Vibration Control
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Module - 4
Vibration Generation Mechanism
Lecture - 3
Flow Induction Vibration

Hi this is Dr. S.P Harsha from mechanical and industrial department IIT Roorkee. In the course of vibration and control we are discussing about the vibration generation mechanism that what exactly the basic physics involved in the generation of these vibrations by various actions. As we know that there are various components in the machine like and these components are just in the rotation or in you know like some other kinds of motion and during this motion. They are generating the oscillation or some kind of the excitations in the system.

So, in the previous class we discussed about the self-excited vibrations under the generation mechanism. We discussed about that what exactly the causes even the system is robust even there is no defect in the system itself, but even after that there is a condition of having the excitation. Sometimes, these excitations even lead the system towards unstability. We discussed all the causes of that or what are the conditions in which we can categorize the system under self-excited vibrations.

Even, we discussed about one of the specific term that is negative damping. The negative damping means you see here as we discussed yesterday, that the feature of the damping means to extract the energy to absorb the energy from the excitation source, but instead of that. If energy is being fed to the system certainly it will try to make system unstable.

This unequilibrium part due to some energy supply is one of the hazardous cause for unstable, which lead the system towards the failure. So, we need to take this issue seriously that when the system is under the self-excited vibration, which always turn the system to the non-homogeneous solution. We need to check it out that how we can control those things. So, today’s lecture is absolutely focused on the other aspect of vibration generation mechanism, that is the flow induced. What exactly the mechanism is because sometimes we see that along the along with the vibration.

There is a huge sound when the flow is being there from various duct or the devices. Either the flow is you know like we can say the liquid or the air or any kind of thing it always created the huge amount of vibration and the noise itself. So, when we are talking about the generation of these sound and vibration. When we are trying to co relate the flow with these two aspects.

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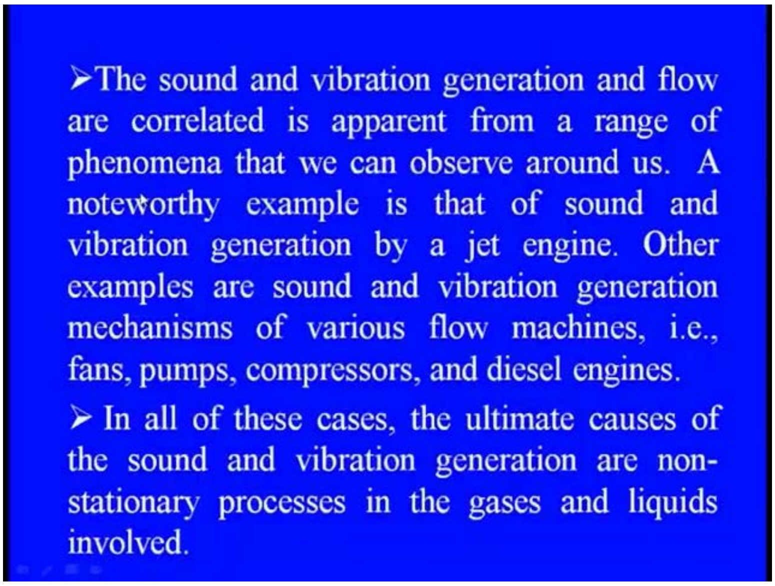

Then certainly we need to check it out that what exactly the effect of these sound and vibration on the surrounding feature. If we are just taking the example of simple the jet engine. Even we can say that there are various flows through the fluid machines or any kind of thing like the fans pumps compressor the diesel engines. They are clearly showing that when the fluid is just moving or when there is a passage of you see. You know like the fluid from the critical locations for the conversion of you see the pressure and kinetic energy. Then certainly there is a huge amount of vibration from vibration generation from the source and transmitted very fastly to all across the component and the surroundings are.

So, these cases, which I talked about are ultimately cause the huge amount of vibration and sound generation, but these waves or these you know like the signals, which are being generated. They are absolutely categorized under the non stationary processes. This is one of the significant criteria when we are trying to measure those things. we need to analyze based on this non stationary feature of this generations irrespective of in the gases or in the liquids. So, you see here in that the basis of the analysis.

As we know that they have the non stationary type of features then these processes, which needs to be analyzed based on you see the acoustic sources. You see the vibration sources is being you know like based on the theory given by professor J Lighthill in somewhere in 1950. Lighthill theory is of flow acoustic sound or vibration radiation basically the expansion is absolutely based on the assumptions.

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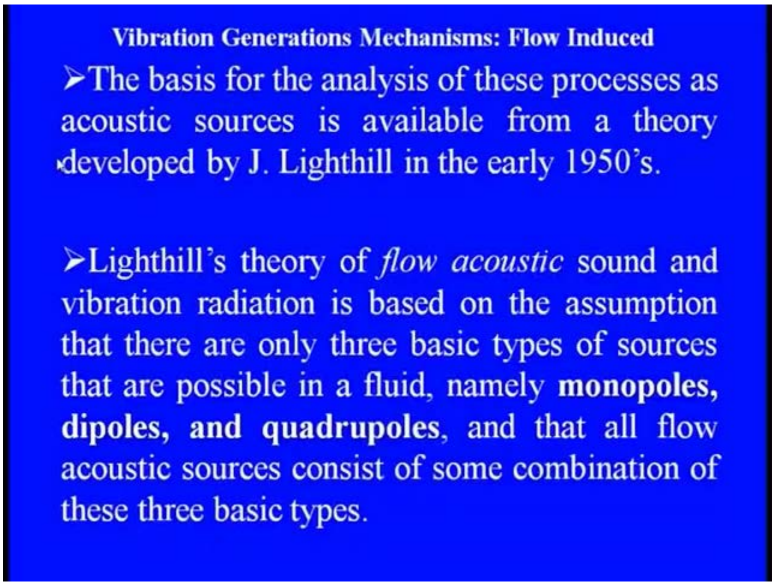

That there are only three basic types of sources, which are being possible in the fluid like the monopoles dipoles and the quadrupoles. All these sources have either in separation or in combination, when they are simply you know like expanding in terms of the radiation. As you can see on this screen when the train is moving the air drags are being there. They are absolutely putting the drag and the lift forces, but when you when we are trying to map the forces the aerodynamic forces all across to the device.

Then you will find that there are you see you know like the lines, where the air movement strikes. You see here according to the shape of the train there is a streamline motion, but there are you know like some kind of, we can say the surfaces just close to the surface of the train. These areas are simply showing a kind of turbulence, when the trains are moving or the vehicles are moving at the high speed. These wet formation or the turbulences are mainly due to pressure fluctuations.

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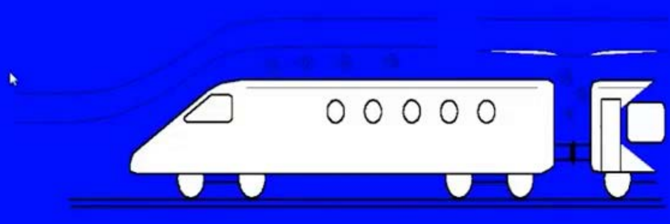

Figure 1 When vehicles move at high speeds, pressure fluctuations are generated, i.e., sound and vibration arises, due to the turbulent boundary layer of the flow field. [1]

These are creating huge amount of sound even not only on the surfaces of that, but also you see in between the two bogie's, where we have a gap. These you see you know like the kind of irregularities are being formed in the air. They are creating the huge amount of sound or vibration due to the turbulence effect. So, these turbulent boundary layer theory in the flow field is being created due to the pressure fluctuations at the surfaces. They are the basic cause for the vibrations or the sound when the train is passing at the high speed or even we can see little more inside. We can see that the kind of you see you know like this surfaces or which this turbulent effects are there.

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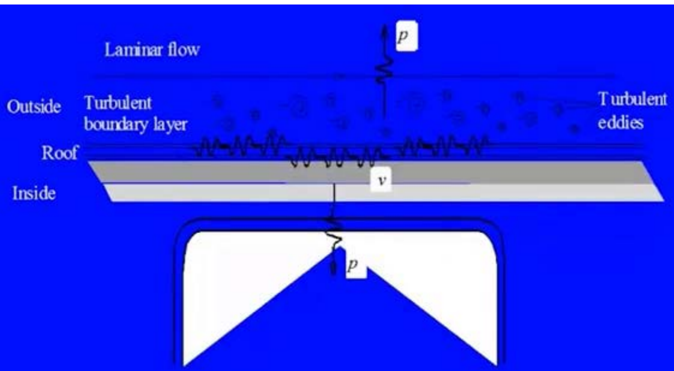

Figure 2 The pressure fluctuations generated by the turbulent vortices are responsible for noise both inside and outside of the vehicle. [1]

You can see like these are all turbulent eddies are there you see and they are basically even the entire fluid flow across the like the train or any vehicle is of the combination of the turbulent and the laminar. Because, somewhere you see the steady flows are being there according to the stream line conditions, but somewhere because of these pressure fluctuations in between the air and the surface interactions. These turbulent boundary layer theories the boundary layers are being created. We can apply this theory to formulate that how much turbulence is there according to the speed and air velocity. These eddies are the basic cause even for creating you see not only the vibrations, but also the transmission towards the inside of the vehicle.

So, we need to check it out that how much pressure fluctuations are there through, which the turbulence the turbulence or the turbulence vertices are being created. Both are basically responsible for the noise not only outside, but inside the vehicle. So, with these consideration the Lighthill theory it just you know like give a proper justification about that we have the nonstationary waves on that.

