Noise and vibration generated by fluid flow

In fluid mechanics, turbulence refers to disturbance in a flow, which under other circumstances would be ordered, and as such would be laminar. These disturbances exert an effect on the flow itself, as well as on the elements it contains, or which are submerged in it. Flowing gases or liquids can generate high sound pressure levels when they interact with a solid structure or as a free stream jet. In addition the machines generating the flow, as for instance compressors pumps and IC-engines usually give high pressure pulsations in the connected pipes. The pressure pulsations can however also excite the structure and generate structural vibrations which produce sound. Figure 2-17 shows an example of a circulation pump producing pressure pulsations in the water in a heating system. The sound waves are transmitted through the pipes to the radiators, where the large metal surfaces vibrate and radiate sound. This is similar to how the vibrations of the strings in a musical instrument are transmitted through the bridge to the sound box. When the sound box vibrates, sound is transmitted to the air.

Interest in flow induced vibrations (FIV) lies in the fact that the source of vibration is dissipated energy caused by turbulence, or in other cases, by eddies that produce oscillating lift forces that impregnate objects immersed in the fluid with a vibratory movement.

There are two basic FIV mechanisms:

- a self-induced vibrating mechanism
- a forced vibration mechanism.

Turbulent fluid flow in pipes also produces sound which can be radiated from the pipes and transmitted to the building structure. This noise and vibration can be controlled by reducing the turbulence in the pipe or covering the pipe with sound absorbing material. The vibrations can be isolated from the wall or ceiling with flexible connecting mechanisms.
Turbulence collaterally generates pressure and density variation in the fluid. By means of the turbulent stress tensor the turbulence produces variations in pressure and density. The former cause the noise, and as such, are deemed to be sound sources.

There are many practical applications of the analysis of turbulence generated noise. Two particularly curious, albeit useful ones, have solved some serious problems. The two situations in question are:
- Determination of leaks through the seat of safety relief valves from the outside by means of non-intrusive techniques.
- Element breakage due to resonance frequencies.

The first of the above situations has been used to detect safety relief valve leaks in BWR nuclear plants. The theoretical principle employed is that the seat leak flow produces turbulence which in turn generates a characteristic sound. Turbulence, which in general, manifests itself as vortices or eddies, will in the Von Karman sense, give off a determined frequency. Moreover, the lower scale turbulence will have its own frequency in accordance with the Lighthill model. Thus, the pressure waves that are generated with a defined frequency will constitute an external dryer load that increases its total dynamic load.

The fluid instabilities, though more specifically with that which makes the flow bistable, given that this represents a transition within the turbulent system. Notwithstanding, what follows is a brief description of other instabilities about which references and studies abound. Turbulent flow, as has been above, is a generalised process, whereas instability is different. This is an unexpected situation, and one which, in principle, should not be happening. Quite often it is associated with the local formation of turbulence in a laminar, ordered flow. The most widely known instabilities model and study turbulence of this type of situation, but there are other instabilities in a turbulent flow that cause changes to the flow pattern. As with turbulent flow and its transition, instabilities possess factors that give rise to same instability. One of the most absurd process features is that the white noise can induce order in a system that is non linear and non stationary, is not in equilibrium. That is, a chaotic system can be ordered by itself.
Figure 0-18 Example of noise and vibration control by reduction of turbulence generated vibrations in pipes. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

When air passes an object at certain speeds, a strong pure tone, known as a Strohal tone, can be produced. This can be prevented by making the object longer in the direction of flow, such as with a "tail," or by making the object's shape irregular.

Figure 2-19 Sound generation by air flow past an object in an air stream. For the circular cross section bar a loud Strohal tone is produced. Noise and vibration control
measures include disturbing the regular production of vortices. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

This type of sound generation can be of importance for instance around chimneys at certain wind speeds. A possible solution is to mount a strip of sheet metal on the chimney in a spiral. The pitch of the spiral must not be constant. Regardless of the wind direction, it encounters an irregular object. An example of this type of sound generation can be found in a cutter wheel revolving under no-load conditions, where sound can arise from the track for holding the plane blade. An air stream is being chopped, creating a siren (pure tone) noise and vibration. Minimizing the cavities by filling the empty space in the track with a rubber plate reduces the pumping action and the noise and vibration. A strong tonal sound is generated by vortices formed at the edge interacting with the cavity at certain frequencies. After filling the cavity the character of the sound becomes broad band.

![Diagram](image.png)

Figure 0-20 Noise and vibration control of a cutter wheel by filling the cavity with a rubber material. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

When a gas or liquid flows in ducts or pipes there is always some turbulence exciting the duct walls. The noise and vibration from turbulence is increased if the flow must rapidly change direction, if the flow moves at a fast rate, and if objects blocking the flow are close together.
**Figure 0-21** Smooth pipe walls without discontinuities give less turbulence exciting duct wall vibrations and sound. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

Figure 2-22 shows a branch of a steam line having three valves which produce a loud shrieking sound. The branch has two sharp bends which also produce a lot of noise and vibration. To control the noise and vibration a new branch was created with softer bends. Tubing pieces were placed between the valves, so that turbulence was reduced before the stream reaches the next valve.
Figure 0-23 Noise and vibration control of a steam line by introducing softer bends and increasing the distance between valves. Both measures reduce the turbulence incident on the valve. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

When a flowing gas mixes with a non-moving gas so called jet noise and vibration will be generated. This has already been discussed in chapter 10. A lower outflow speed will produce a lower sound level. For speeds below 200 m/s the sound power is proportional to the flow speed to the power of 8 ($U^8$). A reduction of the speed by half will therefore mean that the sound will be reduced by about 24 dB.
Figure 0-24 Jet noise and vibration generating by free stream turbulence. The sound generation is increased by disturbances in the stream. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

Since, the jet noise and vibration level is determined by the speed of the jet stream in relation to the speed of the surrounding air, noise and vibration production can be greatly reduced by using an air stream with a lower speed outside the jet stream.

