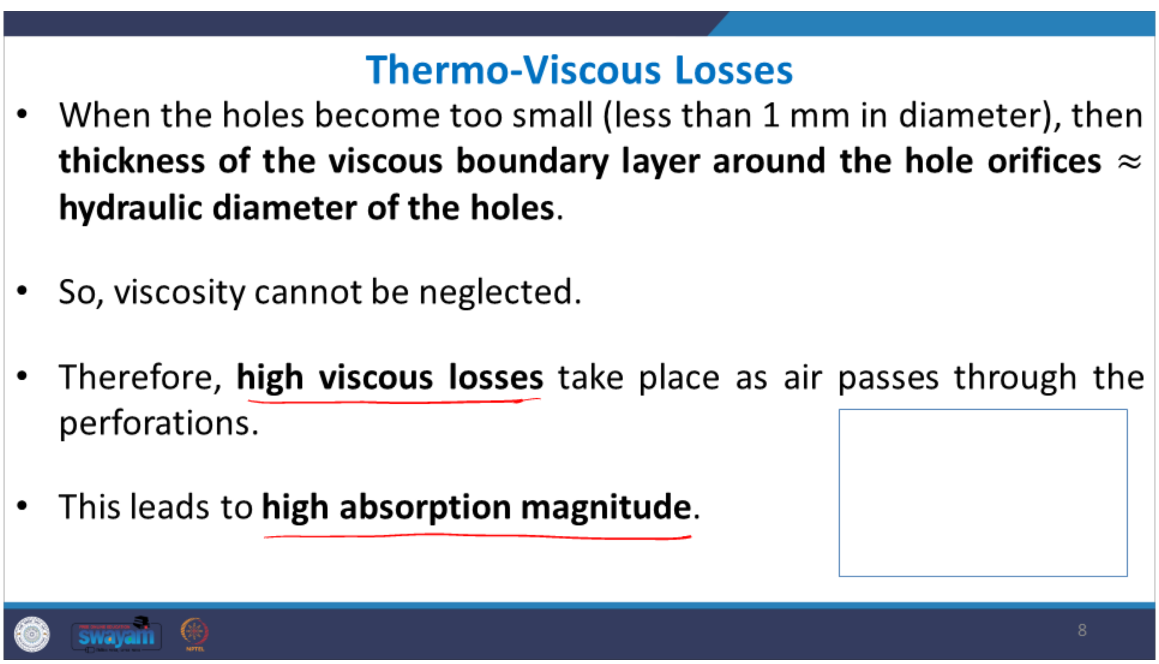

So, let us see the working principle. So, you know, most of the working principle is the same as what we have seen in the case of perforated panel absorbers. So, what is happening? The sound is being incident on the MPP, and then it sets at resonance frequency. There is at resonance when the incident frequency matches with the fundamental frequency. So, at those frequencies, this amplifies. So, the air vibrates through these perforations in the panel, and this is through these perforations, it goes into the air cavity, which is confined in nature, and hence, because of its bulk modulus, it tends to oppose the motion and acts like the restoring spring of the oscillator. Ok, and the mass or the small tubes of air act as the mass which is being oscillated. So, the sound energy losses happen due to the resonance. We are setting this mass-spring oscillator into resonance, but at the same time, there is also some additional energy loss due to the thermal and viscous effects, or combinedly, we call them the thermo-viscous effects, Ok. So, this is the additional mechanism that comes into play, and this is quite similar. So, here in the resonance, it is behaving as a mass-spring oscillator. The small tubes of air that are oscillating to and fro—the mass of these acts as the mass of the oscillator, and the air confined within the cavity, with its bulk modulus, acts as the spring. But other than the dissipation in the resonance, or the resonance-based dissipation, we also have the dissipation. So, sound energy dissipation means the loss of sound energy as heat. So, there is either the dissipation due to the resonance vibration, or there is dissipation or loss due to the thermo-viscous effects.



