NOISE CONTROL IN MECHANICAL SYSTEMS

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Week:11

Lecture:54

Lecture 54: Noise in Mechanical Systems 2

Hello and welcome back to this lecture series on noise control in mechanical systems with myself, Professor Sneha Singh. We have been discussing our new module where we are seeing what the noise generated in the mechanical systems is. What are the main types of noise in the mechanical system? How they are created?, how are they transmitted ? and what are the various kinds of control measures that we can apply? That we have been discussing. We began our discussion on the mechanisms for noise generation in these systems and we already studied about the first mechanism which is vibration induced noise generation.

Summary of previous lecture

Noise in Mechanical Systems

Outline

- Key Mechanisms of Noise Generation in Mechanical Systems

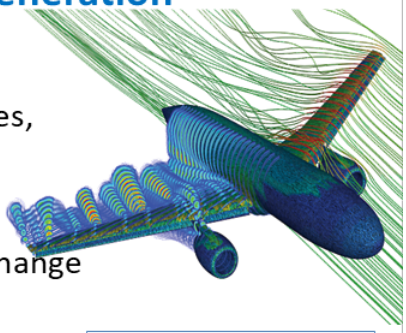
Vibration - Induced.

Let us study about the other mechanisms. Just a quick recap. This is a primary mechanism of noise generation. It is for the first two vibrations, then we have impact, then we have the fluid flow and then we have the fluid structure interaction. Let us study about the other three types of mechanisms.

Key Mechanisms of Noise Generation

- Primary mechanisms of noise generation in mechanical systems:

1) **Vibration :** Structure or machine parts oscillates, leading to sound generation.
2) **Impact:** Noise due to collision between solid objects, leading to sudden acoustic pressure change in the medium.
3) **Fluid Flow:** Turbulence and pressure variation in moving fluids.
4) **Fluid - structure interaction:** Interaction of fluid with solid boundaries causing vibration of structure.



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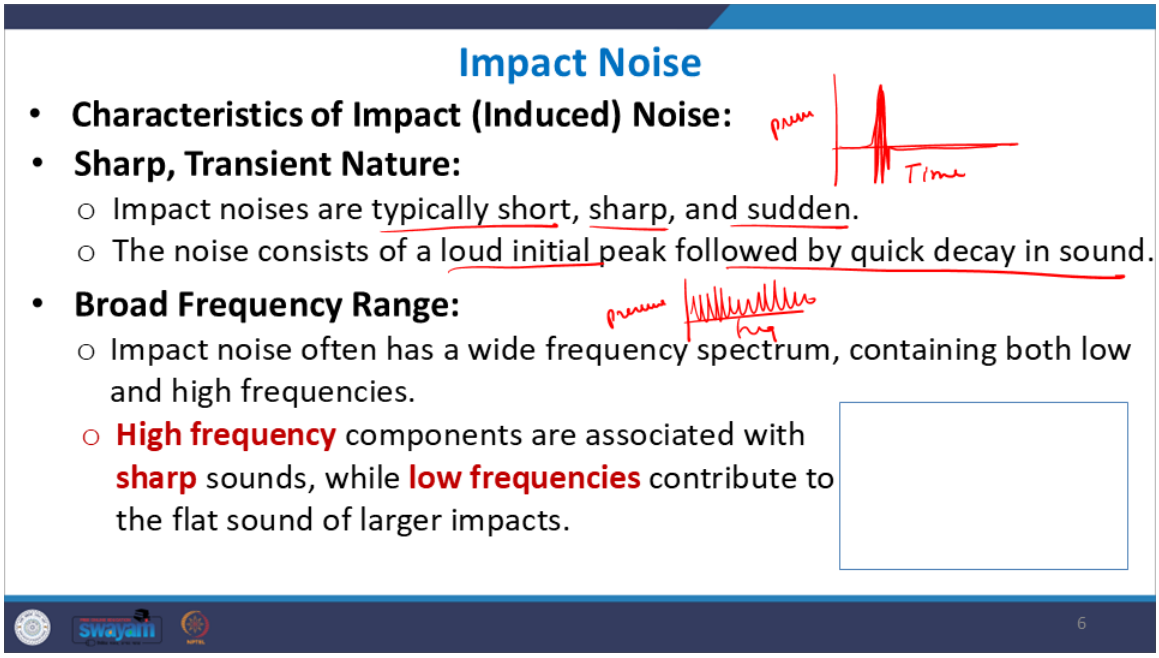
Impact Noise

- **Impact Noise:**
  Impact noise is caused by the collision of two or more objects, resulting in a sharp, short-duration sound.
- **Energy Transfer:**
  When an impact occurs, kinetic energy is suddenly transferred from one object to another. A portion of this energy is converted into mechanical vibrations, which radiate as sound waves.
- **Pressure Waves:** The rapid compression and release of air molecules during impact generate high-pressure sound waves that spread outward as noise.

Image source : https://anchorsmachinery.com/

What is the impact noise? Impact noise is caused by the collision of two or more objects which results in a very sharp short duration sound ok. it is an impulsive force which comes into play of when two objects they collide an impulsive force is generated which is a very high magnitude force acting over a short period of time. And in response to this, the noise waveform is also the same way. It is a high amplitude sound wave resulting for a very short period of time. It has high-amplitude sound waves over a very short period of time resulting

from the impacts and collisions. What is the typical energy transfer that takes place? Whenever any impact occurs, the kinetic energy is suddenly transferred from one object, which is impacting and in motion, to another object, which was stationary in most cases. And this sudden transfer of kinetic energy means a portion of this energy gets converted into mechanical waves as well. A portion of the kinetic energy then creates mechanical vibrations, which then radiate as sound waves into the air. The kind of pressure waves we have involve rapid compression and some rapid release of air molecules during the impact, which generally generates high-pressure sound waves that spread outward as noise. These are high-pressure sound waves that spread across a short duration of time corresponding to the impact.