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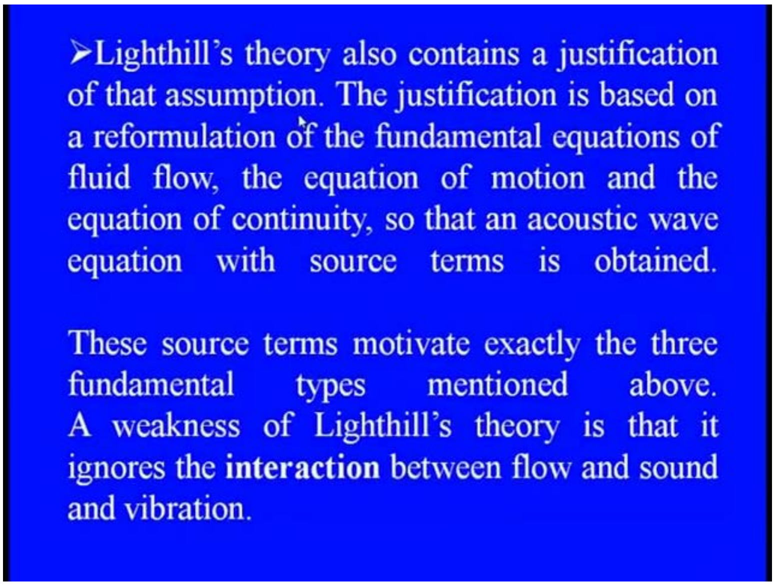

This justification is based on the reformulation of the fundamental equations of fluid flow in which we need to consider. Not only the equations of motion, but also the continuity equation in such a way that the turbulence effect due to the pressure fluctuations, when you see this pressure energy is being converted into the velocity.

Then we need to consider this non-linear impact of that and the source terms certainly motivates exactly into three main fundamental types. As we discussed already monopole dipole and quadrupole part, but one of the weakness also in this theory is it always ignores the basic interaction between the fluid flow. You see here how the sound and vibrations are being generated exactly means, it cannot give you some kind of empirical situations, where the relations are being set up between these two. Sometimes we can say that there is certainly, when the fluid flow is there the kind of exciting forces, which are being generated.

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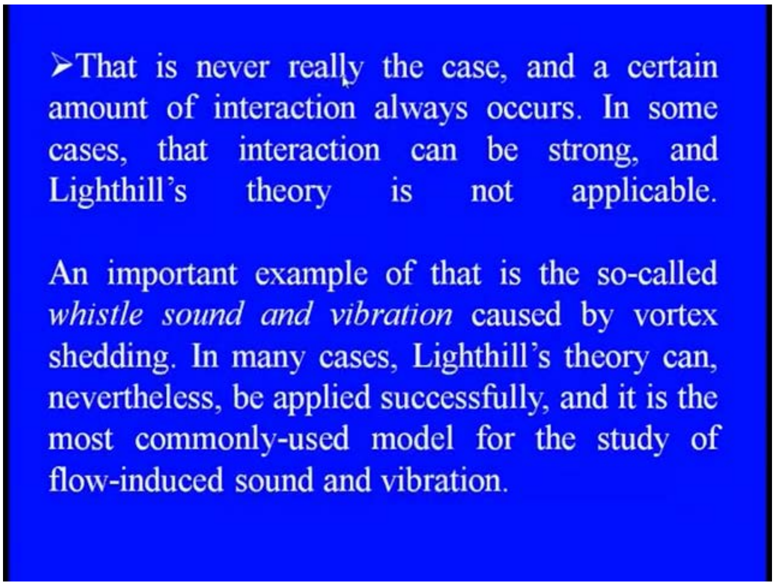

The impact forces are being occurred on these surfaces they are absolutely creating the sound and vibrations. So, we cannot ignore this where the interactions is significant. So, at that time the Lighthill theory is somewhat not matching to the accurate results. Just like you see the whistle sound or the we can say the vibrations. When we are just using a whistle feature and this is basically being caused by the vortex shedding. So, you see here sometimes we need to say that if this kind of interaction is not that significant. We can apply the lighthill theory to find out that how much you see, like in particular all these three types of poles.

How these relations are being set up or how we can analyze the basic physical theories with that. So, as you can see we can straight way take all three types of sources. We can find that what exactly the physical mechanism is there in that part. So, if you see that the table clearly shows that we have the source say monopole type.

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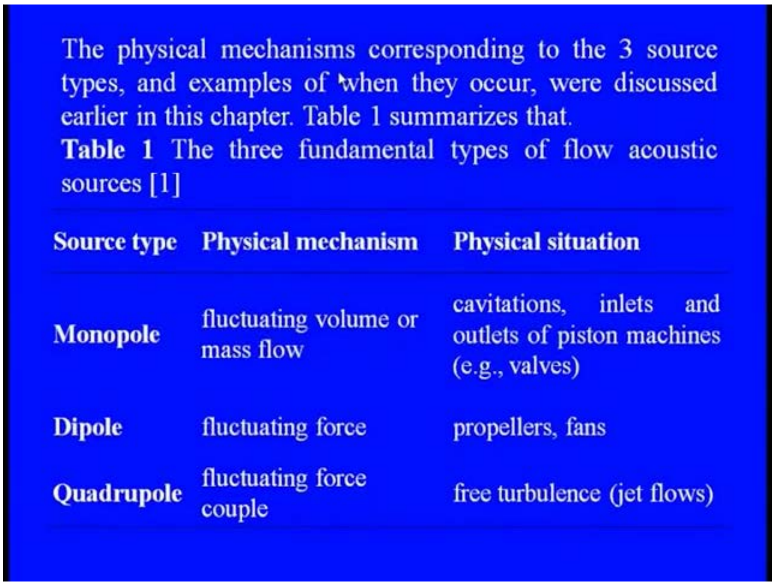

Then it is clear that the physical sense is saying that we have up clear fluctuations in the volume or the mass flow. Because, in the fluid flow the continuity equation says that the rate of inflow and rate of outflow is same. If it is the steady state phenomena then certainly you see we can say that the streamline flows are there. We can apply straight way the control mass to get the continuity equations, but when you have even the monopole. We need to check it out that even in that there is you there is a sound and vibration creations.

So, we need to understand the basic physical system and we need to check it out what exactly the fluctuations are there in the mass flow or in the entire volume, because there are situations in that in which the cavitations or inlet outlet piston part or inlet outlet valves. Even you see here when there are some different cross section of the pipes and abrupt changes are there certainly, it is the clear situations where we have the sound and vibrations generations.

The second is the dipole in which it is a clear fluctuations of the forces. So, these forces even we can say some exertion part is there for through popular or the fans. Any kind of you see like the external source this can clearly interact. These forces interact forces or you see the exciting forces clearly interact with the surfaces and induced vibrations or the sound it is and the quadra flow quadrupole is something in which you see here. It is a clear not only the force, but the moment couple or any kind of the combination of means.

We cannot say that you see only the force, which is being you know like the responsible figure, but the force when it is being applied through the line of action or if it is being applied at certain distance can create the couple. Even you see here this couple is also responsible for having the huge sound or vibration generation. Just like the basic example is the jet flow in jet flow. We know that there is a significant amount of the noise or vibration, because of the free turbulence. This free turbulence is not coming only because of the force, but it is coming, because of the various force directions and the couples together.

So, there is you see the coupling of the various types of forces together. So, all three types the monopole dipole and quadrupole are basically, responsible for having a vibration and the sound in which you see the various conditions are there. So, in order to find out the sound and vibration generation and how you see like these things are being generated a certain type of source is being there.

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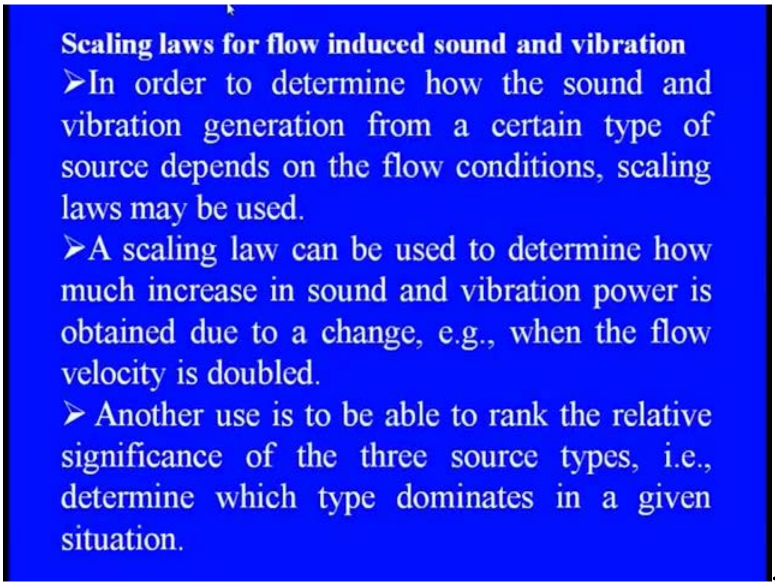

All the flow conditions or you see you know like the situations, which are being there is absolutely depends on these boundary conditions operating conditions. The scaling laws can straight way used for that to analyze the system. So, scaling law can be used to determine how much increase is there in the vibration power or the sound. How it can be obtained due to the change when you see like say the velocity is increased the pressure is dropped, any external source is being added through that. You see the some forces are being added.

So, how we can use these things? Or else we can say that another use is to be able to rank the relative significance of these three types, because we know that when the things are being changing, what exactly the relation in between that? What exactly the significance of these on the propagation of that? So, you see like this theory is giving us the domains, which we can find out the dominant effect of these features. So, what is the scaling law?

