NOISE CONTROL IN MECHANICAL SYSTEMS

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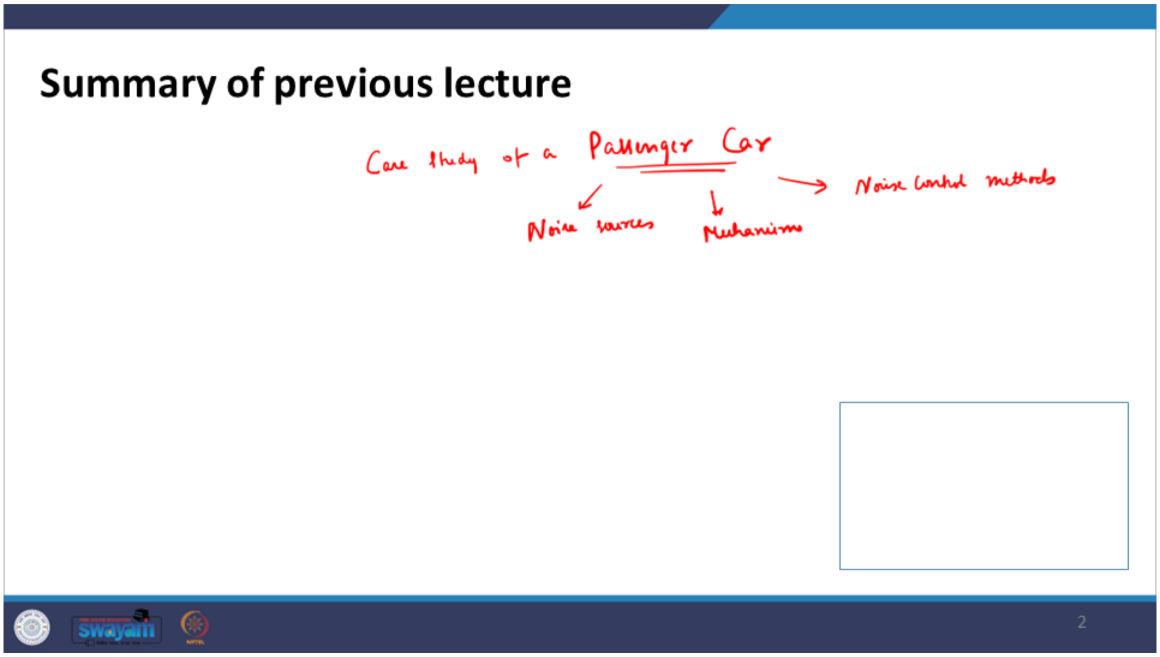
Week: 12

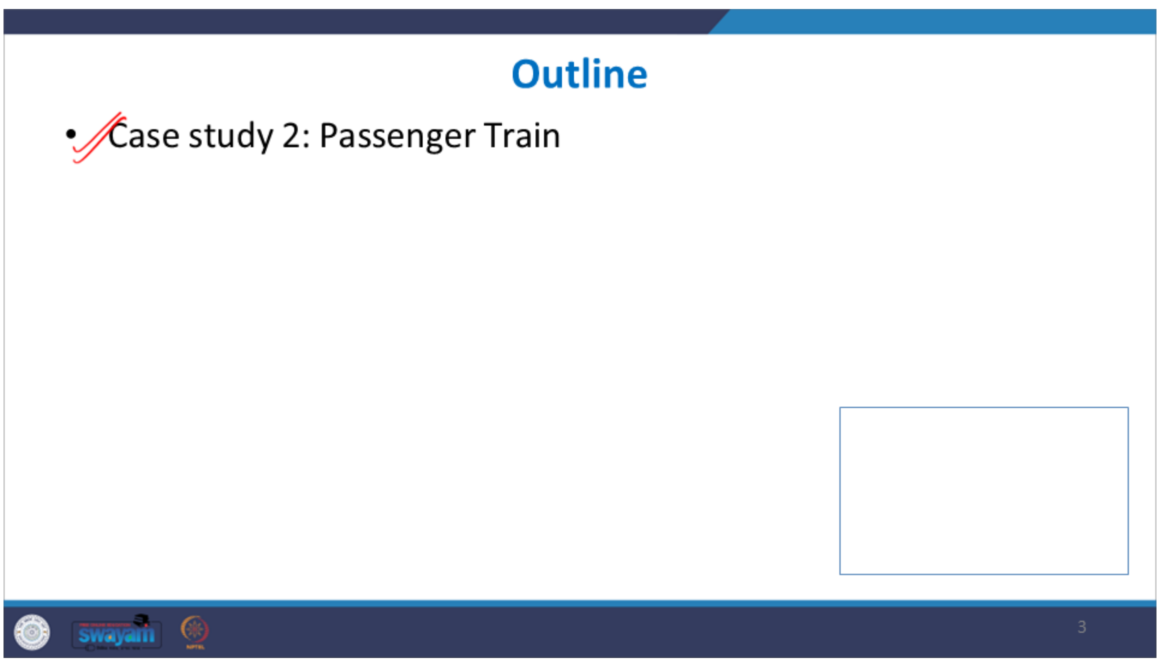
Lecture: 57

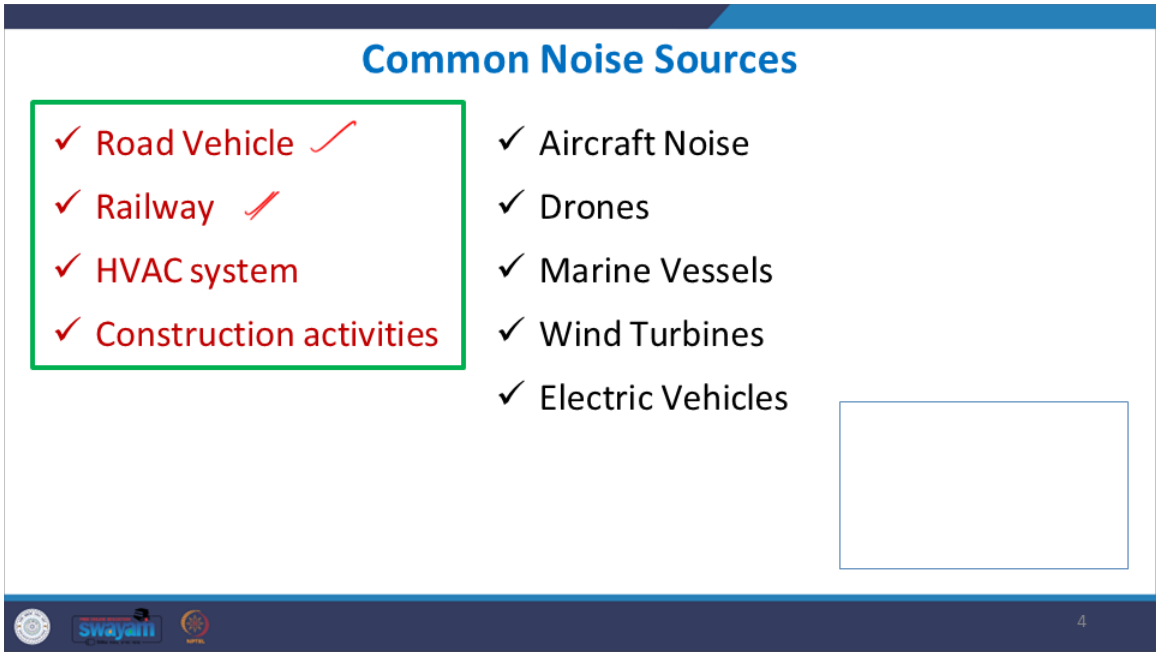
Lecture 57: Case Studies of Noise in Mechanical Systems 2

Hello and welcome to this lecture course on noise control in mechanical systems with myself, Professor Sneha Singh from IIT Roorkee. So, we have been discussing some case studies of noise in mechanical systems, and we have just finished the case study of a passenger train sorry, a passenger car. And what are the typical noise sources within this passenger car? What are the mechanisms involved?