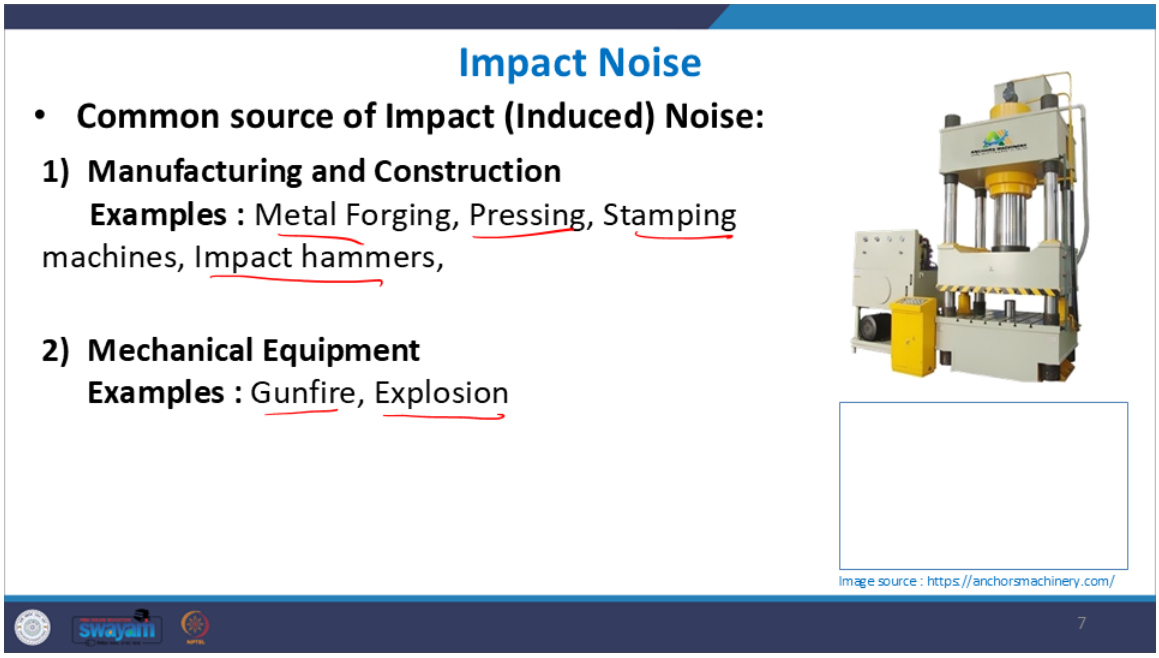
What are the other characteristics of this impact-induced noise? They usually have a very sharp transient nature, just like impulsive forces—typically short, sharp, and sudden in nature. The noise consists of a loud initial peak followed by quick decay.

Temporarily, if you think about the time variation then you can think about the pressure as a very high-pressure wave with a sudden decay. It is a very transient nature—a very high-amplitude, short-duration sound.

What is the broad frequency range? this was the temporal content of the sound.

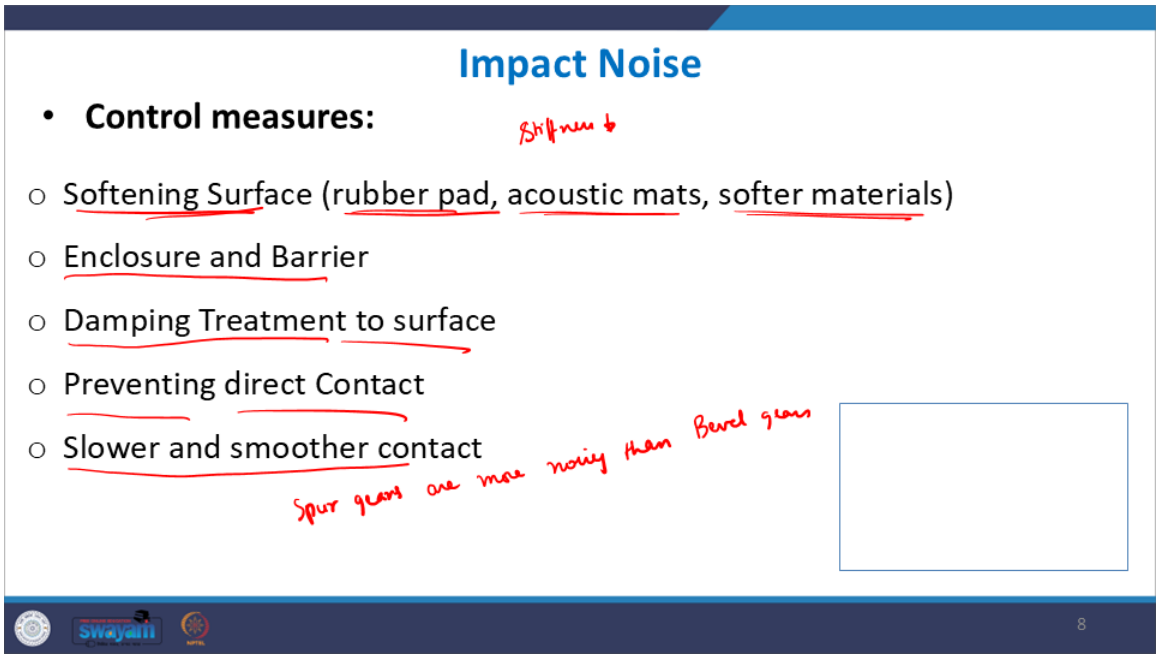
Then, what is the frequency content like? It is a broadband frequency content, which means that with respect to frequency, how is the pressure varied? It contains various kinds of frequencies. It is not a tonal sound.

Impact noise has a wide frequency spectrum, containing both low as well as high frequencies. The high-frequency component is usually associated with sharp sounds, and the low frequencies with the flatter sounds of the larger impacting bodies.



What are some of the common sources where this kind of impact noise may be generated? for example, in manufacturing and construction, operations such as metal forging, pressing and stamping operations, the stamping of coins, and the pressing of metal sheets. The stamping of coins and embossing of structures, then the use of impact hammers to shape various kinds of metallic structures—all of this is going to create impact noise. And then, in other mechanical equipment, such as explosions or gunfire, these phenomena will also create impact noise.