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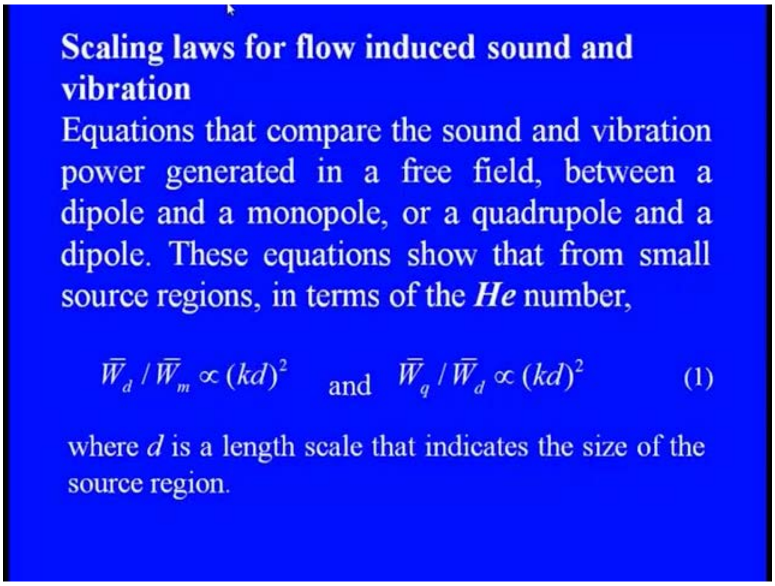

So, we can use you see the equations that can straight way compare the power generated in the free field in between the dipole monopole or even the quadrupole and dipole. That how much you see the power generations are there, when these transformations are there. These equations basically can also be termed by he and it is you see you know like the professor He the Chinese scientist who simply gave set of these relations.

So, we can see that the power ratio between the dipole and the monopole is nothing but equals to proportionate k d square, where k is the wave number and d is the length. Whatever the scale length is there, it simply indicates that what the size of the source region is is. So, that is for the small we can say the source region this theory is absolutely valid, because whatever the ratio is there. Whatever the proportions are there in between the transformation is absolutely depending on how much distance and the wave numbers are and the square term.

Even similar theories can be set up for the ratio the power ratio of quadrupole to the dipole. It is also giving, because there is a straight one phase difference it is giving k d square, where we discussed that k and d. So, you see when we are applying these things for the flow acoustics you see whatever the acoustic radiations are being coming through the system.

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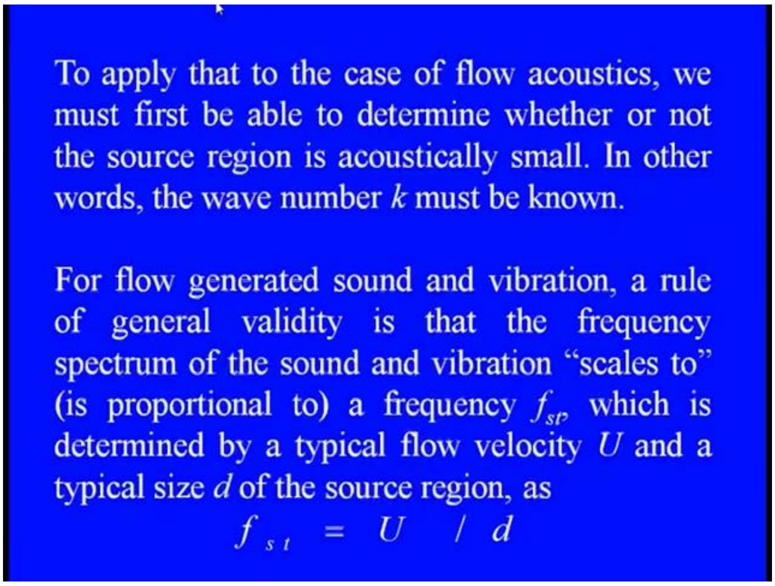

We can say that it can be straight way determine whether or the source region is acoustically small or what we can straight way say that it is absolutely depending on the two main feature. The wave number that you see what exactly like how many waves are being coming out in a rapid way and the transmission feature. Then the second is what is the region, where you see these free expansions are there.

So, for flow generated these vibrations and the sound a rule can be straight way like put. The valid key of this is absolutely based on the frequency spectrum, because we need to ultimately find out what exactly the proportion limit is. For that you see we need to find out you see what exactly the frequency components are being associated with the typical flow velocity and the sizes. Because, ultimately all these powers are being generated based on the flow velocity.

So, we can relate this frequency say this frequency is nothing but the scale frequency f s t is nothing but equals to the flow velocity divided by the size. Where, the free expansions are there in the source region U by d. This characteristic frequency, which is a dedicated frequency for the flow generated vibration, is usually called the Strouhal frequency.

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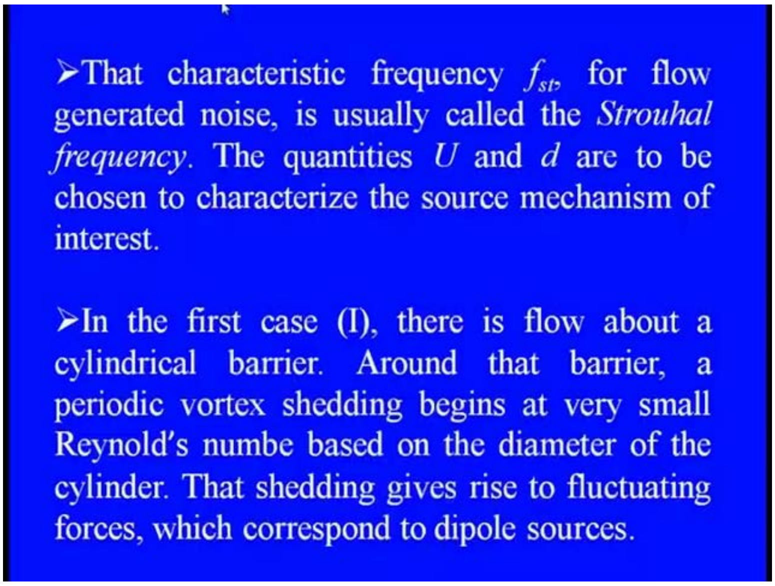

So, we can say that we can straight way find out that how much frequencies are being generated. We can either co relate that how much velocity is there in the flow field region or else you see here how what is the flow field region and the velocity is there corresponding dedicated frequencies are being generated in this.

So, now you see here we are going to consider the various cases in that and we are the three cases. In that you see we are trying to analyze that how you see these frequency and the regions are there. So, in the first case which am going to show you we have the flow about the cylindrical barrier. Around the barrier we have clear periodic vertex features are there and through that the shedding is begins at the very small number. Even, we can say the Reynolds number, where the flow is pretty along the diameter of the cylinder. This shedding effect is simply giving the fluctuation in the forces and you see here through that the dipoles sources can be related in this.

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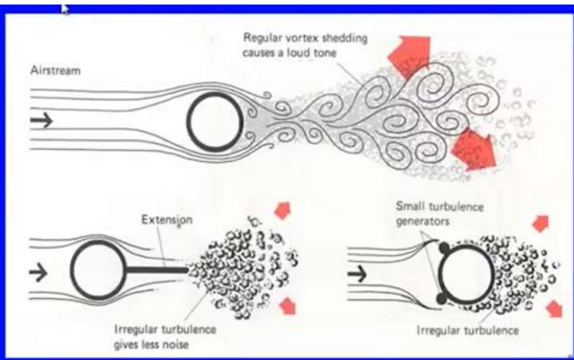

Figure 3 For a cylindrical pole in an air flow, there is a periodic shedding of vortices that gives rise to fluctuating forces. Sound and vibration generated in that way is called a Strouhal or aeolian tone. (Picture: Asf , Bullerbekämpning, 1977, Ill: Claes Folkesson.)

So, in any way this equation is just showing you see that how the cylindrical poles are being there. How the air streams are being you know like crossing to this one is creating the huge amount of sound and noise and spreading in faster way. So, we can by putting some extension at the right region the exit region of the cylindrical pole, can reduce the kind of you see the sound and vibrations generation. Because, of the stream line sections being provided or else even we can just put the small turbulence regions. You see the generators throughout that you see here when the small energies interacted with this. There is a interaction in between the flow path and clear variation is there in this.

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In the second case (II), a non-pulsating turbulent jet flow exits a duct. The jet corresponds to a distribution of quadrupole sources. The Strouhal frequency is obtained by choosing U to be the jet's velocity and d to be the diameter of duct. The sound and vibration generated is broad-banded, with a frequency content that "scales to", i.e., is proportional to, f_{st}.

In the third case (III), a propeller rotates in an otherwise still fluid, at a rotational frequency f_0. The blades of the propeller generate time-varying forces on the surrounding fluid, and thereby constitute dipole-type sources.

So, even in these cases whatever the vibration of the sound is generated is basically as, we already told that it is the Strouhal or aeolian tones are there. We need to check it out that what exactly the shedding effect is there, which can straight way relate towards the dipole feature. So, we are also going to discuss about the second case in this, that is nothing but you see a jet phenomena in which the non-pulsating turbulences are being there. In the flow when they are just passing through the duct they can straight way create the quadrupole features. Because, of the disturbance in the jet flow sources and this strouhal frequency can straight way obtained using the jet flow velocity and the diameter of the duct. We know that since it is a clear quadrupole feature.