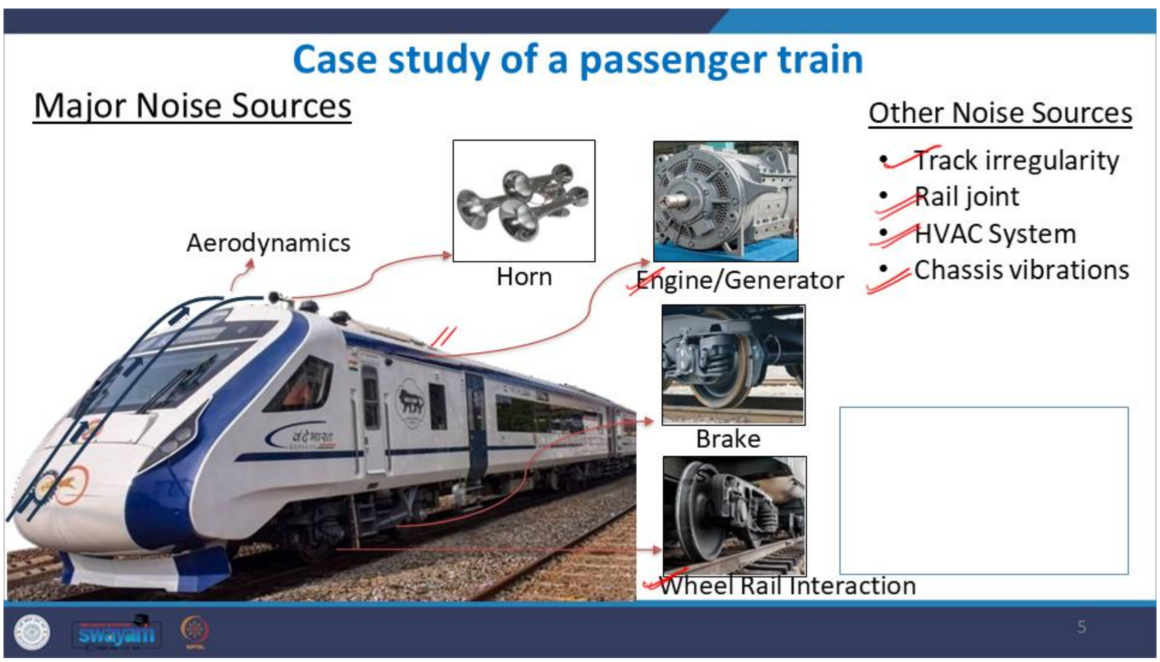


What are the noise control methods used in modern passenger cars for proper noise control? So, in today's lecture, we will study the second case study, which is the case study of a passenger train. So, again, these are the common noise sources that we are discussing. We have discussed a car, then we are discussing a railway a passenger train—and after that, we will discuss an HVAC system as a case study.



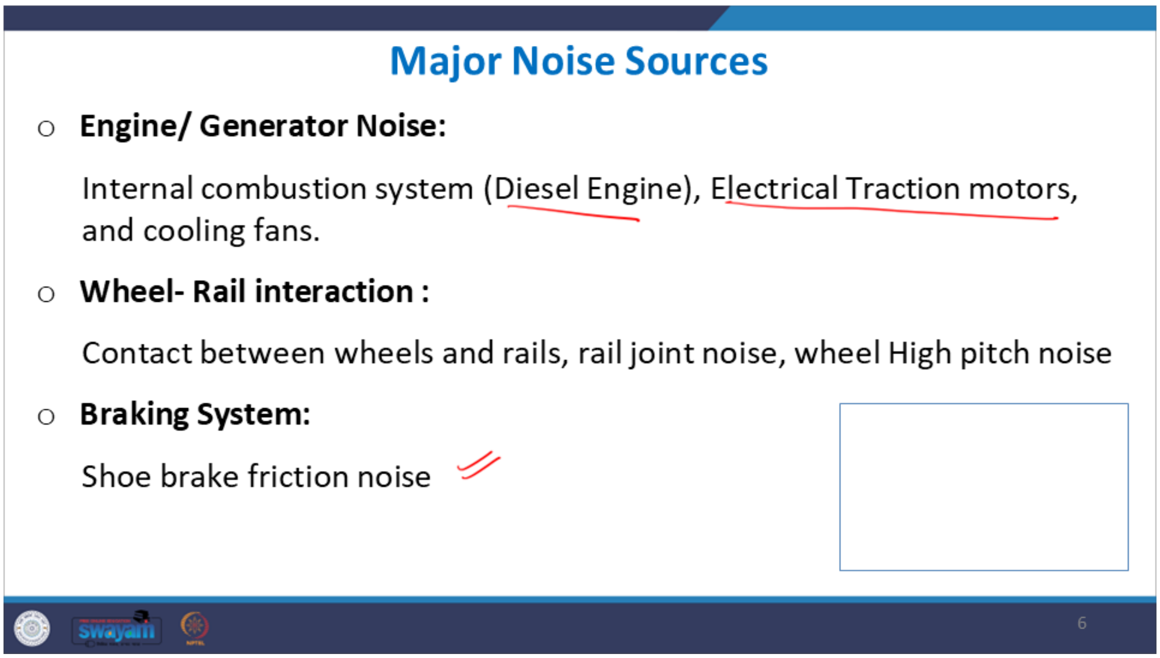


So, the case study of a passenger train.



So, as you can see, this is one of the latest semi-high-speed trains in India, which is the Vande Bharat, whose picture has been shown to you. With reference to this particular train, we are seeing what the various noise sources are. So, as you can see, first and most importantly, the power source of this train drives it, which could be the engine or the generator utilized inside this train. Then you have the braking system that is used, the wheel-rail interaction—which is one of the major noise sources—and then the aerodynamic noise due to the airflow over the train, as well as noise from the horn and whistles of the train. What you see is that the major noise sources—because both a passenger car and a passenger train are automobiles—are similar.