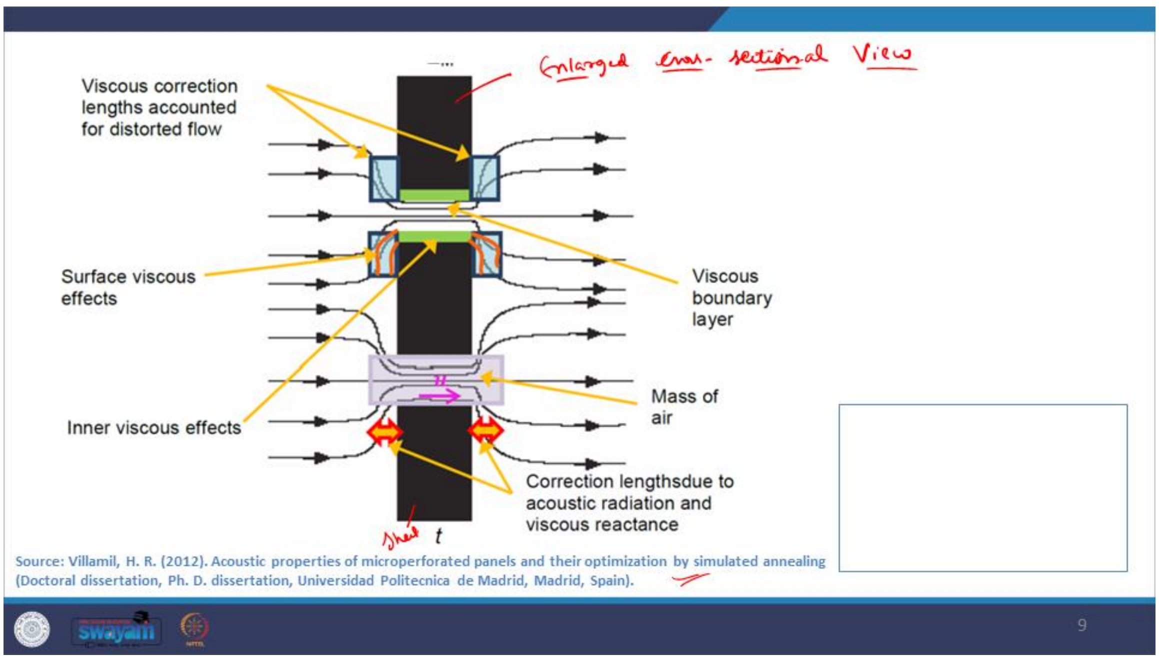

Let us see what that is. So, you know, this is the same—you know, the neck is the, the neck, in this case here, also the MPP absorbers, they act as a large number of Helmholtz resonators with very small necks, and this thin neck is the thickness of the sheet. Ok, here the neck becomes or the length of the neck becomes the thickness of the sheet, and the air volume is simply the air volume which is enclosed between the panel and the backing.



Now, what is this additional absorption mechanism? The rest of the thing is the same as a perforated panel. So, what happens is that when these small holes or perforations They are becoming very small—less than 1 millimeter. Then the thickness of the viscous boundary layer around the hole orifice becomes of a similar order of magnitude as the hydraulic diameter of the hole. So, whatever the diameter of the hole is, it is approaching the viscous boundary—the thickness of the viscous boundary layer between that solid and the fluid interface. And hence, within this small range, when the boundary layer and the hole dimension are of the same order of magnitude, okay. Both of them are now of the same order of magnitude, so we cannot neglect viscosity. So, high viscous losses are observed. So, when the fluid flows through these perforations, essentially it is a flow—when the sound waves enter the perforations. What are sound waves? They are longitudinal fluctuations or longitudinal oscillations of the air particles. So, essentially, what is happening is that these air particles are oscillating to and fro and passing through these holes, but now the movement of these air particles is being sort of resisted because of the viscous effect. So, there is a viscous drag that opposes the flow of the air particles through the holes. So, a high amount of viscous losses occurs, and this leads to a rise in the absorption magnitude, okay.



So, as you can see here, this is from one paper where they have explained what it is, okay. So, what we have is that this shows again an enlarged cross-sectional view. So, we have an enlarged cross-sectional view, and here what we can see is that this is the sheet or the panel and the various holes. Now, the viscous boundary layer and the hole dimensions are of the same order of magnitude, and this is how the viscous drag comes into play—it sort of resists the motion in and around the solid surface.