So, a broad band frequency spectrums are being obtained, which we need to find out that how we can simply featured out in the scaling part. Now, also you see in the third case, which we are going to discuss about the propeller. Propeller is rotating means some extra features are being added to the system. Then we have a clear rotational frequency as the propeller rotating at that frequency. The blades of the propeller can immediately generate a time varying forces. They are the responsible feature for creating a huge amount of vibration. So, here it is you see we have all three force all three types of cases from a proper periodic vortex shedding to the propeller action.

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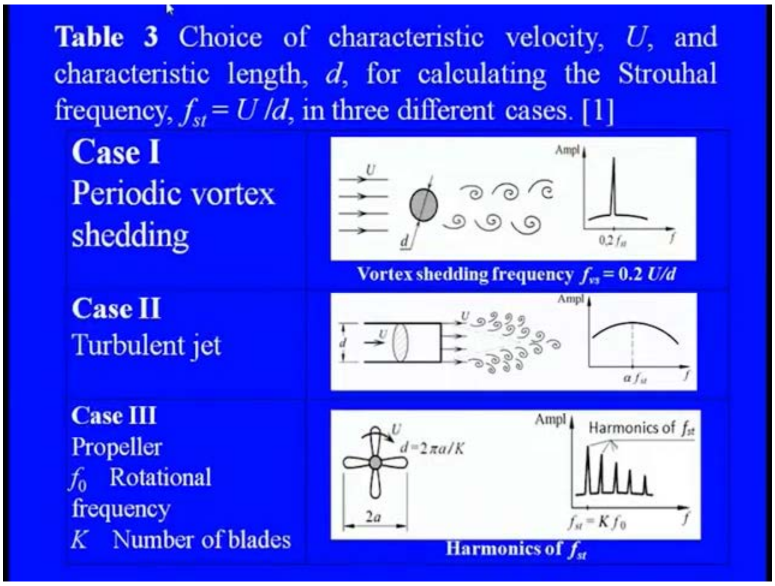

You can see that when a periodic vortex shedding’s are there. There is you see the U velocity which is all along the stream line. When they are passing through the cylindrical barrier, then we have some kind of wet formation. Whatever, the excitations are coming they are absolutely a well featured excitations instead dipole excitation. We can get this vortex shedding frequencies just equals to 0.2 times of U by d. Because, ultimately we are assuming that this much conversions are being there to excite the system.

In the second flow, where a quadrupole features are there in turbulent jet, you can see that in this particular a jet diameter the flow velocities are being there. They are creating a huge amount of vortex formations and in the excitation. It is very much clear that how much you see the exciting features are being there. According to this alpha and f s t and the third case, where we have known input frequency f 0, which is nothing but the rotational frequency and with the number of blade k.

We can get the harmonics of the exciting frequency f s t, which is U by d. You can see this when this U the velocity is interacted with the blades, then we have a clear interaction. These interactions are clearly shown there that how many number of blades are there. Correspondingly the frequencies are being there and these are all the harmonics in that. So, these three cases are clearly showing that how the interactions are there and how we can featured out based on the monopole, this dipole and the quadrupol. In that also you see if you are saying that the angle is being divided by the frequency 2 omega f 0.

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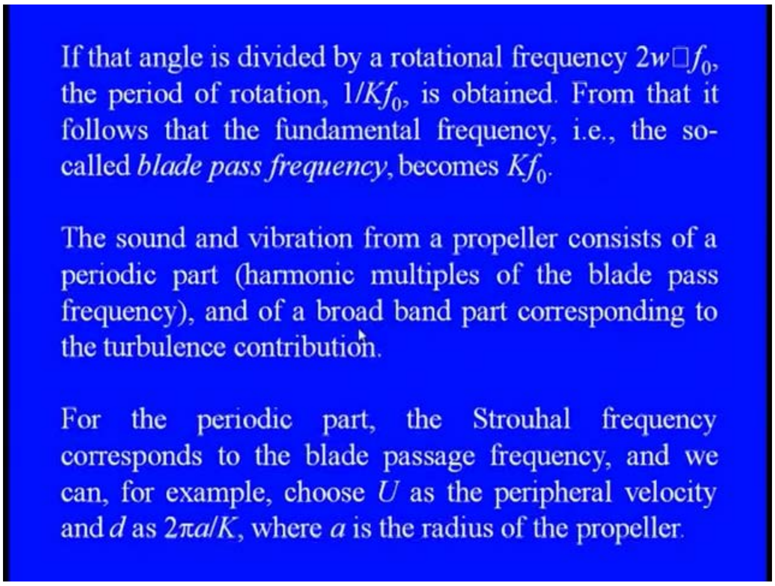

Then we can straight way get the kind of frequency, because you see when we need to divide with the number of blades. Then the frequency, which is coming out is nothing but the blade passage frequency. This is something we can say the natural frequency of the system according to the blade design, the number of blade at which you see the excitations are coming without any defect.

So, blade passage frequency is we can say the characteristic frequency for such kind of systems. We can say rather it is a fundamental frequency. When you see the vibration of the sound, which is coming out due to the through the propeller, it consist of a periodic part, means there are various harmonic features are there. That means you know like the multiple excitations are there according to the harmonics of blade passage frequency. Also, we have the broadband and this broad band is basically showing the turbulence effect existed in this flowed flow motion. Because, of that the huge amount of amplitudes are being created.

So, for a periodic part by Strouhal frequency corresponding, which is corresponding to the blade passage frequency. We can simply find out that you see how much these peripheral velocity. We can say the diameter is there correspondingly we can get that, which is clearly showing that, according to the radius of propeller the frequencies are being like varying. We can get this by 2 pi a divided by k, where the k is the number of plates. So, if we are just putting those things in the He number.

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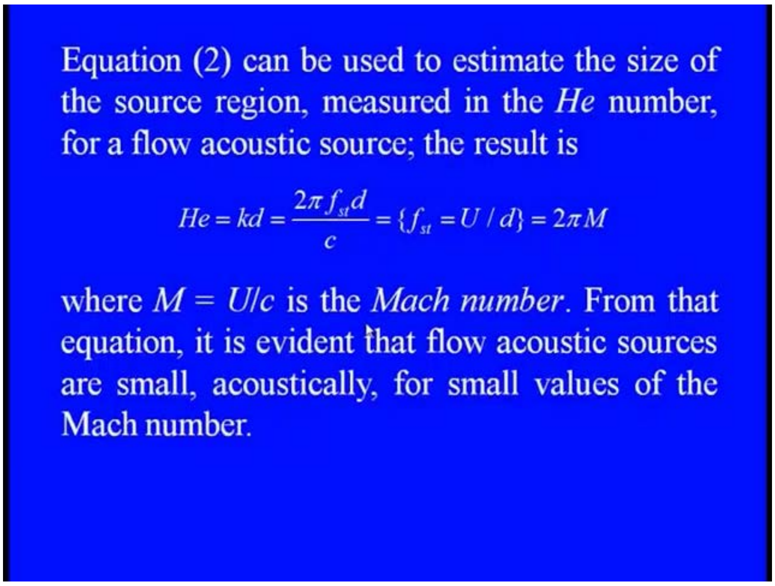

Then we can find that the He number is nothing but equals to the k d or 2 pi f 0. The f 0 is the rotational frequency into the d diameter divided by c. Or else even we can say that this is nothing but equals to the 2 pi m where m, which is very common phenomena is the mach number U by c. We can say that the flow is simply you know like from the acoustic source. If it is a small, we have a small mach number. We can categorize the flow velocity with the sonic, sub sonic, supersonic part the these comparison of the flow velocity and the c. With this you see y like the mach numbers even we can now adopt this into our He's formulations.

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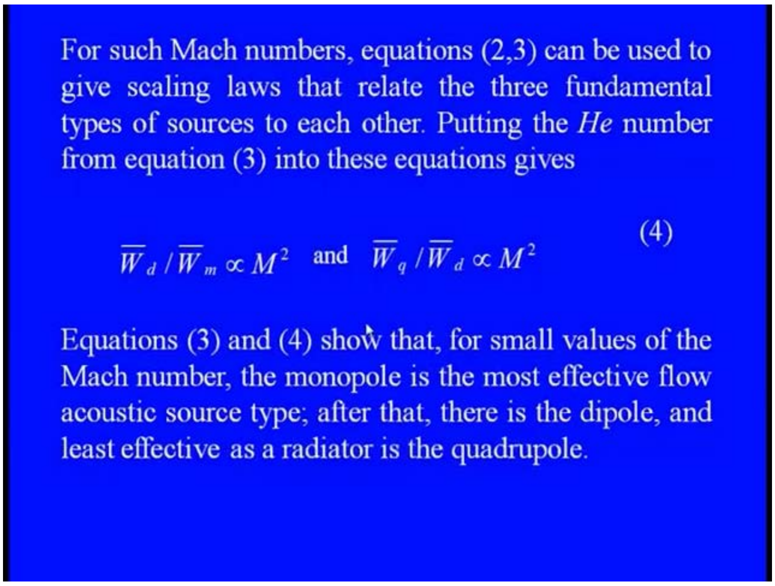

So, it is nothing but equals to when the power dissipation or the you know like the power ratio's are there in between the dipole and the monopole. It is proportional to the M square or even for the quadrupole and dipole. It is also proportional to the M square and for a small values of mach number the monopole is the most effective flow acoustic source. After that there are you see the dipole and the monopoles are having the less effect in the radiator feature or in the radiation feature, the propagations are there in the sound.