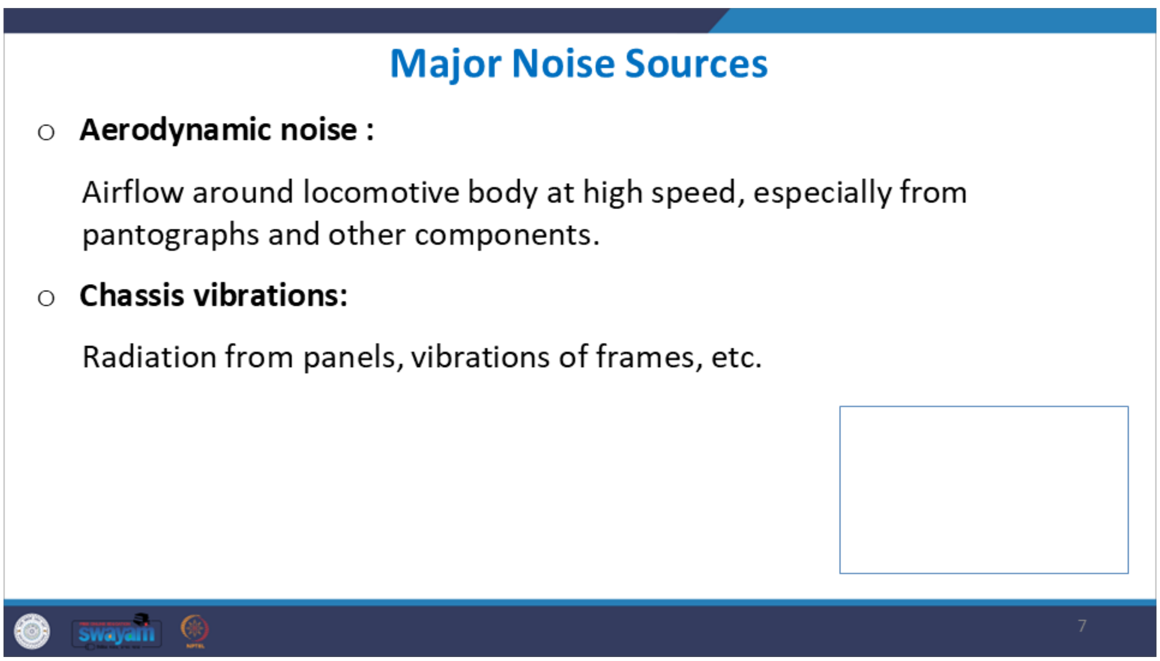
So they will have quite similar kinds of noise sources and also quite similar kinds of mitigation mechanisms. So let us individually see all of these noise sources. Some other noise sources include track irregularity, rail joint interaction, the HVAC system that might be employed within this passenger train, as well as chassis vibrations. So let's see them one by one. The engine or generator noise is the power source of the passenger train that drives the train.



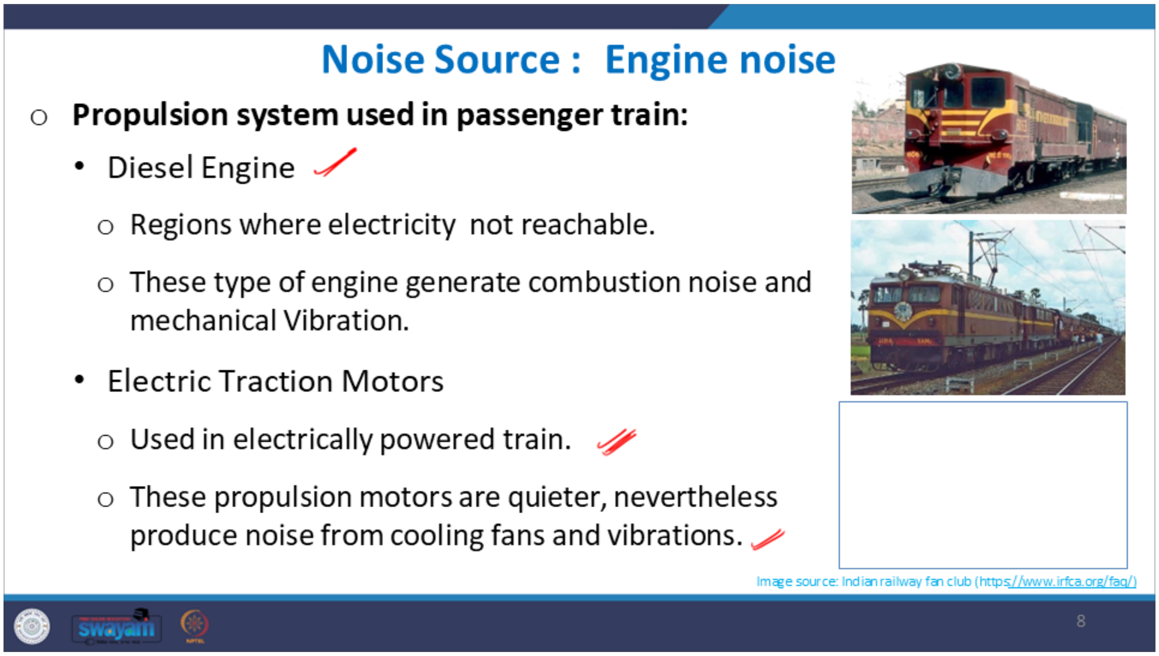
It can either have an internal combustion engine, a diesel engine installed, or electrical traction motors used along with cooling fans. In most of the new—I mean, slowly India is heading towards electrification of its railway fleet. So most of the newly developed trains, they are coming as electrically powered trains where electric traction motors are used. But in some older versions of trains, especially those operating in areas where the electricity line is still not continuous—in some of these rudimentary areas—we still have diesel engine trains. Wheel-rail interaction is mainly the noise due to the contact between the wheels and the rails, as well as the various kinds of noises that could be generated when they make contact.

The first could be rolling noise, just from the wheels rolling over the rail. Then there could be—since railways are spread all across India—between any two rail tracks, you have joints where they are welded together. So at these rail joints, there could be certain disjunctions, or at the time when railways are turning and shifting from one track to another. At that time, there could also be a disjunction or discontinuity between the railway tracks, and all of these joints and discontinuities will lead to sudden jerks, vibrations, and noise. As well as sometimes, you have this high-pitched noise that comes from the wheel-rail interaction.