![Diagram of jet noise and vibration](image)

Figure 0-25 Principle for jet noise and vibration reduction by introducing a secondary air stream around the core jet exhaust to reduce the relative flow speed difference between the jet stream and the surrounding air. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

This principle can be used to reduce the noise and vibration from cleaning of machine parts with compressed air after processing which is often carried out with simple tubular mouthpieces. Very high exit speeds are required, and a strong high frequency noise and vibration develops. The simple tubular mouthpiece can be replaced by mouthpieces which produce less noise and vibration, such as a dual flow mouthpiece. In this mouthpiece, part of the compressed air moves at a lower speed outside the central stream.
Figure 0-26 Noise and vibration reduction by introducing a secondary air stream around the core jet exhaust in the form of a dual flow mouthpiece. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

If the diameter of a gas outlet is large, the noise and vibration will peak at the low frequency. If the diameter is small the noise and vibration will peak at high frequency. The low frequency noise and vibration can be reduced by replacing a large outlet with several small ones. To some extent this will increase the high frequency noise and vibration, but this is more easily controlled.
Figure 0-27 Principle for jet noise and vibration reduction by dividing the core jet stream into several smaller jet streams. This reduces the turbulent mixing area and the noise and vibration generation. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.)

Steam safety valves may discharge many times each day. Sound production during steam escape can produce high level, low frequency sound. To control the noise and vibration a diffuser was formed as a perforated cone. The holes produce many small jet streams and high frequency noise and vibration which is absorbed in the downstream pack.

Figure 0-28 Jet noise and vibration reduction in a steam safety valve by dividing the core jet stream into several smaller jet streams. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson) [1]

The inflow to fans is very important for sound generation. If there is an inflow disturbance giving a lot of turbulence the sound will be more intense. The same principle applies, for example, to propellers in water.
Figure 0-29 Principle fan and propeller sound generation. Inflow disturbances generating inflow turbulence increases the noise and vibration generation. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]

Fans should therefore not be placed close to any discontinuities in a duct. In Figure 2-30 examples are shown where the fan is placed too close to control vanes, and too close to a sharp bend. The flow is disturbed and the noise and vibration at the outlet is increased. To control the noise and vibration the control vanes can be moved farther from the fan so that the turbulence has time to die down. In the other case, the bend can be made smoother, and the fan moved away from the bend. Guide vanes can also be used to give a smoother flow through the bend.

Figure 0-30 Fan noise and vibration control by increasing the distance between duct discontinuities and the fan. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.) [1]
Turbulence will form if the pressure in a liquid system drops rapidly. Gas is released in the form of bubbles and produces a roaring noise and vibration. The pressure drop can be produced by a large, rapid change in volume. Noise and vibration is avoided by a slow change in volume.

![Diagram of turbulence and bubbles](image)

**Figure 0-312** Principle for noise and vibration reduction in a liquid filled pipe using smooth duct transitions. Because a rapid pressure drop is avoided less gas bubbles are formed. (Picture: Asf, Bullerbekämpning, 1977, Illustrator: Claes Folkesson.)[1]

**Rotating Balance & Unbalance**

Unbalance is the most common source of vibration in machine with rotating parts. It is a very important factor to be considered in the modern machine design, especially where high speed and reliability are significant considerations. Balancing of rotors prevents excessive loading of bearings and avoids fatigue failure, thus increasing the useful life. Unbalance in a rotor is the result of an uneven distribution of mass, which causes the rotor to vibrate. The vibration is produced by the interaction of an unbalanced mass component with the radial acceleration due to rotation, which together generate a centrifugal force. Since the mass component rotates, the force also rotates and tries to move the rotor along the line of action of the force. The vibration will be transmitted to the rotor's bearings, and any point on the bearing will experience this force once per revolution. Balancing is the process of attempting to improve the mass distribution of a rotor, so that it rotates in its bearings without uncompensated centrifugal forces.

**Dynamic Unbalance**, illustrated in Fig. 2.27, is a combination of static and couple unbalances and is the most common type of unbalance found in rotors. To correct
dynamic unbalance, it is necessary to make vibration measurements while the machine is running and to add balancing masses in two planes.

Fig 2.32: Dynamic unbalance

A rotor is balanced by placing a correction mass of a certain size in a position where it counteracts the unbalance in the rotor. The size and position of the correction mass must be determined. The principle of performing field balancing is to make (usually temporary) alterations to the mass distribution of the rotor, by adding trial masses, and to measure the resulting phase and magnitude of bearing vibration. The effects of these trial corrections enable the amount and position of the required correction mass to be determined. Any fixed point on the bearing experiences the centrifugal force due to the unbalance, once per revolution of the rotor. Therefore in a frequency spectrum of the vibration signal, unbalance is seen as an increase in the vibration at the frequency of rotation. The vibration due to the unbalance is measured by means of an accelerometer mounted on the bearing housing. The vibration signal is passed through a filter tuned to the rotational frequency of the rotor, so that only the component of the vibration at the rotational frequency is measured. The filtered signal is passed to a vibration meter, which displays the magnitude. The indicated vibration level is directly proportional to the force produced by the unbalanced mass.

“Fundamentals of Sound and Vibrations” by KTH Sweden [1], this book is used under IITR-KTH MOU for course development. Turbulence, Vibrations, Noise and Fluid Instabilities, Practical Approach by Carlos Gavilán Moreno [2]