So, that is what it is you see here when we are just treating the system in the sub sonic flow. We need to take care whether the system is you know like the monopole. Then we can say that it has maximum impact for the flow acoustic source. So, this is what you see one of the conclusion for this Lighthill theory with this He number that how the things are being there.

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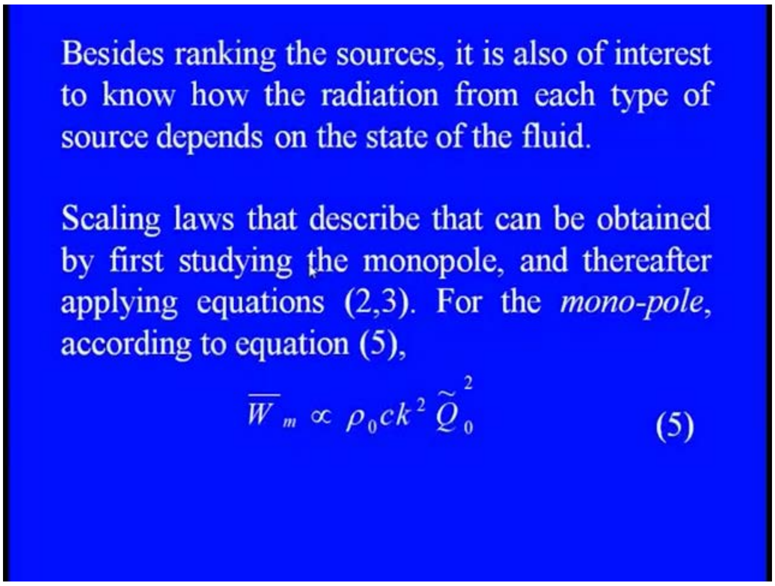

So, besides the ranking from the monopole to dipole to quadrupole for such systems in which you see the small mach numbers are there. We also need to see it is one of the interesting figure that how the radiations of each source type is depending on the state of fluid. Because, the fluid is sometimes you see you know like when they are passing sometimes it is changing, it is state.

So, we can use again the same scaling law through, which we can describe that how you see such you know like such sources are being, depending on the phases of the state of the fluid. So, if you are taking first the monopole then we can apply you see the equation straight way to monopole, say the monopole power source is W m. Then W m is proportional to the density rho 0 c k square q 0 square. The q 0 square is basically the volume, like the discharge part through the volume that how you see the variations are there in that. The density is also one of the important figure here that how the variations are there in this. So, if we are considering this volume flow q in the scale feature, then we know that it is nothing but equals to U d square.

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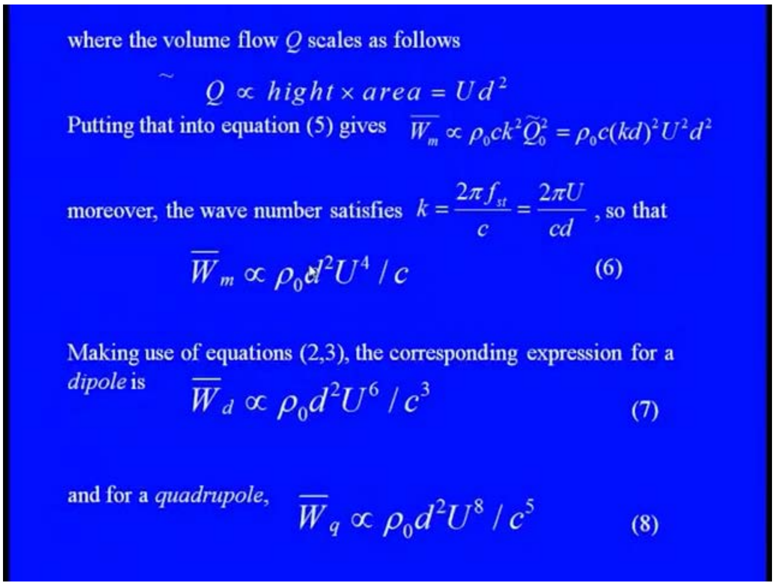

When we are keeping this into our main formula of our monopole power then W m is nothing but equals to rho 0 c k d square. As we know that the k d square is straight way coming with the wave number. The distance in which the fluid flow fluid flow propagation is there into U square d square, even we can simply put. The wave number k, which is nothing but equals to 2 pi f s t divided by c. Or else we can say that it is 2 pi U by c d, if we are just replacing this f c by that.

So, ultimately we have the power in the monopole, what are the power generations are there through the monopole source is proportional to 0 d square U 4 by c. So, you see that this monopole source, how it is depending on the velocity? It is the fourth order of velocity. So, it is highly sensitive to that and even if we are just putting this equation for dipole. Then you can see that it is rho 0 d square U to the power 6, but divided by c cube. Now, you see this U 6 by c cube is now just reducing the intensity of this phenomena. Even, if are just trying to apply this concept to quadrupole.

Then we have the W q is proportional to rho 0 d square U to the power a divided by c 5. That means are pretty simple, that you see here. When we are just trying to go from monopole to dipole, dipole to quadrupole the variations in the velocity and in the velocity the fluid flow velocity, in the sound velocity is significant there.

We are absolutely putting the c c cube and c 5, when we are just trying to approach from monopole to dipole, dipole to quadrupole. So, we can see the variations of such parameters and the effect of these parameters on the wave generations or we can say the vibration generation. So, the equations, which we just show there you see just describe that how the motions are there in the fluid flow.

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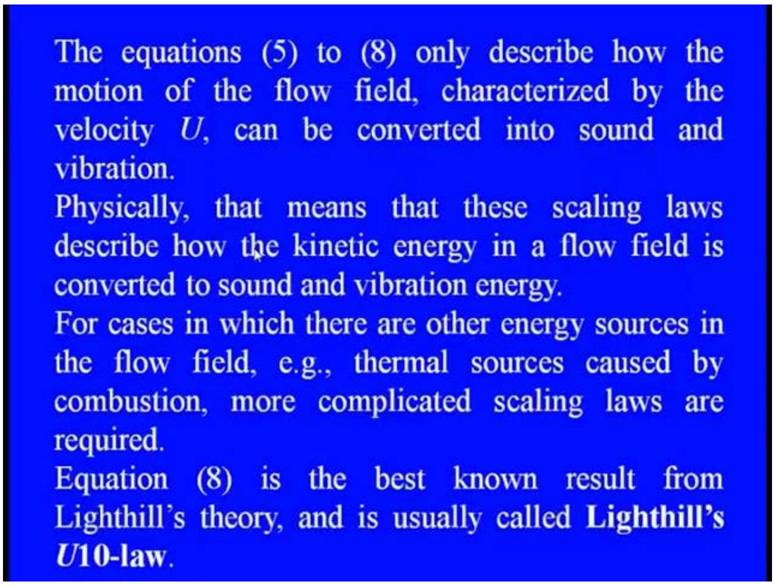

How we can characterize the fluid flow motion with the flow velocity U, which can be converted into the vibrations. So, if you are just talking in the physical sense. That means that the scaling law clearly describes that how the kinetic energy in the fluid flow is converted into the excitation energy. Or how this energy is being used for creating, the excitation features in the system in the monopole, quadrupole and the dipoles.

So, for the cases in which you see there are some other energy sources in the fluid flow, like the thermal, like energies are there through various sources, like due to combustion or due to various other features. Then we need to incorporate these features in the scaling law, which makes somewhat more complex scaling laws are right. Now, only we are looking towards the flow velocity and the sound velocity.

We are just trying to compare you know like these things to characterize the fluid motion. To understand the basic physical mean of the vibration generations. Whatever the equation, which we shown like you know like for quadra for the dipole and for monopole power generation is called the Lighthill U 10 law. That means you see here in this it is clearly showing that how in the Lighthill theories how the fluid velocity is creating the vibrations. The same time the sound in the system when the fluid flows are there.

We can see that the variation of a clear sound level that how much sound level are being created, when the fluid velocities are there through the jet. So, in that the velocity dependence on this vibration and the sound generation is absolutely depending on the two main features. How much waves are generated and you see here what the fluid velocity is.

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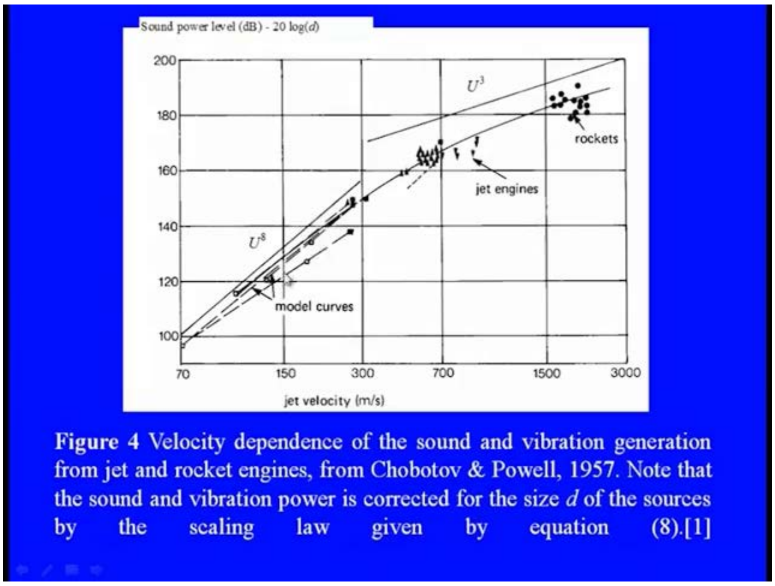

Figure 4 Velocity dependence of the sound and vibration generation from jet and rocket engines, from Chobotov & Powell, 1957. Note that the sound and vibration power is corrected for the size *d* of the sources by the scaling law given by equation (8).[1]

So, as we are just going with the model source. You can see that it is absolutely depending on the U 8 that was you see for quadrapole. Then how the variations are there you can clearly see that these dotted lines, which are clearly showing the model curves in that, which are being recorded by the Chobotov and the Powell in 1997 in which you see here the sound and power is absolutely connected to the size of the jet diameter of the source. Also, it is depending on the wave generation that how many wave generations are there.