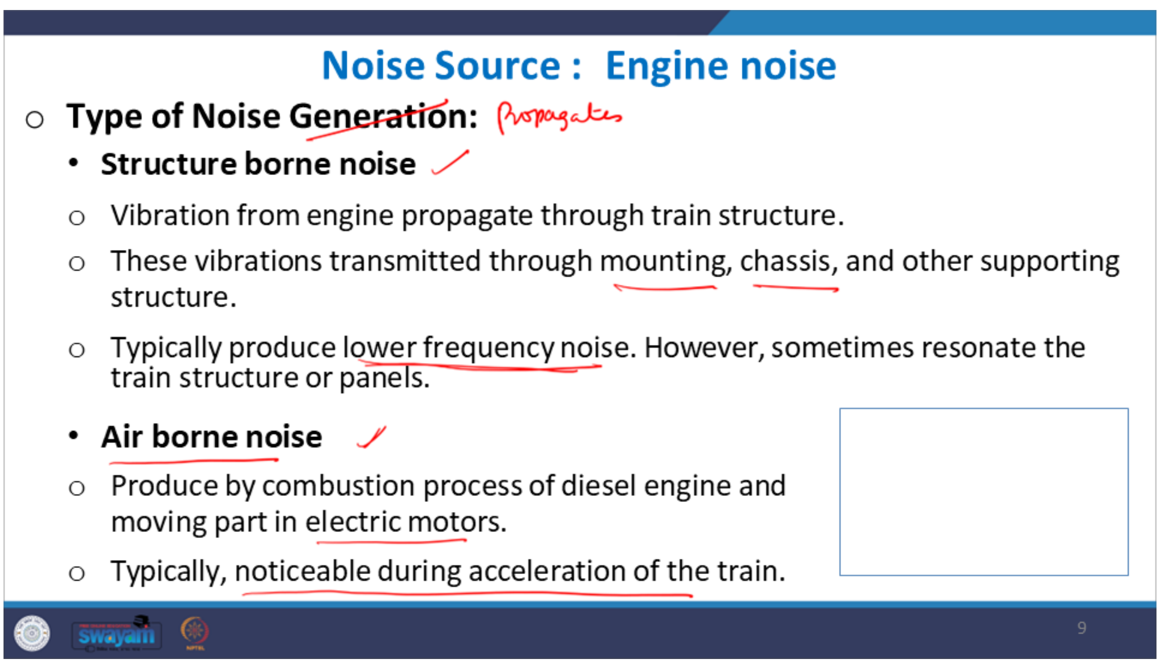
The braking system, usually the shoe brake friction noise, is generated using the braking system of typical passenger trains. Then, you have the aerodynamic noise. So, the airflow around the locomotive body at high speed around various other outer body components, such as the pantographs or various other exposed components of the train. Whenever the train is moving at high speed, the air flows around it, and due to this, turbulence is created, and the aerodynamic noise occurs. Then, we have the chassis vibrations, which are usually the vibrations from the frames.



From the various other components, as well as the radiation from the panels, all of this is structure-borne noise. Then, let us see what the typical engine noise is that is created. So, as already discussed, the propulsion systems used in passenger trains are the diesel engines and the electric traction motors. So, the diesel engines are used in regions where electricity is not very accessible, and these engines generate combustion noise and mechanical vibrations. The electric traction motors are usually used in most modern passenger trains, and here, the propulsion motors are much quieter.



Nevertheless, they produce noise from the cooling fans and vibrations. So, in the engine noise, what is the mechanism of the propagation of the noise? Rather, the mechanism through which the noise propagates—we already know the sources. The sources could be the engine itself, the cooling fans, or the vibration of the various components present in the engine or the motor. Then, how do they propagate through?



They can obviously exist either as structure-borne noise or as air-borne noise. So, what happens in the structure-borne noise? The vibration from the engine propagates through the train structure. And these vibrations are transmitted through the mounting, the chassis, and the other supporting structures. And they typically produce low-frequency noise, as already discussed in the previous lecture, where we made a distinction between the structure-borne and the air-borne noise.

You know that structure-borne noise is typically low-frequency because those noises propagate very easily through the structures. So, the high-frequency noises attenuate. So, low-frequency noise propagates through the structure in terms of the vibration of various engine components, OK, and goes through the mountings, the support structures, the chassis, and other things, and finally enters inside the cabin. And not just that—engine noise cannot only propagate as structure-borne noise; it can also propagate as air-borne noise. And that could be due to the combustion process of the diesel engine.

The process of combustion and the process of the release of exhaust will create noise. And in the case of an electrically powered train, the moving parts in the electrically powered train—the moving parts of the electric motor that are directly exposed to the outside atmosphere—will again radiate noise indirectly into the air as airborne noise, and this airborne noise becomes typically noticeable during high speed or when the air is accelerating at a high rate. Let us see the noise characteristics of the engine noise. So, what you see here are the various sources.

Noise Source : Engine noise

- **Noise Characteristics:**

Source	Frequency ranges-Hz	Factor effecting
Combustion noise	500-8000	In cylinder pressure
Piston slap	2300-8000	Skirt-liner gap
Valve noise	500-2000	Acceleration ,valve seat gap
Cooling fan	200-2000	Engine speed
Intake	50-5000	Engine speed
Exhaust	50-5000	Engine speed
Injection	2000	Pump type
Gear	4000	Number of tooth
Accessory	3000	Alignment

Source: N., Nair. (2016). ANALYSIS OF VARIOUS NVH SOURCES OF A COMBUSTION ENGINE. Tehnicki glasnik. 10. 29-37.

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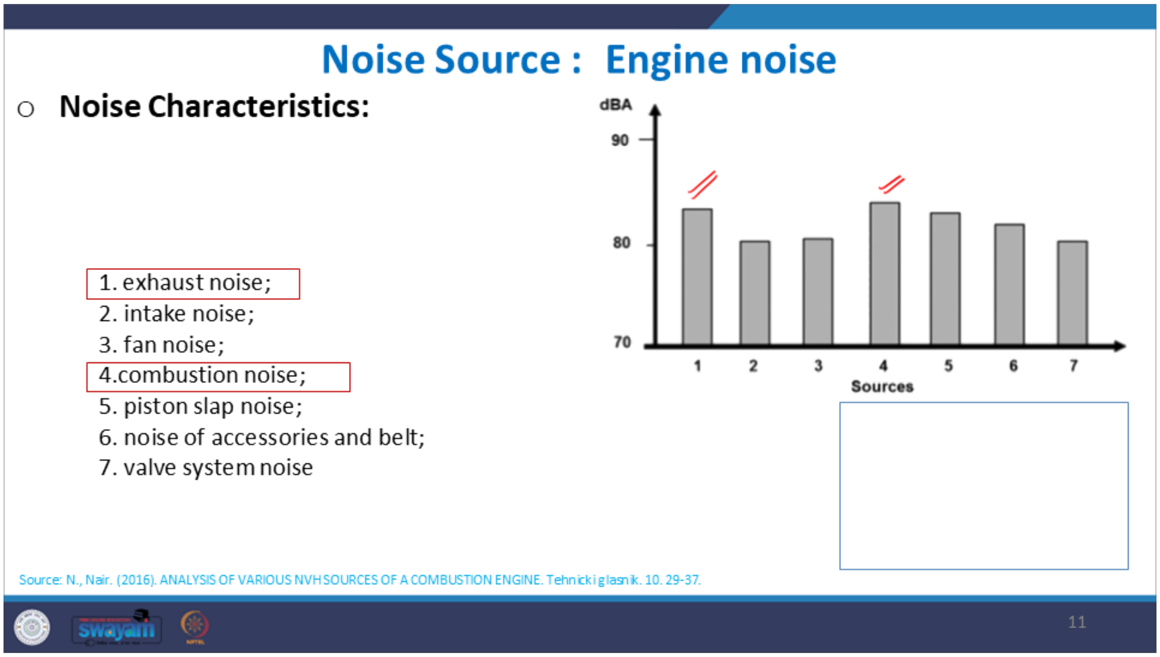
We have the combustion noise, the piston slap, valve noise, cooling fan, the intake, exhaust, injection, gear, and accessory. These are the various sources and the typical frequency ranges that are observed. For the combustion noise, we have between 500 to 8000 Hz. Similarly, for the exhaust, you have between again 50 to 5000 Hertz and so on. And what are the factors that affect it?