What are the control measures? What is happening here is that two bodies are colliding together, and because of the collision, energy is being transferred, with some of the energy being converted into vibrations of the structures that are colliding. If you can make the structures that are colliding softer. How can you make them softer?

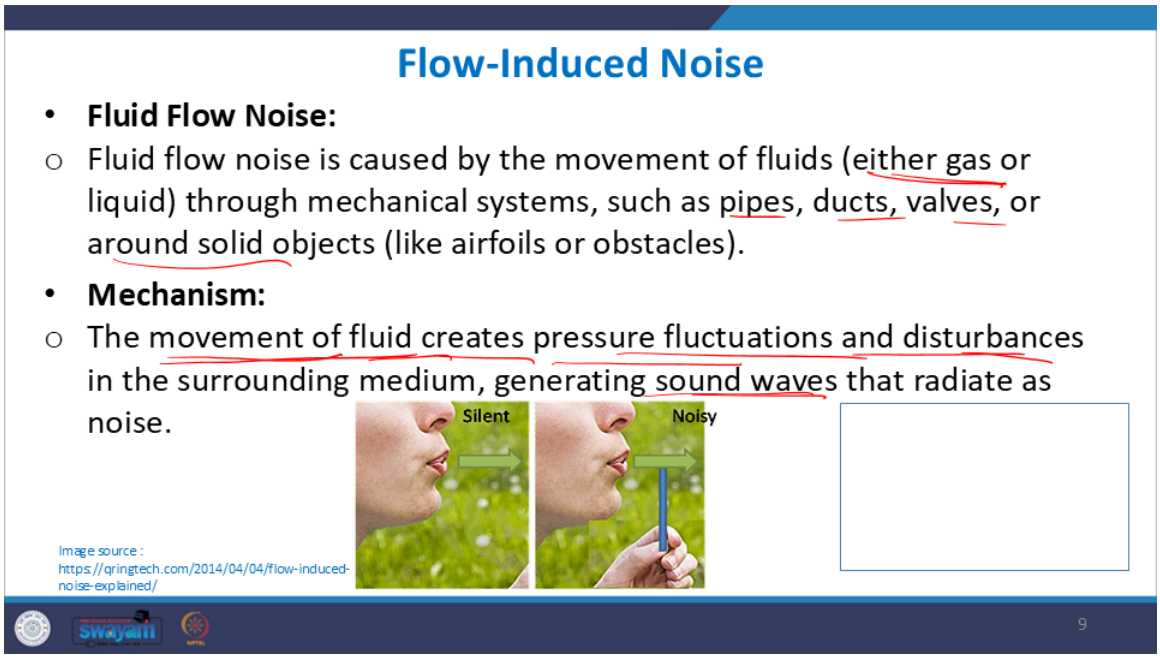


You can decrease the stiffness of the structure and make it softer in nature and what happens that this softening will create will reduce the impact of the noise. The amplitude of the impact noise is going to go down if you can make lower stiffness or a softer structure. You can make use of rubber pads, acoustic mats or softer materials. in the impacting bodies.

The other way would be use of enclosure and the barriers in any kind of mechanical manufacturing plant where you have in which where you have the process of pressing stamping or other kind of impacting process going on that particular part of the machinery can be enclosed using barrier materials. You can also put some damping treatment on the surface that is impacting. You can also create machinery where you don't need to have direct impact. You can redesign the machinery where impacting is the need for the bodies to collide together is less. Direct contact is less than between the various moving components of the machinery.

Then there could be another way could be that if suppose you cannot avoid the contact between the components then you can design it in a way that you get slower and smoother contact. Let us say for example in a gear meshing system the spur gears are noisier compared to the bevel gears. And here are both the gears what happens that the gears that are meshing together are colliding, and they are coming in contact. Whenever you engage the gear in any automotive system you sort of press the gear lever and you engage the gears together. Suppose they were spur gears this engagement would be like in the form of the

impact between the two gear teeth. The gears that are coming together so that impact would be created at the moment of engagement. For spur gears, it would be noisier. Why? Because a lot of them are coming together and impacting. Whereas, with bevel gears, the impact happens in a slower way because of the helical structure. In spur gears, you have a linear kind of teeth. The impact happens all at once throughout. Whereas in the case of bevel gears, they slowly make contact. The contact happens at a slower and smoother rate, and that is why they are less noisy. You can redesign the components so that when they are impacting together, they are impacting slowly and in a smoother manner. These are some of the ways in which you can control the impacting noise.