So, because of that, what happens is that—and we know that the

$$F_{viscous} \propto \frac{\partial v}{\partial r}$$

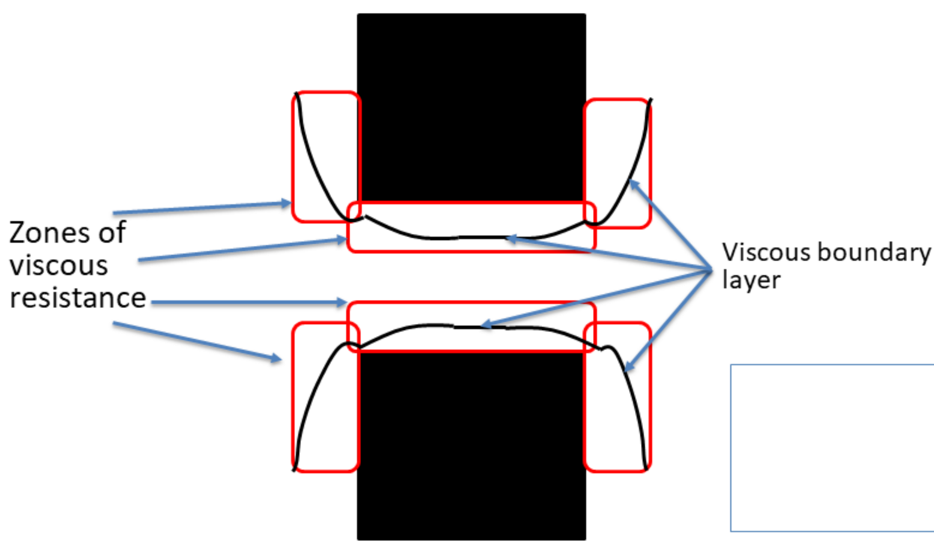
as the resonance happens, which means that as the acoustic particle velocity or the vibrations increase in magnitude, there will be more viscous losses. So, the vibrations are the maximum when the fundamental frequency and the incident frequency are the same. So, there the viscous losses will increase even further. So, at the peak, the viscous losses will be even higher, and the peak will suddenly shoot up and rise in magnitude.

## Dissipation mechanisms in MPP

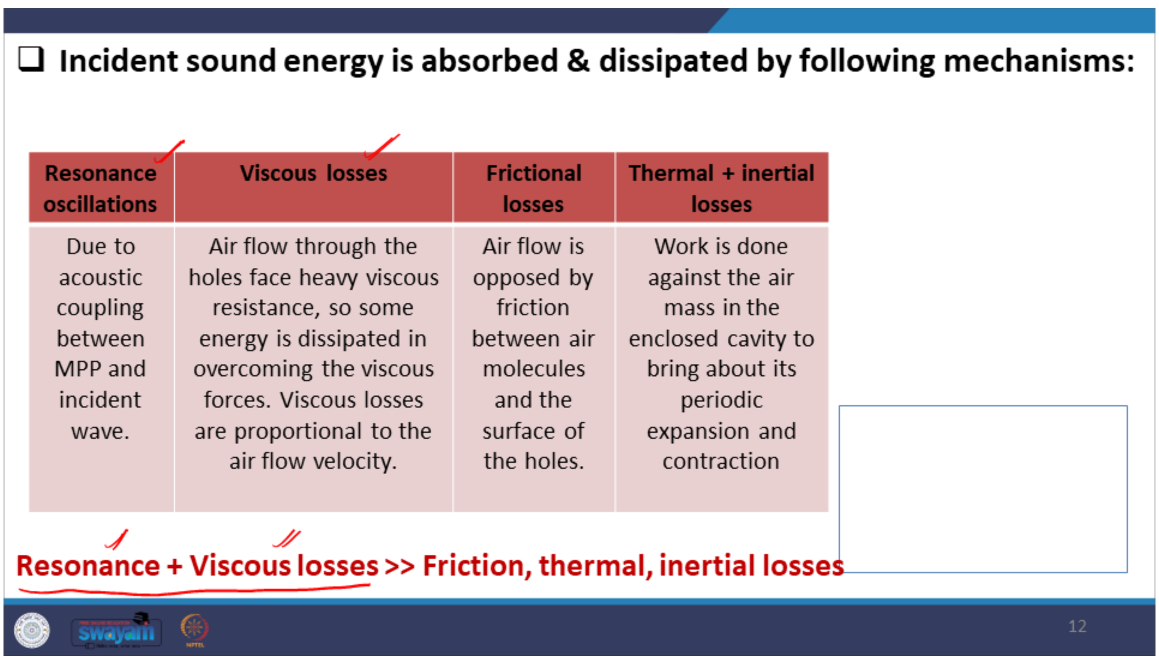
- There is heavy viscous drag between boundary of air and hole boundary surfaces. Effect of viscous drag is observed throughout the hole, as hole diameter ≈ viscous boundary layer.
- Air flow is opposed by the viscous force that is and air velocity changes radially. $F_{viscous} \propto \frac{\partial v}{\partial r}$