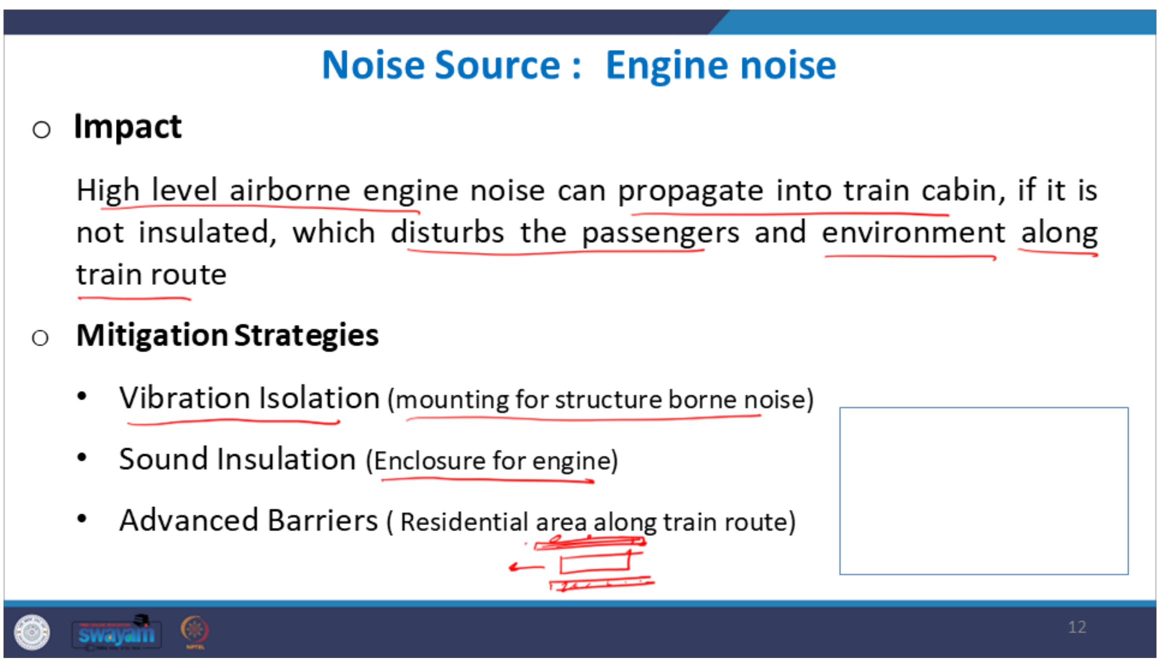
For example, in the case of combustion noise, it is the typical, you know, make of the engine, and the pressure and the temperature at which the cylinder of the engine is operating will decide how much combustion is taking place and what is the noise produced. In the case of the piston slap as well, the skirt liner gap between these components is going to decide the noise. The valves that are present—again, the acceleration of the vehicle—because if it is accelerating at a high rate, a wide throttle condition is there, the valve will be opening more, there will be a larger valve seat gap, and hence a higher amount of valve noise will be generated, and vice versa. The cooling fans that are used in these engines and motors again create noise, and typically the noise depends on the engine speed because the higher the speed of the engine, the more is the heat generated, the more is the combustion taking place. So, more is the heat being generated, and hence you need the fan to move at a higher rate, which leads to higher noise in the cooling fan.

In the same way, the intake, exhaust—all of them are directly linked to the engine speed because the engine speed, or simply what you typically call the engine RPM. How fast the engine is operating will decide what are the number of intake cycles in one second, what are the number of injection or exhaust cycles in one second, and the higher the speed, the more will be the rate of intake, the more will be the rate of emission of the exhaust, the more will be the combustion taking place. And hence, the more will be the noise that is generated. If the gear systems are being used in the engine, then the number of teeth in the gear will decide the frequency content of the noise. And for various other accessories that are being used, the typical condition of the accessory—for example, the alignment of the accessory or the mass balancing, how much the mass is being balanced, whether it is aligned properly or not, the lubrication, and the maintenance condition of these accessories.

Will decide the level as well as the frequency content of the noise due to the other auxiliary components of the engine. So, from this paper, what the authors have observed is that they measured the noise due to the individual components within the engine, and what is seen is that the combustion noise is the noise number 4. And the exhaust noise, or the source number one, they are the two most dominant noise sources.

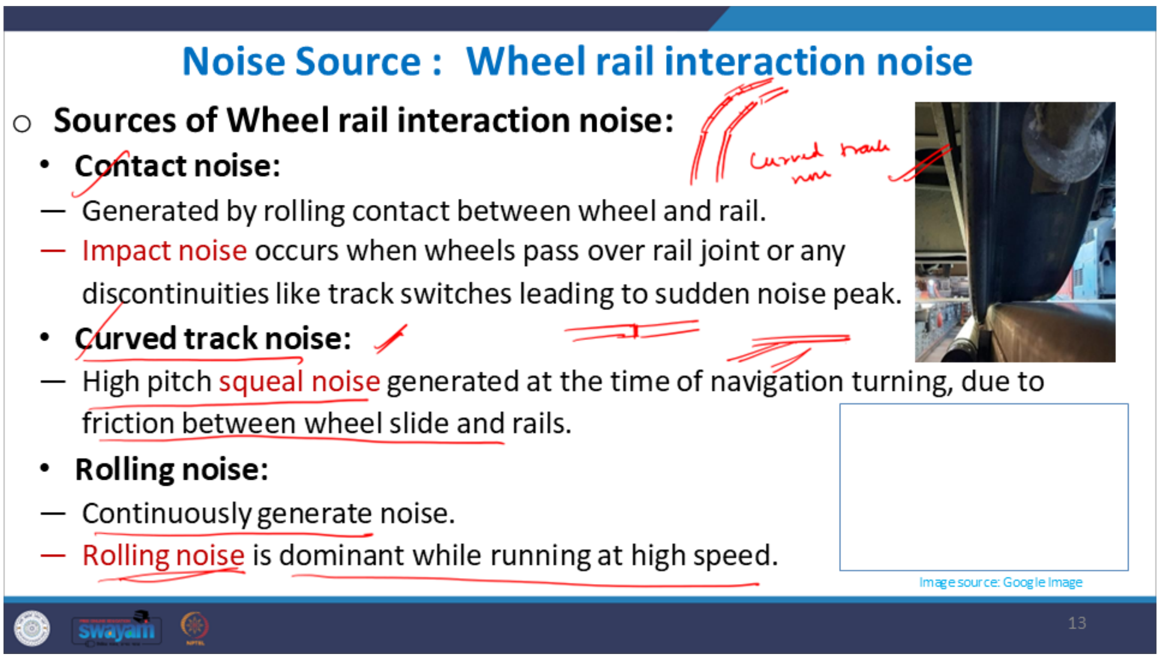


Now, what is the impact of this engine noise? High-level airborne engine noise can propagate into the train cabin.



And if the train cabin is not properly insulated, obviously, it's going to cause disturbance to the passengers. And when the air is passing through, this airborne noise can propagate into the nearby environment, whichever is present along the train route. So, what would be the mitigation strategies? Because we know that engine noise propagates both as structure-borne as well as airborne. So, for the structure-borne component of the engine noise, the typical vibration isolation strategies can be used.

So, the mounting for the structure-borne noise can be used, and sound insulation can be done, or the engine can be enclosed. Then, advanced barriers such as the residential area along the train route. If residential areas are present along the train route—suppose this is your train that is moving and there are some residential areas—then typical barriers can be installed. On both sides to isolate the train noise from propagating into the residential areas nearby. The other source of noise is the wheel-rail interaction noise.