So, you can see you know like this is what it is. When we are going towards the jet engines, it is a clear you see here you know like the things are being very rapid, when the high velocities are there. Accordingly you see the sound generation is very large, which can be computed based on 20 log t. When we are going towards even the rockets, we know that the flow velocity is quite significant here. This is the third portion and there you see here the sound generation is very significant. Even the flow variation is just in the cubic form of the velocity. So, what that means are that you see the variation and the sound velocity are the two significant criteria to generate the sound or the vibrations in the structure, when they are just going in the common model source or the jet engines or the rockets itself.

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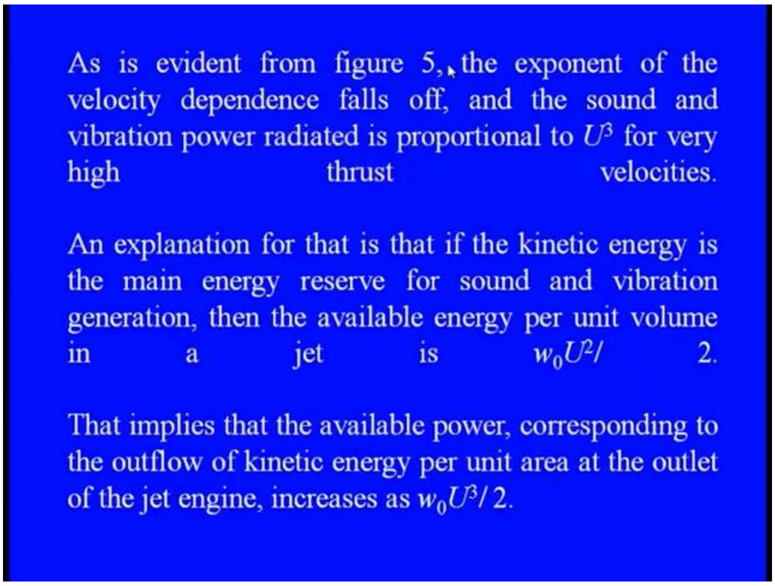

So, you see here we can say that the exponent of velocity is absolutely like showing the dependence of the fall of the sound and vibrations power related to these features. Whatever, the sound level, which is being or the vibration level is being generated is absolutely depending on these exponent. So, when you are just going for a high level of thrust velocity we have the proportional features in the rocket. Even the jet engine is a U cube. We can say that if we are just going back to the basic theory. That if the kinetic energy is the main energy reserve for this vibration of the sound generation. Then the available energy per unit volume for any kind of jet is w 0 U square by 2. Because, we know that when we are just trying to apply this theory then this is just giving the available power.

So, that means you see the available power, which corresponds to the out flow of this much kinetic energy per unit area. If you are just trying to see that then every time there is an increment of the kinetic energy as w 0 U cube by 2. Because, we know that when we are trying for the jet flow every time, there is a increase in the velocity in the proportion of U cube only. The basic energy is U 0 w 0, which is you see the initial power U square by 2. When we are just going beyond that then it is always being expansion in the increment of U 0 W 0 U cube by 2. This is what my kinetic energy with whatever you see you know like the mass per unit area is W 0 is you know like putting on that way.

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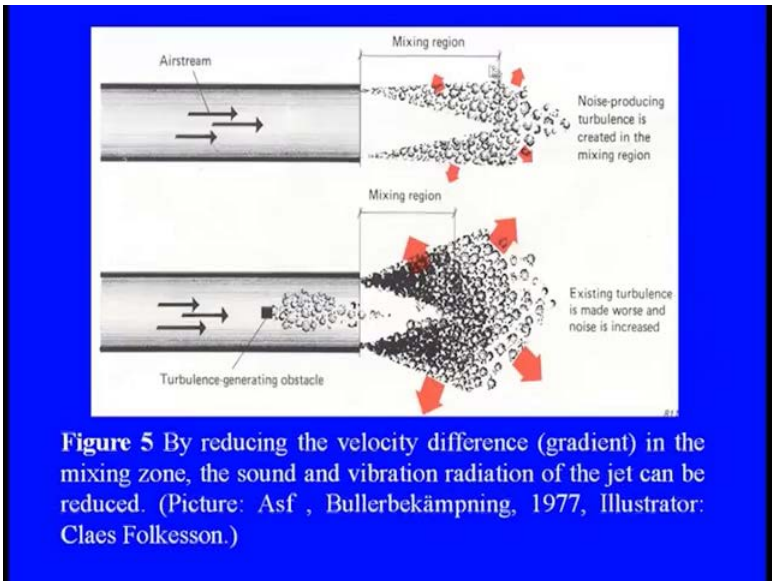

Figure 5 By reducing the velocity difference (gradient) in the mixing zone, the sound and vibration radiation of the jet can be reduced. (Picture: Asf , Bullerbekämpning, 1977, Illustrator: Claes Folkesson.)

You can see that the kind of effect of turbulence, you see when we are just trying to see the gradient of the velocity, as it is just passing through the long tube. So, we can see this is what my air streams are and when they are just passing the clear interaction of these molecules are creating the turbulence effect there itself. We have the two mixed region the closed area is just showing the less intensity of the turbulence. You see here after certain area of the free expense.

We have the huge effect of these turbulence feature. With that you see the maximum noise or the sounds or the vibrations are being generated there, but as we put any small. We can say the obstruction in between that then even you see here in the air stream. In the second figure you see here the turbulence effect starts from here, which creates the huge turbulent effect at the just exit part of the pipe or the ducties.

So, you can see that even at the beginning, we have a huge mixed region. This mixed region is just showing a turbulence effect on that. So, the mean is that you see even if we have any obstruction through that the irregularities are being generated. With these irregularities the turbulence effect is quite significant in those parts. So, we know that when we are just going towards the three dimensional features of that We want to apply the scaling law, we need to put certain assumptions that the vibration field and the free field conditions are always be along the flow path, even in the 3 D way.

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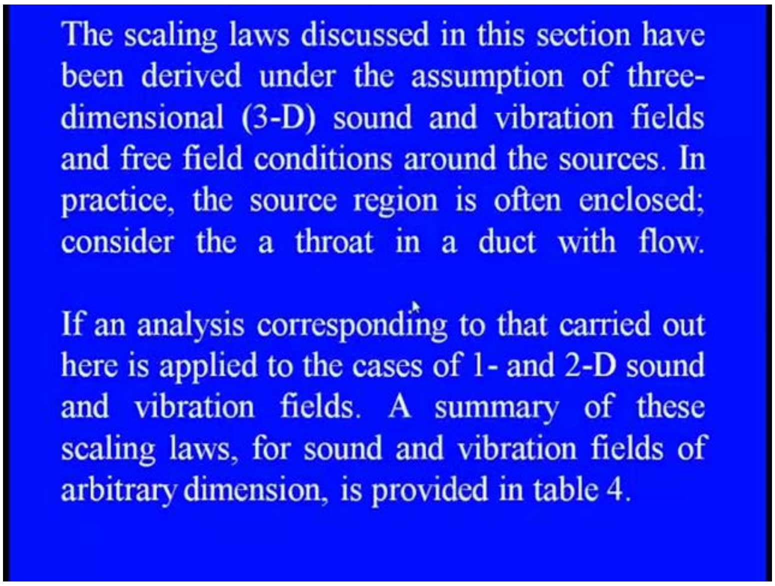

In practice sometimes we are saying that the source region is often you see you know like in the enclosed feature, just gave a thought to the duct with the flow. So, that the variation is there in the pressure energy to kinetic energy will be along the streamline. Not like any obstruction by we are putting and creating the turbulence part. If an analysis corresponds to the cases like 1 D or 2 D sound or we can say the vibration field. Then we need to check it out that how we can analyze with any kind of arbitrary dimension. So, you see here we have all three types of dimensions in which the flow induced vibrations are there.

We want to apply the scaling law to find out the variation of these with the different dimensions of the velocity in monopole dipole and the quadrupole. Then this table is clearly showing that when we have the dimension one dimensional feature, the monopole variation the monopole power with the variation of U is rho d c d rho 0 c d square U square. As we are just moving to two dimensional and the three dimensional, there is a clear impact in the velocity formation. We have the rho 0 d square U cube. Even the 3 D the scaling law clearly says that our characteristic velocity feature is now variation with U 4 by c.