So, this shows a more enlarged view. These are the zones of viscous resistance, and this is the overall, sort of, hole. What you can see is that proportionally, a lot of losses are taking place through these small holes.



So, there are some additional mechanisms as well. So, we have already studied what resonance oscillations and viscous losses are. We also have frictional losses, which occur when the airflow is opposed by the friction between the air molecules and the surface of the hole. So, this is typical frictional resistance. At the same time, you have some additional thermal and inertial losses because what is happening is that these molecules, or these air particles which are vibrating to and fro, are trying to compress or expand the air enclosed within the cavity, as well as the panel they are hitting. And this periodic expansion and contraction can lead to some thermal losses. But they are not of much consequence in general; the resonance and the viscothermal losses, or the viscous losses, dominate the absorption phenomenon, okay? And the other forms of losses do not have that much of a significant effect.




| Resonance oscillations | Viscous losses | Frictional losses | Thermal + inertial losses |
|---|---|---|---|
| Due to acoustic coupling between MPP and incident wave. | Air flow through the holes face heavy viscous resistance, so some energy is dissipated in overcoming the viscous forces. Viscous losses are proportional to the air flow velocity. | Air flow is opposed by friction between air molecules and the surface of the holes. | Work is done against the air mass in the enclosed cavity to bring about its periodic expansion and contraction |

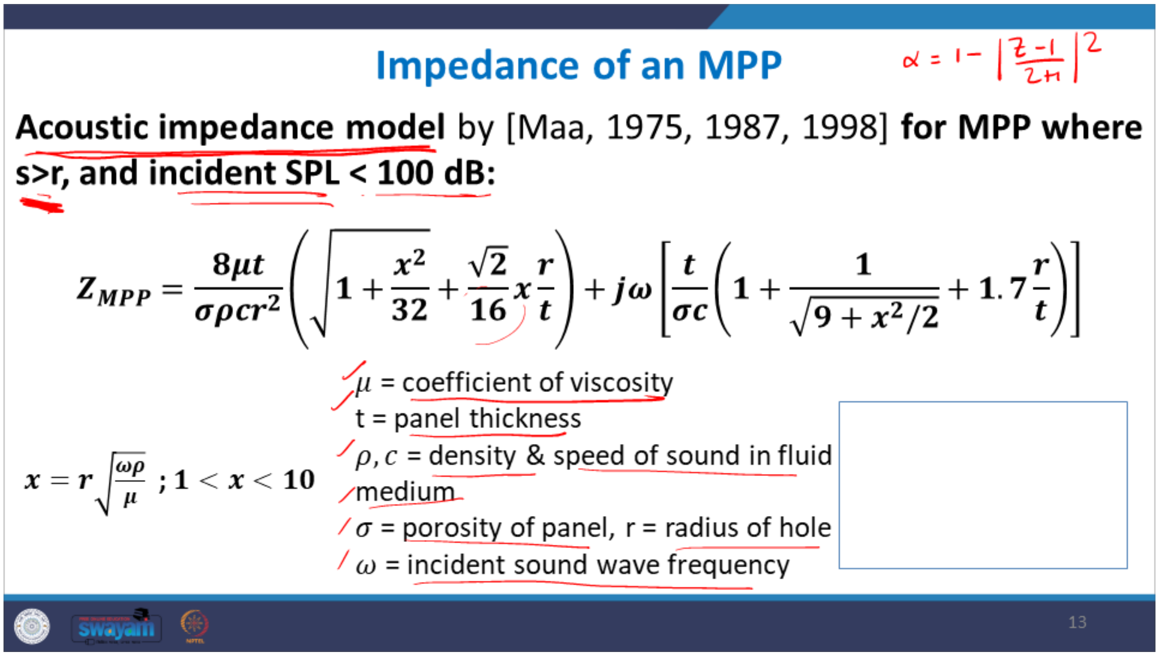
So, just like in the case of other resonance absorbers, the fundamental frequency matters a lot because that is what these frequencies are. So, at the fundamental frequency and its multiples integral multiples you should be getting an absorption peak. So, the fundamental frequency matters. So, therefore, the fundamental frequency of the MPP also needs to be obtained, but because of these viscous effects and the micro-size dimensions, usually it is not that easy; you do not have a very easy formulation of the fundamental frequency you rather have a very complicated model. So, again, you know, the acoustic impedance model for an MPP is quite complicated in nature, and this is for MPPs wherever the hole spacing is much larger compared to the radius of the hole. For this case, an acoustic impedance model has been derived. So, this is given by this complicated, huge expression here.