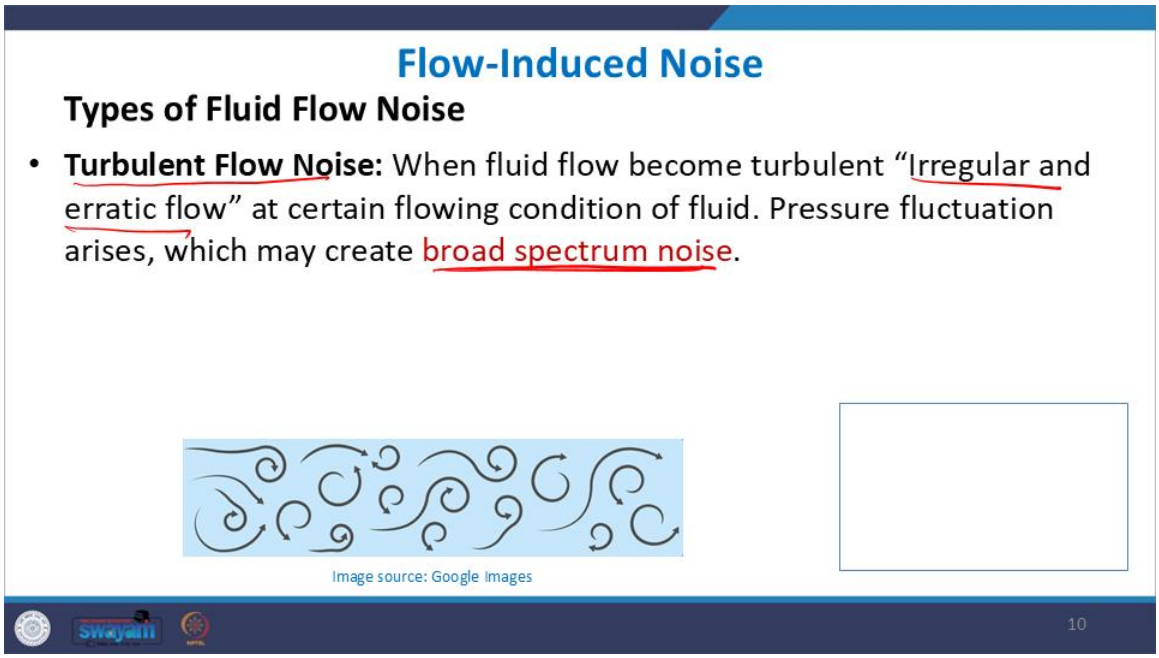


Then, the other type of noise is the flow-induced noise. The fluid flow and the movement of the fluid itself are creating the noise here. What is happening? The gases or the fluids might be going at very high rates through the various mechanical systems, such as the pipes, ducts, valves, etc. And in and around the solid objects. Such as obstacles, and they might be creating noise by means of their flow.

Why do they create noise? The movement of the fluid—because what is it? Noise or sound, in general, is a pressure fluctuation that is being carried forward in air. The pressure fluctuation in the air is being perceived by us as noise.

When the fluid is flowing, due to the disturbed fluid flow, these pressure fluctuations might be created in the process. And these pressure fluctuations, created due to the movement of

the fluid itself, propagate as disturbances or sound waves. Suppose you blow into the open air; it won't be very noisy. But if you place a hard obstacle and then blow into it, it will disturb the airflow. And because of the significant disturbance and turbulence created, some extra pressure fluctuations will result, and that will create noise.



What are the types of fluid flow noise? Within that, you have turbulent flow noise. If you study fluid mechanics, you will find that the airflow could be laminar in nature, which is a more streamlined airflow. And then there is turbulent flow, which means the airflow is very haphazard and disturbed. Very irregular and erratic flow lines result; it is not a streamlined flow. This irregular, erratic flow can happen under certain fluid conditions, such as very high speeds can result in turbulence. The presence of obstacles can result in turbulence. Changes in viscosity can result in turbulence, and so on.

And because of these conditions, pressure fluctuations will result, and they typically give you a broad-spectrum noise. The turbulent flow gives a broad-spectrum noise. Then, the other kind of fluid flow noise is the vortex shedding, which is the oscillating flow. This is the schematic of what is happening. What happens is that the fluid is flowing through, and it is flowing in a perfect manner. And then, suddenly, a bluff body is encountered, or some kind of big obstacle is encountered on the pathway of the fluid. Then what happens? Suddenly, the eddies are formed. Some alternating fluid patterns or oscillations result behind the obstacle.

Flow-Induced Noise

Types of Fluid Flow Noise

- **Vortex Shedding (Oscillating flow):** when fluid flows around obstacle, it forms eddies. Oscillating flow happens at certain velocities, depending on the size and shape of the body. In this flow, alternating low-pressure vortices are created at the back of the body and detach periodically from either side of the body and shed at vortex shedding frequency. Tonal noise is produced.

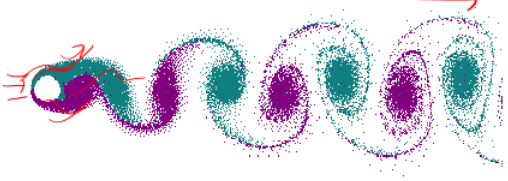


Image source: Wikipedia.org

As you can see here, the fluid is flowing perfectly, and because of the scattering around, suddenly these oscillating pressures are created, and they are created at the vortex shedding frequency, and some tonal noise is produced because of this. This is the oscillating flow that is resulting in pressure fluctuation because of the presence of a certain obstacle in the pathway of the fluid flow.

Flow-Induced Noise

Types of Fluid Flow Noise

- **Flow Separation:** When fluid flow separates from solid surface, it creates region of low pressure and high pressure, can lead to noise generation. Example: Air flow over vehicle or aircraft wing.

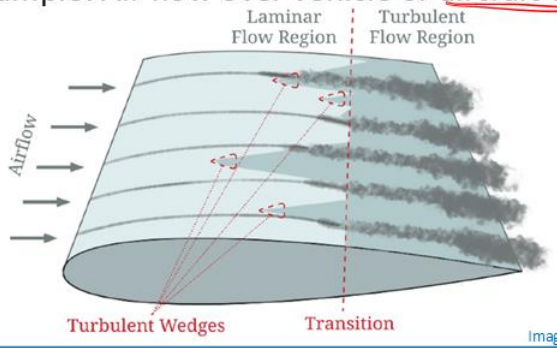
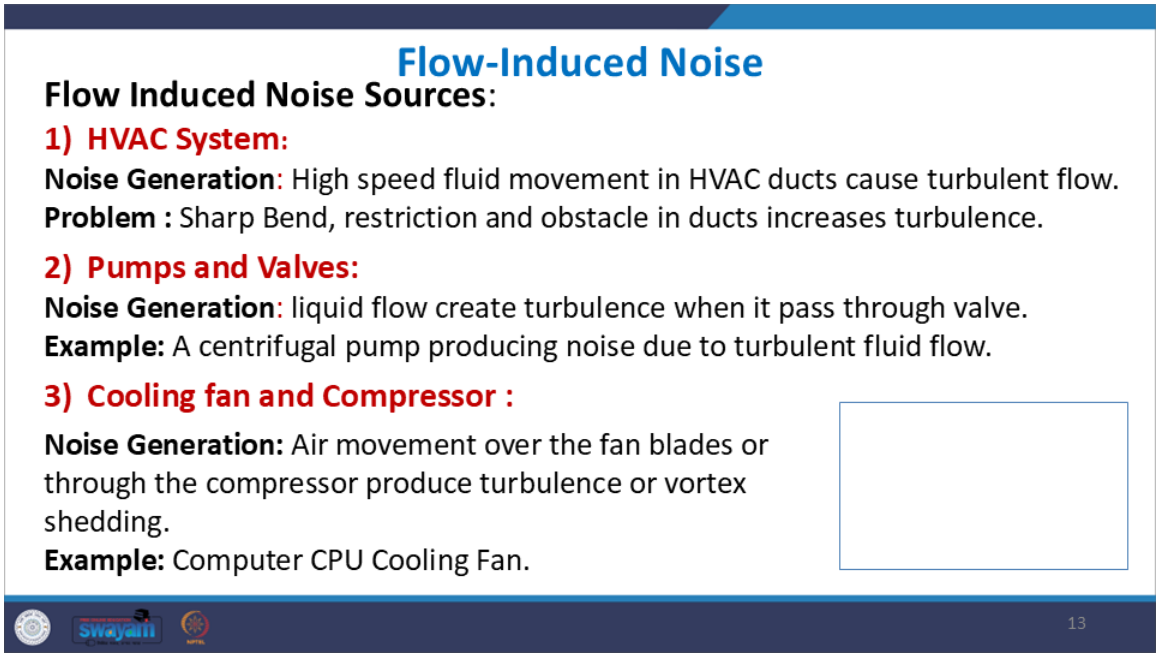