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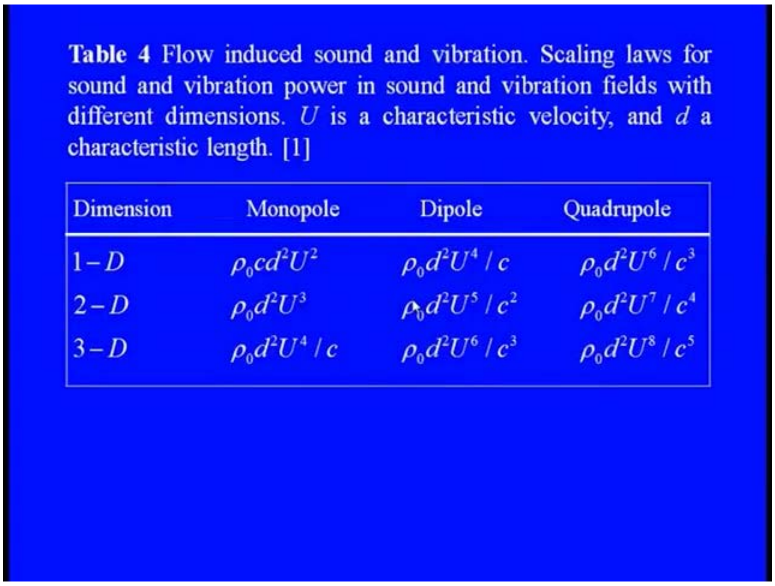

Table 4 Flow induced sound and vibration. Scaling laws for sound and vibration power in sound and vibration fields with different dimensions. U is a characteristic velocity, and d a characteristic length. [1]

Dimension	Monopole	Dipole	Quadrupole
$1-D$	$\rho_0 c d^2 U^2$	$\rho_0 d^2 U^4 / c$	$\rho_0 d^2 U^6 / c^3$
$2-D$	$\rho_0 d^2 U^3$	$\rho_0 d^2 U^5 / c^2$	$\rho_0 d^2 U^7 / c^4$
$3-D$	$\rho_0 d^2 U^4 / c$	$\rho_0 d^2 U^6 / c^3$	$\rho_0 d^2 U^8 / c^5$

If we are just going to dipole and tri this quadrupole, then we have a clear variation. Like you see here we have in 1 D the rho 0 d square U to the power 4 by c in dipole in 2 D structure the variation of this W w d is rho 0 d square U 5 by d c square. If you are going to 3 D, then it is U 6 by c cube. So, how you see the variations are become, so significant and in the non-linear nature. That is why, you see a more and more turbulences are being created in that, if we are going to the qudrupole. Even in the 1 D part we have the clear variation of the characteristic velocity U 6 by c cube in 2 D it is U seven, in 3 D it is U 8 by c 5.

So, you see here these features are clearly showing that how the sound or vibration fields are being generated under these monopole dipole and quadrupole. When these things are being passes passing or when the space is being used the space region in 1 D or 2 D or three dimensional regions. We can see that when we are in the worst condition. When we are under the qudrupole and three dimensional feature the power, which is being generated there is rho 0 d square U 8 by c 5, which is of a significant part here. So, you see here when we are going to the basic application there, then we have the whistle sound as we discussed.

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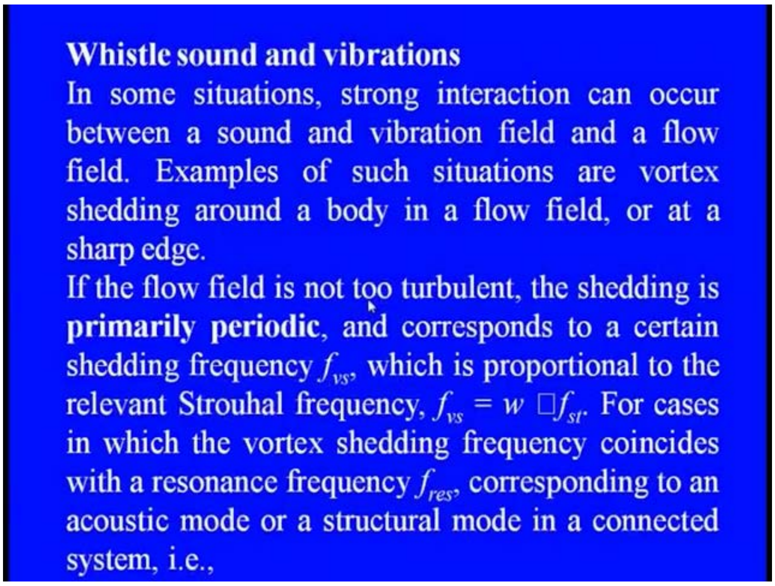

So, in this kind of thing sometimes the Lighthill rules are somewhat you see up not appropriate. Because, there is a strong interactions are there in between the vibration field and the flow field. In this you see here the vortex shedding's are being generated around the body of flow field, or we can say at the sharp edge. If the flow field is not significant in the turbulence part, then the shedding is always being the periodic, which corresponds to a particular dedicated frequency, which is the characterized frequency of the shedding called the shedding frequency.

This frequency is proportional to the relevant Strouhal frequency like f v s. We can say omega into f s t and for these cases we can say that the vortex shedding frequencies are absolutely coinciding with the resonant frequency of the system. Gives us the resonant features of that the huge amount of excitations. So, we can say the alpha f s t is nothing but equals to the resonant frequencies.

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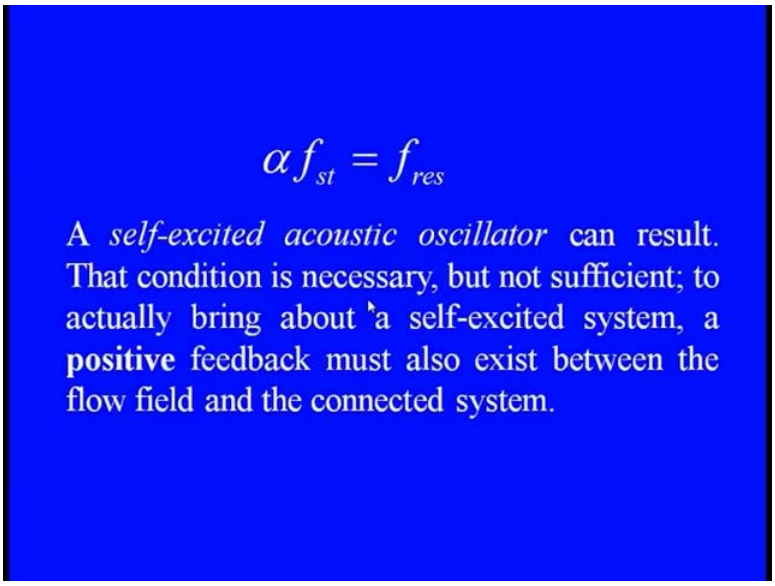

This condition is coming under the self-excited acoustic oscillation feature. This condition is really necessary, but sometimes it is not that significant because you see this is the self-excited system. We know that a positive feedback can always be there in between the flow field and the vibration fields and how we can co relate that. Because, if you know like the things are being coming through a self-excitation, sometimes it can lead the system towards the unstable feature also.

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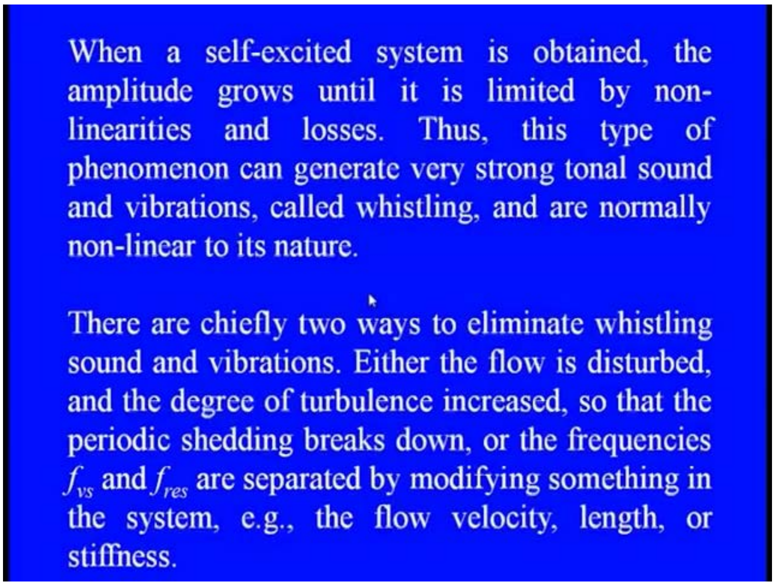

So, when this self excited system is obtained the amplitude is certainly growing until it is not approaching up to the nonlinearities and the losses. This phenomena can generate a very strong tonal or the vibration excitation, which we are saying that the whistling feature of the system. This whistling feature of the propagation of the sound or vibration is always non-linear in it is nature. We can say that there are two ways to eliminate this part the whistling sound or vibrations. Either we need to put some kind of obstruction in the flow. So, that we can straight way reduce the degree of turbulence we can reduce the effect and by increasing the degree of turbulence.

So, what will happen in this case, the periodic shedling, whatever you see the excitations are there it simply breaks down. We have you see the two different frequencies are there not at the resonant conditions. Or else we can modify in the system like we can say we can increase the flow velocity or we just increase some dimensional features or even we change the material property.

So, that the resonance will not come into the system, we can avoid this whistling feature in the system, because whistling feature is one of the; we can say dangerous or drastic feature in the system through which we can have a huge amount of vibration and the sound. So, we can see you see there are two fall one as we discussed.