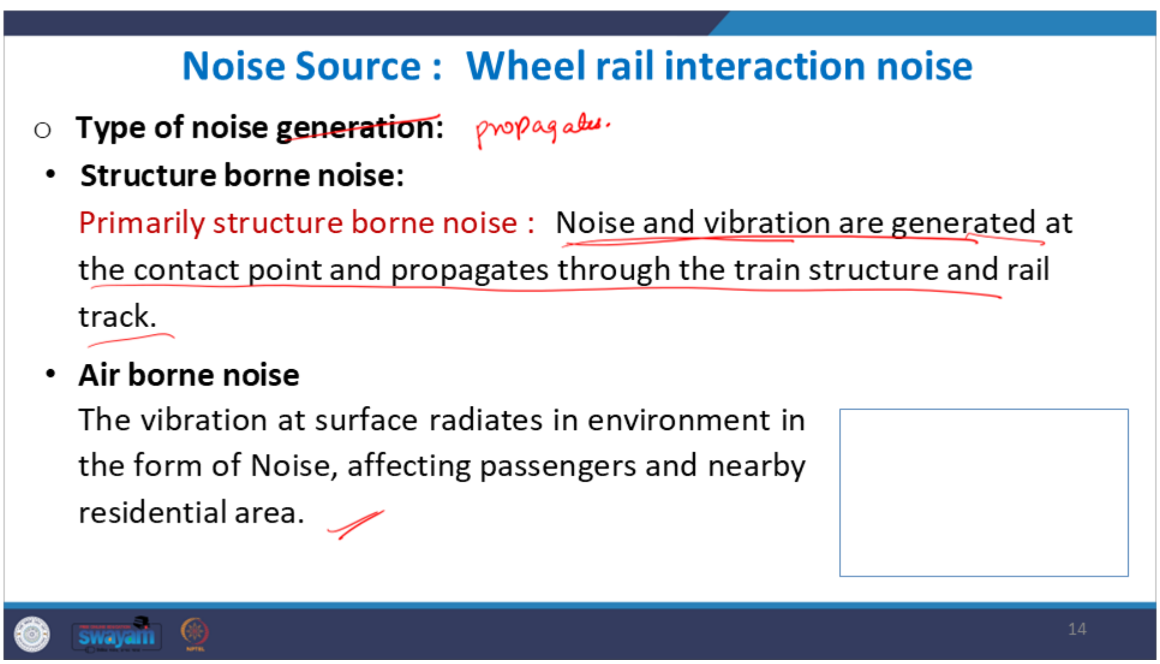


As seen in this picture, So, the wheel rail interaction noise can be either you know in the form of contact noise. So, what happens here is that this contact noise is generated by the rolling contact between the wheel and the rail okay. So, the contact noise is generated by the rolling contact between the wheel and the rail and this you know. is in the form of the impact noise that occurs when the wheel pass over the rail joint or any other form of discontinuities that might be present in the track.

For example, whenever two tracks are being joined together using welding or something or whenever there is a change in the track, So, any kind of such discontinuities that might take place will impact the contact noise. The curved track noise, typically when you know the train track, the train is going to move along and it is sort of turning along some curved path, okay, this curved track noise. What happens is that continuously the path is changing so there are continuous there continuously there is you know this disjoint or discontinuities in the smooth train track and in this particular scenario some high pitch squeal noises

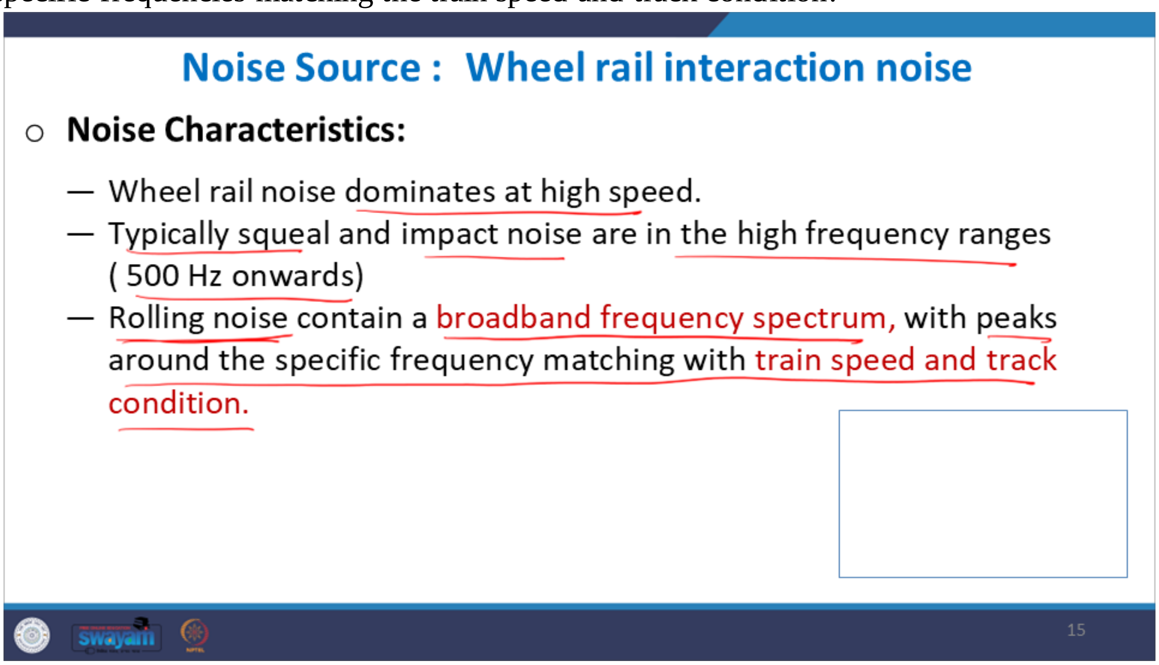
generated at the time of navigation turning and this is mainly because of the friction between the wheel slides and the rail they create this tonal high pitch noise because of the friction during the turning paths the rolling noise so in the wheel rail interaction just the mere contact It propagates the sound, the passing through the curve generates high pitch squeal noise and just the mere phenomenon of the wheel rolling over the track, this rolling phenomenon itself creates the noise and this is the continuously generated noise which is present and it is very dominant at high speed. In fact, what we have observed in the case of a car is that the rolling noise typically increases sharply with the increase in the speed and very soon it takes over and becomes the most dominant noise. So, at low speed conditions usually the engine noise is more dominant but as the speed increases the rolling noise takes over and becomes the most dominant noise source. And in the case of train also, the same pattern is observed which means that as the speed of the train increases, the rolling noise becomes highly dominant.

Now, let us see how this noise propagates. So, the wheel-rail interaction noise is primarily structure-borne noise, okay, unlike the engine noise where we have almost equal contribution of the air-borne and the structure-borne component. In the wheel-rail interaction noise, the structure-borne component has a much higher contribution, and the air-borne component is low. So, the structure-borne component is primarily because it is a structure-borne noise.