Image source: Google Images

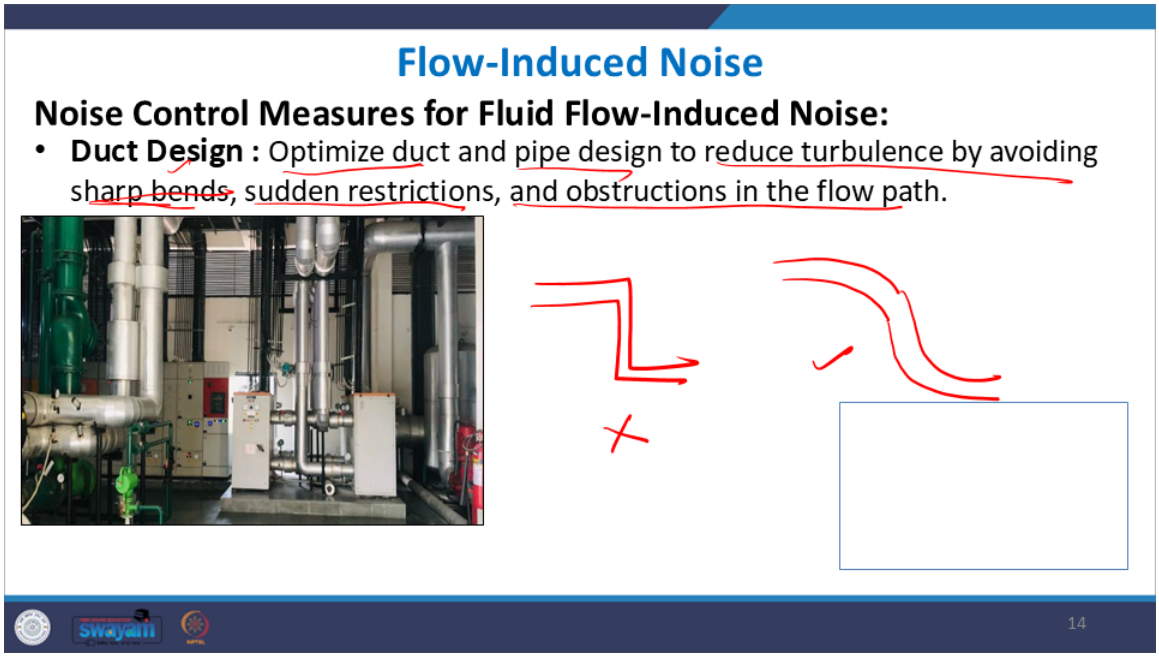
Then, due to flow separation as well, it can happen. Let us see, you have somewhat usually happened when the air is flowing through some kind of solid structure. When the air is flowing over some solid structure, such as over the cabin—over the outside, cabin of a vehicle—or when the air is flowing through the aircraft wing, which is a classic example of this flow separation.

What happens? when it is flowing through it, and suddenly laminar flow changes into turbulent flow while flowing over the surface of this kind of mechanical structure? When this change in the flow happens, some extra fluctuations are created as the air flowing through the structure suddenly separates away from it. Let us say this was your structure, and the air was flowing through it. Due to a sudden change in the geometry at this point, the flow starts to separate from the structure, and some extra fluctuations are created.