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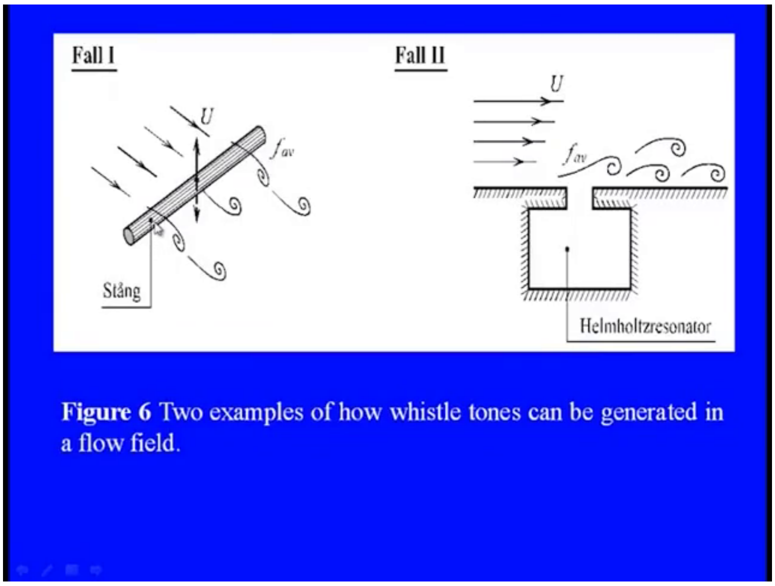

Figure 6 Two examples of how whistle tones can be generated in a flow field.

When we are putting some kind of you see the obstruction. So, that there is a deviation or we are just changing the mutual property. We are just putting some you know like we can say abrupt change in dimensional features in that. So, that you know like the things are not being coming into the flow field. So, you see here, but these two cases are clearly showing that when the things are not being adopted, accordingly the whistling tones are being there. So, either the periodic vortex shedding is there from the bar of bending vibration.

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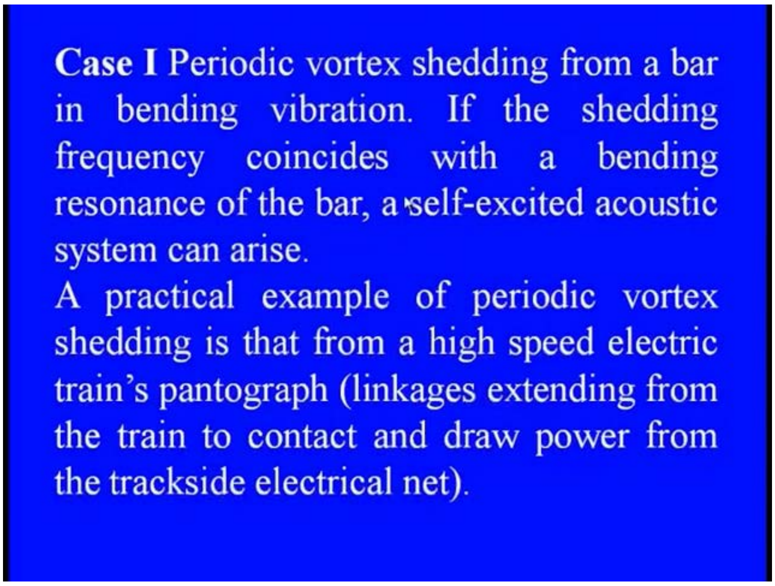

We can say that the self excitation vibration and the acoustic will be generated. Then you see here either we are just saying that when the high speed electric train is passing and the linkage, which is extending from the train to any. We can say the electric net track side net is creating this kind of self-excited vibrations by the shedding frequency, when they are coinciding to that bending resonances. In the second case we can even take the periodic vortex shedding at the whole, when they are just you know like just passing to the sharp edges of these things.

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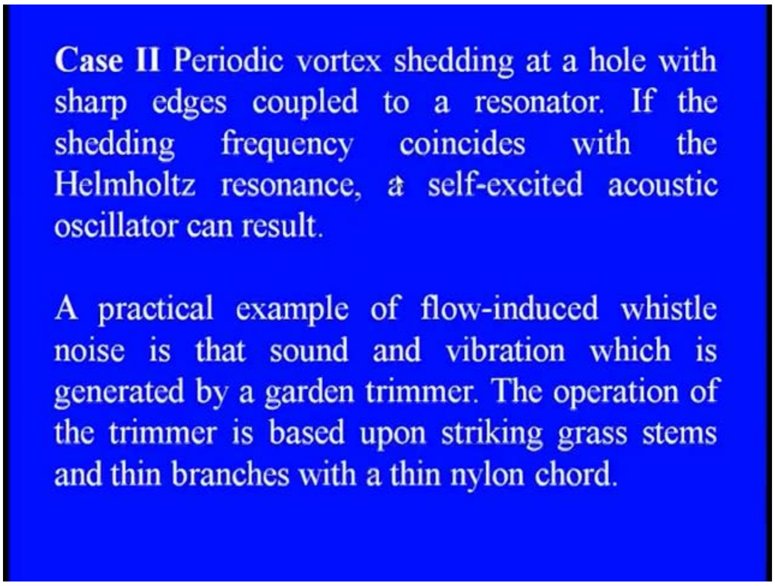

It can straight way go into the resonance conditions in that. If the shedding frequency is coinciding with these Helmholtz resonances as I shown in the previous case. Suddenly, we have the resonant condition and the huge amount of vibrations are being generated. Like, we know the simple example is the flow induced whistle noise, when they are being generated by the gardener trimmer.

This is basically like we can simply say it is absolutely based on the striking grass steam and thin branches are there. When these things are being just going towards the Nylon chord, we have a clear huge sound is there or the vibrations are there. Or else even we can say that the wind generated tones when they are just passing through the high smoke stacks.

Then certainly we have a clear periodic vortexes are there and through which the vibrations are being generated. So, that is why you see the spiral shaped flanges are being like there, which are being wrapped around the smoke sticks. So, that whatever the velocities are being passing through, we can at least obstruct or we can disturb these flow, so that the vortex shedding can be disturbed here. So, you see here this is what it is we have a clear spiral features are there.

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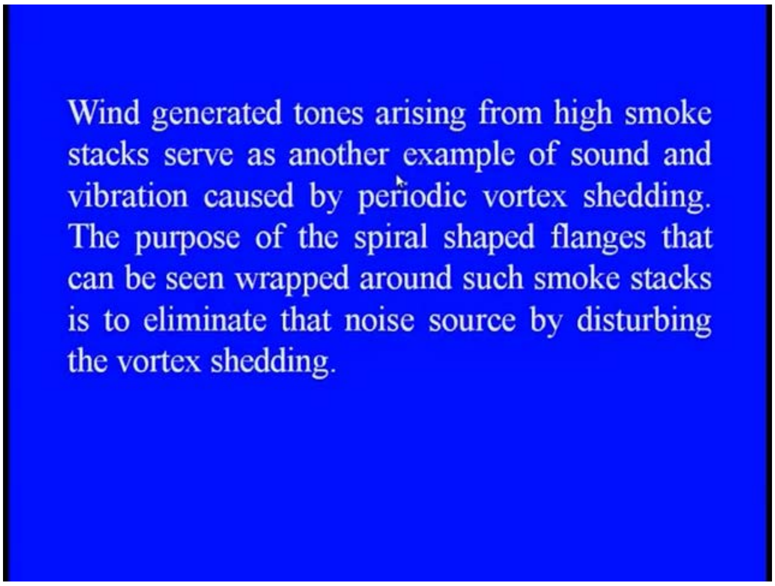

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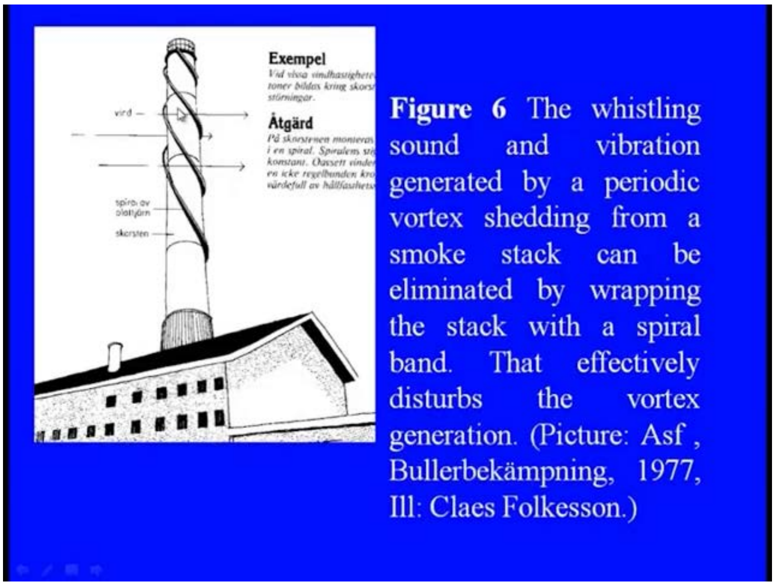

These are just to avoid the whistling sound feature in the entire smoke stack. So, that we can have a clear distribution of those vortex generation features are. So, in this lecture we mainly discussed about the flow field and the vibration field interaction. How you see the flow induced vibrations are there in that, then what exactly the basic mechanism by putting the Lighthill laws.

Even you see when we have a clear interaction of the flow field to the surfaces and how the things are being significant. Also, we discussed about that how we can adopt like the different strategy to reduce the whistling feature of the sound and vibrations. Because, we know that at certain condition the resonances are being occurred. It is creating the huge amount of damage to the system itself.

Now, in the next lecture we are again going to discuss about the vibration generation mechanism, but it is absolutely with the mechanical component, like the flexible rotor or misalignment rotors are there. So, you see here we know that the rotor is one of the basic rotating element in those cases. They can create the huge amount of the sound and vibrations. When they are operating at high speed or when even you know like during their operations how the other features are being affected, when this propagations are there. Because, this is a solid media where the propagation is very fast and can damage to the entire system.

Thank you.