$$Z_{MPP} = \frac{8\mu t}{\sigma\rho c r^2}\left(\sqrt{1+\frac{x^2}{32}}+\frac{\sqrt{2}}{16}x\frac{r}{t}\right)+j\omega\left[\frac{t}{\sigma c}\left(1+\frac{1}{\sqrt{9+x^2/2}}+1.7\frac{r}{t}\right)\right]$$

Where various things, you know like the coefficient of viscosity, the thickness of the panel, the density and the speed of sound in the fluid medium, the porosity of the panel, the radius of the hole, and the incident sound wave frequency—all of them come into the picture. So, all of these are going to affect the overall acoustic impedance of an MPP. And we know that α is what?

$$\alpha = 1 - \left|\frac{Z-1}{Z+1}\right|^2$$

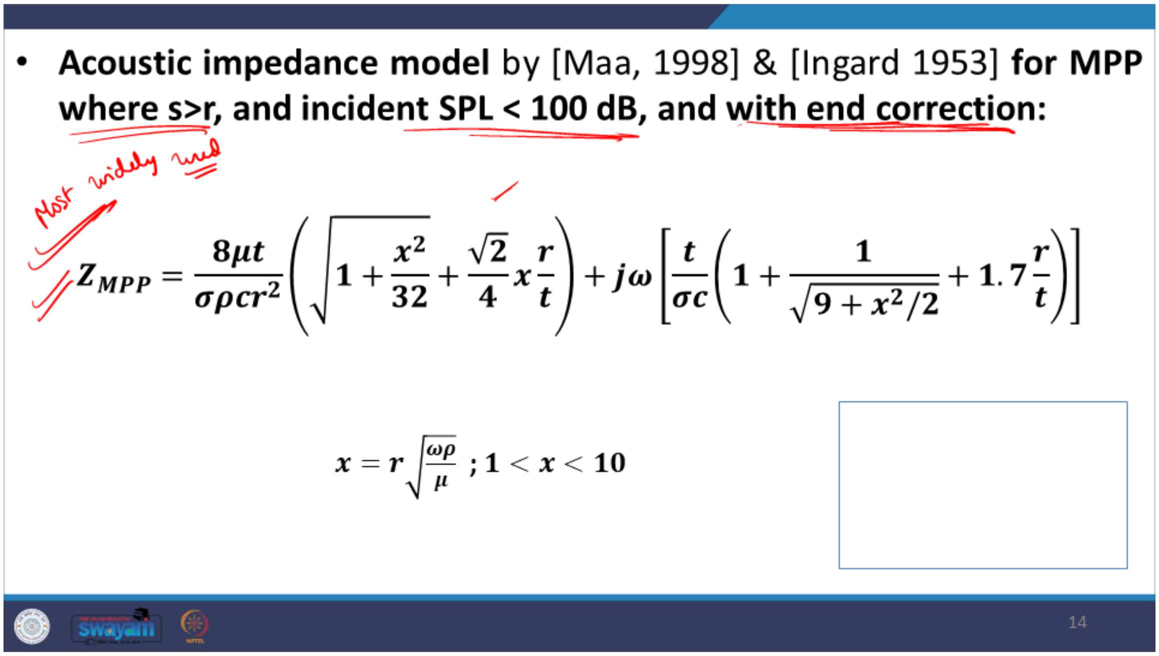
For the interaction. So, if they are affecting the acoustic impedance, they will also affect the absorption coefficient. So, all of these parameters now are going to affect your absorption.