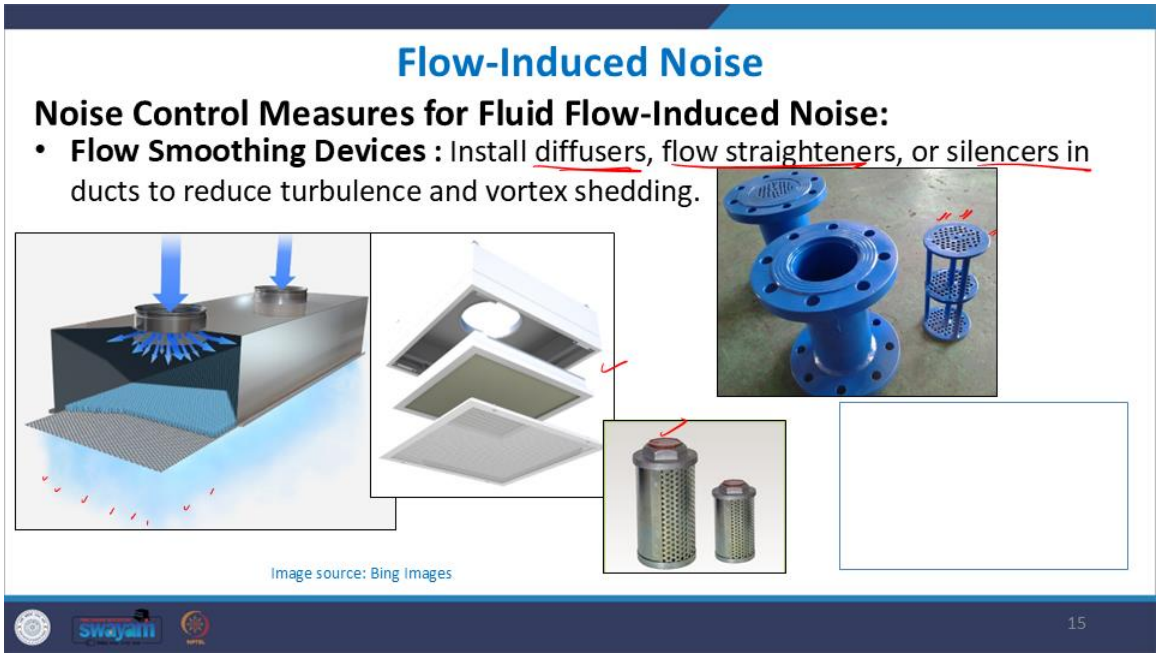


The flow-induced noise sources in HVAC systems are mostly due to the flow of various fluids moving through them. What is the problem? Usually, sharp bends, restrictions, or obstacles present in the ducts of these HVAC systems can create turbulence. Any kind of resistance to the smooth functioning of machinery can create noise. in an HVAC system—suppose an HVAC system is there for a big building— the air flows through the ducts and pipelines. If there are sharp bends, restrictions, dust particles, or any kind of obstacles present along the pathway of these ducts or along the airflow, any such obstacle will lead to disturbance in the flow and increase the noise. Then, in pumps and valves, the fluid flows at very high pressure, and the centrifugal pump produces noise due to turbulent fluid flow.

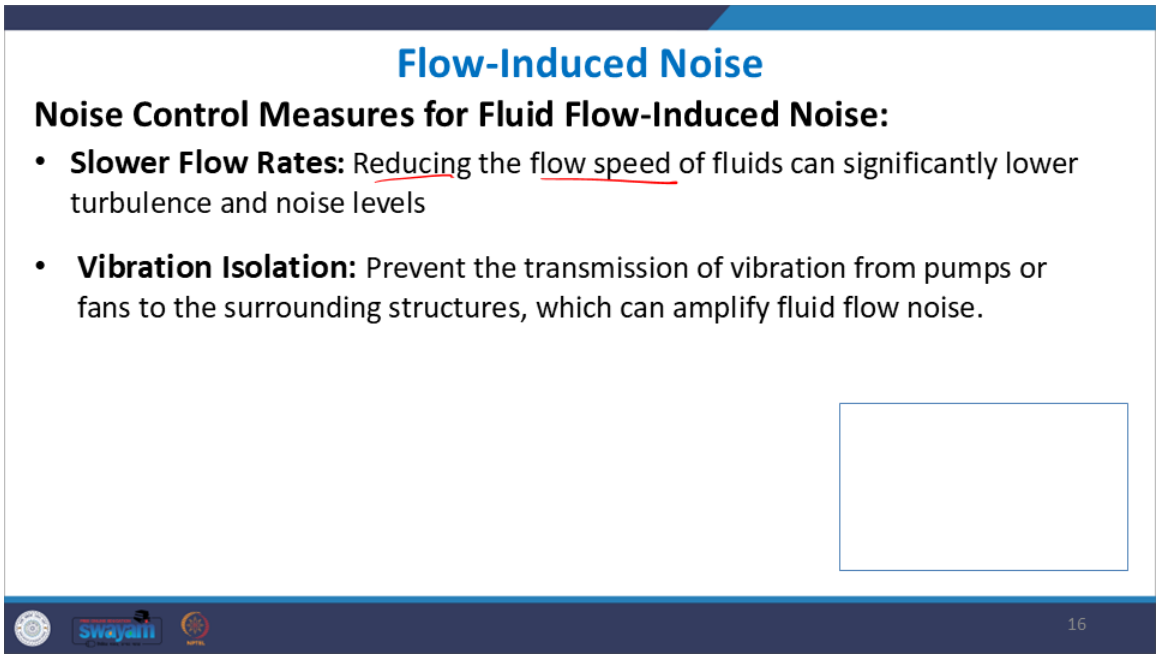
Similarly, cooling fans and compressors involve air movement, and as the fan blades rotate and cut through the fluid, they produce both turbulence and vortex shedding noise. For example, you might have observed that the computer CPU fan makes a lot of noise.



Then, the flow-induced noise is present. The noise control measures that can be used for this flow-induced noise include: First, you can design your duct so that it is smoother. There should be fewer obstructions to the path of the airflow. You can optimize the duct and pipe design to reduce turbulence and avoid disturbances. What can you do? You can avoid sharp bends, certain restrictions, and transitions in the pipe pathway or obstructions in the flow path. For example, instead of having a pipeway like this, you can have smoother bends in the pipeline. This will create less resistance to the airflow and less noise.



Then, you can use various flow-smoothing devices. , there are various devices such as flow diffusers. You have these flow diffusers, flow straighteners, and silencers in the ducts. All of these are used to reduce disturbances in the airflow or reduce turbulence and vortex shedding that may occur during fluid flow through these pipelines and ducts. What are diffusers? Essentially, what diffusers do is diffuse the air and make it pass through regularized sieves so that the flow is uniformly distributed. The concentrated, disturbed flow gets uniformly distributed after passing through these diffusers. They are made of sieve-like structures that evenly distribute the airflow. Then, these are the flow straighteners, which again contain hole-like patterns. When the disturbed airflow passes from one end to the other, it has to pass through these regular orifices, which help make the flow more streamlined and reduce disturbances in the airflow. The air has to pass through these sieve-like structures or regular orifices, which help control the airflow and gives it a streamlined path.



What are the other noise control measures? You can have slower flow rates. You can have the machinery, where the flow speeds could be reduced. It is going to significantly lower your turbulence and noise levels. Then vibration isolation. Because of the fluid flow the pipe that is carrying it could start vibrating so you can have the pipe could be better fixed to the structure so that the vibration could be reduced. Some vibration isolators could be used proper fixing of the pipe could be done so that the vibration could be done. The last type of noise is the fluid structure interaction noise.