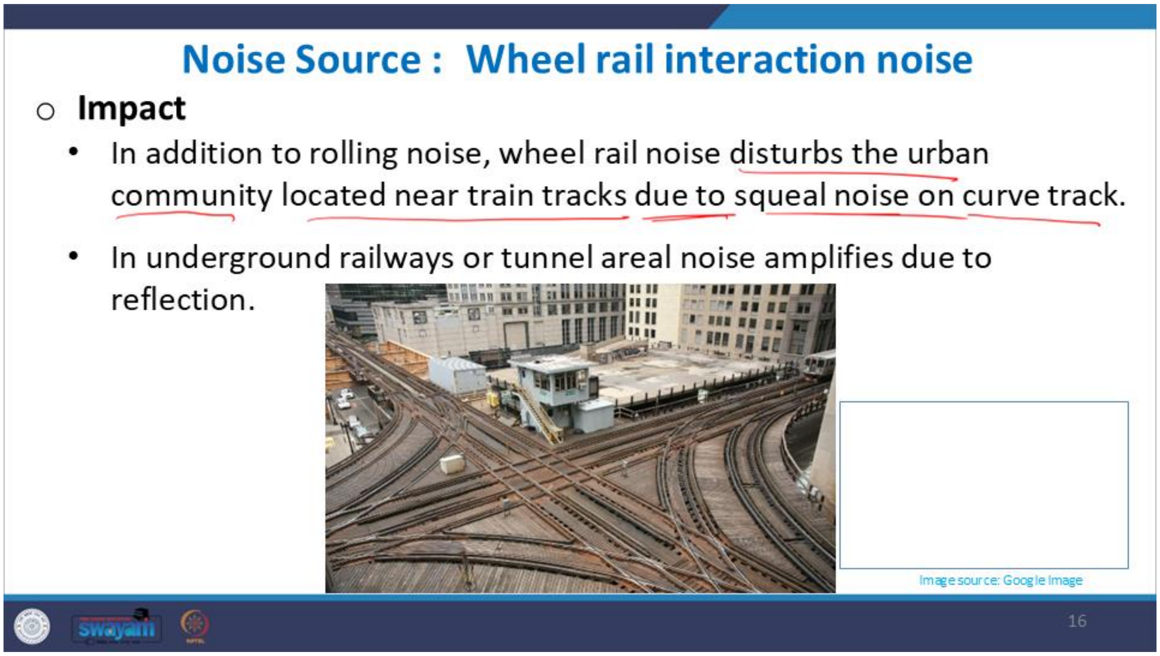


It is due to the contact between the wheel and rail, and whatever road inputs are there—whatever discontinuity or roughness in the wheel-rail interaction—it will be passed on as vibration. And from the wheels into the rest of the structure of the train. So, basically, this contact and curved track noise is the structure-borne noise. It will propagate, and even the phenomenon of rolling will be perceived and passed on as the vibration of the wheel, which will further propagate into the body of the train as structure-borne noise. The air-borne noise Again, the vibration at the surface radiates into the environment in the form of noise, affecting the passengers and nearby residential areas.

So, the wheel-rail noise, as already mentioned, dominates at high-speed conditions. Typically, the squeal and the impact noise are in the high-frequency ranges, 500 Hz onwards. But the rolling noise, which is continuously generated due to the wheel-rail interaction, has more of a broadband frequency spectrum. It has small peaks around specific frequencies matching the train speed and track condition.



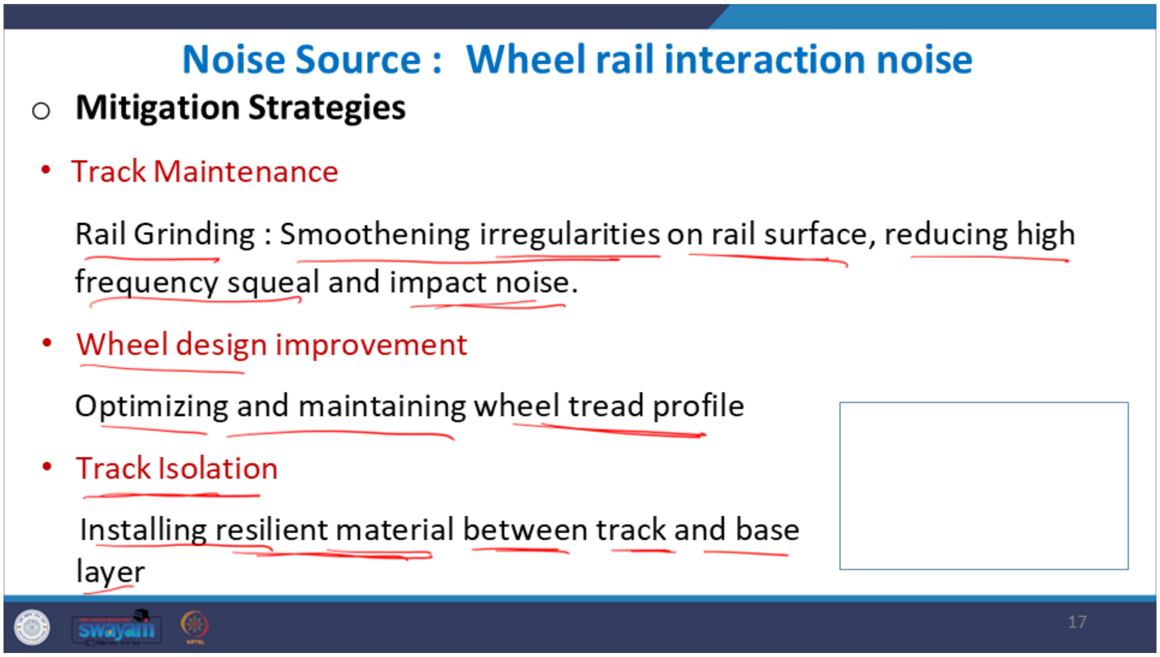
So, what is the impact of this wheel-rail interaction noise?



As already mentioned, in most trains, as soon as the train attains a certain higher speed—and most of the time, trains run at high speeds—okay. So, for most of the duration of the train's run, you can say. So, for most of the duration of the train's run, it is the wheel-rail noise that is the most dominant noise created by the train. And definitely, it is the most dominant or the loudest noise. It is going to create a lot of disturbance.