So, this is the acoustic impedance model. When you know the spacing between the holes is much larger than the radius of the hole and the incident sound pressure level is smaller than 100 dB, the same model applies. Same conditions, but now with some end correction added to it. After end correction, the new formulation here is that some of the things are changing, as you can see. This particular character changes, and this becomes your new formulation. So, usually, this is the formulation that is most used. The one with the end correction.

$$Z_{MPP} = \frac{8\mu t}{\sigma\rho c r^2}\left(\sqrt{1+\frac{x^2}{32}}+\frac{\sqrt{2}}{4}x\frac{r}{t}\right) + j\omega\left[\frac{t}{\sigma c}\left(1+\frac{1}{\sqrt{9+x^2/2}}+1.7\frac{r}{t}\right)\right]$$

So, this formulation is something just to keep in mind because it is a very complex formulation. But when dealing with MPP, noise control engineers have to remember this formulation.



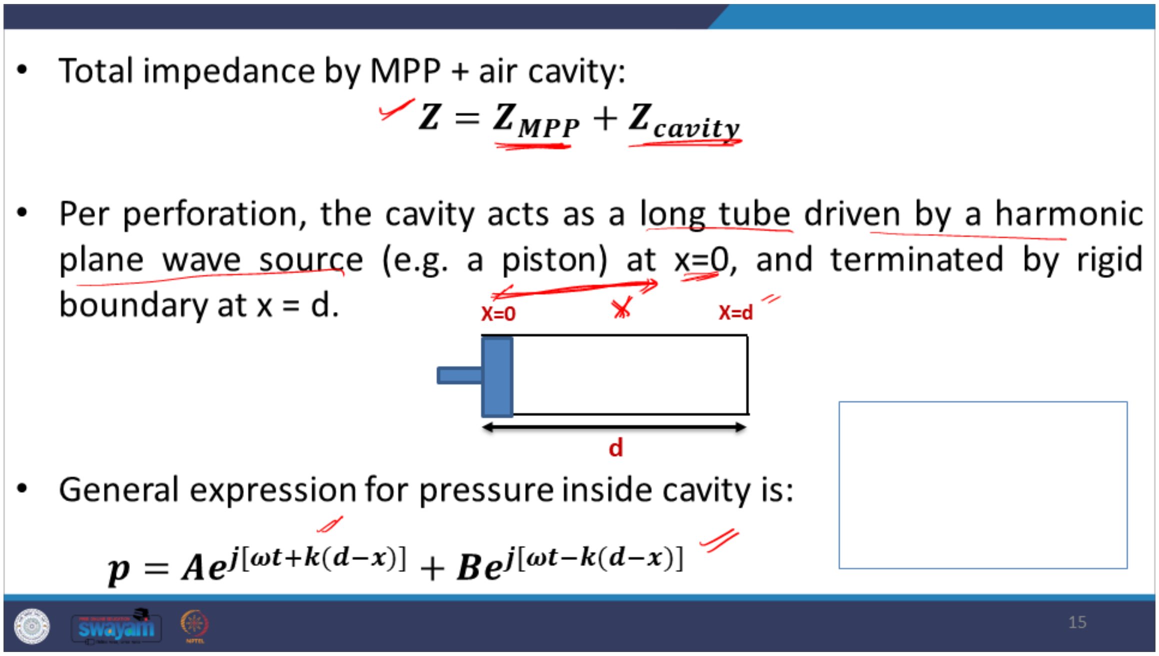

Now, we know that this is going to give us the surface impedance of the micro-perforated panel. But the micro-perforated panel does not act alone in isolation. The panel is backed up, in most cases, by a rigid backing or a cavity. Then, so this is the Z of MPP—this is the Z of the micro-perforated panel. But the total absorber is composed of an MPP plus a rigid backing. An air cavity a confined air cavity with a rigid backing. So, for that, the impedance due to this confined air cavity also needs to be obtained. So, the impedance—the total Z of the micro-perforated panel absorber would be

$$Z = Z_{MPP} + Z_{cavity}$$

So, you can think of this you know that this cavity is like a long tube. Which is being driven by a harmonic plane wave source. And if you imagine this just to derive a formulation you can imagine that this end, the beginning of the air cavity, as your x = 0. And here you are so this is your x-axis, Ok? Here you have x = 0, and here you have x = d. And in this One-dimensional wave equation, you can obtain. So, the pressure wave is given by this formulation.

$$p = Ae^{j[\omega t + k(d-x)]} + Be^{j[\omega t - k(d-x)]}$$

So, it could be a combination of a wave a pressure going in the forward x-axis and a wave going in the backward x-axis. So, just a generic formulation is given for a plane harmonic wave.