Fluid structure interaction Noise

- **Fluid-Structure Interaction**

Interaction between fluid flow and a solid structure, where the motion of the fluid affects the structure, and the structural motion, in turn, influences the fluid flow.

- **Dynamic Coupling:** Fluid (air or water) and the structure (e.g., walls of pipes, ducts, or mechanical parts) respond to each other's motion, causing a two-way dynamic interaction.
- **Noise Generation:** As the structure vibrates due to fluid forces, it radiates sound waves into the surrounding air, resulting in audible noise.

What happens is that the fluid is flowing through, and it is creating noise. When the fluid flow itself is creating a noise that is called the fluid induced noise or simply fluid flow noise. But when this fluid flow encounters a solid structure and excites the structure so that the structure now starts vibrating because of the fluid that had flown into it. Fluid flow has set the structure into vibration and now this solid structure radiates the noise because of its vibration that is called the fluid structure interaction. Fluid flow is exciting the solid structure and then the solid structure which is exciting is now creating the noise. The dynamic coupling happens between them and the noise gets generated and usually it is the audible noise because of the radiation of the sound waves from this excited solid structure.

Fluid structure interaction Noise

Types of Fluid-Structure Interaction-Induced Noise:

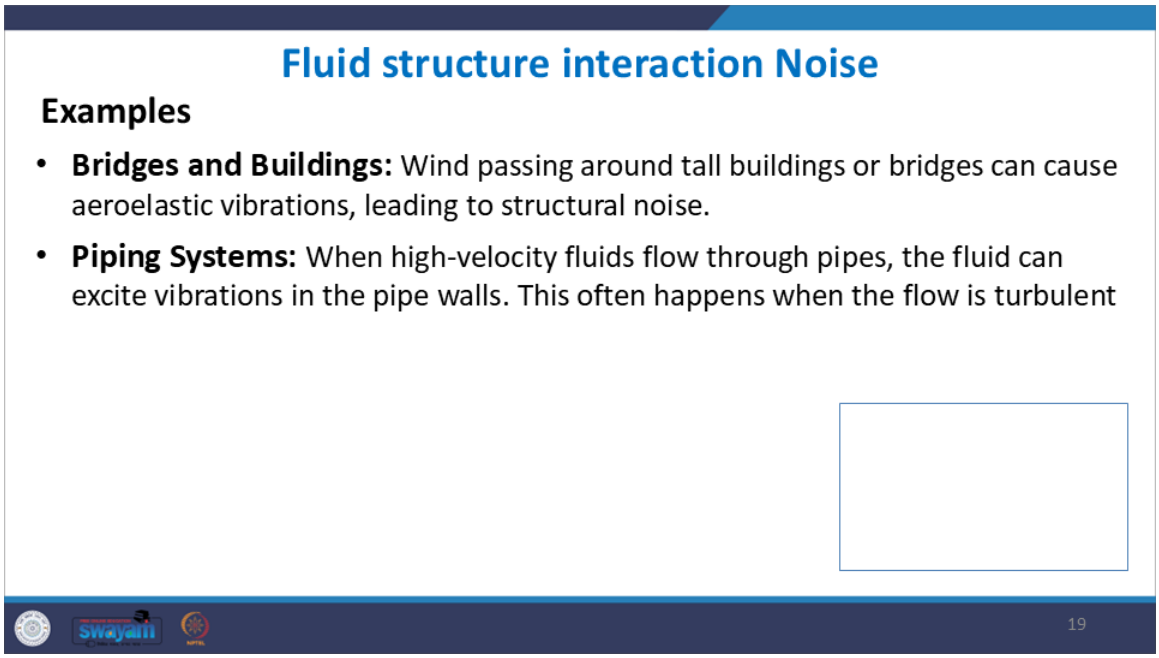
1) **Aeroelastic Flutter:** Fluid flow induces self-excited oscillations in a structure, such as an aircraft wing or a turbine blade. This leads to both vibration and noise.
2) **Flow-Induced Vibrations:** When fluid flow causes structures like pipes or beams to vibrate. These vibrations may result in audible noise if the flow velocity is high enough.
3) **Acoustic Resonance:** When the frequency of the fluid flow-induced vibrations matches the natural frequency of the structure. This leads to amplified vibrations and high noise levels.

Image Source : https://makeagif.com/ /gif/airflow-during-a-stall-f-hV1_

Where do you encounter them? usually it could be encountered in the form of aeroelastic flutter. For example, suppose you take your journey on an airplane, and you just notice the wings. Sometimes, especially when the wings are cutting through the air of the atmosphere, and particularly during turbulence, it can set the wings into motion.

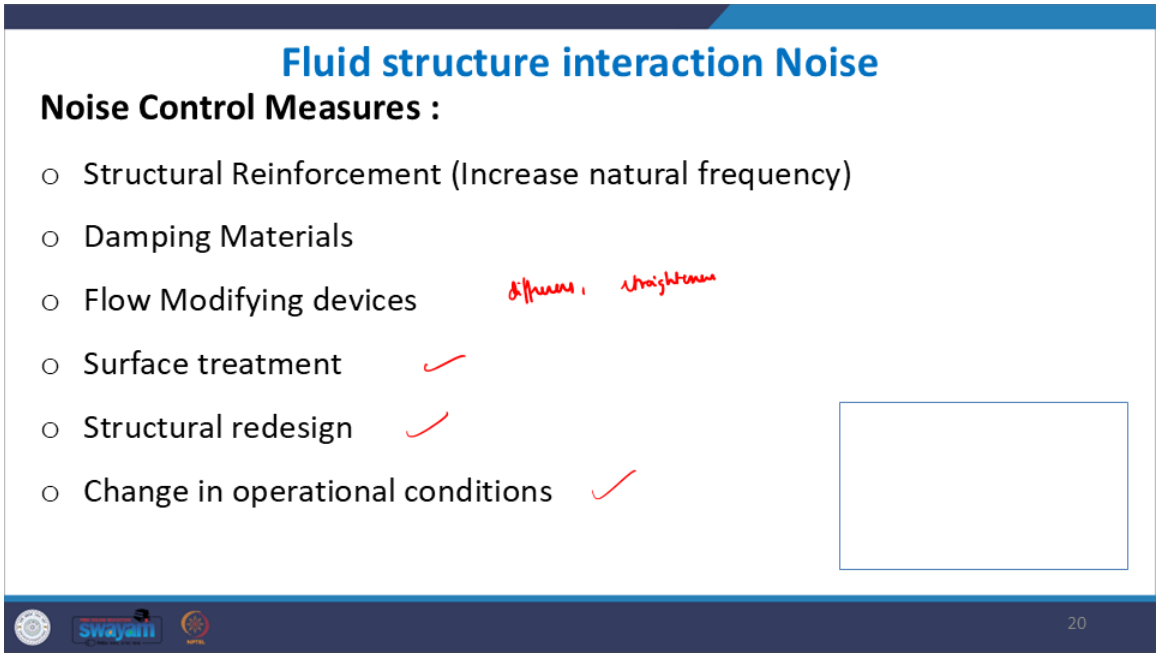
What is happening? The flow of the air is setting the wings into oscillatory motion, and this creates the noise. This is again a fluid-structure-induced noise. The fluid flow is inducing some self-excited oscillations in the structure, such as in the aircraft wings or a turbine blade.