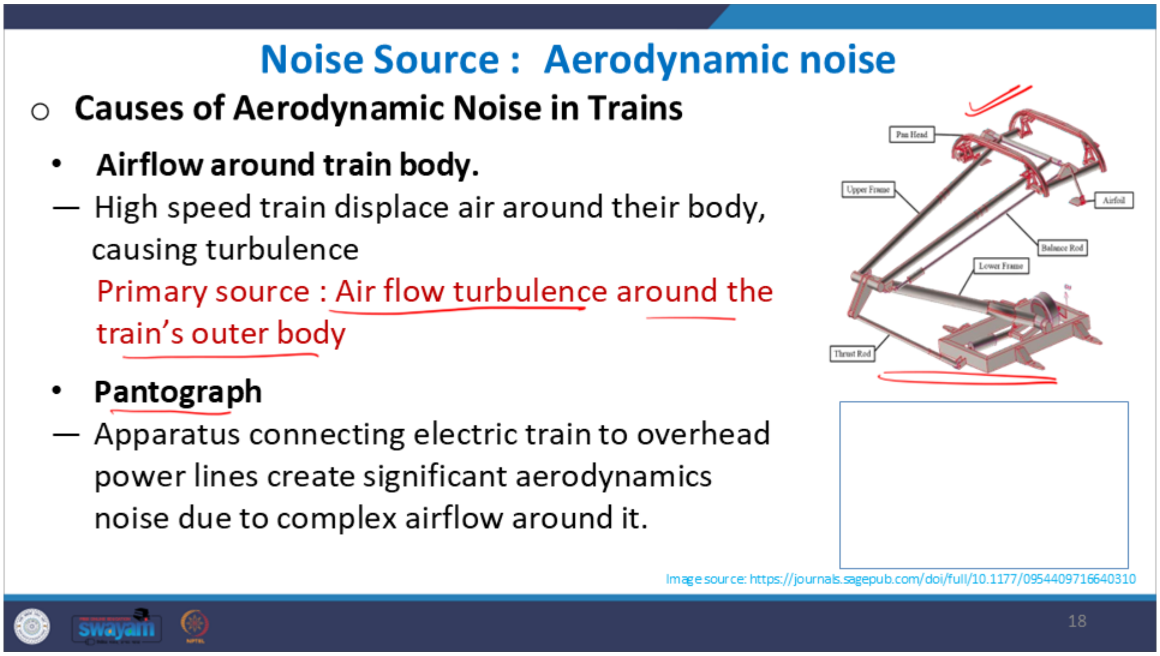
In the urban communities located near the train tracks, particularly due to the squeal noise on curved tracks. Usually, trains are in open areas, in open environments, and even then, they create a lot of disturbance when near residential areas or human settlements. And this problem amplifies even more with trains like metros, underground subways, or underground railways, or when the train passes through a long tunnel, etc. So, in such enclosed areas. The noise amplifies—why? Because now we do not have free-field conditions; instead, we have perfect reverberant conditions. Due to reflections inside the underground or the tunnel, the noise further amplifies. What are the mitigation strategies for this wheel-rail interaction noise?

So, first of all, because most wheel-rail interaction noise depends on the condition of the wheel and the condition of the track. These are the two most important things to keep in mind. So, proper track maintenance is required. You can use techniques such as rail grinding. This will smoothen any kind of irregularities on the rail surface.



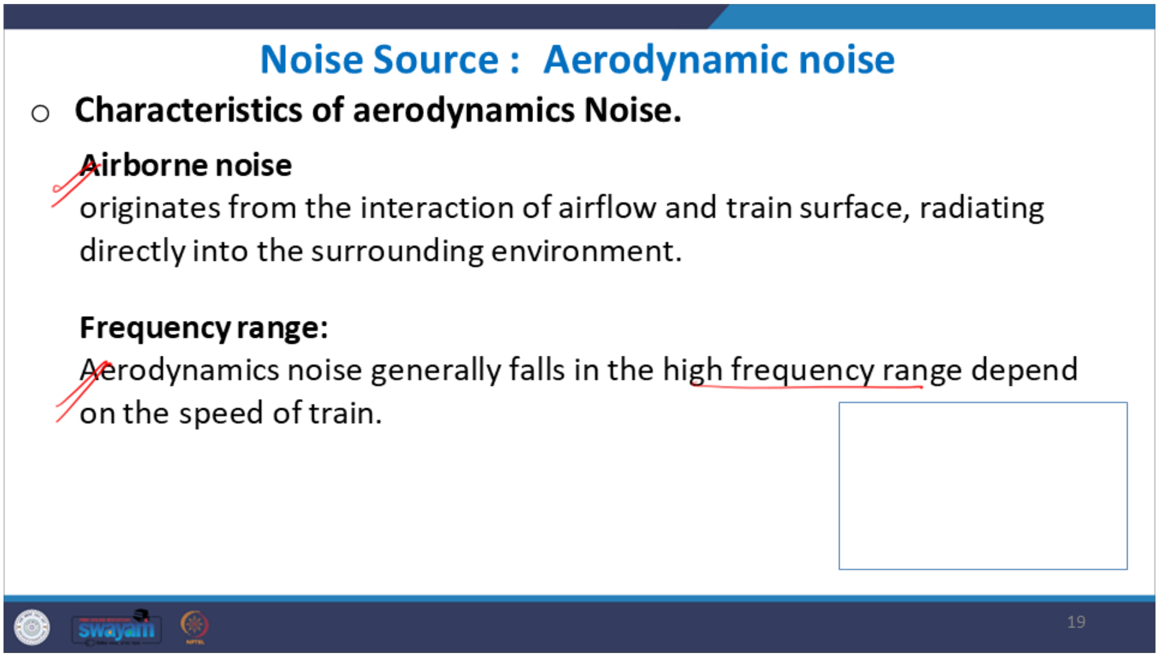
It will lead to a reduction in the high-frequency squeal as well as the impact noise. Then, the wheel design improvement—so the wheel tread profile could be optimized and maintained—ensures they create minimal friction and less noise due to the interaction with the track. Then, some kind of vibration isolators or vibration-resilient material, such as viscoelastic material like rubber, etc. So, these viscoelastic materials can be installed at regular intervals in the track and the base layer. So, what will that do is that it will

break the vibration path and suppress the noise due to the vibration of the railway track that may propagate into the train. Then, we have the aerodynamic noise. What are the causes of aerodynamic noise in trains? Obviously, when the train is moving at high speed, it displaces the air around its body. And just like in the case of a passenger train, when the air is displaced around its body, turbulence can be created, and fluid flow noise is generated.



So, the primary source is obviously the airflow turbulence that occurs around the train's outer body. So, not just the train's outer body—even the pantograph, which is this particular component at the top of each coach and the engine. So, this component is there at the top of each coach. to derive electricity from the electrical lines. Even this pantograph is exposed to the air, and this apparatus, when it interacts, the air flows in a very haphazard way through it, creating a lot of turbulence. This also creates a lot of aerodynamic noise. Here, just like in the case of a car, where turbulence was only through the interaction of air with the car's outer body, here we also have the interaction of the airflow.

On the outer body of the train, but also due to the interaction of the airflow over the pantograph component. So, what are the typical characteristics of this aerodynamic noise? First, you know, most of it is airborne noise, as the name itself suggests. Aerodynamic noise is created by the air, by the turbulence in the airflow over the structural components. And it directly radiates into the atmosphere, so it is fully airborne noise. It originates from the interaction of the airflow and the train's outer surface, and it radiates directly into the surrounding environment.



What are the typical frequency ranges? The aerodynamic noise generally falls in the high-frequency range, depending on the speed of the train. What are the strategies that we can adopt to mitigate this aerodynamic noise? So, we need to reduce the turbulence that might be caused when the air flows over the body. And hence, a more streamlined design is required.

So, it is again just the same case as that of a passenger car. You have streamlined designs for modern cars. In the same way, in modern trains, you can see this kind of streamlined design. So, the outer body has a streamlined design instead of having, you know, sharp bends. Okay, so instead of having sharp bends, now it is more streamlined and smooth on the outer body, which can reduce the

You know, turbulence is created in the same way because now we do not just have the body, we also have the pantograph. The pantograph can create aerodynamic noise. So, we can have some streamlined cover over this pantograph fairing, and this can also bring down the noise level. So, with this, I would like to close this lecture. Thank you for listening.