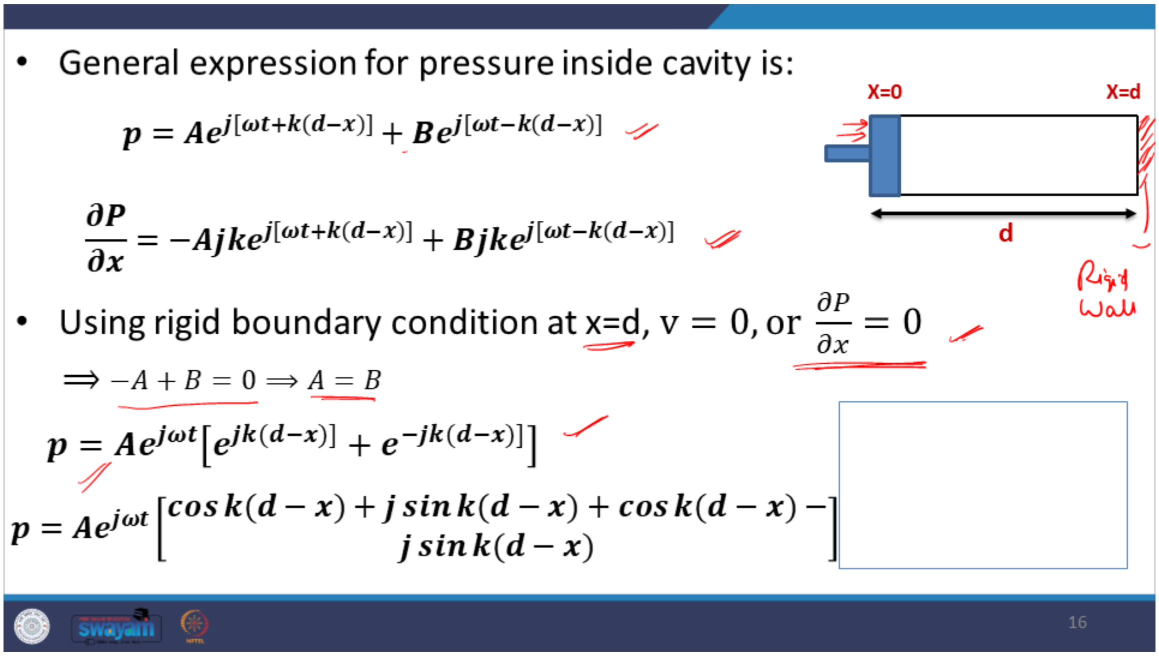

So, this is the general expression for any kind of plane harmonic wavefront in this cavity.

$$p = Ae^{j[\omega t+k(d-x)]} + Be^{j[\omega t-k(d-x)]}$$

If you differentiate this expression, this is what you will get.

$$\frac{\partial P}{\partial x} = -Ajke^{j[\omega t+k(d-x)]} + Bjke^{j[\omega t-k(d-x)]}$$

Now, you can apply the rigid boundary condition. So, at d, we will have a rigid backing when the air cavity ends, but here we have the opening because the sound molecules are entering through this. So, there is no rigid backing here, but here we have some rigid backing. So, the rigid wall condition is imposed. So, the velocity here has to become 0, which means that $\partial P/\partial x$ has to become 0 at x is equal to d. So, once you have this, you can set $\partial P/\partial x$ at x is equal to d as 0. So, when you substitute this into the equation, you will get this formulation here. This is what you will end up getting. And you can then obtain an equation for pressure by setting A equal to B, okay.