Then again, flow-induced vibrations could result when the fluid flow causes the structures in the pipes or the beams to vibrate, which is known as flow-induced vibrations. Then, resonance again—when the frequency, suppose the fluid is flowing and interacting with the structure, and if this happens at the frequency of the structure, when the natural frequency of the structure matches with the flow-induced vibrations because of the fluid, then the same flow-induced vibration at resonance gives you amplified vibrations and high noise levels.



Usually this is encountered in bridges and buildings when the wind is passing around the tall buildings and bridges, causing these aeroelastic vibrations and structural noise. Even in the piping system, high-velocity fluids are flowing through and leading to the excitation of the pipes, setting them into vibration.

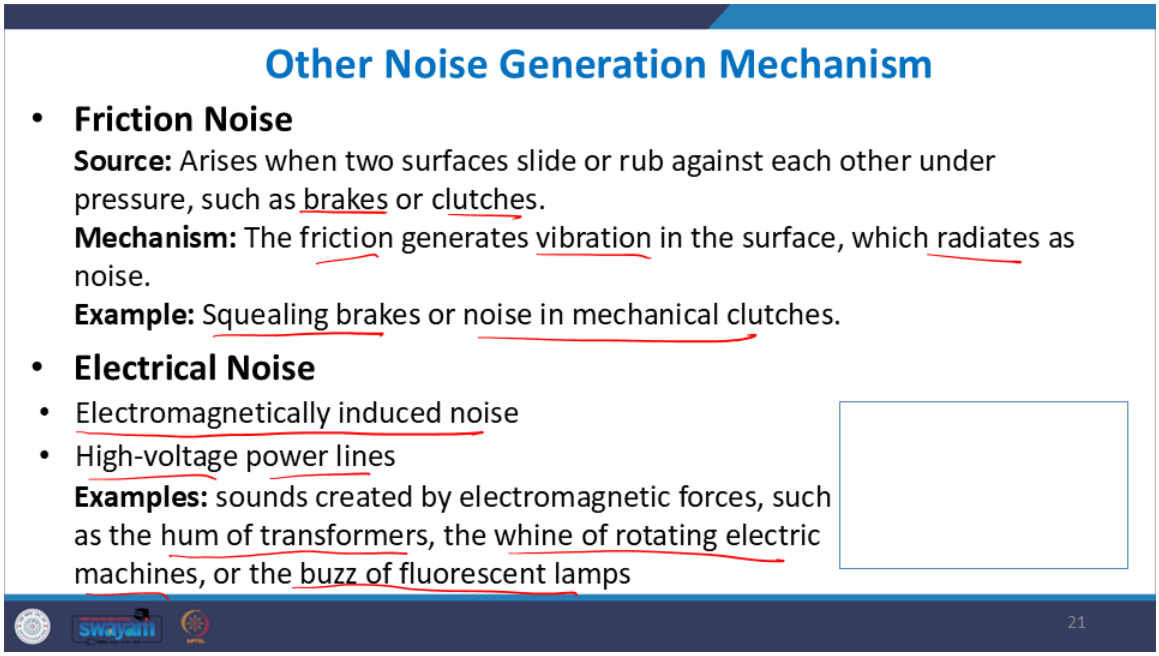
And especially when the flow is turbulent, this can happen.



What are the noise control measures? Structural reinforcement can help increase the natural frequency. When you increase the natural frequency of the structure, even if the fluid flow excites it, it will not excite it at its natural frequency. So at least the resonant vibration can be avoided, because resonance will create a much higher amplitude vibration and a much higher noise level. If you can make the natural frequency of the structure very high, much higher than the frequency of the flow-induced vibrations—then you can also control the noise. You can use damping materials or various flow-modifying devices like diffusers. The straighteners, which we have already studied in the case of fluid flow noise. These devices can also be used so that the fluid flow becomes smoother and does not excite the structure sharply. Surface treatment could be done, such as modifying the design of the structure so that the fluid flow does not couple with the structure directly. Then, a redesign of the structure can be done. Changes in the operational conditions can be made, and all of this can result in controlling the fluid-structure interaction noise.

Various other mechanisms are also there, such as frictional noise, which arises whenever two surfaces slide and rub against each other, such as in brakes and clutches. Again, the friction generated creates vibrations in the surface, which then radiate into the air as noise. For example, the squealing brakes or the noise in mechanical clutches are typically the

noise due to friction between the two components. This friction itself creates vibration, which radiates as noise.



We also have electrical noise in many of these mechanical components. These are electromagnetically induced noise. High voltage power lines usually encounter this. The sound is created by the electromagnetic forces. Again, this is an unbalanced force which leads to the vibration of the structure or pressure fluctuations, which are then converted into sound, such as the hum in the transformers that you observe, the whine in the rotating electrical machines, the buzz of the fluorescent lamps. All of this creates noise, and this is typically electrical noise that is being produced. with this, I would like to close this lecture. Thank you for listening.