And once you solve it further, ultimately what you will get is this kind of wave equation, okay.

$$p = 2A \cos k(d-x)\, e^{j\omega t}$$

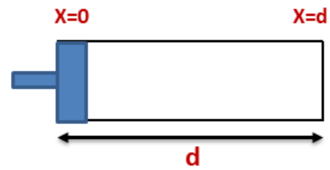
and then you can use some properties of the acoustic medium, which in the acoustic fundamentals module we studied, that

$$\rho_0 \frac{\partial \vec{u}}{\partial t} = -\frac{\partial p}{\partial x}$$

So, you can use this property and find the equation for the acoustic particle velocity. You already know the equation for the acoustic pressure. Then P/V is going to give you the Z.

- Acoustic pressure inside cavity is:

$$p = 2A\cos k(d-x)\, e^{j\omega t} \qquad \textbf{Eq. (1)}$$




- By property of acoustic medium

$$\boxed{\rho_0 \frac{\partial \vec{u}}{\partial t} = -\frac{\partial p}{\partial x}} \qquad \vec{v} = -\frac{1}{\rho_0}\int_0^t \frac{\partial p}{\partial x}$$

$$\vec{v} = -\frac{1}{\rho_0}\int_0^t 2Ak\sin k(d-x)e^{j\omega t} = -\frac{2Ak}{j\rho_0\omega}\sin k(d-x)e^{j\omega t} \qquad \textbf{Eq. (2)}$$

So, you can do the P by V at x is equal to 0 to get the surface impedance of this cavity. Once you solve this expression, this is like a homework assignment that you can do. The derivation is kept here, but I am not going into the details of it. So, just the step-by-step what you need to do, and when you put P by V, this is what you are going to get. Okay,

$$z = \left(\frac{p}{\vec{v}}\right)_{x=0} = \left[-\frac{j\rho_0\omega}{k} cot\, k(d-x)\right]_{x=0}$$

$$Z_{cavity} = -j\rho_0 c_0 \cot(kd)$$

ultimately, so anyways, the end result is going to be once you follow this process, you know, step by step. You take a generic expression of the pressure wave, you put the boundary condition as at x is equal to d, your velocity is becoming 0, which means that the pressure gradient is going to 0, and then you solve. You get an equation for P, you solve further, and then you use this particular property and find the equation for V and P by V, you get and solve it. So, this becomes your Z of cavity. So, with this, what will happen now, you know this formulation. So, you can simply say that the Z of MPP is already known by this formulation,

$$Z_{MPP} = \frac{8\mu t}{\sigma \rho c r^2}\left(\sqrt{1 + \frac{x^2}{32}} + \frac{\sqrt{2}}{4} x \frac{r}{t}\right) + j\omega\left[\frac{t}{\sigma c}\left(1 + \frac{1}{\sqrt{9 + x^2/2}} + 1.7\frac{r}{t}\right)\right]$$

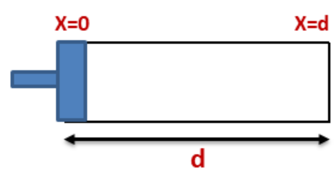
and now the Z of cavity is known by this formulation.

$$Z_{cavity} = -j\rho_0 c_0 \cot(kd)$$

So, you can get the total impedance of the MPP sound absorber, and once you have this, then you can find out the absorption coefficient. So, as you can see, it is very complicated and very complex. So, a straightforward solution is not there, you know. Usually, people use various kinds of, you know, data-driven approaches and techniques to actually solve the impedance of the micro-perforated panel, and for this particular lecture course. We are not going to go into the detail of what kind of data-driven approaches are actually used to solve various MPP-based kinds of problems where you find out the absorption coefficient of an MPP. It is not within the scope of this particular introductory lecture. So, just you see the expressions, and in the next class, we will see that based on the expressions that are derived. What is the effect of the various parameters on the overall acoustic impedance, and what is the effect of these parameters on the absorption coefficient?

- From eq. (1) and eq. (2), acoustic impedance due to the cavity measured at the boundary of the perforation is:

$$z = \left(\frac{p}{\vec{v}}\right)_{x=0} = \left[-\frac{j\rho_0\omega}{k}\cot k(d-x)\right]_{x=0}$$




$$Z_{cavity} = -j\rho_0 c_0 \cot(kd)$$

Okay. So, with this, we will close the first lecture on MPP. Thank you.